ROW SPACING AND SEEDING RATE INTERACTIONS IN PERENNIAL RYEGRASS AND TALL FESCUE SWARDS ESTABLISHED BY DIRECT DRILLING (NO-TILLAGE)

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ABSTRACT

Direct drilling is a popular and cost-effective method of introducing new, more productive pasture species into existing pasture on farms in New Zealand. The technique conserves both time and money, reduces moisture loss and the risk of soil erosion and offers some management benefits in intensive agricultural systems.

Seed drills in New Zealand commonly used for pasture establishment sow seeds in rows at 150 mm centres. While this is an acceptable row spacing for cereal crops, eg. barley and wheat, closer row spacing has been proposed for establishing pastures. However, little research has been carried out to determine optimal row spacing or seeding rates. The benefit of cross-drilling with two passes of the drill, which is a practice thought to overcome the perceived inadequacies of 150mm row spacing, is also uncertain. This study was designed to investigate the effects of row spacing and cross-drilling, and the relative importance of plant population per unit area and per unit length of drill row on pasture establishment and development.

Single pass sowing, at both 150 and 75mm row spacings together with cross-drilling were compared in an autumn sown field experiment. Two species of contrasting establishment vigour, perennial ryegrass (*Lolium perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.) and two seeding rates (12 and 23 and 17 and 31 kg ha^{-1} for perennial ryegrass and tall fescue respectively) were also compared. The trial was grazed by dairy cattle throughout the measurement periods.

Emergence of 84 and 71 % of sown perennial ryegrass and tall fescue seed respectively, resulted in establishment of approximately 400-500 and 700-800 seedlings m^{-2} for medium and high seeding rates respectively for both species. Two years after sowing, medium to high seeding rates offered no advantage in terms of weed suppression or yield compared with low seeding rates.

Cross-drilling offered no advantage for either species. Total herbage yield and the proportion of sown species was the same for perennial ryegrass and tall fescue established in either cross-drilled or 150 mm rows. This was the most important result, as far as the farmer is concerned, with potential cost savings of up to $100 per hectare by not carrying a second pass of the seed drill required for cross-drilling.

The establishment performance of tall fescue in terms of herbage mass and suppression of weeds in the sward was initially improved with closer row spacing. These benefits were not apparent for perennial ryegrass. The advantage gained for fescue from reduced row spacing declined with time and by the second spring after sowing no difference was apparent between 150 and 75mm row spacing treatments. Thus, overall, drilling method had only a minor influence on botanical composition.

Tall fescue was slower establishing and had more clover and weed in the sward compared with perennial ryegrass. This contrast in growth revealed the subtle influences of drilling method and seeding rate on pasture composition.

A second trial, sown in the subsequent autumn, investigated the use of nitrogen with tall fescue at the time of sowing in both single pass and cross-drilling. The results supported those found for the effects of drilling pattern in the first trial. The use of nitrogen fertiliser in the damp, cool conditions of late autumn did not benefit sward development. Emergence of tall fescue was poorer at this time.

In contrast to the results of Trial 1, increasing the seeding rate resulted in increases in initial seedling population and improved the performance of tall fescue. There was a higher proportion and herbage mass of sown species in the sward sown at the higher seed rate. This suggests that higher seeding rates may be required for tall fescue as conditions at sowing become cooler. However, the early advantage from the higher seeding rates was not apparent 10 months after sowing.

Clover emergence was low at 46 and 52% of sown viable seed for the first and second trials respectively. However, a clover seedling population in excess of 150 plants m^{-2} was established in both trials which proved to be an adequate population for development of productive pasture.

Drills designed for sowing aggressive species such as perennial ryegrass need not incorporate the option of reducing row spacing from the common 150mm with the subsequent cost disadvantages. However, the option of reduced row spacing may be appropriate for drills designed for sowing less vigorous alternative species such as tall fescue. Increased seeding rates and cross-drilling should not be necessary for successful establishment of a productive pasture sward of temperate species. This leads to improvements in efficiency of seed drill operation in the field.

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1. INTRODUCTION

The aim of farmers in establishing perennial pasture species is to maximise the contribution of sown species to the overall herbage mass at the expense of unsown species, namely broadleaf and grass weeds, in order to exploit the full yield potential of sown species both over the short and long term, and to guard against sward deterioration. A distinct shift in pasture establishment practises from traditional conventional cultivation to direct drilling has occurred in New Zealand and Australia over the last 10 to 15 years (Ritchie, 1986b; Thom et al., 1987b; Barker et al., 1989; Bellotti and Blair, 1989a). In the context of this thesis, conventional cultivation is defined as full cultivation based on the mouldboard plough, and direct drilling as the drilling of seeds into uncultivated seedbeds, the vegetation on which has been suppressed or killed by herbicides or natural mortality (Baker, 1983). This is distinct from overdrilling (where some competition remains) or oversowing (which does not involve mechanical drilling of seed). These are intermediate processes and are not involved in this study.

Sward development is likely to be modified depending on the establishment system used. For example, under direct drilling there is a reduction in weed seedling germination (Froud-Williams, 1988), soil moisture loss (Phillips, 1984), soil erosion (Stinner, 1989) and mineralisation of soil nutrients with possible nitrogen deficiency (Haynes and Knight, 1989) compared with conventional cultivation. Also, soil trafficability and root anchorage is improved because little soil disturbance occurs (Francis et al., 1988). As a result the pasture pest habitat is preserved, increasing the risk of damage to new seedlings (Barker, 1987) and the uneven surface micro-contour variations and crop residue often result in sub-optimal seeding depth, depressing emergence, this places special constraints on drill design and function (Barr, 1981, Campbell, 1981). These factors have ramifications on the population dynamics of establishing pastures, specifically the response to grazing and structure of the sward competitive environment. Thus while un-tilled seedbeds have several advantages over cultivated seedbeds for establishing permanent pasture they also impose some important constraints. This study will focus on one of these constraints, namely row spacing.

Pasture seed, sown in cultivated seedbeds has been either broadcast on the soil surface and harrowed, or sown in 75mm rows following a "Vee" ring roller drill (Cross 1959; Ashworth, 1961a). Seeds are spread evenly (but not equidistantly) with broadcast sowing, so plant spacing approaches a square pattern which, in theory, is the optimum pattern for sown crops in terms of utilising moisture, light and nutrients (Donald, 1963). This minimises the time taken to obtain ground cover which is necessary to suppress weed seed germination and emergence (Cullen and Meeklah, 1959). Systems based on direct drilling have limited opportunity for square planting, eg. 30mm row spacing would be required to square plant 1000 seeds m^{-2} (approx. 15kg ryegrass and 3kg white clover ha^{-1}). The narrowest row spacing is commonly 150mm to allow drills used for direct drilling to handle varying levels and types of crop residue

(Barr, 1981).

"Cross-drilling", "Diamond-drilling" or Double-drilling" are synonymous and describe a practise undertaken in order to reduce the space between plants and to improve ground cover for light interception of the sown species and suppress weeds in an attempt to overcome the perceived inadequacy of 150mm row spacing for pasture establishment (Thom and Ritchie, 1987). A second pass of the drill is made at an angle to the first to effect a criss-cross plant pattern (Cross, 1959; Ashworth, 1961b; Ritchie, 1986b). Narrower row spacing is possible with cultivated seedbeds and has been tested by Hallgren (1976a b and c) in the range 50 to 400 mm for various pasture species (clover, grasses and lucerne) on the basis of herbage yield. Similar comparisons have not been made for pastures sown by direct drilling, although some equipment is available which is capable of sowing at 75mm row spacing (Mr C. Bruce pers. comm., 1990).

Traditionally, seeding rates in tilled seedbeds have been high (25-40 kg/ha) in order to suppress weeds in developing swards (Brougham, 1954a,b&d; Cullen, 1958; Cullen and Meeklah, 1959; Culleton and Murphy, 1987), to compensate for poor seedling emergence rates (Cross, 1959; Ritchie, 1986b; Pedersen and Ball, 1990) and have been shown to depress the yield of slower establishing companion species (Brougham, 1954a&d; Cullen, 1966; Culleton et al., 1986). High sowing rates have also been used in an attempt to ensure the survival of introduced species when oversowing or drilling into unsprayed pasture, and to compensate for poor drilling technique (Thom et al., 1985; Ritchie, 1986b). Several authors (Brougham, 1954d; Ashworth, 1961b; Kruez, 1977; Ritchie, 1986b; Cox et al., 1988; Robinson and Whalley, 1988) have questioned the wisdom of higher seeding rates, the use of which may be detrimental to long term production and sward longevity, and have suggested that seeding rates should show closer resemblance to equilibrium populations of established pasture.

In contrast to cultivated seedbeds, there is a dearth of information regarding the effect of seeding rate in no-tilled seedbeds. Previous studies, on the effect of seeding rate on pasture establishment and sward development have used the conventionally cultivated, broadcast method for establishment (Holliday, 1953; Brougham, 1954a,b&d; Cullen, 1958; Cullen and Meeklah, 1959; Kruez, 1969, 1977; Ryan et al., 1979; Keane, 1980; Culleton et al., 1986; Frame and Boyd, 1986; Culleton and Murphy, 1987; Robinson and Whalley, 1988). If cross-drilling improves the proportion and accumulation of sown species in establishing perennial pasture, will a higher seeding rate enhance that effect through greater weed suppression or can increased seeding rate negate the requirement for cross-drilling?

Perennial ryegrass (*Lolium perenne* L.) in combination with one or two clover species, forms the basis of pastures sown by farmers in New Zealand (Sangakkara et al., 1982; Lancashire, 1985; Belgrave et al., 1990). Ryegrass has a high capacity for tillering and increasing in size to occupy available space (Jewiss, 1972; Kays and Harper, 1974; Simon and Lemaire, 1987). White clover, commonly sown in a pasture mix as a companion species, has a stoloniferous growth habit and, provided it is not shaded out by the grass component of the sward, will occupy bare spaces between grass plants and prevent weed invasion (Johnstone-Wallace, 1937). Recent droughts have highlighted the susceptibility of perennial ryegrass to dry soils, insect damage and stock health problems (Lancashire and Brock, 1983; Thomson et al., 1988; Milne and Fraser, 1990). The uptake of alternatives to ryegrass has been slow in New Zealand. Farmers have been reluctant to use unfamiliar species, mainly due to a lack of understanding in their use (Lancashire, 1985, Belgrave et al., 1990) and poorer emergence performance which has resulted in more failures (Charlton and Thom, 1984). However, species such as tall fescue (*Festuca arundinacea* Schreb.) are becoming more popular with farmers as they are more drought tolerant and less susceptible to insect damage once they are established than perennial ryegrass (Milne and Fraser, 1990). If closer row spacing has a role in perennial ryegrass establishment (to reduce weed invasion and improve the success of sown species in the sward), close row spacing, or indeed cross-drilling, might be expected to be of even greater benefit to slower establishing, alternative species.

The importance of livestock grazing to the normal development of a high producing mixture of grasses and clovers through dung and urine return has long been recognised (Sears, 1953). However, it can also be detrimental to sward development through physical removal of plants from the soil, termed "pulling" (Brock, 1982; Thom et al., 1986b). Trampling and stolon burial is also likely to affect plant development (Matthew et al., 1989). The timing and severity of defoliation influences the structure of the sward and may also change the competitive environment for individual plants (Hughes and Jackson, 1974; L`Huillier, 1987). The grazing animal is an integral part of the system and should be included in pasture establishment studies if possible.

The following field study was designed to investigate the relative importance of drilling method (row spacing and arrangement), seeding rate and species to the establishment of perennial pastures by direct drilling. The study consisted of two autumn sown field experiments. The first and main field experiment examined drilling patterns, seeding rates and interactions with pasture species. This is dealt with in Chapters 3 and 4 of the thesis. Chapter 5 describes the second field experiment, sown in the following year which ran concurrently with the first trial. This trial further examined drilling patterns and seeding rates along with the effect of nitrogen application on establishing pasture. The thesis concludes with an integrating discussion in Chapter 6.

2. LITERATURE REVIEW

The review which follows is a generalised appraisal of the areas which influenced this study or impinged on it in non-specific areas. More specific analysis of work closely related to results reported in this thesis are given in the Results and Discussion Section.

2.1 Pasture Establishment by Direct Drilling

2.1.1 Pasture Establishment

The term 'pasture establishment' encompasses a wide range of situations where new genetic forage plant material is introduced into a pastoral system. Reference to the term in the literature is often ambiguous and holds different meanings depending on context. Of interest to the pastoral manager, grazier, consultant or researcher is the agronomic perspective, defined by Snaydon (1978) as the period until a closed stand is formed. The absolute length of time this may take is mostly a function of the environment (temperature, moisture and soil fertility) and the type of species introduced. In New Zealand, a temperate country with moderate rainfall (Brougham, 1979), the establishment phase is generally considered to be the first 12 months after drilling (Thom et al., 1987a).

The focus of this study was to describe and understand the process of pasture establishment as it was affected by manipulating cultural techniques. In order to understand that process the boundaries set by Bellotti and Blair (1989c) are considered the most appropriate on which to model the establishment process. They described the three distinct phases involved in pasture establishment as:

1. Seed germination
2. Seedling emergence
3. Seedling survival and contribution to a productive sward

Seeds must pass through the 'germination', 'emergence' and 'survival' phases or "filters" to persist as a stabilised population. Distinction of these phases within pasture establishment is critical to evaluating and communicating the processes and techniques involved and these distinctions are consistent with the notable workers in this area (Brougham, 1954a,b&c; Harris et al., 1973; Brock, 1982; Thom et al., 1986 a,b&c) who addressed system stability and persistence concerns. Although studies concerned with only germination, emergence and early seedling growth (McWilliam et al., 1970) provide useful information on pasture establishment they do not provide the data required to satisfy decision-makers involved with pastoral systems as to the long-term outcomes associated with pasture establishment. Of prime interest to them is productivity and persistence of new pastures. The most useful studies with respect to productivity and persistence of newly established pasture are those which include grazing animals. The comprehensive study by Thom et al., (1986a,b&c) is an example of this.

Bellotti (1984) suggested that the term 'pasture establishment' should go beyond the point where seedlings become dependent on photosynthesis for their energy source. He also noted that to refer only to the germination, emergence, and early seedling growth stages as a description of 'pasture establishment' was unacceptable because seedlings had not by then survived periods of high mortality risk and consequently, had not stabilised as populations. The success of establishing new pasture is largely dependent on establishing a sufficient population of plants to affect seasonal or total production (Baker, 1980; Campbell and Kunelius, 1984), controlling competition from existing vegetation (Kunelius et al., 1982; Ritchie, 1986a), and weeds which may invade establishing pasture, especially where slow establishing species are used (Brock, 1982; Bellotti and Blair, 1989a). It is clear that the resultant sward is a function of interactions between seedlings and their environment which occur after early stages of growth.

By way of contrast to the enlightened approach taken by Bellotti (loc cit) is an earlier study by Charles (1961) which recorded 25% survival of viable *Lolium perenne* seed only 2 months after a spring sowing at Aberystwyth, Wales, at 21 kg ha^{-1}. Sowing method was not specified but is presumed to be by conventional cultivation as there were no reports of pasture establishment by direct drilling in the United Kingdom at that stage but it is not known if the plants were concentrated in rows or were broadcast sown. The authors did not address the issue of whether or not plant loss occurred after or before seedling emergence. Their figures for plant loss were abnormally high and considering the short time span at which 'survival' was recorded it may have been more accurate to describe the situation as 'poor establishment' rather than 'poor survival'.

2.1.2 Direct Drilling

The term 'direct drilling' is also often misapplied or used erroneously. Direct drilling, overdrilling, sod seeding, undersowing, direct seeding, zero-tillage, no-tillage and chemical ploughing are sometimes used synonymously. While each refers to sowing seed into undisturbed soil, there are subtle differences between these terms which are related to the level of control of the vegetation present at the time of sowing. Failure to distinguish between these terms for pasture establishment does not acknowledge the important seedling / resident vegetation relations that occur during seedling establishment which often determine final sward composition from pasture sowings.

Direct drilling is the term given to the practice of sowing seed directly into undisturbed soil where the previous vegetation has been killed or suppressed by herbicides (blanket spraying) or natural mortality (Baker, 1983). With the complete removal of existing vegetation, plant competition is limited to introduced species only. Overdrilling is described as the special branch of direct drilling where pasture or crop seeds are drilled into living (and therefore competing) pasture (Baker loc cit). The term is also used when only partial control of resident herbage is sought, eg band spraying at drilling (Ritchie 1986a). Overdrilling is often referred to as 'undersowing' (Mr S. Moloney, pers comm. 1991). This term more properly describes the situation where pasture seeds are drilled into cultivated soil at the same time as a crop (Smetham, 1979). Sod seeding is synonymous with direct drilling because it deals exclusively with undisturbed pasture, turf or rangeland.

Oversowing pasture (broadcasting seed onto either killed or live vegetation on the soil surface) was not recommended for pasture renovation on drillable soil surfaces due to high mortality of seed (Cullen, 1966; Robertson and Thom, 1987). The method is highly dependent on climatic conditions after sowing (Barker et al., 1988) and will not be considered further in this thesis.

2.1.3 Development of pasture establishment techniques in New Zealand

Changing pasture composition to improve the quality and quantity of feed available to stock (eg. increasing carrying capacity with winter active grasses or providing quality feed for lamb finishing in the autumn with legumes or herbs) has been the goal of pastoral farmers in New Zealand and elsewhere for many years. Improving pastures by establishing new species using methods requiring little or no soil disturbance has been under investigation in New Zealand since the early 1950's and began with the experiments of Blackmore (1952), using chemicals to control resident vegetation. Some of the initial drive came from the necessity to find alternative establishment methods where land was too steep for cultivation (Blackmore and Matthews, 1958) but the need to reduce the potential for soil erosion, to reduce time and energy inputs as cost saving measures and maintain soil structure was also recognised (Cross, 1963; Robinson and Cross, 1960).

Chemicals such as dalapon and amitrol were used in combination to kill existing vegetation, a technique widely referred to as 'chemical ploughing' (Ferens, 1958, Matthews, 1958). However, these chemicals had residual toxicity, so pasture and other seeds could be adversely affected if sown within 10 to 20 days of spraying (Matthews, 1959; Thompson, 1960). Broadleaved weeds such as dandelions (*Taraxacum officinale* Weber) and plantains (*Plantago spp*) and annual weed grasses such as annual poa (*Poa annua*) and thistles (nodding and winged, *Carduus spp*) sometimes re-established from seed during the intervening period between spraying and sowing, to compete with newly introduced species (Smetham, 1979).

The availability of bipyridyl herbicides (paraquat, diquat) in the early 1960's offered major advantages to the no-tillage system because they were rapidly inactivated on contact with the soil and seed could be safely sown immediately after spraying (Blackmore, 1964). Simultaneous application of paraquat at the time of drilling has also been successful (Collins, 1970). However, unlike dalapon, paraquat had little effect on stoloniferous and rhizomatous species such as paspalum (*Paspalum dilatatum*) and couch (*Agropyron repens*) since it was only taken up through the leaf and not translocated. The addition of dicamba to paraquat increased the effectiveness against broadleaved weeds and was required where destruction of white clover (*Trifolium repens* L.) was necessary, however this precluded the sowing of a legume crop until 8 weeks after spraying (O'Connor, 1990).

Glyphosate, a chemical which became available in the mid 1970's, has proved to be ideally suited to no-tillage. Absorbed through the foliage, readily and quickly translocated into the root system, and inactivated on soil contact, glyphosate kills a wide range of herbaceous plants including strongly rhizomatous grasses like couch, paspalum and browntop (*Agrostis tenuis*) (O'Conner, 1990). White clover is not killed by glyphosate but is usually suppressed for a period of time. Despite the advantages of glyphosate, paraquat was widely used in New Zealand for killing turf until the mid 1980's when the cost of glyphosate was reduced to a price similar to paraquat. Glyphosate also became more popular because it was safer to use than paraquat (J.F. Maber, pers comm., 1991).

Blackmore (1958a) distinguished two categories when considering pasture establishment using chemicals. These were pasture renewal and pasture renovation. Later, Ritchie (1986b) ratified these distinctions. Pasture renewal describes the situation where a radical change in pasture species is required (eg. from a browntop dominant sward to ryegrass-white clover sward) it has long been recognised that control of resident vegetation was essential for successful establishment of new species (Blackmore and Matthews, 1958), particularly in the immediate seedling zone (Ritchie, 1986a). This involves a complete kill of vegetation with either a blanket application of herbicide or by cultivation. Pasture renovation describes the situation where more subtle changes in composition are required (eg increasing the population of desirable species in an 'open' pasture by overdrilling).

As well as using chemicals to remove competition, mechanical methods were also advocated by early workers. Blackmore (1958b) designed a special drill opener for bursting the soil surface aside, known as the 'Blackmore grassland tip'. The main limitations were high wear rate on abrasive soils and blockage by trash. Cross (1957) favoured the use of dished disc openers to scuff aside a 40-50mm plant free strip where seed was deposited on a substantial groove. This included disc openers with a skimmer. The 'slot-seeder' described by Squires et al., (1979) worked on a similar principle but had two disc coulters and a mouldboard shaped tine to remove a narrow strip of turf (25mm). More recently, rotary cultivators have been used to pulverise and mix a 100mm strip into which seed and fertiliser are deposited (Dunbar et al., 1980, Anonymous, 1986). The system was moderately successful but was slow in comparison with other drilling equipment and had high running costs associated with driving the rotors.

Later workers showed that mechanical modification of the seedling environment to avoid competition and provision of a suitable microenvironment for reliable seedling establishment were in conflict (Baker, 1980). Retaining a vegetative cover (mulch) over the drilled seed was found to insulate the seed groove from drying out (Baker, 1976b) and was also found to improve emergence in wet soils (Chaudhry et al., 1987). The performance of various direct drill openers is further addressed in section 2.1.5.1. For direct drill openers which create little ground disturbance there is little mechanical effect in reducing competition. Early trials showed that spraying a band of vegetation bordering each side of the seed groove with herbicide (50-80mm width) to temporarily remove localised competition was a practical alternative to mechanical removal of competition leaving the vegetative cover intact, but equipment and herbicides were limited (disc or tine openers and paraquat, Blackmore, 1962, Collins, 1970, Barr, 1980). More recent work using press wheels to roll-on glyphosate in strips either side of closed "inverted T"-shaped slot proved to be a simpler and more effective system (Ritchie, 1986a) than previous systems. However, banded herbicide application has never been popular amongst farmers or contractors because of the increased complexity of the drilling operation (Baker, 1980), a greater dependency on intensive and controlled grazing management for successful establishment of new species (Ritchie, 1986a), and limited long term success relative to blanket application (Lane et al., 1993). Also, the cost of herbicides is less of a concern compared with other inputs such as seed, machinery and labour costs at present than it was 10-15 years ago.

2.1.4 Tillage Effects on Soil Relative to Pasture Establishment

Conventional cultivation involves inverting or mixing 100% of topsoil (0-300mm) using a mouldboard plough leaving a bare soil surface. Concern over lost productivity and pollution of waterways resulting from soil erosion has become apparent over the last 20 years (Unger and McCalla, 1980; Moldenhauer et al., 1985; Stinner and House, 1989). It is widely accepted that maintaining a groundcover of vegetative residue is the most effective means of protecting the soil from both water (Edwards and Amerman, 1984; Rose, 1985; Roth et al., 1988) and wind erosion (Woodruff and Siddoway, 1965; Skidmore, 1988). These concerns have led to a dramatic increase in the use of crop establishment systems which leave a larger proportion of vegetative residue on the soil surface (ie. systems termed "conservation tillage") than conventional cultivation. No-tillage is described as the most effective means of erosion control of the various conservation tillage systems practiced (Stinner and House, 1989). The area under no-tillage in the USA is estimated to have increased by nearly 700% over the period from 1972 to 1992 (Lessiter, 1992). Sloping land is more responsive in terms of percentage reduction in soil loss in this respect than flat land (Rose, 1985; Naylor, 1983) which is of particular interest in New Zealand.

The popularity of no-tillage as a method of pasture establishment in New Zealand has also increased in recent years, mostly for economic reasons, rather than the soil conservation concerns driving the increases shown in the USA. Full cultivation is unpopular amongst New Zealand farmers as it is more costly in terms of time, energy, capital input, and lost pasture production compared to direct drilling or overdrilling (Thom et al., 1987b). Also soil consolidation is reduced and soil structure is destroyed with full cultivation. Full cultivation is generally not considered necessary unless levelling of the paddock is required (Ritchie, 1986b). Protection of the soil from rain drop impact, exposure to wind, improved water infiltration and moisture conservation and reduced run-off, and maintenance or improvement of soil organic matter levels and soil aggregate stability are demonstrated benefits of retaining surface residues in cropping systems (Unger and McCalla, 1980; Lal, 1982; Francis et al., 1987). Estimates for total energy savings possible for no-tillage as compared with conventional cultivation range from 50 to 80% (Allen et al. 1975; Phillips et al. 1980; Crosson et al. 1986).

Problems associated with resident insect pests such as foliar feeding Argentine stem weevil (*Listronotus bonariensis* Kuschel). porina larvae (*Wiseana cervinata*) and root feeding grass grub (*Costelytra zealandica*) and non-insect pests such as slugs (*Decorceras spp, Malix gagates*) (McCallum and Thomson, 1990) are compounded by no-tillage because the destructive effects of intensive cultivation on pest populations and their habitats do not occur (Barker et al., 1989). Resident pests turn their attention to tender and succulent seedlings as they germinate and emerge. Follas (1982) cited numerous reports which apparently indicated a general increase in pest problems under no-tillage with slugs appearing to be of particular concern. The drill slots themselves provide pests with a convenient pathway from one seedling to the next (Allen, 1979). Interaction between drill slot geometry and slug damage in that favourable moisture regimes within the slot may harbour slugs (Baker, 1976a) but this is as yet unproven (Follas, 1982).

Until the advent of herbicides, weed control was the primary reason for cultivation (Witt, 1984). Although cultivation kills weeds it also brings weed seeds to the surface where they may subsequently germinate (Roberts and Feast, 1973). The pool of buried weed seeds the soil may harbour is staggering. Estimates range from 1400 to 19000 seeds m^{-2}, including fresh unburied seeds in the cultivation zone to between 650 and 1170 from 3 to 20 cm deep (Wesson and Wareing, 1969). The advantage of lower weed burdens during establishment, attributable to direct drilled pastures as compared with cultivated seedbeds, has long been recognised (Blackmore and Matthews, 1958). Inwood (1990) reported that twice the number of weed seedlings were present with conventional cultivation as compared with direct drilled areas at 56 days after sowing. In fact, in a cropping situation if weeds are prevented from seeding, continuous direct drilling offers the possibility of exhausting the seeds in the soil surface so that after a period of time no new seedlings emerge (Wilson, 1981). There are reports of nil herbicide use in continuous direct drill cropping regimes (Kohn, 1989).

In New Zealand the timing of sowing is determined by the potential for weed ingress into the developing sward. Cross (1959) suggested that autumn sowing was more popular than spring sowing because of reduced weed competition and more reliable moisture regime associated with autumn sowing. This was later reaffirmed by Askin (1990) and is evidenced from farmer survey results (Sangakkara et al., 1982; Empson, 1992). However, autumn may not be appropriate for all localities or for all pasture species (Harris et al., 1973; Milne and Fraser, 1993).

Retention of surface residues in crop or pasture establishment systems not only has implications for edaphic factors such as stability, potential for erosion, chemical nature, water relations, the balance of soil flora and fauna and weed population, but has important implications for machinery design also. Plant residue on the soil surface adversely affects some soil engaging tools and the placement of chemicals and seed on or into the ground (Erbach et al., 1983), which places special constraints on drill design and function (Barr, 1981). In order to cope with surface residues direct drill openers may either chop it up, bury it, push it into the slot, or sweep it aside for mechanical expediency (Baker and Choudhary, 1988). This is contrary to the macro-management strategy over the field which focuses on retaining surface cover. The requirement for direct drill openers to pass through surface residues, and sow seed without physical machine blockages may determine the spacing between openers and staggering between banks of openers to allow 'trash flow' on a direct or no-tillage seed drill. In other words mechanical constraints set the boundaries within which seedlings must establish and contribute to a sward. This may not coincide with optimal row spacing for the sown species, especially perennial grass species.

2.1.5 Soil Microenvironment Effects on Germination and Emergence of Pasture Species

2.1.5.1 Opener Design Considerations.

Soil moisture and temperature are the main factors of the physical environment influencing seed dormancy, germination and emergence (McKeon and Kalma, 1977; Smith and Yonts, 1989). In practice, as far as temperate pasture species are concerned, moisture is the dominant factor (McWilliam and Dowling, 1970). It follows that the influence that openers for no-tillage seed drills have on moisture relations between seed, soil and ambient conditions (soil and atmosphere) is important to germination and emergence (Bufton, 1984; Baker and Choudhary, 1988). The important physical factors which no-till openers may modify were identified by Choudhary (1985) to be control of vegetation competition, seed groove shape, seed depth control, crop residue handling, fertiliser placement and pest management, with interrelationships between many of these also noted. Seed groove shape and the nature and quantity of slot cover as effected by opener design have been shown to be most important to seed germination and subsurface seedling survival (Baker, 1976b).

Baker and his colleagues at Massey University in Palmerston North, New Zealand during the period from the early 1970's until the late 1980's carried out intensive research focusing on the biological consequences of opener design and successfully quantified why 'failures' had occurred. While groove shape is of little significance under ideal conditions (Choudhary, 1985), Baker (1995) maintained that for no-tillage to be widely accepted by farmers, a fail safe system had to be developed to cope with a range of conditions. This philosophy drove the development of the successful Cross-Slot™ design no-till opener (Baker and Saxton, 1988; Saxton and Baker, 1990).

The groove into which seed is deposited by no-tillage openers can be categorised as forming one of three general shapes: "V"-shaped, "U"-shaped or "inverted T"-shaped. The formation, strengths and weaknesses of these contrasting shapes are described below.

The "V"-shaped slot, commonly formed by inclined double or triple disc configuration, is most popular because the opener handles residue without blockages and are relatively inexpensive to maintain (Baker, 1985). However, the wedging action of the discs in the soil imposes stresses on the germinating seed because of the tendency to smear and compact slot walls and produce little or no loose material for use as covering material. These problems are more prevalent in 'heavy' high clay content soils than 'light' more friable volcanic and sandier soils (Ward et al., 1991). Baker, (1976a) and Choudhary and Baker, (1980; 1981a, b; 1982) showed that although initial seed/soil contact was good and usually seed germinated better than for "U" shaped grooves, final emergence was often poor under drying conditions, because seedlings became desiccated as seed cover was limited. In wet soils, the increase in bulk density in the immediate seed zone led to a reduction in earthworm numbers resulting in reduced oxygen diffusion rates, emerged seedlings and seedling growth (Chaudhry et al., 1987). Double and triple disc openers also suffer from a problem known as "hairpinning" or "tucking". Uncut residue is forced into the slot with the seed which may hinder seed/soil contact reducing the chance of germination in dry soils and in wet soils, phytotoxins produced by decomposing residues in the slot may reduce emergence by adversely affecting germinating seedlings (Lynch 1978). This illustrates the significance of 'micro-management' of residue by no-till openers to seed germination and emergence of the seedling (Baker and Choudhary, 1988).

The "U"-shaped slots may be formed by a range of openers, including simple hoe coulters, flat angled and dished discs and power-till openers. Depending on the opener used and soil moisture content and soil type, formation of the "U"-shaped slot produces varying amounts of loose soil available for seed coverage, more so than "V"-shaped slots. This improved moisture retention in the seed groove reduces the risk of seedling desiccation but results in poorer seed-soil contact relative to the latter slot shape (Choudhary and Baker, 1980; 1981a, b; 1982). Hoe-type openers tend to push the residue aside. While this avoids 'hairpinning', control over moisture loss is lost as residue is not maintained strictly over the drill slot (Baker and Choudhary, 1988). The rigid shanks to which hoe-type openers are attached predispose them to blockages by surface residue more readily than rolling discs (Erbach et al., 1983).

The "inverted T"-shaped slot formed by an opener initially referred to as a "chisel" opener (Baker, 1976b), but known commercially as the "Baker Boot", led to the development of a Bio-Blade™ (Baker et al., 1979). Earlier forms of this opener were also referred to as "winged" openers as they were essentially a rigid tine with slightly inclined wings on either side. The opener is now referred to as the Cross-Slot™ opener. With this opener two residue-covered soil flaps on either side of the central disc are lifted upwards and outwards and then pressed back into place by the following press wheels to form the slot shape, resulting in almost complete soil and residue cover over the seed (Baker and Choudhary, 1988). The opener can plant through a wide range of residue conditions without compromising slot shape or seed placement, while avoiding hairpinning (Baker et al., 1979). Extensive laboratory and field trials showed that the "inverted T"-shaped slot to have a significant advantage over alternative slot shapes in terms of percentage seedling emergence in dry soil conditions (Baker, 1976; Choudhary and Baker, 1980; 1981a, b; 1982, Charles et al., 1991a; Wilkins et al., 1992). Moisture vapour retention in the seed groove was the determinant factor in emergence and these experiments led to the classification of slot shape according to their ability to retain vapour phase moisture (described as "moisture vapour potential captivity" - MVPC). Low, medium and high MVPC were associated with "V"-, "U"- and "inverted T"-shaped slots respectively.

Slot geometry had equal significance in wet soils (Baker et al., 1987, 1988; Chaudhry et al., 1987; Chaudhry and Baker, 1988). Sustaining oxygen diffusion rates in the immediate seed zone by encouraging earthworms and maintaining residue cover were found to be essential to successful seedling emergence in wet soils (Choudhary and Baker, 1988). In this respect, "winged" and hoe openers ("inverted T"- and "U"-shaped slots respectively) performed better than "V"-shaped slots (Baker et al., 1988; Chaudhry et al., 1987).

Slot geometry is also important where fertiliser is required at sowing. Sub-surface banding was more effective in supplying nitrogen fertiliser to emerging seedlings as compared with surface-applied broadcast fertiliser (Baker and Afzal, 1981; Babowicz et al., 1985; Locke and Hons, 1988; Choudhary et al., 1988). Given that fertiliser is to be placed in the slot at sowing, it is desirable to physically separate seed and fertiliser in the drill slot to avoid damage to the emerging seedling (Mason, 1971, 1985; Menzies, 1982a; Baker and Afzal, 1986). The potential for seedling damage is higher when using high analysis nitrogenous fertilisers (eg. Diammonium phosphate) (Babowicz et al., 1985) as compared with lower analysis phosphatic fertilisers (eg superphosphate) (Mason, 1971). Dry soil conditions were thought to exacerbate this problem (Baker and Afzal, 1986). Separation is difficult with both "V"- and "U"-shaped slots (Payton et al., 1985; Hyde et al., 1987; Wilkins et al., 1983) and simple rigid tine openers which form "inverted T"-shaped slots. Separation in the horizontal plane is a feature of the Cross-Slot™ opener (Baker and Saxton, 1988; Choudhary et al., 1988).

2.1.5.2. Influence of seed depth.

It is well recognised that the depth of seed placement has a major influence on seed germination and seedling emergence. This is dealt with broadly and briefly here and in more specific detail in the discussion sections (4.1.1.3 and 4.1.2.3), as are temperature effects which follow.

Numerous studies of the relationship between seed depth and seed germination and seedling emergence have been carried out for a wide range of agronomically significant species in laboratory and field situations for seedbeds prepared by conventional cultivation (Cereals - Banks and Gilmour, 1979; Giblett, 1983; Goodman and Scott, 1985: Pasture - Murphy and Arny, 1939; Moore, 1943; Erikson, 1946; Black, 1959; Cullen, 1966; Arnott, 1969; Brock, 1973; 1983). Generally seedling emergence is improved as seed depth is increased from 0 to 15mm because of improved moisture availability and protection from surface predators but may or may not increase as depth is increased beyond 15mm depending on moisture availability and species.

Hadfield (1993), who carried out a field trial on seed depth effects on direct drilled wheat (*Triticum aestivum*) and lupin (*Lupinus angustifolius*) emergence cited numerous reports of similar trials for no-tillage grain crops. In contrast there is a paucity of detailed information relating to the response of pasture species (grasses and legumes) to variation in seed depth under no-tillage. A series of studies by B.D. Campbell (Campbell, 1981; Campbell, 1985; Campbell et al., 1983; Campbell et al., 1985) with direct drilled red clover (*Trifolium pratense*) provides a useful starting point for later discussion. It is worth noting that clovers are part of the dicotyledenous legume family with an epigeal pattern of germination whereby the elongation of the hypocotyl after germination carries the cotyledons upwards above soil level (Langer 1982). Such species tend to have more problems emerging than grass seedlings (monocotyledonous plants) which have a hypogeal pattern of germination (Martin et al., 1976, Cooper, 1977; Hadfield, 1993). Several authors have shown that seed depth has a major impact on clover emergence (Murphy and Arny, 1939; Moore, 1943; Arndt, 1965; Cooper, 1977; Campbell, 1981; 1985; Campbell et al., 1985; Hayes and Williams, 1986; Charles et al., 1991b).

Controlling seed depth to optimise soil physical conditions (moisture, temperature, aeration and soil impedance or strength) for maximal seedling emergence with seed drills is more difficult for no-till situations than for conventional cultivation as rough surfaces or surface residues present physical obstacles to machinery operation (Erbach et al., 1983). Increasing variation in seed depth placement has been shown to reduce emergence of peas (*Pisum sativum*)and fodder radish (*Raphanus sativus*) (Choudhary et al., 1985).

In discussing seed depth effects on emergence, slot shape must be considered for reasons previously mentioned. The nature and quantity of slot or seed cover is commonly a crucial factor. Seed sown at 20mm depth below the immediate soil surface by a double disc opener producing a "V"-shaped slot will have a different depth of cover compared with seed sown with a Cross-Slot opener in an "inverted T"-shaped slot at the same nominal "depth" (ie. seed depth below the soil surface is not necessarily synonymous with depth of seed cover). Results from a recent direct drilling trial illustrate the range in field emergence responses possible from depth variation (from 38% for "Grasslands Harkari" mountain broome (*Bromus sitchensis*) to 1.6 % for pawera red clover 5 weeks after sowing with depth varying from 2 to 60mm (Woodman et al., 1990). It was not stated what type of opener was used on the drill or whether the trial was harrowed after drilling.

Clearly, depth control and control over seed cover achieved by a direct drill opener is an important aspect of pasture establishment by direct drilling, but is not extensively reported in the literature. Most of the literature concerned have dealt with these factors with conventionally cultivated soils. Legitimate concerns have been raised over the extrapolation of results from the tilled to untilled situations (Baker, 1976b; Baker and Choudhary, 1982). Untilled seedbeds were thought to be less "forgiving" of variation of seed depth/seed cover than tilled seedbeds.

2.1.5.3 Temperature effects.

Providing adequate moisture is available to the seed, temperature is the main factor determining the rate of seedling emergence (McWilliam et al., 1970; Hill et al., 1985; Charles et al., 1991b). Generally as temperature increases in the range 3 to 30° C, the time for germination and emergence is reduced. Slower emergence increases the risk of seedlings succumbing to unfavourable moisture conditions, insect and disease attack (Campbell and Swain, 1973; Askin, 1990). Temperature-germination relationships show that total germination (percent) of herbage grasses (Charlton et al., 1986) and herbage legumes (Hampton et al., 1987) is less affected by temperature than the rate of germination (% germination of viable seed per day). For example Charles et al., (1991b) reported 100% emergence for surface sown clover in cold storage (3°C). In that case emergence was recorded when the shoot length exceeded 2mm so germination percentage was synonymous with emergence percentage. Interestingly their study also reported that when the temperature of clover seeds held at 3 and 6°C and sown at 15-45mm depth was raised to 24°C no further germination of clover seeds occurred, indicating seeds had already germinated but failed to emerge.

2.2 Plants Relationships in Establishing Pasture

Relationships between seedlings establishing from sown seeds and between establishing seedlings and unsown vegetation are key determinants of final pasture composition. Individual plants within establishing swards are continually changing in size and density through the effects of interspecific and intraspecific competition.

Interpretations of 'competition' vary amongst authors but are generally based on the concept of combined demand of individuals exceeding the resources available to them. The classic definition of competition provided by Donald (1963) seems appropriate for this study, that is:

> "competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms".

Plants must be in close proximity before competition will occur. The most common factors for which competition occurs are water, nutrients and light, termed the "supply" factors, (Donald, 1963); these are modified by temperature, defoliation, presence of grazing animals and soil microbiological effects, termed the "conditioning" factors (Harper, 1977).

Competition may occur above or below ground, the outcome dependent on the relative abilities of each plant to capture and utilise available resources. Superior relative growth rate, especially root growth rate and earlier emergence appeared to be a regular feature of plants which dominated a particular stand during establishment (Frame et al., 1985; Ford and Diggle, 1981; Benjamin and Hardwick, 1986; Brock, 1973; 1983; Harper, 1977; Rhodes, 1968a & b; Eagles, 1972). Seed size was found to be positively related to the relative aggressiveness of a seedling within an establishing population (Evans, 1973; Brougham, 1959; Hill et al., 1985) although the relationship was not linear across all species (Brock, 1983; Hoen, 1968).

Competition is one aspect of a wider consideration of interactions between neighbouring plants known as 'interference' which may be competitive or symbiotic in nature (Hall, 1974; Grime, 1979). With direct drilling, seeds are placed in discrete rows and the existing vegetation is completely removed so for a given seed rate, the opportunity for competition or 'interference' within introduced species is greater than where seeds have been broadcast sown. Plant relationships in establishing pasture have been studied since the turn of the century. For example, Rhodes (1968a) cited the work of Gilchrist in 1909 which outlined the difficulty of obtaining stands of species such as meadow fescue and cocksfoot when sown in association the more aggressive perennial ryegrass. By contrast, the plant population dynamics of direct drilled pasture has received little attention in the literature compared with pasture sown by broadcasting seed on to cultivated soil.

2.2.1 Effect of Seed Density

The form and growth rate of a plant are influenced by the proximity of neighbours which alter the environment of the individual. Harper (1977) noted that grassland plants react to density stress by plastic responses in plant form as well as by mortality. The plastic nature of grassland plants is well illustrated by Pinero and Harris (1978). They measured 8000 to 10000 tillers m^{-2} in cattle pasture as compared with 15000 to 20000 tillers m^{-2} reflecting rotational and set stocked grazing management systems, respectively.

Ellison (1987) noted that studies of individual plant response to competition in monocultures have resulted in the development of a self thinning rule, the one "law" of plant ecology. Yoda et al., (1963) working with a variety of dicotyledonous species showed that there was a stable mathematical relationship between mean plant size of surviving plants and residual density at various stages in the development of a population. The number of surviving individuals is related to their mean weight. This has become known as the $^3/_2$ power law of self thinning and has been reviewed by Westoby (1984). Plant relations at high density lead to smaller plants of lower dry weight than those grown at low densities. The relationship was thought to encompass a complete size range of plants from high density populations of small plants (annual herbs and perennials with short lived shoots), to sparse populations of large trees (Begon et al., 1986). However, recent literature (post 1987) has virtually rejected the 'law' after re-evaluation of original and new data sets which have shown wide variability for slope and are not suitable to support a generalised law (Weller, 1987). Lonsdale, (1990) showed that some of this variability was related to inclusion of inappropriate data sets. Lonsdale (1990) concurred with Weller (1987) suggesting that there was no evidence for a $-^{3}/_{2}$ power rule of self thinning, but unlike Weller did not dismiss the idea of the existence of "an ideal slope".

The slope of the line which compares plant size to density has been tested with grassland species (*Lolium* sp, Kays and Harper, 1974; Lonsdale and Watkinson, 1982). The slope of the lines changes with the age and density of stand in a constant environment. For a range of densities sown (320 to 10000 seeds m^{-2}) initially there is a 'Competition-Density effect' where the slope is -1, where after a sufficient period of growth, the stress of competition reduces plant size but no plant death occurs. This occurs earlier at higher densities (Donald, 1963). At a later stage plants are at the $-^{3}/_{2}$ line when plant death occurs. Mortality was driven by the rate of biomass accumulation and was slower when conditions for growth were poor. Westoby (1984) suggested that a change in an environmental factor such as light may move the line closer or further from the origin.

With perennial grassland species (eg. ryegrass) the situation is confounded by the fact that both genets (plants) and modules (tillers) are present in the population. Module numbers can increase with time but there is less opportunity for an increase in genet number especially in the controlled and near optimal environment under which most of these experiments take place. This is evidenced by data from Kays and Harper (1974) and Lonsdale and Watkinson (1982) which showed good agreement with the $-^{3}/_{2}$ thinning law at densities above 1000 plants m^{-2} but a variable relationship below this density.

The density of sown pasture is likely to fall in the range 250-2000 seeds m^{-2} (5-35 kg ha^{-1}, *L. perenne* at 0.0019 g per seed), similar to the lower densities of the experiments cited above. Plant populations of sown pasture will exhibit size-density compensation. While the slope of the sown pasture line is closer to -1 and approaches $-^{3}/_{2}$ initially (up to 6 months after sowing before grazing), data from Matthew (1992) show that the resultant slope for grazed pasture is steeper than $-^{3}/_{2}$. This is apparently a function of the non-constant leaf-area-index associated with differences in defoliation intensity (Dr. C Matthew, pers comm, 1994). In the experiments of Kays and Harper (1974) and Lonsdale and Watkinson (1982) seeds were broadcast sown ie. sown evenly but not equidistantly, therefore resultant seedlings were likely to be further from their nearest neighbour (on average) in the work cited than in a situation where pasture species are drilled in rows. Whether or not the size-density relationships will be similar for pasture plants at similar densities which are sown in rows as compared with broadcast sown is not addressed in the literature.

Begon et al., (1986) described another pattern frequently uncovered by plant ecologists, that of "the law of constant final yield". This describes the situation where initial yields increase with seed density but eventually become similar for all seeding densities (Donald, 1951; Brougham, 1954a; Harper, 1977). However, this relationship only remains true for vegetative yield and not reproductive yield (Donald, 1963).

Within a population, plants vary in their size (Weiner, 1985). Measures of the variability of plant size within a population have been used successfully to describe the level and timing of competitive stress within grassland populations in controlled experiments (Harris and Sedcole, 1974) and in the field (Bellotti and Blair, 1987). Populations that exhibited "normal" size frequency distributions initially, tended to exhibit an increasingly positively skewed distribution with the passage of time. The resulting 'L-shaped' frequency distribution of plant weight is explained by the idea that differences in size were exacerbated as large plants usurped resources and grew at the expense of smaller plants. This was termed "dominance and suppression" (Harper, 1977). From a study of the effect of plant density (range 68 to 2232 plants m^{-2}) with *Kochia scorparia*, an annual plant, Franco and Harper (1988) concluded that competition for "space" (as a source of light, nutrients and water) resulted in a regular periodic distribution of dominant and suppressed plants they termed "competition-effect-wave" and was thought to be caused by "neighbour effects". Plants which dominated (shaded) their neighbours released their neighbours' neighbour from competition. Apparently work by Mead, cited by Harper (loc cit) showed a similar effect with carrots (*Daucus carota*). Where self thinning has occurred Benjamin and Hardwick (1986) and Ford and Diggle (1981) suggested that the distribution of plant size within a population would return to a normal distribution. The concept of size frequency distribution is discussed further in section 4.3.1.

Sowing or seed rates (kg ha^{-1}) determine the number of viable seeds sown per unit area (depending on seed weight). Emergence performance of the seeds (influenced by moisture availability, temperature and light) determine the density of an establishing sward which affects interspecific and intraspecific competition. Many studies of establishing pasture have demonstrated that high seeding rates of perennial ryegrass (20-35 kg ha^{-1}) have little advantage over low seeding rates (6-15 kg ha^{-1}) in terms of annual accumulation of herbage mass (Brougham, 1954a,b &d; Cullen and Meeklah, 1959; Ashworth, 1961b; Kruez 1977; Keane, 1980; Frame and Boyd, 1986). Those studies were carried out using conventional cultivation. Only a limited number of trials have been sown by direct drilling (Ryan et al., 1979). Brougham (1954a) speculated that larger individuals (particularly ryegrass) in the pastures developing from lighter seed rates (17 kg ha^{-1}) had a larger supply of stored plant nutrients available for regrowth and recovered better from hard grazing than smaller plants developed from seeds sown at high sowing rates.

Where other less aggressive species were sown in conjunction with perennial ryegrass, greater suppression of these species was noted as ryegrass seed rates increased. Cullen and Meeklah (1959) reported better suppression of weeds with higher ryegrass seeding rates. Where low rates of ryegrass seed were used, low ryegrass yields were recorded until 6 months from sowing, after which yields were similar from both high and low sowing rates. However, where plots were sprayed for weed control with phenoxybutyrics there was no difference in the yield of ryegrass from high and low seeding rates 3 months after sowing.

Equilibrium plant number in an established sward has been estimated at 3-400 plants m^{-2} (Kruez, 1977; Sangakkara and Roberts, 1982). Simon and Lemaire (1987) found that *L. perenne* ceased tillering at 73 days after sowing. Swards had reached a leaf area index of approximately 3, and 6000 tillers m^{-2} independent of initial sowing rate, which ranged from 5 to 35 kg ha^{-1}. This illustrates the tillering capacity of ryegrass and the flexibility possible in seeding rates. However, there is usually some time delay to reach these yield levels with lower seeding rates (Brougham, 1954d).

If every perennial grass seed sown, germinated and emerged, only 7.2 kg ha^{-1} of *L. perenne* (0.0018 g/seed) would be required to provide 400 seeds m^{-2}. Therefore, current seeding rate recommendations for direct drilled perennial ryegrass based pasture of 10 to 15 kg ha^{-1} (Thom et al., 1987b; Ritchie, 1986b) are close to the practical minimum considering field emergence will always be less than 100% of viable seed sown because of the risk of poor emergence associated with the drilling technology currently in use under less than optimal conditions, the requirement for sown species to compete with unsown species (ie. some 'weed suppression' is needed) and to withstand pest and disease attack.

Donald (1963) highlighted the relationship between population density and moisture status. Lower plant populations were reported to yield more than high plant populations where water stress became a problem ie. in areas or seasons of reduced water availability compared with areas or seasons which were well watered and could sustain higher populations. He thought that the larger plants which developed at lower densities had improved water status and suffered less from water stress. Later Hoen (1968) concluded that survival of a plant depends on it's ability to take up the moisture needed during the first summer after sowing. In his study of *Dactylis glomerata* and *Phalaris aquatica* he found that relatively larger plants (assumed to have proportionally larger root mass) survived a summer better than smaller plants. The experiment was conducted at Wagga Wagga (New South Wales, Australia) which has a summer rainfall of 150 mm. An example of how seeding rates are adjusted to match the yield potential of the environment is a comparison of the relatively low seeding rates used by Bellotti (1984) (6-7 kg ha^{-1}, perennial ryegrass) in a cool dry climate, with seed rates commonly used in the temperate climate of New Zealand (15-30 kg ha^{-1}, perennial ryegrass).

2.2.2 Root Competition

Plant roots compete for water and nutrients in the soil. When a crop is at seedling stage the roots will be far enough apart for uptake by one radicle not to interfere with supplies of soil factors to it's nearest neighbour. However, the soil soon becomes crowded as total root surface area may be over 100 times that of shoot and competition for supplies may begin (Trenbath, 1977). The supply of nutrients to the root surface depends on the concentration of nutrients in the soil solution. Nutrient movement within the soil is either by mass flow of the soil solution towards the root surface as a result of transpiration stream or by diffusion into the depleted root zone. Water and nitrate ions (NO^{3-}) are more mobile than potassium (K^{+}), phosphorus (HPO^{4-}) and ammonium ions (NH^{4+}) and are usually taken up at faster rate. The zones of water and NO^{3-} depletion around active roots are expected to overlap earliest (Brady, 1954). Non mobile nutrients (NH^{4+}, HPO^{4-}, K^{+}, Ca^{2+}) being strongly adsorbed onto the surfaces of soil particles, are at low concentrations in the soil water and therefore move almost exclusively down a concentration gradient (M. A. Hedley pers comm, 1988). Since diffusion is a relatively slow process, a HPO^{4-} depletion zone may extend only 7 mm in a week whereas an NO^{3-} depletion zone may extend up to 120 mm in the same time (Trenbath, 1977). Therefore competition for nitrogen is likely to occur before and at lower root density than competition for phosphorus because depletion shells overlap sooner (Nye and Tinker, 1977).

A study by Donald (1963) demonstrated the relationship between density and nutrient availability. The total yield of *Bromus willdenowii* was the same at densities of 1,3,6,12 or 50 plants/ pot where 0 or 150 mg N were added (ie 1 big plant equalled the yield of 50 little plants). However, with higher nutrient availability (addition of 700 mg N) more large plants (3-6) were required to equate with the yield of 50 small plants. This was the simplest of a number of examples given which showed that higher densities were required to maximise yield of annual crops, as nutrient status was increased. A further experiment with *Lolium rigidum* showed that percentage N fell from 1.8 at low densities to 1 in extremely crowded densities. More total N was taken up at low densities. This was thought to be due to the shallower rooting depth or less efficient soil exploration by poorly grown plants at high densities.

Genotypes adapted to low nutrient soils by increased root/shoot ratio had reduced prospects in competition for light when they were sown in a mixture with genotypes adapted to high fertility soils (Trenbath, 1977). The species adapted to high nutrient conditions usually responded more to increased nutrient supplies than the former. Thus the relative aggressiveness of a genotype in a given mixture varies greatly in response to changes in environmental conditions.

It is well known that the application of N fertiliser affects the grass/legume balance in a pasture (Donald, 1963; Frame and Boyd, 1986). Depressed white clover performance occurred where N fertiliser was used. On the other hand K fertiliser has been shown to encourage white clover growth (Blaser and Brady, 1950).

Brougham (1959) and Ashworth (1961b) reported that ryegrass suffered from N deficiency in the first spring following sowing where either high seed rates of ryegrass had been used or poor grazing management had caused the loss of white clover plants. The reduction in grass growth allows white clover to recover (if some plants are present) to an extent that N fixation begins and grass growth recommences. Cullen (1966) described this "see-saw" effect where clovers frequently dominate in the second year after establishment. He and Brougham (1959) reported that in general, the suppression of clovers by grasses was more marked under conditions of high fertility.

Cook (1985) demonstrated that root competition for nutrients between introduced seedlings of green panic grass and *Heteropogon contortus* (a native grassland sward of Queensland, Australia) was largely overcome by fertiliser application. N was supplied in a split dressing, 75 kg ha^{-1} at sowing, and 50 kg ha^{-1} 21 days after sowing. He concluded that fertiliser requirements of pasture oversown into live swards were greater compared to herbicide (glyphosate) treated swards. However, live swards also respond to N application. For this reason it is recommended that for overdrilling, application of nitrogen be delayed until seedlings are better able to utilise the nitrogen to help them to compete with resident plants (Barr, 1980; O'Connor, 1993).

The availability of different nutrients and the ability of a plant to explore the soil environment also appears to have a bearing on the competitive ability of particular individuals within a population.

Most studies of plant competition have dealt with a glasshouse situation where water and nutrients were thought to be non-limiting and shoot competition for light was considered the governing factor in both intra- and inter-specific competition. In contrast to this, root competition was found to occur sooner and with greater severity than shoot competition in field studies of establishing swards. A recent study by Seager (1987), where root and shoot competition were partitioned, confirmed earlier work by Rhodes (1968a); Eagles (1972); Sangakkara (1983); Cook and Ratcliff (1984) and Cook (1985), which clearly showed the significance of root competition. It's significance was also illustrated by Weiner (1985) who, from a glasshouse study showed that root interference occurred soon after germination of *Ipomea tricolor* (an annual vine) when sown at only 16 plants m^{-2}. He stated that "root competition was far more severe than shoot competition in its effect on plant size".

The below ground portion of pasture plants have been shown to be more sensitive to competition than above ground parts, so the investigation of the response of root systems to the 'competition-density' effect would provide useful information on processes involved in plant population dynamics. However, studies of plant root systems are laborious and time consuming and generally are of destructive rather than monitoring nature. Thus they are difficult to carry out but may provide useful information (Matthew, 1992)

2.2.3 Effect of Seed Size

Seed size has been shown to be an important determinant of the competitive ability of a seedling. Generally increasing seed size is implicated in the development of relatively larger, more vigorous seedlings within a stand (Arnott, 1969; Evans, 1973; Hill et al., 1985; Hampton, 1986). For example, Sangakkara and Roberts (1982) demonstrated that Matua prairie grass *(Bromus willdenowii)* at 0.010 g/seed, suppressed both perennial ryegrass and cocksfoot *(Dactylis glomerata)* at 0.0018 and 0.00084 g/seed, respectively, while ryegrass had a similar effect on cocksfoot. However, this was not always the case. Hill et al., (1985) reported that Italian ryegrass *(Lolium multiflorum)* at 0.0025-0.0043 g/seed was the species best adapted to variations in environment and competition at sowing because it had higher relative growth and tillering rates than prairie grass and tall fescue at 0.010 and 0.0018-0.0024 g/seed, respectively). Thus the aggressiveness of a seedling is a species characteristic as well as a function of seed size.

Seed size is significant to pasture establishment by direct drilling because early growth rate is a determining factor in the competitive ability of a seedling and so will influence the success of a seedling which may have to compete with unsown species for 'supply factors' the outcome of which will impact on the balance of species in the resulting pasture. Those individuals which have an early size advantage tend to remain at a competitive advantage throughout the establishment of the sward (Donald, 1963; Brougham and Harris, 1970; Evans, 1973; Harper, 1977; Trenbath, 1977; Ford and Diggle, 1981; Eagles, 1983; Hill et al., 1985; Begon et al., 1986; Benjamin and Hardwick, 1986).

2.2.4 Interspecific Competition

The 'classical' experiments designed to quantify the effects of one species on another are the "additive" design (Donald, 1963) and the "replacement series" design devised by de Wit (1960). In the additive design one species is grown at a constant standard density, the other species at a range of densities. The confounding effects of both proportional composition and density changes reduce the usefulness of these experiments (Harper, 1977). In the replacement series or substitution design, two species are sown in varying proportions while maintaining a constant overall density. The derivation of coefficients describing the performance of the two species, and called "relative crowding coefficient" (aggressiveness), relative yield total, relative replacement rate and ratio diagrams are clearly explained by Harper (1977).

Seager (1987) noted that the two major criticisms of both designs were lack of recognition of intraspecific competition and the confounding effects of shoot and root partitions. She cited Milthorpe as having stated that many of the arguments advanced with regard to interspecific competition also apply to intraspecific competition. The distinction between the two is rather artificial as both always operate in a mixed association and the differences are of degree rather than kind.

2.2.5 Plant Arrangement

Equally spaced plants (square planting) as opposed to random spacing or concentration in a row will give the minimum interference between neighbours and this will presumably lead to maximal plant yield and yield per unit area (Donald, 1963). Brown and Blaser (1968) suggested that regular, equidistant spaced plants required lower leaf area index to intercept a given percentage of light than randomly placed plants because of differences in leaf dispersion. However, Donald noted that the evidence of improved yields is not wholly consistent. This was reiterated by Weiner (1985).

Establishing pastures by direct drilling imposes mechanical constraints on seed distribution ie. speed, terrain and surface residue limits precision sowing within the rows and imposes restrictions on groove/opener widths and row spacing between rows.

The row spacing of drills commonly used for direct drilling and overdrilling in New Zealand is 150mm (Aitchison Industries, Wanganui; Clough Group, Timaru; AgrowPlow, Christchurch; Conner Shea, Morrrinsville). Row spacing may be wider than 150mm in other countries with arid areas which require comparatively lower populations consistent with lower potential yields where 'supply' factors are obviously limiting. However, in New Zealand many direct drill operators perceive 150mm row spacing as too wide for successful establishment of pasture. Concerns exist over the gap left between rows for weeds to colonise and that exposed soil indicates reduced interception of photosynthetically active radiation. This may be because previous pasture establishment experience is likely to have been with conventional cultivation where seed is broadcast or sown in 75mm rows with a "V-ring" roller drill (Ashworth, 1961a) and there are relatively fewer 'gaps' between sown plants. Direct drill operators have the option of using two passes of the drill, each at half the single pass rate, resulting in rows of a diamond or square pattern (Thom and Ritchie, 1987). Ritchie (1986a) suggested that competition between sown seedlings within a row or 'intra-row' competition would be reduced if two passes of the drill where carried out in a 'diamond' or 'crossed' pattern. Crossing drill rows of the first pass at 30-45° with the second pass was thought to give the best coverage of the paddock relative to alternative patterns (Thom and Ritchie, 1987). Also the potential for competition between seedlings at row intersections was thought to be reduced where drill rows crossed at those angles compared with square drilling pattern (crossing at 90°).

The premise that pasture seedlings should be sown closer than the 150mm row spacing possible with direct drills based on experience with conventional cultivation can not be assumed to be correct because the flora and fauna of the environment into which the direct drilled seedling emerges is vastly different from that which a conventionally sown seedling emerges. For example, less weed seeds are likely to germinate in the direct drilled situation so the nature of the competitive environment is different. As noted previously, it may be erroneous to apply knowledge gained with conventionally cultivated seedbeds to untilled seedbeds.

Limited investigations have been carried out into the effects of row spacing on perennial pasture establishment. Hallgren (1976b) showed that yields of pasture species from a cultivated seedbed including *Phleum pratense*, *Festuca pratensis*, *Dactylis glomerata*, *Lolium perenne*, *Trifolium pratense*, *Medicago sativa* and a mixture of *Phleum pratense*, *Festuca pratensis* and *Trifolium pratense* were highest at the narrow row spacings and diminished as the space increased from 50 to 400mm. *Dactylis glomerata* and *Trifolium pratense* yielded as much at medium row spacing (150-200 mm) as at narrow row spacing (50-100 mm). Two methods of seeding were used: a constant seed rate per unit row length and a constant seed rate per unit area. Although the yields appeared different, no clear yield differences were reported between the two methods of seeding. There was high variation in the data which may explain why no statistical differences were detected between seeding methods. Weed growth increased as row spacing increased.

Hallgren cited work by Bengtsson who apparently demonstrated that narrow row spacing was important for a high yield of timothy and red clover, and weed suppression in the year after sowing. Row spacing was in the range 11-22 cm. High seeding rate did not compensate for the reduction in yield at wide row spaces. Hallgren (1976a) showed that rows of pasture plants bordering "gaps" (ie. where a row was missed in a stand sown at 10 cm row spacing) outyielded rows farther away from the gaps, and thought this was due to the better light conditions for these plants. However, the increased yield/plant did not compensate for the yield loss associated with wider row spacing.

Reducing row spacing below the 150mm achievable with commonly available machinery used for direct drilling has had advantages in terms or yield and weed suppression in a cultivated seedbed. However, using current direct drilling opener technology at reduced row spacing would require some compromise with either trash handling capability or the range of soil conditions in which they could be reliably operated. The whole question as to whether the mechanical constraints imposed by drills on the plant spacing/arrangement of perennial grass seed/seedling/plant influence the outcome in terms of a productive sward remains unanswered. The wider agronomic question of the relative importance of seedling density within the rows as compared with the influence of average density per unit area on pastures established by direct drilling is important for prescribing design requirements for future direct drills.

2.2.6 Grazing Management

The performance of an establishing pasture and survival of various pasture species is influenced by grazing management (defoliation) and grazing animals (animal effects). The grazing animal has substantial influence on pasture composition and is important to the outcome of pasture establishment. While grazing ecology is acknowledged as an important determinant of pasture establishment, it is a complex issue, and is not the subject of this study. Therefore some of the more salient elements are dealt with briefly in the following sections, including interactions between pasture plants and grazing animals, principally the influence of grazing management on species response to changes in light relations in the developing sward and the impact of grazing livestock. Grazing management is a controllable factor in pasture development, production and persistence compared with other influences such as insect pest attack which may be difficult and expensive to control and costly in terms of lost production (eg. grass grub, East, 1980 and Argentine stem weevil, Prestidge et al., 1991).

2.2.6.1 Defoliation

Defoliation is defined as the process of the complete or partial removal of the above-ground parts of plants, living or dead, by grazing animals or cutting machines (Hodgson, 1979). The process is commonly described by its frequency - the interval between consecutive grazings, intensity - the mass of herbage left after grazing and timing - relative to season and developmental stage of plants or swards. Variation of these factors of defoliation by grazing animals combine to provide the most important influence on pasture production and botanical composition (Harris, 1978).

Light relations in a sward are significantly altered by defoliation as photosynthetically active material is removed and light is able penetrate to the base of the sward. Mobilisation of the carbohydrate reserves may occur until leaf area is re-established and reduce reserves. However, in general carbohydrate reserves are not significant in the recovery of ryegrass / white clover swards after defoliation in New Zealand (Harris, 1978) except possibly in high country situations, but their importance is recognised in the management of lucerne (*Medicago sativa*) (Langer, 1982). An interesting aspect of plant growth is the partitioning of photosynthate between roots and shoots. The general effect of defoliation is to reduce root growth (Chu, 1971; Evans, 1973; Christiansen and Svejcar, 1988). Heavy grazing reduces the relative weight of roots as photosynthate is directed into shoot growth to boost the photosynthetic area of a plant (Evans, 1973). However, this appears to be modified by the availability of soil moisture, as Davidson (1978) reported that root growth is stimulated to meet soil desiccation stress at the expense of shoot growth. Therefore the response of pasture plants to defoliation is modified by plant species and environment and has marked effect on pasture establishment.

Where a mixture of species is sown (eg grass/legume pasture mix), repeated defoliation during pasture establishment is required to avoid excessive shading of less vigorous species (Brougham, 1960; Evans, 1973). Jewiss (1972) considered early grazing to be important in initiating tillering so that seedlings can produce sufficient leaf area for complete light interception and successfully compete with weeds. Later, Ritchie (1986b) suggested that similar management may allow grass species to fill the gaps between rows of drilled pasture plants. With decreased grazing pressure the opportunity for dietary selection increases and proportionally less of the less preferred portions are consumed (Hodgson, 1979; Rattray and Clark, 1984; Poppi et al., 1987). The most palatable species such as newly sown grasses and legumes and some volunteer grasses will be preferentially grazed, unpalatable broadleaf and grass weeds are left ungrazed and are therefore positioned above sown species in the canopy and have a competitive advantage for light. Therefore a high concentration of stock for a short period of time eg. 300 stock units/ha/day, sufficient to ensure non-selective grazing of both sown species and weeds down to ground level in one or two days, has been advocated (Ritchie, 1986a). Seedlings of slow establishing species (red and white clover, cocksfoot, phalaris, tall fescue) may also be released from competition for light with other quicker establishing species (ryegrass, prairie grass) (Brougham et al., 1978; Campbell and Kunelius, 1984). High grazing pressure may also aid consolidation of cultivated seedbeds, an important consideration for post-establishment grazing. However, continued hard grazing in spring can reduce ryegrass vigour (Jewiss, 1972; Davies, 1966; Korte et al., 1984; Korte and Chu, 1983; Brougham, 1960), and delay recovery after the subsequent summer drought (Barker et al., 1985; L'Huillier, 1987). Thus timing of grazing and environmental conditions also influence survival of sown species.

Early work by Brougham in the 1950's showed that grazing management during the early stages of sward development was critical to clover survival. This was reaffirmed by a later report which showed nearly a 50% reduction in survival of clover plants where establishing pasture was grazed at 220 mm compared with 75 mm (Brougham, 1969). Differences in survival were attributed to interspecies competition for light. Excessive shading resulted in the death of clover plants where grazing was carried out at the higher herbage mass. In discussions on sowing rates and grazing management both Cross (1959) and Brougham (1954a), noted that lower sowing rates of ryegrass (11-17 kg ha^{-1}) should be used as increased latitude in frequency of grazing is obtained. This is especially important where pastures are sown at a time when adequate feed is available for grazing, and when the profuse growth resulting from a high seeding rates (35-45 kg ha^{-1}) may not be adequately controlled which increases the risk of clover plant death occurring. As previously mentioned, suppression of clover plants in an establishing sward may lead to N deficiency, further affecting sward composition (Brougham, 1959; Ashworth, 1961c; Cullen, 1966).

Grazing management has been described as being the most controllable factor influencing the productivity and persistence of introduced cultivars (Charlton and Thom, 1984). Baker (1980) noted that it was a common recommendation to hard graze right up to the time of drilling, and even continue this after drilling until emergence. Lancashire and Brock (1983) and Thom et al., (1985) noted that there was a lack of definitive information with regard to the grazing management required to ensure the survival and optimum productivity of newly released, 'alternative' specialised pasture cultivars. These alternative species include 'Roa' tall fescue, *F. arundinacea*, 'Kara' cocksfoot, *D. glomerata* and 'Maru' phalaris, *P. aquatica* which have become more widely sown in regions in New Zealand which have experienced drought in recent years (Fraser and Milne, 1993). Some information has since been published for establishment on cultivated seedbeds (Hume and Fraser, 1985), productivity and persistence in hill country (Stevens et al., 1989) and response to various cutting regimes (Kerrisk and Thomson, 1990). These species tend to establish less vigorously than *Lolium* sp and some authors suggest that establishing swards containing these species and without *Lolium* sp should be grazed less frequently than *Lolium* based swards (Charlton and Thom, 1984). Grazing recommendations for 'alternative' species appear to be based on pastures established by conventional cultivation. There is a lack of information detailing the grazing requirements for these species where they have been established by direct drilling. As mentioned previously, direct drilled and cultivated seedbeds differ significantly and may influence grazing management during establishment. For example, where ground conditions are wet for long periods of time (after autumn sowing) grazing on cultivated seedbeds may have to be delayed until the soil dries out sufficiently to support stock. This may increase the competitive stress on slower establishing species and reduce their future contribution to yield. Direct drilled soils are less susceptible to this problem as the soil has been left relatively undisturbed so may have some advantage in terms of weed control and clover release.

The specificity of grazing requirements to establishment is illustrated by the response of red clover (*T. pratense*) to similar grazing regimes applied at different phases of sward development, establishment and production. Campbell and Kunelius (1984), demonstrated the effect of grazing on survival of red clover seedlings in the first year. Hard, frequent grazing (grazed with sheep to 20 mm at 3 weekly intervals) improved the survival of overdrilled (with band-spraying) red clover seedlings compared with other grazing treatments, (hard infrequent, lax infrequent and lax frequent). Hard, frequent grazing was required during establishment to control competition from resident pasture species. However, Hay and Ryan (1989) showed that similar grazing management reduced the survival of red clover in the productive sward. Frequent (4 weekly) grazing to a residual herbage mass 300-400mm in autumn reduced plant population and production in comparison to less frequent grazing (every 9 weeks). Repeated grazings depleted carbohydrate reserves and diminished the recovery of red clover from grazing. Persistence was further reduced by winter treading of exposed red clover crowns, which allowed the invasion of bacterial and fungal pathogens. The two situations outlined above illustrate that the distinction between grazing requirements for swards during the establishment and production phases of sward development are necessary.

2.2.6.2 Animal Effects

Understanding the interaction between grazing animals and pasture species is important to managing the survival and production of pasture plants. For example, ryegrass/white clover pastures tend to be very resilient over a range of grazing intensities and recover relatively well from undergrazing or overgrazing. On the other hand lucerne and red clover have specific defoliation requirements and are more susceptible to mismanagement.

Although grazing animals may increase yield by facilitating plant nutrient transfer and cycling, grazing itself is unavoidably associated with an adverse effect on growth (Langer 1982). Both sheep and cattle cause treading damage which influences both growth and botanical composition of pastures (Edmond 1970). In a detailed review of Edmond's work Brown and Evans (1973) concluded "The fundamental concept Edmond developed was that all treading damages pasture irrespective of soil type, soil moisture level, plant species, or kind of animal". Reductions in herbage production from direct hoof impact are the result of leaf crushing and bruising, physical root damage and plant displacement or burial leading to low plant densities (Edmond, 1963). An indirect consequence of stock treading is a reduction in both soil bulk density and macroporosity (Kellet, 1978; Climo and Richardson, 1984) which may decrease plant growth. Generally production of herbage mass is inversely related to treading severity (Edmond, 1963; 1974; Kellet, 1978; Climo and Richardson, 1984; Horne and Tillman, 1984). Although reports on the effects of treading on herbage production are inconsistent (Campbell, 1966; Charles, 1979; Brown, 1971). From a review of the literature which dealt with the effects of grazing animals, Charles (1979) concluded that the variable responses of pasture to treading were 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. Damage to pasture and reduction in herbage production is more likely as soil moisture level increases (Gradwell, 1968; Brown and Evans, 1973; Kellet, 1978; Climo and Richardson, 1984; Richardson, 1986).

Hay (1987) describes morphological adaptations that enable forage plants to survive repeated partial defoliations. A key adaptation is the location of shoot meristems (growing points) near the soil surface (Harris, 1978). Ryegrass crowns (Matthew et al., 1989) and white clover stolons (Hay et al., 1987) go through an annual cycle consisting of burial of in the winter, and re-emergence of growing points in spring. This provides protection of desirable grasses and stoloniferous legumes as the growing points are beneath the soil surface. However, this protection is reduced if the soil becomes wet as stock treading may damage growing points which are 20-40 mm below the soil surface (Edmond, 1960; Edmond, 1964). At other times of year when proportionally more stolons were on the surface the number of growing points were reduced during periods of drought because pasture growth was restricted and intensive grazing by sheep removed white clover stolon (Hay et al., 1987). On the other hand other forage legumes like red clover, lucerne and sainfoin, have a perennating tap root with a well marked crown of stem buds and short shoots. They are more susceptible to damage from defoliation and treading by grazing animals, and invasion by pest and disease which are exacerbated by wet conditions (Hay et al., 1979; Hay and Ryan, 1989; Langer, 1982). These erect legumes cannot spread and death of individual plants results in thinning crops, although surviving plants will, increases in size, within limits, to compensate for the loss. So not only are these species less protected but they are less likely to increase the number of growing points per unit area because they rely on reseeding and re-establishment for perenniality (Leach, 1978). Allowing these crops to grow uninterrupted to produce seed offers little scope for increasing density as legume growth is slower than grasses in winter and seedlings rarely survive competition from established plants (loc cit).

Diet selection is a function of preference modified by accessibility. Selective removal of one species makes resources available to other species (Harris, 1978). Thus, diet selection influences species persistence (Leach, 1978). Diet selection is also a function of stock type (Lambert et al., 1986; Cosgrove et al., 1985). Varying stock types not only impinges on diet selection effects but also on the nature of treading damage which may also be a determinant of species persistence (Brown and Evans, 1973; Watkin and Clements, 1978).

One aspect of the effect which livestock have on pasture plants which has received some attention in the literature (Hodgson, 1973; Charles, 1979; Brock, 1982; Prestidge et al., 1989) but for which little quantitative information has been available until recently (Thom et al., 1986b), is that of plant or tiller loss from 'pulling'. Livestock, particularly cattle, have been reported to uproot tillers or plants during grazing. This is termed 'pulling'. Significant plant loss can occur during dry periods with intensive grazing in ryegrass based swards resulting in the development of bare areas (Thom et al., 1986b) and so the balance of pasture species may be altered in a localised area of the sward.

Grazing management is an important variable in the development of pasture, perhaps the most important in the temperate climate of New Zealand , and certainly at farm level it is a variable which has less direct cost associated with its use compared with controlling major insect pests or the process of sowing new pasture. It is a dominant feature of the pasture development on farms and should be incorporated wherever possible when appraising various establishment options in research trials.

2.3 Summary

The recent fundamental change from establishing pastures on cultivated seedbeds to sowing into essentially undisturbed soil, brings with it changes in the environment into which pasture seedlings emerge. The mechanical constraints of machines used 25-30 years, may not be optimal for seeding modern cultivars by direct drilling. For example, competition from unsown species may be less or simply of a different nature, the potential for pest attack reducing seedling vigour is increased and the grazing regime may also be altered. Along with this, sowing 'alternative' pasture species to traditional ryegrass based mixtures presents new challenges with respect to successful establishment of these less vigorous species. Early growth of a plant appears to be the major determinant of its survival in an establishing population, and root growth may be far more important than shoot growth in determining the survival of a plant in a competitive situation. This may stem from the fact that plants generally compete less for light than for water and nutrients, and that shoot growth is closely related to root growth.

Population dynamics within an establishing pasture is influenced by a complex array of interactions between the factors affecting the growth of individual plants within the population. The final botanical composition of an establishing sward depends on the outcome of competition between dominant and suppressed species. This outcome depends not only on the inherent competitive ability or aggressiveness of a species (which may be influenced by seed size) but also on the "supply" and "conditioning" factors, water, nutrients and light; and temperature, grazing management and soil microbiological effects, respectively.

Pasture establishment is a complex system, encompassing factors from soil type and location, to interactions between sown and unsown species, and grazing regime. Many of these complexities have been explained by other workers. However, the application of direct drilling to pasture establishment introduces factors, each of which must be recognised and understood. Cognisance of the way in which those factors interact is also necessary if direct drilling is to achieve the desired outcomes of pasture establishment.

3. METHODS AND MATERIALS

3.1 Introduction to Experimental Procedure

Given that the process of pasture establishment is a complex one and that information relating to the application of these processes is required at a practical level, it seemed appropriate to carry out a field study to ascertain how factors such as plant arrangement (row spacing and drilling pattern) and seeding rate interact for direct drilled pasture. In New Zealand there are no seed drills available on the market which are specifically designed for establishing pasture species, and all pasture which is established by direct drilling is sown with multipurpose drills which sow brassica, cereal and pasture crops. The fundamental question which this trial set out to answer was; for a given seeding rate is there any advantage from cross-drilling compared with single pass drilling? Answering this question would help to determine whether or not a seed drill designed for establishing perennial pasture species by direct drilling should sow seeds at closer row spacings than machines currently available. The trial also sought to determine the influence of seed rate and the vigour of the sown species on the botanical composition and production of the resulting pasture.

The balance of species in the pasture during establishment and resulting botanical composition is a function of the cultural practices used, the relative aggressiveness of both sown and unsown species which may be present, and subsequent grazing management. Although field studies, are subject to a somewhat wider range of uncontrolled variables than small scale plot trials and laboratory experiments, potentially they may provide information which is more readily applied. A trial which sought to isolate all the factors and the interactions would be enormous, so there will always be compromises. However, including as many factors as possible would provide a useful charter of events during pasture establishment. For this reason, factors such as grazing management were applied as consistently as possible, post emergence weed spraying was not carried out at all and fertiliser was applied as a blanket application.

As dairy farmers are more likely to carry out pasture renewal than those in other pastoral enterprises in New Zealand (Belgrave et al., 1990), the trial was situated on a dairy farm and grazed exclusively with dairy cattle.

The results and discussion for the main trial follow in Chapter 4, which is divided into three major sections corresponding to the various stages of pasture development. These divisions are described in the introduction to the Chapter. Within each period or division, results for different aspects of pasture development are presented and discussed in discrete sections. These sections of results and discussion are summarised at the end of each of the three major divisions within Chapter 4. This layout has been adapted to follow the sequence of stages in pasture establishment and development, and the interaction between them.

3.2 Description of Trial Site

Location

The field experiment described in this Chapter and Chapter 4 occupied the whole of paddock 18 (1.6 ha) at No. 1 Dairy Farm, Massey University, Palmerston North, New Zealand, situated 1.4km west of the main University Campus (latitude 40° 23' S, longitude 175° 37' E, altitude 33.52m above sea level). The river plains of the Manawatu region support intensive mixed livestock and cropping farms.

Climate

The region is classified as moist temperate (Brougham, 1979) with a moderate average air temperature of 13°C. The area does not experience extreme temperatures, with a daily temperature range of 8 or 9° throughout the year. Temperatures exceeding 30°C are seldom recorded (Burgess, 1988) but regularly reach over 25°C in the summer. Frosts may occur between March and November but are usually only slight (-1 to -2.9°C) with some (30 to 40%) being of moderate intensity (-3.0 to -5.9°C) and few below -5.9C. Rainfall is reliable with a 30 year average of 990mm annually (Burgess, loc cit). Weather data for the trial period was acquired from a meteorological station located approximately 500m from the trial site operated by the New Zealand Pastoral Agriculture Research Institute Ltd (AgResearch).

Soil Type

The soil profile has been described by Clothier et al., (1977). A recent soil of alluvial origin, the Manawatu fine sandy loam (Mfsl) is described as a coarse-layered soil subdivided into three elements. The first 500mm consists of a fine sandy loam, which is underlain to a depth of 900mm by a fine sand and beyond 900mm by a gravelly coarse sand which extends for several more metres. The soils of the Manawatu series typically are made up of these three elements. The trial area has been subject to infrequent flooding for short periods, being on the second terrace of the Manawatu river, the east bank of which was 300m to the west. The trial area was virtually flat with a slight incline away from the river end of the paddock and there was variation in soil across the trial area with shallow loamy sand towards the river end (also described as Manawatu sandy loam, gravelly phase (Cowie, 1972)) but the area was predominantly Mfsl. The Ap horizon of the Mfsl extended to a depth of approximately 230mm and was a dark greyish-brown fine sandy to silt loam. At Palmerston North, pasture growth usually suffers from a soil moisture deficit from mid January until April. The Manawatu fine sandy loam topsoil has been described as moderately well to excessively drained (Cowie, 1972) and is a seasonally dry soil which reaches permanent wilting point in most summers and in dry years for 2-3 months at a time (Lancashire and Brock, 1983) which was in part why this soil type was chosen.

The two summers previous to establishing this trial had been dry and the perennial ryegrass (*Lolium perenne* L.) /prairie grass (*Bromus willdenowii* Kunth) /white clover (*Trifolium repens*

L.) mix which was sown after a turnip crop in 1985, had deteriorated to an 'open' pasture with a large number of undesirable species including temperate C4 grasses (summer grass (*Digitaria sanguinalis* (L.) Scop. and paspalum (*Paspalum dilatatum* Poir), and couch (*Elytrigia repens* L.Nevski) and a number of broadleaf weeds predominantly both broad-leaved and narrow leaved plantain (*Plantago major* L. and *P. lanceolata* L., respectively), yarrow (*Achillea millefolium* L.), storksbill (*Erodium cicutarium* L.) and large-flowered mallow (*Malva sylvestris* L.) with red clover, crested dogstail (Cynosurus L.), brown top (*Agrostis tenuis*) and sweet vernal (*Anthoxanthum odoratum* L.). The paddock had deteriorated from the original species through a combination of insect damage (Argentine stem weevil, grass grub and white fringed weevil), hard grazing and successive droughts (G. Lynch pers. comm., 1990).

The trial area had previously received annual autumn maintenance dressings of 28 and 11 kg/ha of phosphorus and sulphur, respectively as Hiphos S. Soil tests taken over the trial area just prior to sowing indicated a medium phosphate fertility (Olsen P 15) and the recent alluvial soil has been described as having high levels of exchangeable potassium and magnesium (Cornforth and Sinclair, 1984). The average pH in the upper 75mm of soil was 5.8. In general the soils of the type of the trial area are considered to be of high natural fertility (Cowie, 1972; During, 1984).

Site Preparation

The paddock required for the trial was sprayed on 22 March 1990 with 6l/ha Roundup® (2.16kgha^{-1} glyphosate as active ingredient) on actively growing, existing vegetation which had been allowed to 'recover' after grazing. A relatively high rate of Roundup® was required to control the couch and summer grass component of the existing vegetation. No green plant material was evident on the trial area three weeks after spraying suggesting good control of resident vegetation. The establishment of sown clover was to be assessed along with perennial grasses so better control than that afforded by Roundup® was required. Granstar® at a rate of 30g/ha (22.5gha^{-1} tribenuron methyl as active ingredient) was tank-mixed with Roundup. Granstar® was chosen as it had the shortest residual action in the soil against clover (minimum delay for sowing clover, 3 weeks) of the range of herbicides suitable for clover control (B. O'Conner, pers. comm. 1990). A clean up grazing with dry cows to remove as much existing vegetation as possible was carried out on the paddock 7 days after spraying (Thom et al., 1987b) and the paddock was harrowed afterwards to disperse and dry dung pats, as damp cow dung might have interfered with direct drill opener operation (W. R. Ritchie pers. comm. 1990).

3.3 Experimental Design and Treatments

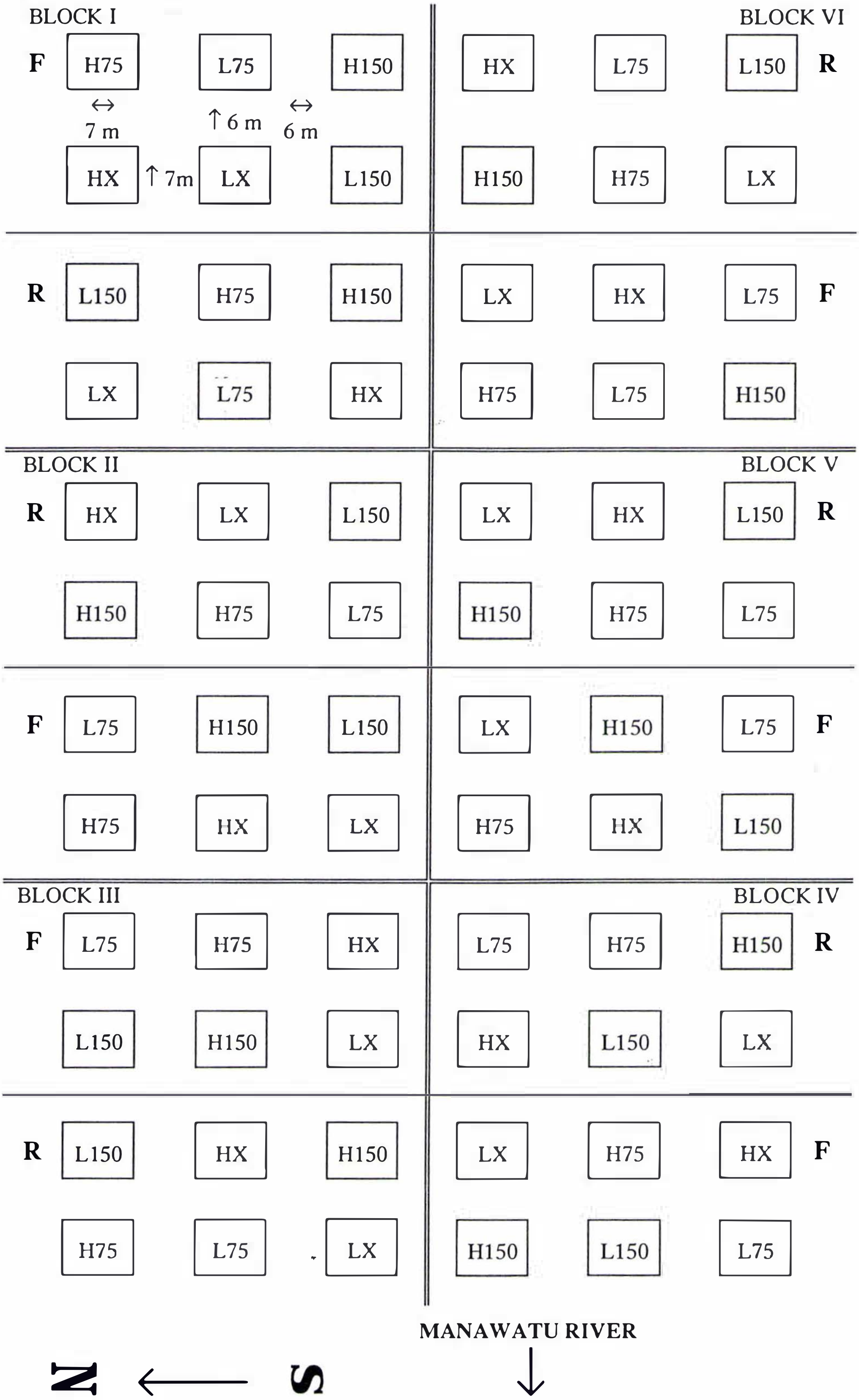
Three drilling methods, two seeding rates and two species were factorially combined in a trial layout with six replicates in a randomised complete block design. Species were allocated to main plots because of grazing considerations. There was a variation in the proportions of coarse sand, fine sand and fine sandy loam in a diagonal line across the paddock, with the finer sandy loam furthest from the river end of the paddock. For this reason it was decided to site blocks in relatively uniform soil type location and avoid the possibility of soil type variation across blocks, rather than the traditional method of running the blocks across the entire width of the trial area. This also resulted in a more square shaped area for easier stock movement during grazing rather than a long thin rectangular shape.

Seed rates and drill methods were used in factorial combinations for fescue and ryegrass. This system overcomes both the confounding effects of plant population with spatial arrangement where row width is altered but in-row spacing is constant, and the greater crowding within a row associated with higher in-row populations where seeding rate is constant and row width is altered (Holliday, 1963). Thus comparisons were available of seeds sown at both a constant rate per unit area and constant rate per unit row length. The trial was sown on 12 April, 1990.

Plots were 7m x 7m so that they were large enough to provide sufficient area for grazing cattle with consideration of the fact that some portions of the plots would be subject to dung and urine deposition with implications for grazing selection. A headland area around each side of the plots was necessary for turning the tractor and drill when sowing the cross drilled treatment, so there was a 6 m buffer between each plot in the trial (Figure 3.3.1). Each block covered 0.2 ha. Six replications were laid down so that the whole paddock was covered to ease later grazing management. The end result was;

2 species x 2 seeding rates x 3 drilling methods x 6 replications = 72 plots.

Figure 3.3.1 Layout Of Trial Plots (Not To Scale) With Main Plots Differentiated By Double Lines And Sub-Plots By Single Lines



Note * **F** = Tall fescue, **R** = Perennial ryegrass

* 75 = 75mm row spacing, 150 = 150mm row spacing X = Cross-drilling

* L = Low seed rate, H = High seed rate

Treatment Descriptions

Species

Two perennial temperate grasses were sown separately:

Perennial ryegrass (*Lolium perenne* L.) cv "Grasslands SuperNui", and Tall fescue (*Festuca arundinacea* Schreb.) cv "AU Triumph".

These two grasses will be referred to as ryegrass and fescue, respectively, throughout this thesis. Ryegrass is the most common perennial grass species sown in New Zealand (Sangakkara et al., 1982; Belgrave et al., 1990). Fescue is a relatively new species but is gaining acceptance in drier and/or in areas with pest problems (Thomson et al., 1988; Milne and Fraser, 1990). Both species have been used on the farm where the current trial was established. "Grasslands SuperNui" ryegrass is a high-endophyte Nui, officially certified to be more than 70% of seed infected with *Acremonium lolii* (Lancashire, 1990), the endophyte thought necessary to protect plants from Argentine stem weevil (*Listronotus bonariensis* (Kushel)) (Pottinger et al., 1985; Prestidge and Gallagher, 1985). "AU Triumph" is a recently imported tall fescue cultivar from the United States with no endophyte and greater vigour at establishment than "Grasslands Roa" tall fescue (Easton and Pennell, 1993) and was expected to be better suited to a mid April sowing (Hay pers. comm., 1990). Seed from commercial lines, certified first generation, of ryegrass and fescue were used. All seed was treated with fungicide (120g of 80% captan 100kg^{-1} of seed) but were uncoated.

Seeding Rate

Two seeding rates were used for each species, based on target populations of:
500 plants m^{-2} for low seeding rate and 1000 plants m^{-2} for high seeding rate.

These targets are equivalent to approximately 12 and 24kg ryegrass ha^{-1} and are representative of the low to medium range of typical seeding rates used where ryegrass is the main component of the mixture (Sangakkara et al., 1982; Anon, 1990; Empson, 1992). Since the trial was to compare the population dynamics of fescue and ryegrass and because more is known about seeding rates used for ryegrass, the fescue rate was based on the ryegrass rate and not vice versa. The target population for the low seed rate was more than the estimated equilibrium population of an established pasture (Sangakkara and Roberts, 1982). The actual seeding rates used are listed in Table 3.3.1.

Drilling Method

The three drilling methods were:
Single pass drilling at 150mm row spacing; two pass drilling at 150mm row spacing in a diamond pattern, with the second pass of the drill crossing the first at 30°, which is the treatment referred to as cross-drilling; and narrow row spacing (75mm). Sowing direction for the single pass treatments was East-West and for the first pass of the cross-drilled treatments.

The seed drill used for this trial was an "Aitchison Seedmatic 1100" series, mounted on a 64 kW tractor. The drill was fitted with "Baker boot" inverted T openers, attached to spring tines suspended from a rigid frame, the height of which was determined by adjustable land wheels on either side of the machine. Each opener was preceded by a disc to cut through surface trash. Because a drill with comparable opener type and discs at 75mm spacing was not available nor was it practical to alter the row spacing of the machine used, the 75mm row spacing treatment was sown by two passes at 150mm row spacing, the second pass bisecting the first. This was not always successful as the openers on the second pass tended to wander into the grooves made by the first pass of the drill. When this happened, whole drill widths were discarded and the 75mm treatment plots selected were at least 1.8m wide (one drill width). This was considered adequate for the measurements of individual plants and sufficient area was available for all but the later, long term yield measurements to be carried out. A "run in" of at least 1 metre was allowed to ensure that seed and insecticide reached the seed groove before the drill entered the plot area. Despite better seed placement and reliability for seed emergence claimed for the Cross Slot™ drill as compared with most other direct drills (Baker and Saxton, 1988), its requirement for a larger turning circle than the Aitchison drill precluded its use in this trial.

Table 3.3.1 describes the desired and actual seed rates used in the trial along with the average number of viable seeds sown for each treatment. Desired seed rates were calculated[1] on the basis of seed weight ('Supernui' 2.23 and 'AU Triumph' 2.5 mg seed^{-1}), and field emergence for ryegrass which was expected to be 85% of seed sown based on previous experience with that opener used to sow the trial (inverted "T", Baker, 1976a; Choudhary, 1979) and field experience with the drill used to sow the trial (W.R. Ritchie, 1990). Germination percentages of both tall fescue and perennial ryegrass seed was 97%. Germination tests were carried out by the Seed Technology Centre, Massey University on the actual seed lines used in this experiment. The seed rate for tall fescue was increased by 10%, (ie. expected field emergence of 75%) because of the relatively cool weather conditions for the time of sowing (mid autumn), (K. Hill, pers. comm. 1990). Subsequent work by Hamilton-Manns (1994) confirmed that emergence of fescue was likely to be adversely affected by cool and / or wet weather.

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[1] The equation used to determine desired seeding rates

((Target Plants m^{-2} / Germination %) X 100) X Thousand Seed Weight (gms) / Effective Field Emergence (%)

Table 3.3.1 Target Seeding Rate and Seeding Rate Achieved for Fescue and Ryegrass

SPECIES	SEEDING RATE	Drill Method	DESIRED kg ha-1	DESIRED Viable Seeds m-2	ACTUAL kg ha-1	ACTUAL Viable Seeds m-2	ACTUAL Viable Seeds m-1 row
Ryegrass	**High**	75 mm and Cross Drill	27	1170	22.4	973	73
		150 mm rows	27	1170	23.6	1026	154
	Low	75 mm and Cross Drill	13.5	590	12.6	548	41
		150 mm rows	13.5	590	11.5	500	74
Fescue	**High**	75 mm and Cross Drill	34	1320	31.6	1226	92
		150 mm rows	34	1320	28.9	1121	168
	Low	75 mm and Cross Drill	17	660	18.5	717	53
		150 mm rows	17	660	14.5	565	85

Grass seed output from the drill had to be altered 8 times during sowing, so drill calibration was carried out the day before drilling and the required output positions were marked on the seed adjustment quadrant to minimise delays in the field. A check of grass seed output was made just prior to drilling by collecting the seed from four openers which was later weighed to determine actual seeding rate. A discrepancy between desired and actual seeding rate was recorded during the drilling procedure (Table 3.3.1). This was not caused by commonly reported problems with this seeder such as worn foam pads on the seeder (as they were new) or hysteresis in the adjustment mechanism (because the rate was set by moving the lever in the same direction each time); but was thought to have been due to variation in output caused by change in moisture content of the foam pads (A.J. Chadwick pers. comm., 1990). Seed output was not altered between the cross drill and 75 mm treatments within the same seedling rate and species. Therefore those treatments were sown with the same number of viable seeds m^{-2}, on average 866 m^{-2}. The calibration was altered for the 150 mm treatment and an attempt was made to maintain a constant number of seeds m^{-2}. However, because of mechanical imperfections, slightly less viable seeds (803 m^{-2}) were sown in that treatment.

White clover (*Trifolium repens*) cv 'Pitau' was sown at a constant rate of 3kg ha^{-1} over the whole trial through the small seeds box of the drill. This avoided the problem of preparing numerous clover/grass seed mixtures to achieve the desired seeding rates. Five kg ha^{-1} Phorate® granular insecticide (200 g/kg phorate) was mixed with clover seed. Seed grooves were covered after drilling by towing chain harrows in the direction of the drill rows within 6 hours of drilling. The cross-drilled plots were harrowed in the direction taken by the second pass of the drill (at 30° to East-West). After harrowing, 10kg ha^{-1} granular Blitzem® molluscicide (27g/kg metaldehyde) was broadcast onto drilled areas within 24 hours of drilling to control slugs. Headlands were sown with the same species as the plots they surrounded at a median seed rate. Figure 3.3.2 shows the trial paddock after the first grazing.

Figure 3.3.2 Trial Paddock

3.4 Fertiliser Policy, Weed Control and Irrigation

No fertiliser was applied at sowing but 400kg ha^{-1} 15.10.10.8 (60, 40, 40, 32kg ha^{-1} of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S), respectively), was applied on 21 October 1990 to lift phosphorus levels, as there had been a decline over past years from an Olsen P of 32 (1988) down to 19 (1990), and to generally increase the slow growth which had been evident to that stage. Olsen P had increased at April 1991 and a further maintenance dressing of 25 kg P/ha was applied as 15% potassic super (0.8.8.10) along with 20 kg N/ha as Urea (46.0.0.0) on 30 August 1991. Fertiliser was broadcast in two bouts perpendicular to one another to ensure as even spread as was possible. No lime was applied during the experimental period, as pH was relatively stable at 5.6-5.8. All soil tests were carried out by the Fertiliser and Lime Research Centre at Massey University.

Although it is often practiced when establishing pasture, no post emergence herbicide was used so that sown species were in competition with spontaneously appearing weeds in order to observe weed growth that may occur in response to the various treatments.

Irrigation facilities were available but were only intended for use during the initial establishment phase (first spring) to avoid pasture desiccation. A water balance was calculated from rainfall and evaporation readings from the nearby meteorological station mentioned above. Readily available soil water content, defined as the plant available soil water held between field capacity at a suction of -5 to -20 kPa and stress point (-100 kPa) for Manawatu fine sandy loam, was estimated to be 40 mm within the rooting depth of pasture (D.R Scotter, pers. comm., 1990) based on work in a study conducted in the field adjacent to the trial (Clothier et al., 1977). A water deficit of over 40mm was recorded at the end of October 1990 (Figure A2.1, Appendix 2) and 40mm of irrigation water was applied. During the last two shifts of irrigation equipment some 40mm of rain also fell but the irrigation was completed for all plots.

3.5 Grazing Management

Grazing management was determined by two distinct stages of pasture development: the establishment stage where short hard grazings were required (Ritchie, 1986b; Thom et al., 1987b) and the production phase where the trial area was included in the normal grazing rotation of the farm. During the two year-trial period the plots were subjected to 3 grazings by young dairy stock (9 to 15 month heifers) and 13 grazings by dairy cows.

Fescue and ryegrass were grazed at the same time, except for the first grazing when only ryegrass was grazed. This occurred at 55 days after sowing (d.a.s.) but little herbage was removed. Because both species were grazed simultaneously, thereafter the timing of grazing in terms of plant growth stage was not always optimised in terms of production and/or utilisation for either species because fescue reaches anthesis a full month earlier than ryegrass and generally grows slower than ryegrass during establishment. Two-wire temporary electric fences were used to confine cattle to one species period during the establishment phase (until 246 d.a.s.) ie. grazed in half blocks at this stage. Table 3.5.1 shows the schedule for grazing and topping in terms of d.a.s. and calender date.

Table 3.5.1 Schedule for Grazing and Topping

Phase of Development	d.a.s.	Date	Grazing				Topping				Sward Measurement		
			Heifers		Cows		Forage Harvester		Disc Mower		Herbage Composition and Mass	Herbage Mass Only	Pre- & Post-Graze Herbage Mass
			F	R	F	R	F	R	F	R			
Establishment	55	6 June 1990		√							√		
	150	9 Sept 1990	√	√							√		
	182	11 Oct 1990	√	√								√	
	212	10 Nov 1990			√	√	√	√			√		
	246	18 Dec 1990			√	√						√	√
	278	20 Jan 1991			√	√					√		√
	315	27 Feb 1991			√	√							√
	393	15 May 1991			√	√					√		√
Production	444	6 July 1991			√	√							√
	496	28 Aug 1991			√	√					√		√
	521	23 Sept 1991			√	√							√
	540	12 Oct 1991			√	√							√
	576	9 Nov 1991			√	√			√	√	√		√
	591	3 Dec 1991			√	√							√
	625	7 Jan 1992			√	√							√
	684	6 Mar 1992			√	√					√		

Note * F = Tall Fescue, **R** = Perennial ryegrass

Grazing during the establishment phase at 150, 182 and 212 d.a.s. (September, October and November) usually took place over six days with approximately 40 x 15 month-old heifers (300-350 kgs liveweight, 400 heifers/ha equivalent). Cattle were taken off an area when a target stubble height of 40-60mm was reached, usually in 8 -14 hours. The sequence in which blocks were grazed was the same throughout the study period. The November grazing was not grazed to an acceptable stubble height (especially ryegrass which was in the reproductive phase of growth) so herbage was removed with a forage harvester set to a height of 80mm. This cut fescue seedheads but was above most of the fescue stubble, and was low enough to remove ryegrass which had become lodged, mostly in urine affected areas.

The trial paddock was grazed intermittently by lactating dairy cows from 246 until 625 d.a.s. (the production phase) so that cows had access to both species simultaneously. Lactating cows razed the trial area within 24 hours. Averaged over the trial period for summer, autumn, winter and spring-summer, combined species herbage mass for pre- and post-grazing assessments were 3176 and 2490, 3056 and 1605, 2439 and 1557, and 3389 and 1944kgDMha^{-1}, respectively.

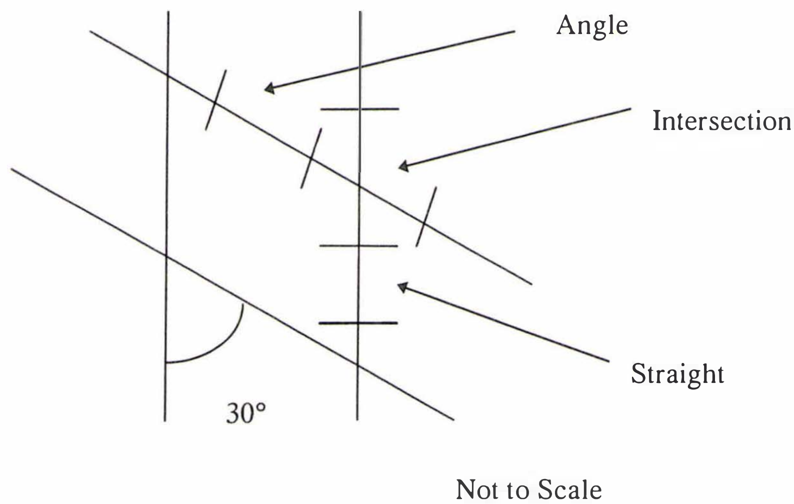
3.6 Sampling Procedure

3.6.1 Emergence of Sown Grass Seed

Emergence of sown seed was assessed at 21 and 42 d.a.s.. The numbers of emerged seedlings per 0.4m row were counted at six positions randomly selected by casting a 0.4m long rod onto each plot of the 75 and 150mm row spacing treatments. The population count of the cross-drilled plots involved delineating certain portions of the drilled row according to their association with one another. Figure 3.6.1 illustrates the three sections termed 'angle', 'straight' and 'intersection' which were delineated for seedling counts. The 'straight' portion is a section of row from the first pass of the drill undisturbed by the second pass of the drill. The 'angle' is the section of row sown by the second pass of the drill between the rows of the first pass of the drill. The 'intersection' is the position where the two passes of the drill crossed one another. A template was constructed to place over the intersection of drilled rows (Figure 3.6.2). Each section of row was 200mm long. Six positions were sampled in each of the cross drilled plots (0.6m row equivalent per sample).

There was a problem with randomly allocating the template for emergence count of cross drilled plots. At 21 d.a.s. plants were very small and centering the template on the intersection was difficult so the template tended to be placed where rows were more clearly defined. This led to an overestimation of the emerged population which was detected by calculating over 100% emergence. At 42 d.a.s. the placement of the 0.4m rod and the template was determined by random number tables. The first two numbers determined which of the 48 rows was to be sampled in each plot and the third number determined how far up the 7m row to go. The conversion factors used to calculate plants m^{-1} row, plants m^{-2} and percent emergence for all treatments are listed in Tables A1.2 and A1.3, Appendix 1, respectively.

Figure 3.6.1 Diagram of the Three Possible Seed Positions in the Cross Drill Treatment



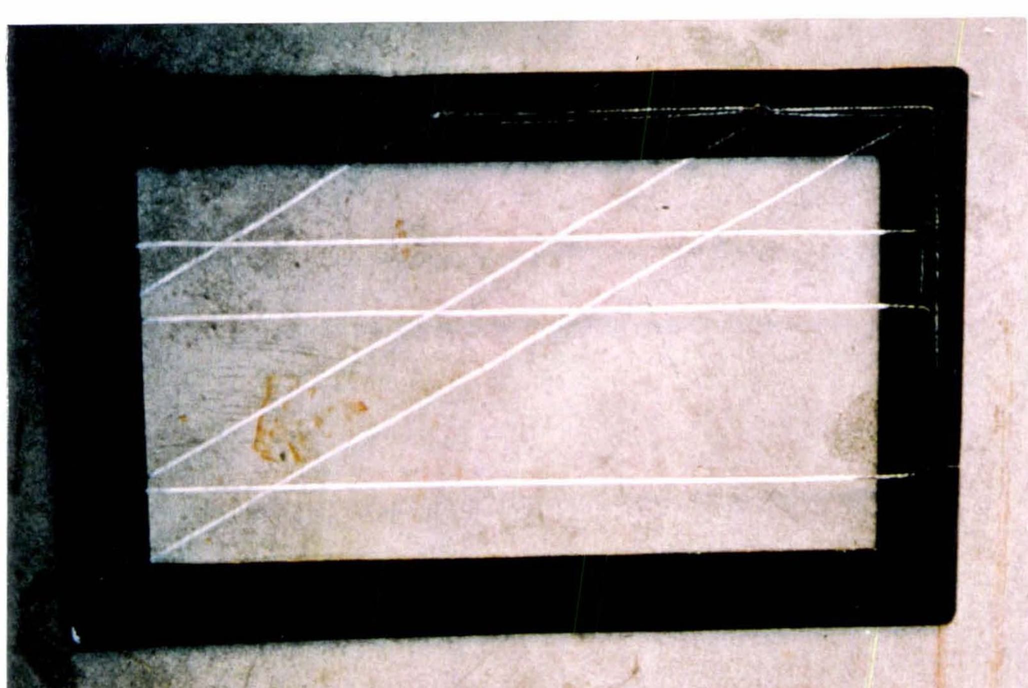


Figure 3.6.2 The Template Used for Emergence Counts of the Cross Drilled Plots

3.6.2 Clover and Weed Emergence

The number of clover plants, broadleaf and grass weeds were counted at 37 d.a.s.. Quadrats (0.2 x 0.35m, 0.07 m^2) were placed with the longest edge of the quadrat perpendicular to the drill rows. Quadrat size was such that it could only be placed across 3 x 150mm rows, or 6x 75mm rows so that the same amount of bare ground between rows was surveyed each time. Three samples per plot were assessed, approximately one square metre for each treatment. Quadrat position was allocated by random number in the same manner as described above.

3.6.3 Individual Seedling Weight

Ten seedlings per plot were collected at 26, 49, 85 and 135 d.a.s.. A string was randomly extended across the plots and any plant which touched the string at marked 0.5m intervals was cut off at ground level with a scalpel. Leaf number and length of seedlings collected at 26 d.a.s. were measured in the laboratory. All seedlings were weighed after drying in a forced air oven at 84° for 24 hours. Only the weight of seedlings was recorded at 49, 85 and 135 d.a.s. as measurement of other plant characteristics was carried out for 'tagged' plants (Section 3.6.6) and time constraints did not allow extensive measurements for both tagged and cut plants. Seedling weight (shoot dry weight) is referred to as shoot weight for the remainder of this thesis.

Mean relative growth rate was calculated for each time interval between measurement dates for seedling weight from the following equation (Hunt, 1972).

$$\text{Mean relative growth rate} = \frac{\log_{10}(wt_1) - \log_{10}(wt_2)}{t_2 - t_1}$$

Where wt = $\log_{10}$ seedling weight and $t_2 - t_1$ was the time-interval (days) between measurements.

3.6.4 Seedling Root Weight

The root weight of ryegrass was measured at 54 d.a.s.. Because only a limited investigation was possible, ryegrass was chosen because of its faster growth rate which was thought more likely to reflect changes in population density than fescue. Twelve samples of 150mm long, 150mm wide and 200mm deep were taken at random from along drill rows. Six samples were taken from the high seeding rate, 150mm row (H 150) treatment and six were taken from the low seeding rate, 75mm row treatment (L 75) (one/block, six/treatment). These two treatments provided the widest contrast in in-row population. Plants from each sample were separated from the soil by washing with all roots attached to each plant. These were counted and a representative subsample of 6 to 10 plants was taken from each sample. The number of tillers, nodal roots on the main tiller, nodal roots on daughter tillers (as described by Hunt and Field 1979), and dry weight all the roots were recorded for each of the subsampled plants. Nodal roots on the main and daughter tillers are termed main and daughter roots, respectively in the context of this thesis.

3.6.5 Transmission of Photosynthetically Active Radiation (PAR)

The transmission of PAR to 30mm above the soil at a midpoint between drill rows was measured at 35 and 65 d.a.s.. PAR was measured using the Lambda® quantum sensor (LI-190S) which measures radiation in the 400-700mm wave band. The sensor was used in conjunction with the Lambda® LI-170 quantum/radiometer/photometer to give a direct readout of PAR in microeinsteins m^{-2} sec^{-1}.

Measurement of PAR was carried out on cloudless, calm days between 1200 and 1300 hours. Measurements were carried out for each treatment within one block which was representative of the average growth for all blocks as assessed by eye. Measurements of PAR above the canopy were made before measurement of each individual treatment. Transmitted PAR was expressed as a percentage of the total available PAR.

3.6.6 Identification of Individual Plants

The history of seedlings was recorded in a similar fashion to the method described by Thom (1984). During May 1990, 288 ryegrass and 288 fescue seedlings were permanently identified to determine survival rate of establishing seedlings. A string was randomly extended across each plot and six seedlings were randomly selected along the string. These seedlings were 'tagged' using a loop of coloured telephone wire around the base of the plant formed by twisting the ends of the wire together and inserting that portion into the ground to act as an anchor. The ring size was periodically enlarged to prevent damage as the plant grew. In the cross-drilling treatment twelve plants were tagged per plot. Six were located at the 'Intersection' where the two passes of the drilling crossed over, and six 'Between' the intersections of the row. These plants may have occurred on the 'Angle' or 'Straight' portion of the row (Figure 3.6.1). 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 covered by soil as a result of animal trampling or earthworm activity), the frequency of the plot mean was reduced by one.

3.6.6.1 Measurements on Individual Plants

Sequential growth assessment was carried out during the life cycle of each of the tagged seedlings. All measurements were of necessity non-destructive. Tiller and leaf counts and the length of the longest vegetative tiller were recorded before each of the first five grazings (May-December) of the trial period, and tiller number only for the following two grazings (January and February). A tiller was counted once its first leaf had unfolded. All emerged tillers on each plant were counted at each time. Leaves were counted when they were fully expanded. The tiller length measurement was made from the base of the plant to the extended tip of the longest leaf. After grazing plants were checked to ascertain whether or not they had been removed during grazing, any dung deposited on or near ringed plants during grazing was removed using a trowel, but a few plants were inadvertently left covered and in some cases died.

3.6.7 Herbage Mass

Herbage mass (Hodgson, 1979) in this series of trials included living and dead herbaceous plant material above ground level at a given point in time, but excluded soil, dung and other contaminates, which were removed by washing. Herbage mass was in all cases determined by cutting the herbage to ground level in a number of quadrats per plot using a motorised shearing handpiece. Plot samples were bulked and the total amount of herbage was weighed after washing and drying as above. Care was taken to avoid double cutting of herbage which results in small pieces of herbage where herbage samples were destined for dissection. Slightly different sampling techniques were used with respect to the phases of sward development as follows:

(i) The establishment phase. At 55, 150 and 219 d.a.s., herbage was cut from four, $0.1m^2$ (0.2 x 0.5m) quadrats. Quadrats were thrown at random onto plots but were not sited in the vicinity of identified plants (Section 3.6.6), where dung and/or urine had been deposited or where quadrats had previously been cut. The quadrat was positioned with the longest edge perpendicular across 3 x 150mm drill rows or 6 x 75mm drill rows rather than along the rows.

(ii) The production phase. From 246 to 625 d.a.s. (December 1990 to January 1992), pre- and post-grazing herbage mass was assessed to determine herbage accumulation. By 246 d.a.s., there was a large variation in pasture height as above within individual plots mainly due to urine deposition. It was not possible to avoid these areas at each sampling so longer, narrower quadrats were used (0.165 x 0.910, 0.15 m^2) as they were expected to give more representative samples of height-variable vegetation (Hodgson et al., 1981). Estimates of herbage mass per plot were derived from weighted means of quadrat measurements made on 'High', 'Low' and Medium' areas and placed to avoid tagged plants, dung and/or urine-soiled areas or previously cut areas (3 quadrats for each plot). Again the quadrats were placed perpendicular to drill rows. The quadrat was made to a length such that it accommodated 12 x 75mm drill rows or 6 x 150mm drill rows.

An area $0.9m^2$ (2 x $0.45m^2$) of each plot was cut at each grazing and assuming a buffer zone of that same area surrounding a cut area, the same spot was not revisited by a quadrat cut during the 13 grazings of the trial period. However, some of the plots of the 75mm row spacing treatments were not the full size due to difficulties at drilling (Section 3.3), so assessment had to be discontinued after 393 d.a.s. because in some cases areas where quadrats had previously been cut were still recognisable at a subsequent sampling.

Where botanical composition only was assessed (75mm treatment at 576 d.a.s.), three, 1 metre long samples per plot were cut with electric handpiece (100 mm wide) to ground level at right angles to drill rows before grazing. Botanical analysis of these samples was carried as described in section 3.6.8.

(iii) One estimate of herbage accumulation was made by using a mechanical procedure which overcame the difficulty of measuring pasture growth where several days elapsed between the start and finish of grazing on the trial area. Pasture regrowth was measured using the 'pre-trim' technique (Boswell, date not specified) using a 'REM' plot harvester to cut and collect herbage. A 1m wide strip through each plot was trimmed before grazing to a height of 30mm 139 d.a.s. (1/9/90) to establish a base level for all plots. Increased growth in urine patches was obvious in ryegrass and those areas were avoided. Cages were placed over the trimmed areas as protection from stock which grazed the balance of the plots at 150 d.a.s. (Figure 4.1.5.4). Forty three days later (182 d.a.s.), the regrowth from a 0.6m x 6m strip was harvested to the pre-trim height with the REM. The fresh weight was recorded and a sub-sample (about 400g green material) from each plot was oven dried and weighed so that mass in kg $DMha^{-1}$ could be calculated.

3.6.8 Botanical Composition

Botanical dissection of pre-graze herbage samples was carried out at 55, 150, 212, 278, 393, 496, 567 and 684 d.a.s. (Table 3.5.1). The fresh sample, bulked from 3 quadrat cuts, was well mixed in the laboratory. Good mixing of the bulked sample was achieved as there were few small pieces of herbage present in the sample and after washing a sub-sample (4-8g for short herbage, up to 40g for long herbage) was obtained using the quartering technique (Boswell, loc cit) for dissection into component species. The green component of the sub-sample was dissected into; sown species, white clover, weed grasses, and broadleaf weeds. Any herbage which was no longer green was classified dead, partly dead leaves were separated into green and dead fractions. Dissected material was dried as described above and 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 sample.

3.7 Statistical Analysis

Generally the data were analysed as a split plot factorial with species allocated to main plots and the drilling method and seeding rate combinations allocated to split plots. Where 'Position' of plants was included in the analysis of tagged plants, data were analysed as a split/split plot with position as a further split. Individual species were analysed separately in some cases, for instance where a species by main treatment interaction was found, these instances are indicated in the text. The Genstat® 5 statistical analysis software package (Lawes Agricultural Trust, Rothamsted Experimental Station) available on the Sun network at Massey University was used for analyses in conjunction with a basic program developed by Mr G.C. Arnold, Statistics Department, Massey University. The data from tagged plants and seedling weight showed a non-normal distribution. Log_{10} transformation was used to reduce this problem. Back transformed values are presented unless stated otherwise, with standard errors converted to percentage values.

3.8 Statement of Conventions

When the F test for a particular source of variance as indicated by the analysis of variance was significant at or below the 5% level, treatment means were separated by calculating least significant differences (Little and Hills, 1978). To avoid congestion in figures and tables the standard errors of the differences are presented. Where comparisons of three or more main treatments occur, letters following means are included to denote significant differences. Significant interactive differences are not denoted by unlike letters.

4 RESULTS AND DISCUSSION

Introduction

The objectives of this study were to identify the important design parameters of no-tillage seed drills which could influence the population of drilled pasture species in such a way as to optimise early establishment and long-term yield potential. In this regard the interactions between species and drilling methods were expected to provide the most useful data. For example fescue and ryegrass are known to grow at different rates during the establishment phase and might be expected to shade bare soil between the rows at different rates depending on row arrangement and speed of growth. This in turn may determine the proportion of weed species which invade the developing sward.

The trial is described in three time periods. Section 4.1 describes the 'EARLY ESTABLISHMENT' period, from sowing until 145 days after sowing (d.a.s.), in which detailed measurements of plant population and size were recorded as well as herbage production. Section 4.2 describes plant size and survival data, together with herbage production, and covers the 'LATE ESTABLISHMENT' period from 145 to 313 d.a.s.. Herbage production and botanical composition data only are presented in Section 4.3 for the 'PRODUCTION PHASE' from 246 to 625 d.a.s. (9 - 21 months after sowing).

The above sequence for presentation is consistent with other reports which compare and contrast various management options and their effects on establishing temperate pastures (Brougham, 1954a,b,c&d; Kruez, 1977; Frame et al., 1985). Other authors who have worked specifically in the area of pasture establishment in un-tilled soils have regarded the first 12 months after sowing to be the establishment phase (Kunelius et al., 1982; Thom et al., 1987a; Bellotti and Blair, 1989c). This period was important to the long-term productivity of the sward as emergence and survival of introduced species and composition of the sward was largely determined by management decisions (eg. species, sowing method, seeding rate, fertility and grazing regime) made during this time. Similar claims were made by Brougham (1954a,b,c&d) and Sears (1953) for pasture established in cultivated soils with regard to the significance of clover survival to sward productivity. The sequence of presentation in this thesis follows the natural progression of sward development starting with a short period of mainly detailed individual plant measurements (early establishment) followed by a period where less detailed measurements were taken but an increasing proportion of herbage mass sampling was used (late establishment). In the production phase only herbage mass and composition were sampled.

The main or overall effects provided by species, seeding rate and drilling method are presented prior to discussing the interactions, since the main effects were reasonably consistent and predictable. In this respect main effects are tabulated only where significant differences existed. Otherwise main effect tables generally appear in the appendices. On the other hand, the interactions between treatment effects justify more detailed presentation and discussion. This order of presentation is used for each set of measurements. All significant differences between main treatments and interactions between main treatments are reported at the 0.05 level of probability or less, unless otherwise stated.

4.1 Early Establishment

4.1.1 Tall Fescue and Perennial Ryegrass Seedling Emergence and Population

4.1.1.1 Introduction

Percentage seedling emergence was calculated by comparing field counts of emerged seedlings with the drill calibration. A more accurate estimate of actual seeds sown may have been obtained by weighing seed into and out of the drill before and after each seeding rate change. However, this was not practical at drilling because of time constraints. There would also have been inaccuracies associated with that method because the drill seeding mechanism was engaged before entering the plot area and some seeds were sown outside the plots to ensure the drill was operating prior to entering the plot area. Another method might have been to use scoop recovery of soil and unsown seeds (Baker, 1976; Bellotti, 1984) but this method is destructive and was considered too time-consuming for such a field study. The exact number of viable seeds per unit area was therefore not known. Thus seedling emergence is quoted as a nominal figure only. However, it was considered that this approximation of percentage seedling emergence was sufficiently accurate and consistent across treatments to make valid comparisons.

4.1.1.2 Results

4.1.1.2.1 Overall Species, Seeding Rate and Drill Method Effects

Table 4.1.1.1 describes main treatment effects on nominal seedling emergence as a percent of viable seeds sown. Stand density (plants m^{-2}) and in-row population (plants m^{-1} row) are also shown as at 23 May, 1990 (42 d.a.s.). It was considered that maximal emergence was likely to have occurred by this time. Ryegrass emergence rate would be expected to be faster than fescue based on results from earlier work (Wright et al., 1978; Brock, 1983; Hill et al., 1985; Charles et al., 1991b). Preliminary population counts of plots sown at 75 and 150 mm row spacings indicated that 69 % of the eventual population catalogued at 42 d.a.s. had emerged by 21 d.a.s. (Table A1.4, Appendix 1).

Ryegrass emergence was significantly greater than fescue. Eighty four percent of sown ryegrass seeds emerged compared with 71 percent for fescue. Reduced emergence of viable fescue seed was anticipated and was compensated for by increasing the fescue seeding rate by

10% (K. Hill, pers. comm., 1990). This resulted in similar populations of ryegrass and fescue becoming established.

Table 4.1.1.1 Effects of Species, Seeding Rate and Drilling Method on Percentage Emergence and Population at 42 Days After Sowing

SPECIES	Nominal Seedling Emergence (% of viable seeds) †	Population (plants m^{-2}) †	In-row Population (plants m^{-1} row) †
Fescue	71	651	63
Ryegrass	84	631	62
S.E.D. ±	2.1	24	2.3
Significance ‡	* * *	n.s.	n.s.
SEEDING RATE			
High	73	795	77
Low	82	487	47
S.E.D. ±	2.3	19	1.9
Significance	* * *	* * *	* * *
DRILLING METHOD			
75 mm rows	79 a	659 A	49 A
Cross Drill	81 a	690 A	52 A
150 mm rows	73 b	573 B	86 B
S.E.D. ±	2.8	24	2.4
Significance	*	* * *	* * *

- † Unlike letters within each column denote significant differences (probability, lower case ≤ 5%, upper case ≤ 1%)
- ‡ Nomenclature for level of Probability (*) = 10% * = 5% * * = 1% * * * = 0.1% n.s. = not significant

Seeding rate had a significant effect on nominal seedling emergence. Higher emergence percentages were recorded at the low seeding rate compared with the high seeding rate (73 and 82 %, respectively). However, the population established from sowing at the high rate was significantly greater than that sown at the low rate.

Drilling method also had a significant effect on nominal seedling emergence. Plots sown at 150 mm row spacing had lower emergence counts than those sown in 75 mm rows or cross drilled. The 150 mm treatment had significantly less plants m^{-2} than the other drilling treatments but had a higher in-row population. This was due to fewer seeds m^{-2} being sown (see below) and because overall emergence was lower from that treatment. The emergence patterns from the three drilling methods were consistent with that shown with the comparison of high and low seeding rate, in that an increase in seed density within a row resulted in a reduction in emergence percentage.

Seeding rate and drill effects on emergence were significant for ryegrass but not for fescue (Table A1.5, Appendix 1). Seeding rate effects were similar for both species but drill effects were not. There were significant drill effects with ryegrass which were reflected in the main effects shown in Table 4.1.1.1 However, with fescue there were no significant drill effects. There were no significant interactions on seedling emergence between seeding rates, species or drill methods.

4.1.1.2.2 Effect of Position in the Cross Drill Treatment on Seedling Emergence and Population

The seeding rate of all three sections of row was the same within a given seeding rate treatment for cross-drilling, allowing an accurate comparison of seedling emergence. The relative positions of the three sections termed 'angle', 'straight' and 'intersection', delineated for seedling counts are illustrated in Figure 3.6.1.

Table 4.1.1.2 describes the effect of seeding rate and position on nominal seedling emergence for combined species and for fescue and ryegrass. Sowing rate had no significant affect on emergence within the cross drill treatment. Significantly higher emergence was evident from the straight and the angle portion of the cross drill rows than at the intersection of the rows. Although the density per unit row length of the seeds sown was the same at the three positions, significantly less seedlings emerged at the intersection. Seeds sown in that position would have been in closer proximity to each other. Seeding rate did not effect seedling emergence in the cross drilled treatments suggesting that density per se may not have caused the reduction in emergence.

The effect of position was significant for both ryegrass and fescue but at a lower level of probability. The population data (plants m^{-2} and plants m^{-1} row) are listed in Table A1.8 (Appendix 1) for both ryegrass and fescue. Analysis of variance showed no significant interaction between species, rate and position in the combined species results, nor was there an interaction between rate and position for individual species.

Table 4.1.1.2 Effect of Seeding Rate and Position (Within the Cross Drill Treatment) on Nominal Seedling Emergence Percentage

	COMBINED SPECIES (% of viable seeds)	FESCUE	RYEGRASS
High	78	74	87
Low	80	71	93
S.E.D. ±	3.3	4.3	5.0
Significance	n.s.	n s	n s
Intersection	68 a	65 (a)	77 (a)
Straight	84 b	76 (b)	90 (b)
Angle	82 b	73 (b)	87 (b)
S.E.D. ±	3.9	5.2	6
Significance	* *	(*)	(*)

- † Unlike letters in parenthesis within each column denote significant differences at a probability of ≤ 10%)

4.1.1.2.3 Effect of Seeding rate on Nominal Seedling Percentage Emergence

A regression analysis of nominal percentage emergence as a function of seeds m^{-2} and seeds m^{-1} row was carried out. Table 4.1.1.3 describes the results for combined and individual species. An increase in seed rate per unit area and per unit row length reduced nominal emergence. The slope of the regression line was significant for ryegrass but not fescue. Seeding rate ranged from 500 to 1026 and 565 to 1226 seeds m^{-2} for ryegrass and fescue, respectively (Table 3.3.1). On an area basis, each extra 150 seeds m^{-2} (20 % increase based on mean) reduced the nominal emergence of ryegrass by 3.9 %. The corresponding reduction in plant space per 150 seeds within that density range was on average 3.55cm^{-2} (range 4.6 to 2.5 cm^{-2}). There was a two-fold reduction in the area per seed (20 to 10 cm^{-2}) where space per seed is compared on an area basis. However, there was almost a four-fold reduction in between-plant spacing where space is compared within a row (40 to 154 seeds m row $^{-1}$). The distance to nearest neighbouring seed ranged from 24 to 6.5 mm. Each extra 19 seeds m^{-1} row (20 % increase based on mean) reduced the nominal seedling emergence of ryegrass by 4.2%. Higher r^2 values were obtained for the regression of seeds per unit row length than for seeds per unit area on nominal ryegrass seedling emergence, which reflected the wider range of between plant spacing.

Table 4.1.1.3 Effect of Seeding rate on Nominal Percentage Emergence

		Combined Species	**Fescue**	**Ryegrass**
SEEDS **per unit area**	Mean Emergence	78 %	71 %	84 %
	Slope (%/100 seeds)	-2.4	-0.9	-2.6
	level of significance for slope of regression line	0.1 %	n.s.	5 %
	r^2	0.2	0.05	0.22
SEEDS **per unit row length**				
	Slope (%/100 seeds)	-17	-7	-21
	level of significance for slope of regression line	0.01 %	n.s.	0.01 %
	r^2	0.23	0.07	0.36

4.1.1.2.4 Population Achieved for Each Treatment

Table 4.1.1.4 describes the seedling population achieved. The rationale behind comparing seeding rates and drill row spacing treatments was to assess the interactions between in-row plant population and population on an area basis. The objective of establishing comparative swards sown at both a constant seed rate per unit row length, and a constant seed rate per unit area were mostly met. The in-row population of 75 mm rows sown at the high rate was the same as the in-row population of 150 mm rows sown at the low rate, but population on a area basis was different. The number of plants m^{-2} of 150 mm row spacing treatment was significantly less than those sown at 75 mm row spacing or cross drilled, partly because seeding rate was not exactly doubled for 150 mm row spacing (Table 3.3.1) and seedling emergence was reduced with 150 mm rows (Table 4.1.1.3), but the values were within 100 plants m^{-2} of one another.

Table 4.1.1.4 Comparison of Plant Populations of Fescue and Ryegrass 42 d.a.s. in Order of Increasing Plant Density.

Sowing Rate	Low	Low	High	Low	High	High
Drill Method	Cross	75 mm	75 mm	150 mm	Cross	150 mm
Fescue	38§ (509)¥	39 (523)	61 (820)	65 (435)	67 (901)	108 (718)
Ryegrass	38 (507)	39 (530)	57 (763)	62 (416)	63 (844)	109 (725)
S.E.D. ±	3.6 (46)					

- § plants m^{-1} row
- ¥ figures in parenthesis = plants m^{-2}

4.1.1.3 Discussion

Results are discussed under treatment headings.

Species

Seedling emergence is dependent on the interaction of many factors, among which are soil type, soil moisture, compaction, crust strength, oxygen diffusion and temperature (Wright et al., 1978; Bellotti and Blair, 1989b). Nominal seedling emergence percentage was considered to be very good at 84 % and 71 % for ryegrass and tall fescue, respectively, considering that the trial was sown with a drill which had limited contour-following ability and seed-depth control. It is considered that this good field emergence was obtained for a number of reasons.

Soil moisture was optimal for drilling, being dry enough to be friable but moist enough to allow adequate drill opener penetration. Vegetation had been blanket sprayed with herbicide 3 weeks prior to sowing and there was no green vegetation present, which also assisted opener penetration. Adequate loose soil was created during drilling to provide good seed coverage when harrowed after sowing.

Soil moisture at sowing was not only adequate for the operation of the drill but was also sufficient for seed germination. During the 21 days between the time of spraying and sowing 37mm of rain fell and evapotranspiration for that period, based on pan evaporation, was 33 mm (Figure A1.2, Appendix 1). Evaporation/evapotranspiration figures for the period from spraying until seedling emergence are likely to have overestimated moisture loss as the soil was undisturbed and covered with dead mulch (Phillips, 1984). Crop evaporative demand would have been low as pasture and weed seedlings were very small. Gravimetric soil water content was 25 % (dry basis) at the time of drilling (Table A1.1, Appendix 1). Seven mm of rain fell 4 days after sowing, and a further 74 mm of rain fell and was spread relatively evenly during the next 17 days (Figure A1.1, Appendix 1). Field capacity was reached 21 d.a.s. (Figure A1.2, Appendix 1). Consequently soil conditions were moist throughout the germination/emergence period, and seed and seedlings would not have suffered any moisture shortage.

The drill used to sow this trial had limited contour-following ability as openers were mounted on spring tines which were attached to a rigid frame. Soil surface micro-contour variations were minimal. There were a few minor depressions in the paddock (eg ploughing finishes) but these were avoided for the trial and there was little in the way of surface irregularities such as cattle pugging or wheel ruts. Despite this, in order that all seed was covered during drilling, groove depth was set at 20 - 30mm. A shallower setting may have resulted in the opener riding out of the soil where soil density and/or strength was higher or where minor depressions occurred, and may have led to subsequent placement of seed on the soil surface. Target depth was 15-20 mm. No measurements were taken at the time of sowing but, from visual observations by W R Ritchie, M. McKinnon and the author, it was considered that groove depth varied from 20 to 30 mm and seed depth after harrowing varied from 15 to 25 mm. This was within the desirable range reported for ryegrass and fescue varieties (Brock, 1973; Charles et al., 1991b). Despite its limited contour following ability, the drill had winged openers which Baker (1976) had shown promoted a more favourable seed/seedling micro-environment than other opener designs.

Overall emergence was good in this study and the emergence results compare favourably with previous studies of direct drilled pastures (Woodman et al., 1990). However, fescue fared less favourably than ryegrass. Reports of inferior field emergence for fescue compared with ryegrass are common (Hayes, 1976; Brock, 1973, 1983; Brock et al., 1982; Bellotti and Blair, 1989b; McCallum and Thomson, 1990). Poor seedling vigour is cited as a major failing of tall fescue, placing it at a competitive disadvantage in mixed sowings (Brock, 1983).

The emergence of fescue tends to suffer more than ryegrass where conditions are less than optimal. Relatively poor vigour at establishment of tall fescue, as compared with perennial ryegrass, was seen as such a problem by McCallum and Thomson (1990) that they precluded the possibility of tall fescue establishment by direct drilling and recommended against the practice. However, this and other trials have shown that success can be achieved. Charles et al., (1991a) reported 31% establishment of 'Demeter' tall fescue (93 plants m^{-2}) in New South Wales, Northern Tablelands, Australia, at 60 d.a.s. when it was direct drilled in the spring with a machine similar to that used in this study ("Aitchison Seedmatic" with winged openers). On that basis direct drilling was recommended as a successful method of tall fescue establishment.

A distinction was made between 'germination' and 'emergence' when used in the context of the current study. As for other studies of pasture (Bellotti and Blair, 1989b) and crop establishment (Baker, 1976; Baker and Choudhary, 1981b) by direct drilling, the seed/seedling passes through two distinct phases before it is regarded as 'emerged'. Firstly, 'germination' of the seed refers to the imbibition of moisture and elongation of seminal and root and shoot. Secondly, 'emergence' refers to the physical appearance of the shoot above the soil surface. After this it is referred to as an 'emerged seedling'. An emerged seedling may also be referred to as an 'established seedling' but the latter term usually refers to a seedling which has survived for a period of time after emergence (Frame and Hunt, 1964; Bellotti and Blair, 1989b). If the seed is exposed to light, for example, on the soil surface or in the base of an uncovered groove, then 'germination' may be synonymous with 'emergence'.

Work carried out by Charlton et al., (1986) where the germination of 9 grass species were assessed at constant temperatures of 5, 10, 15, 20, 25 and 30 °C would suggest that the final germination percentage of fescue and ryegrass were likely to have been similar. However, the germination rate was greatest for the ryegrasses at all temperatures. Field emergence percentage of fescue was thought to be reduced relative to ryegrass because of modifying factors which determine eventual emergence (seed placement, emergence rate, Bellotti and Blair, 1989b).

Temperature may have been partly responsible for the lower emergence percentage recorded for fescue relative to ryegrass (Table A1.5, Appendix 1). Average air temperature was 11 °C, regularly reached over 15 °C and went below 5 °C on 7 days. Average soil temperature at 10 cm was 10.3 °C. The average diurnal variation in temperature for the period was 15/7 °C. Hill et. al., (1985) suggested that field emergence of fescue was poorer in comparison to ryegrass where temperatures were reduced. Hamilton-Manns, (1994) from a similar field trial carried out recently in the Manawatu during autumn also showed a stronger reduction in fescue emergence compared to ryegrass as soil and ambient temperatures declined. Results from the current trial support work by Charles et al., (1991b) and Hill (1985) which indicated that the temperature window for successful establishment of fescue is wider than reported by Hill et al., (1985) with 71% of sown seeds emerging in the field in 42 d.a.s. at an average air temperature of 11 °C with diurnal variation in temperature of 15/7 °C (Table A1.5, Appendix 1). The 10% increase in seed rate for fescue in comparison to ryegrass to account for an estimated reduction in effective field emergence for fescue due to temperature, proved to be warranted (Section 3.3).

The difference in seedling vigour between the two species was not a function of the weight of seed energy reserves. Brock et al., (1982) on the basis of theirs and other work (Wright, 1971) stated that although the size of the seed is positively correlated with seedling vigour within a cultivar, there is less of a relationship between cultivars and little or none between species. This was demonstrated in this study as the weight of seed ('Supernui' 2.23 and 'AU Triumph' 2.5 mg/seed) did not seem to be related to vigour.

The magnitude of the difference in percentage emergence for perennial ryegrass and tall fescue apparently increases with decreasing temperature (Hill et al., 1985; Charles et al., 1991b). Other factors also influence the number of seedlings which become established such as competition from resident vegetation, soil moisture availability, seed depth, groove and seedbed moisture retention characteristics. As these factors reach suboptimal levels, declining temperature is likely to have a larger impact on tall fescue than perennial ryegrass because of its slower rate of emergence and less vigorous nature. Slower emergence rate predisposes to increased susceptibility to fungal and insect attack (Moore, 1943; Campbell and Swain, 1973) making rapid emergence a desirable attribute for sown populations. In this study, tall fescue suffered a 13% reduction in field emergence percentage in comparison with perennial ryegrass even at the lower end of the temperature range for tall fescue establishment although a similar number of plants m^{-2} were established. Success was thought to be due to adequate soil moisture availability, achieving good control of vegetation and any resident insects, and ensuring correct seed groove depth and seed coverage.

Seeding Rate/Drilling Method

The populations achieved at establishment allow legitimate comparisons of swards with both a constant population per unit row length and a constant population per unit area (Table 4.1.1.4). Equilibrium plant numbers under normal pasture conditions were estimated to be around 400 grass plants m^{-2} (Hill and Shimamoto, 1973) in an established sward. Sangakkara and Roberts

(1982) considered that population to be representative of established pastures in the region in which this study was conducted. On that basis it is suggested that all treatments had a sufficient grass plant population for a productive sward. Populations in this trial ranged from 416 to 901 plants m^{-2} (Table 4.1.1.4) and is representative of pasture establishment on commercial pastoral farms.

Overall emergence (but in particular, ryegrass emergence) was inversely related to seeding rate (Tables 4.1.1.1 and A1.5, Appendix 1). More particularly, 36% of the variation in ryegrass emergence was attributable to variation in the density of seeds m^{-1} row (Table 4.1.1.3). The relationship was not significant for fescue but the same trend was apparent.

At 42 d.a.s. there was a 13 % increase in nominal percentage seedling emergence for ryegrass sown at the low, compared with the high rate (Table A1.5, Appendix 1). Eleven percent increase in emergence was recorded for those seeds sown at the lower in-row density in 75 mm rows and cross drilled, as compared with those in 150 mm rows.

At 21 d.a.s. significantly more (80 %) of the total emerged seedlings, which were later catalogued at 42 d.a.s. were present in the 75 mm row spacing but only 59% of these were present for 150 mm row spacings (Table A1.4, Appendix 1) indicating that emergence rate was not only lower, but also slower from rows sown at 150 mm spacing. Similar proportions of seedlings had emerged from high and low seeding rate treatments at that time, indicating that the average effect of seeding rate over all drill treatments was less severe than the effect of drill treatments at that time (Table A1.4, Appendix 1).

A proportional increase in the in-row seed density had a more marked effect on emergence than a corresponding increase in seed density per unit area (Table 4.1.1.3). The effect was demonstrated by the comparison of 75mm and cross drilled rows with 150mm rows. Inter-seed distance of ryegrass ranged from 24mm at 41 seeds m^{-1} row to 6.5mm at 154 seeds m^{-1} row (Table 3.3.1). To achieve a comparable reduction in the distance between seeds where they are broadcast rather than sown in rows would require a density increase from 1736 to 25000 seeds m^{-2} or 37 to 557kg ha^{-1} of Supernui perennial ryegrass (2.23 mg $seed^{-1}$).

Nominal seedling emergence figures are quoted for overall and within-species comparisons of seeding rate and drill methods. However, where comparisons are made within the cross drilled treatments between positions, comparisons of density effects on emergence are more accurate as each position was sown with the same number of seeds. Overall seedling emergence at the angle and straight sections of cross drilled plots was superior to that for the intersection (Table 4.1.1.2). Data collected from the cross drilled plots at 21 d.a.s. supports this finding. Of the seeds sown, 15 % less had emerged at the intersection than at the angle or straight sections, which themselves had the same number of seedlings by 21 d.a.s. (Table A1.7, Appendix 1). That reduction may have been due in part to the physical disturbance caused by the drill opener passing through the groove made by the first pass of the drill as some seeds may have been uncovered and others buried more deeply. However, if that was the case, then fescue would likely have been more affected than ryegrass, as it is reportedly more sensitive to depth than ryegrass (Moore, 1943; Brock, 1973). This was not so, suggesting that seed density per se influenced seedling emergence.

Inverse relationships between seedling emergence and seeding rate have been previously recorded (Ryan et al., 1979; Tyul'dyukov and Krainev, 1983; Korotkov, Simonova, Grechishnikov, 1985) but this is not a general occurrence. Just what mechanism causes the reduction in percentage emergence with higher seed densities has not been made clear . Some reports do not differentiate between whether or not seedling mortality occurred after germination but before emergence (Williams, 1947; Charles, 1961; Frame and Hunt, 1964), so it is not known when or why seedling mortality occurred. Brougham (1954a) carried out one of the more definitive trials studying the effect of seeding rate on sward development involved short rotation ryegrass (*Lolium perenne* X *L. multiflorum* L.), and found that within the range 11.3 to 68 kg ha^{-1} seeding rate had no significant effect on percentage seedling emergence at 32 d.a.s.. In his trial seed was broadcast with a minimum distance between seeds of approximately 40-50mm at 68 $kgha^{-1}$, which was considerably further apart than seeds in the current trial, which may explain why seeding rate did not affect emergence. However, from a parallel trial Brougham (1954c) reported a reduction in percentage emergence of ryegrass where seeding rate was increased from 13 to 35$kgha^{-1}$. In the current trial, the improvement in seedling emergence at lower seeding rates may have been due to several factors including insect aggregation and predation on rows with higher seed density (Mr G.M. Barker, pers com., 1993) or increased competition between germinating and emerged seedlings.

Some emerged seedlings may have been lost at higher densities through competition, and the apparent reduction in emergence may have been due to early seedling mortality rather than lack of emerged seedlings. The measurements taken in this study can not confirm or refute this possibility. Nevertheless, it is unlikely that seedling mortality occurred once seedlings had emerged under the climatic conditions which prevailed at the time, but may have occurred between seed germination and seedling emergence (Bellotti and Blair, 1989b; Charles et al., 1991b). In other studies, seedling mortality as a function of seeding rate has not usually been apparent until at least 5 to 10 months after sowing (Kruez, 1969; Falloon and Fletcher, 1983; Robinson and Whalley, 1988). In the present study, not all plants had emerged by 21 d.a.s.. Seeds sown at higher in-row densities were somewhat slower to emerge suggesting competition was occurring before emergence.

The fact that the reduction in emergence was more apparent for ryegrass than fescue suggests that intra-row competition was responsible for the effect. Perennial ryegrass seedlings begin utilising external nutrients very soon after imbibition (within 6 days of imbibition at 24/19°C day/night temperatures (McWilliam et. al., 1970) and well before the exhaustion of endogenous seed reserves. Perennial ryegrass has a more vigorous growth pattern than tall fescue during establishment. The higher rate of growth would place a relatively heavier demand on soil resources (moisture and nutrients). Therefore species which utilise the resources rapidly are more likely to be affected by intra-row competition for nutrients than fescue, which would explain why the percentage emergence of ryegrass was more severely affected by increasing in-row density than fescue. Seedlings at that stage of growth may have been competing for below ground resources.

Pests

Broad spectrum pest control was undertaken. Insecticide was placed in the groove with the seed at the time of drilling and molluscicide was distributed on the soil surface directly after the seed was covered by harrowing. Recent work has shown that pest damage may be related to in-row seed density (Mr G.M. Barker, pers com., 1993). Increased aggregation of soil dwelling insects (grass grub) was reported in seedling rows of direct drilled autumn sown ryegrass where initial seed density was higher (range 5 to 20 kg ha^{-1}) and was thought to have reduced percentage emergence. Insect populations were not specifically monitored in such detail in this study but the following observations were made.

The pasture pests thought most likely to be a problem in this trial were grass grub larvae (*Costelytra zealandica* (White)), slugs (*Deroceras* spp) and Argentine stem weevil (ASW) larvae (*Listronotus bonariensis* (Kushel)) (Barker et al., 1993b), but there was little evidence of their effects. Only one grass grub larva was found in twelve, 150 mm soil divots extracted from and centred on seedling rows at 56 d.a.s.. No slugs or slug damage, characterised by hollowed out seeds, dead germinating seedlings and slug slime trails (Ferguson, 1984) was found during establishment. It is unlikely that ASW caused reduced seedling emergence with ryegrass because the seed used was infected with the endophyte *Acremonium lolii.* which is reported to protect that species from new infection by adult ASW (Pottinger et al., 1985; Prestidge and Gallagher, 1988). ASW larvae may have transferred from the dead vegetative matter into which seed was sown (Barker et al., 1984). However, negligible larval damage was found in ryegrass during the study, but was subsequently found to be a noticeable problem in the fescue sward.

An average of 30 per m^{-1} row (5.5 per spade width) white fringed weevil (*Graphognathus lecoloma*) (WFW) larvae were found in the ryegrass sward at 56 d.a.s.. No measurements were available for fescue but populations would be expected to have been similar for the two pasture species as WFW are relatively immobile ground-dwelling insects (Chapmen, 1984). Similar numbers of larvae were detected at both seeding rates. Insufficient measurements were taken to ascertain whether or not there was any drift of WFW between off-row and on-row positions in this trial, or whether populations were related to in-row seed density, as only 12 soil samples were taken. The work of G.M. Barker was not known at the time of sampling. The population found would seem to have warranted control (Barker, 1987) but that was not possible as the only effective method of control is thorough cultivation. It is, however, unlikely that WFW was responsible for the variation in emergence percentage between the two seeding rates for two reasons:

(a) White fringed weevil damage is most extensive on clovers (East, 1983; Barker, 1993). Annual production losses in the order of 28% for a pure white clover sward and 10 % of clover ryegrass/white clover sward have been reported for white fringed weevil infested pasture. White fringed weevil is less likely to affect the grass component of a sward. The selection of WFW towards legumes is such that the establishment of a graminacious crop is a recommended control strategy (Barker, 1987). Feeding patterns and preferences of pests are altered where resident vegetation is killed by herbicides and the only actively growing roots would be those of the seedlings along the rows (Barker, 1986) which presumably would be favoured by any root feeding pest. This was not strictly the case with this trial as resident clover did appear to be recovering at the time the WFW population was counted.

(b) The effect on emergence was not the same for both species. It is not known if WFW show a preference for perennial ryegrass over tall fescue or vice versa. Although established tall fescue is more tolerant of root feeding by soil-dwelling pests such as grass grub (East 1980), this tolerance is conferred by virtue of faster root growth of fescue, relative to ryegrass, rather than a repellent effect. Thus it is unlikely to have been a factor in establishing tall fescue which has relatively slower root growth than ryegrass, and does not explain why the seeding rate effect on emergence was more apparent for ryegrass than fescue. Larvae are naturally tolerant to insecticides but granular insecticides eg. organophosphates, such as those used in this trial, provide some protection (East, 1981).

So it is unlikely that WFW caused the depression in emergence associated with increasing seeding rate. Insect pests were not considered a problem during emergence of grass seedlings in the current trial.

4.1.2 Emergence and Population of Clover and Unsown Species

4.1.2.2 Results

4.1.2.2.1 Overall Species, Seeding rate and Drill Method Effects

The seedling population of white clover, broadleaf weeds and grass weeds were recorded 37 d.a.s.. Maximal emergence was likely to have occurred by this time. Other authors (Squires et al., 1979; Campbell and Swain, 1973; Campbell, 1985; Campbell et al., 1985; Charles et al., 1991b) had reported maximal emergence of white clover under a range of conditions between 15-37 d.a.s..

In this study 'Pitau' white clover was sown at a constant rate of 3 kg ha^{-1}. Germination of clover seed was 90 % as tested by the Seed Technology Centre, Massey University. Thus 360 viable seeds m^{-2} were distributed in all treatments. As for grass species, clover seed was not weighed in and out of the hopper between adjustments to flow rate from the hopper. White clover emergence therefore is reported as a nominal figure. Although Granstar® was used as a pre-drilling herbicide with Roundup®, not all the resident clover was completely killed. Nevertheless, new clover seedlings were distinguishable because regrowth of resident clover arose from stolons and did not have cotyledons or simple leaves, only "true" trifoliate leaves (Langer, 1982).

Some clover seed fell indiscriminately on the soil surface during drilling because of faulty spout connections between the distribution mechanism and the delivery-tubes which carried seed from the seed distributor to the openers. Clover seed was metered separately from the grasses using the "granule" distribution box of the drill and was mixed with the insecticide Phorate®. The spillage problem became apparent only after the drilling had commenced. Because the problem was not easily corrected, was intermittent, and would have had only minor effects on grass seed establishment, drilling was continued. For that reason, new clover seedlings were counted regardless of their proximity to the drill row. A standard germination test of the clover/insecticide mixture was carried out at a constant temperature of 20 °C. No difference in germination of clover was detected for clover seed with or without contact with Phorate® (Table A1.9, Appendix 1).

Table 4.1.2.1 shows the overall effect of species and seeding rate on the seedling population of clover, broadleaf weeds, prairie grass (*Bromus willdenowii*) and other grass weeds, together with the combined total of weeds in a category called "Total Unsown", which did not include clover seedlings. Corresponding details for drill method effects are located in Table A1.11, Appendix 1.

Significantly more clover seedlings were found in fescue than in ryegrass plots (Table 4.1.2.1). Significantly more clover seedlings established in the plots sown at the high rates of grass species compared with those sown at the low rates. Clover establishment was not affected by drill method. The population of clover seedlings ranged from 153 to 177 plants m^{-2} for the three drill methods (Table A1.11, Appendix 1).

The establishment of broadleaf weeds, prairie grass, and grass weeds was not influenced by the grass species sown, the seeding rate or the drilling method used (Tables 4.1.2.1 and A1.11). Analysis of the "Total Unsown Species" gives an overall indication of how many unsown species established in the main treatments. The total of all unsown species was not significantly affected by sown species, seeding rate or drilling method treatments. The population for all treatments was similar at between 603 and 652 plants m^{-2} (Table 4.1.2.1).

Annual mouse eared chickweed (*Cerastium glomeratum* Thuill.) and field speedwell (*Veronica arvenis* L.), both annuals, were the predominant broadleaf weeds established at 37 d.a.s.. Other annuals such as storksbill (*Erodium cicutaruium* L.), shepherds purse (*Capsella bursa-pastoris* (L.) Medic.), and twincress (*Copronopus didymus* (L.) Sm.) were also present along with the perennial narrow-leaved plantain (*Plantago lanceolata* L.) and biennial hawkesbeard (*Crepis capillaris* (L.) Wallr.). Prairie grass has been reported as requiring particular management strategies to maintain a persistent sward on heavier soil types with poor internal drainage, such as the Tokomaru silt loam (Matthews, 1986; Black and Chu, 1989). However, in this study on relatively free draining, lighter soil, it readily established from unsown seed and was considered a weed in the context of this study. The category "other grasses" consisted almost entirely of annual poa (*Poa annua* L.) with some couch (*Agropyron repens* (L.) Nevski).

There were no significant interactions between main treatments.

Table 4.1.2.1 Effect of Species, Seeding Rate and Drill Method on Population of White Clover and Unsown Species Seedlings 37 d.a.s.

	WHITE CLOVER	UNSOWN SPECIES (plants m^{-2})			
SPECIES	(plants m^{-2})	Broadleaf Weeds	Prairie	Other Grasses	Total Unsown
Fescue	190	447	91	114	652
Rye	146	402	114	124	603
S.E.D. ±	13.5	39	21	8	46
Significance	*	n.s.	n.s	n.s	n.s.
SEEDING RATE					
High	184	434	123	123	628
Low	152	415	115	115	627
S.E.D. ±	13	28	15	14	35
Significance	*	n.s	n.s	n.s	n.s

4.1.2.3 Discussion

White Clover

The establishment of "new white clover seedlings" was disappointing. On average 168 seedlings m^{-2} had established by 37 d.a.s., which equates to 46% of viable seeds sown, some of which may have germinated and emerged from hard clover seed (not necessarily white clover) buried in the soil. Some red clover (*Trifolium pratense*) and subterranean clover (*Trifolium subterranean*) seedlings from buried seed may have been inadvertently counted as they were indistinguishable from white clover seedlings at that stage. However, only a few subterranean clover plants and no red clover plants were evident in the ensuing sward, which confirms that white clover seedlings which germinated from sown seed were the dominant "new" seedlings counted.

Mean populations for individual treatments varied from 120 to 220 seedlings m^{-2} with few significant differences between them. In the twelve treatments sown, the clover and phorate® distribution rate (clover and phorate® were mixed) was altered 3 times whereas the grass seed distribution rate was altered 8 times. The clover and phorate® metering rate remained unaltered while drilling the 75 mm and cross drill treatments at both high and low grass seeding rates for one species. Virtually the full range of clover population treatment means (120 -200 seedlings m^{-2}) were apparent for an identical rate within a group of four treatments, indicating the variability of white clover seedling emergence or the problem with the drill outlined previously.

Twenty three percent more clover plants established with tall fescue than with ryegrass. Better compatibility of tall fescue with legumes has been recognised (Hay, 1987; Hay and Hunt, 1989). Seedling perennial ryegrass is more vigorous than tall fescue (Brock, 1973; Brock et al., 1982; Bellotti and Blair, 1989b) and comparatively greater suppression would be expected from ryegrass as seedlings develop in associations. This study has highlighted the fact that this competition effect may occur as early as the emergence phase of pasture establishment. A similar result was reported by Watson (1990) although his results were linked to nematode damage. No measurements of root nematodes were taken at the outset of this trial so there is no way of knowing what effect they may or may not have had. The insecticide phorate® applied in the seed groove at drilling would have had some activity on nematodes and they were unlikely to have reduced the number of clover seedlings emerging, but may have influenced subsequent clover growth (Healy et al., 1973; Watson et al., 1986; Watson, 1990).

More white clover seedlings were found in the plots sown at the high grass seed rate than those sown at the low rate. This result has not been found elsewhere and is somewhat unusual. Even so, the difference was small (17%). Most experience with various grass seeding rates and clover associations have not enumerated the emergence of clover, only its eventual contribution to herbage mass (Frame et al., 1985; Frame and Boyd, 1986). Where clover emergence has been noted, grass seeding rate has had no influence on clover seedling emergence percentage.

Brougham (1954a) reported 70 % emergence of viable white clover seeds at 40 d.a.s. from a conventionally cultivated seedbed which was unaffected by seeding rates of short rotation ryegrass ranging from 0 to 68 kg ha^{-1}. Similar results have been reported from other trials by Sears (1950), Brougham (1954b) and Cullen (1958). Subsequent clover growth, however, has been reportedly disadvantaged with higher grass seeding rates (Brougham, 1954a).

Compared with the establishment of grass species such as perennial ryegrass and tall fescue by direct drilling, there is a dearth of information regarding white clover establishment by the same method. This is most likely due to the fact that the herbicides commonly used with direct drilling (paraquat and glyphosate) do not completely kill resident white clover (O` Conner, 1990). Where success of clover establishment from seed has been limited, clover regeneration might mask a poor emergence result. Difficulties in establishing small-seeded legume species in conventional seedbeds and by direct drilling has been noted from previous studies (Moore, 1943; Campbell, 1985). White clover establishment for this trial was comparable to results from other reports (Squires et al., 1979; Thom et al., 1993).

Most forage legume seeds germinate over a wide range of temperatures. White clover is no exception (Cooper, 1977). Germination rate is however decreased at lower temperatures (McWilliam et al., 1970; Charles et al., (1991b). The soil temperatures which prevailed in this study (8.9 to 11.4 °C) would not have limited germination percentage of clover (McWilliam et al., 1970; Charles et al., 1991b). However, it is not known what effect temperature had on white clover emergence (after germination) in this study.

Charles et al., (loc cit) demonstrated that white clover emergence was the same for 12 and 24°C at a depth of 15 and 30 mm (80 and 20 %, respectively) but decreased as temperature was reduced to 9°C (50 and 6 %, respectively). The average diurnal temperatures for the period from sowing until clover population catalogued in this study was 15/7°C with an average ambient temperature of approximately 11 °C (Table A4.7, Appendix 4). Charles et al., demonstrated that white clover emergence was unaltered by diurnal temperatures of 12/6 °C compared with that attained under a constant temperature of 12 °C. Therefore the results from their work at 12 °C would be comparable to the results under consideration in this report.

The predominant causes of failure in white clover establishment have related to moisture availability and seed depth (Campbell and Swain, 1973; Squires et al., 1979; Campbell, 1985; Campbell et al., 1985; Thom et al., 1993). Insect attack has also been reported, in particular slug damage (Ferguson, 1984) and ant theft (Campbell and Swain, 1973; Campbell, 1985). As previously discussed, (Section 4.1.2) the soil in this study was moist throughout the initial establishment period and would not have limited seedling germination or emergence of sown species. Insects did not cause any obvious problems, although the effect of WFW was not known. As with the fescue establishment in this study it is unlikely that temperature or moisture limited white clover germination, but some seedlings may have been lost between germination and emergence. Seed depth was probably the major factor which caused a reduction in white clover emergence.

After extensive studies of the emergence response of red clover to depth variation under direct drilling, 13mm was the recommended depth for sowing that species (Campbell, 1981, 1985, Campbell and Kunelius, 1984; Campbell et al., 1983, 1985). However, analogous work has not been reported for white clover. Red clover has superior emergence compared with white clover (Moore, 1943; Black, 1959; Cooper, 1977) and comparison of work by Campbell (1985) and Charles et al., (1991) would suggest that white clover is likely to suffer a proportionately greater reduction in emergence than red clover for a similar increment in seed depth. Seed coverage in this trial varied from 15 to 25mm (Section 4.1.2) and was considered to be as shallow as practical, but may have been deeper than optimal for white clover emergence.

Differences in the number of white clover seedlings establishing were reported from a field trial conducted within 2 km of the current trial (Inwood, 1990). Almost 400 white clover plants m^{-2} established in the conventionally sown (broadcast on grooves made by a "Vee" ring roller drill) sward compared with approximately 200 by direct drilling (150mm rows). The direct drill used in that study was common with the one used in the current study. Seed depth is likely to have been a causal factor of that difference. The comparatively better emergence of white clover from cultivated seedbeds reported by Brougham (1954a) was probably attributable to better control over seed depth but may also be a result of the relative reduction in plant density of distance to the nearest neighbouring seedling, which reduced competition between grasses and clover plants during emergence as a result of broadcast sowing and/or closer row spacing.

Emergence percentages for the species sown for this trial ranked in order of best to worst were 84, 71, and 46% of viable seed sown for ryegrass, fescue and white clover. This follows the order which would be predicted from earlier information with respect to the order of susceptibility to deeper-than-optimal seeding depth (Murphy and Arny, 1939; Moore, 1943; Brock, 1973).

The population of white clover which did establish in this trial (168 plants m^{-2}) would seem to be sufficient for development of a productive sward despite the fact that it was a relatively small proportion of the seeds sown. Management guidelines set out by Frame and Newbould (1986) suggested 3-4 kg ha^{-1} of white clover seed should be sown in pasture seed mixes to ensure that an adequate population of white clover establishes in the new swards for balanced pastoral production. Hagger et al., (1985) suggested that populations of about 150 plants m^{-2} 3 months after sowing translated to about 30% ground cover 12 months after sowing, and that 150 plants m^{-2} should be a target for successful pasture establishment.

Weed Population

Minimising the weed population has always been a concern in establishing productive swards (Brougham, 1954a, d; Cullen, 1958: Cullen and Meeklah, 1959; Hallgren, 1976a, b; Harris et al., 1977; Hagger et al., 1985; Charles et al., 1991a). The buried weed seed content of the very recent alluvial soil on which this study was sown was likely to have been very high, as the area was subjected to periodic flooding. Encroachment of broadleaf weeds is a feature of pasture establishment on these soils and normal farm practise is to apply post-emergence herbicide (phenoxybutyrics) for weed control (G.Lynch. pers. com., 1990).

Weed emergence for the types of weeds categorised in the study and for the total of all unsown species was not influenced by the species sown or the seeding rate. The proportion of available light which penetrated to 30mm above the soil surface between the drill rows was measured at 35 and 65 d.a.s.. It was found that for both species and at both seeding rates there was a reduction in the amount of light reaching the soil between the drill rows at 35 d.a.s. as compared with the amount of light above the sward (Table A1.17, Appendix 1). However, the shading effect of sown grass species on the surrounding bare soil between the time of sowing and when population counts were carried out was negligible, and did not affect light relations sufficiently to influence weed seedling emergence or growth. Sown grass species at that stage were about 40 to 100 mm high. The corollary of this, in terms of this study, is that all treatments began the trial with essentially the same potential weed competition (approximately 600 to 650 plants m^{-2}).

On average approximately 420 broadleaf weeds m^{-2} and 200 volunteer grasses m^{-2} established in the current trial by 37 d.a.s.. That is somewhat higher than other reports for weed populations established after spraying and drilling (100 total weeds m^{-2}, Inwood, 1990; 172 total weeds m^{-2}, Roberts and Feast, 1973, 119 total weeds m^{-2}, Pollard and Cussans, 1981) or cultivation in autumn (37 dicotyledonous and 3 to 30 Poa annua m^{-2} Pollard and Cussans, 1976; 138 weeds m^{-2}, Inwood 1990). The potential for weed competition was high in this trial.

The winged drill used in this study caused a considerable amount of soil disturbance. The physical action of the drill was similar to a spring tine cultivator with very rigid tines. Soil disturbance affected soil to only a shallow depth (0-30mm). There was a contrast in soil disturbance between the 150mm (single pass) and 75mm row spacing and with cross-drilling. Harrowing exacerbated that effect. However, no difference in broadleaf or grass weed seedling emergence was detected. The same result was reported by Inwood (1990) who used the same drill in a study on a slightly heavier soil type (silt loam) which was also the product of alluvial deposit and was within two kilometres of the current trial.

Soil disturbance modifies the seed environment and breaks dormancy of some seeds by (i) exposure of seed to light, (ii) alteration of the temperature/moisture regime and (iii) physical abrasion of the seed coat (Wesson and Wareing, 1969; Roberts and Feast, 1973; Grime et al., 1981; Wilson, 1981; Froud-Williams, 1988). The relative proportions of the two dominant types of weeds which germinate in an establishing sward is altered by tillage practices. Dicotyledonous weed establishment for maximal soil disturbance (conventional cultivation) far exceeds that for minimal soil disturbance (direct drilling) (Inwood, 1990). As a proportion, the number of grass weeds (annual and perennial monocotyledonous weeds) may be higher with direct drilling (Pollard and Cussans, 1976, 1981; Froud-Williams, 1988). Seeds of dicotyledonous annuals generally have good dormancy mechanisms and readily germinate on exposure to light when they are brought to the surface by cultivation. The annual monocotyledonous weeds have comparatively poorer dormancy mechanisms and most die after burial by cultivation (K. Harrington pers. comm., 1990). Under direct drilling relatively few dicotyledonous seeds are exposed to light and few monocotyledonous seeds are buried. Thus monocotyledonous weeds contribute more to the weed component of the resultant sward than if it was established on cultivated soil.

4.1.3 Tillering Activity and Plant Leaf Number

4.1.3.1 Introduction

A number of measurements were taken to characterise the development of plants during early establishment. Tiller number, leaf number (fully expanded, live leaves) and extended height of "tagged" plants were recorded. Seedling weight was also determined. Sections 4.1.3 and 4.1.4 describe these results. Section 4.1.3 is largely concerned with tiller and leaf number and tiller weight, section 4.1.4 deals with shoot weight and extended height.

Tiller number and leaf number showed virtually the same response to treatments, so tiller numbers are largely presented here with parallel leaf numbers in appendices. Only leaf number was available at 26 d.a.s. as plants consisted essentially of one tiller. Leaf number is presented and/or highlighted where a difference in response to a particular treatment was found.

Individual size indices were derived from leaf and tiller number and extended height records. Size index, calculated from tiller and leaf number, provides a non-destructive measurement of plant size in a limited, horizontal plane and is presented alongside tiller number in this section and in section 4.2 (late establishment). Plant height was also included as a factor in size index to give a third dimension to derived plant size. Indices with extended height as a factor in their derivation are compared with shoot weight in a later section 4.1.4 and also appear in section 4.2.

The derived size index is best regarded as a composite of plant volume and mass (Harris and Sedcole, 1974). Harris and Sedcole related basal diameter and plant height (measured as the height attained by two thirds of the tillers of the plant when held upright) to individual plant weight for *Lolium perenne* L cv. 'Kangaroo Valley' ryegrass, *L. multiflorum X perenne*, cv. 'Grasslands Manawa' short rotation ryegrass, and *Festuca arundinacea* Schreb cv. 'Demeter'. Multiple regression analysis on plant volume accounted for more than 50% of the variation in plant weight. Indices derived from height, tiller and leaf number accounted for 77-80% of the variation in shoot only, or total weight over a wide range of external conditions (Bellotti, 1984). On the basis of those studies it was decided to employ derived size index as a measure of plant size.

Linear regression analysis of tiller and leaf number as a function of shoot weight was carried out for the current trial. No association between tiller number and shoot weight or between leaf number and shoot weight was found at 43 d.a.s. for either fescue or ryegrass. However, at 145 d.a.s., tiller and leaf number accounted for 60% and 50% of the variation in ryegrass shoot weight, respectively (Table A1.17, Appendix 1), and the regression was significant at $P < 0.001$. There was no significant relationship between fescue shoot weight and tiller or leaf number.

Skewness of tiller number, leaf number and plant size index distribution was determined in an attempt to detect timing and severity of competitive stress operating within the establishing sward (Bellotti and Blair, 1989c). The shape of the curve describing the frequency distribution of plant size describes the size hierarchy of a plant population (Weiner, 1985, 1986; Franco and Harper, 1988). The skewness of the frequency distribution curve may be either positive or negative and is useful to determine the extent and timing of a competition effect where it has occurred in a population of plants. Where interference between plants occurs, the frequency distribution of a population will become positively skewed, (ie. skewed to the left), indicating a preponderance of smaller plants as compared with the proportion of larger plants (Koyama and Kira, 1956; Donald, 1963). A negatively skewed frequency distribution curve may occur where competition between plants has not reached a level sufficient to reduce growth of individuals or where plant mortality has occurred among smaller plants, switching to a dominance of larger plants. The skewness of a population gives an indication of the level of competitive stress occurring in that population and comparisons of skewness between populations can indicate the relative levels of stress of different populations. A more positively skewed population is under more stress than a population with a less positively skewed distribution.

It is usual for population studies to include size class frequency curves of plant sizes (Harris and Sedcole, 1974; Bellotti, 1984). Skewness reflects the trends of the distribution of size class frequency curve and for the purposes of this study it was not considered necessary to develop individual size class frequency curves.

The skewness coefficient was calculated using the following equation after Snedecor and Cochran (1967). Tiller number is used as an example:

$$\frac{Mean\ tiller\ number - Median\ tiller\ number}{\sqrt{Variance}} = Skewness\ Coefficient$$

Skewness of the distribution of plant size index may provide a better indicator of stress in a population than the skewness of individual plant parameters (Harris, 1971; Bellotti and Blair, 1987).

The size frequency distribution was determined by calculating the skewness coefficient for the 10 plants per plot which were removed at 26 d.a.s.. Skewness of tagged, live plants was also determined over the plant size measurement period. Skewness was calculated on a plot by plot basis ie. based on the curve of 10 or 6 plants/plot. Thus the skewness coefficients presented are for 10 plants per plot at 26 d.a.s. and 6 plants per plot at 43 and 145 d.a.s.

The population of plants on an area basis, established within a seeding rate category, was very similar for both species. Plant spatial arrangement effects on plant size were therefore comparable on a constant plants per unit area basis. Combined species results are reported unless an interaction between species and other treatments was found. In general, seeding rate and drill method effects were the same for both species but were always more marked for ryegrass.

Other pasture establishment studies have used tiller weight measurements to plot individual plant development (Holliday, 1953; Brougham, 1954a,c,d; Inwood, 1990). Although tiller weight was not specifically measured in this trial, a close approximation of tiller weight was obtained from shoot dry weight and tiller number data. Tiller number was recorded at 43 and 145 d.a.s. and shoot weight was recorded at 49 and 135 d.a.s.. Tiller number was adjusted by calculating accumulation rate/day, multiplying that figure by the difference in days between tiller number and shoot weight recordings, and adding or subtracting that number accordingly. Shoot weight was then divided by the adjusted tiller number. No tiller weights for seedlings from the cross drilled treatment were calculated as shoot weight was not recorded from separate positions, only from the treatment as a whole. Only the 75 and 150mm rows data are presented for drill method comparisons.

4.1.3.2 Results

4.1.3.2.1 Overall Species, Seeding rate and Drill Method Effects

Table 4.1.3.1 lists the overall effects of species, seeding rate and drill method on the number of leaves per plant at 26 d.a.s. and tillers per plant at 43 and 145 d.a.s.. Parallel leaf number data are contained in Table A1.12 Appendix 1, and the skewness coefficients for leaf number are contained in Table A1.33 Appendix 1. Where there was a difference in tiller number there was a difference in leaf number because of the relative uniformity of leaves per tiller at any given stage up to 145 d.a.s., although the reverse was not always true.

Table 4.1.3.1 Effect of Species, Sowing Rate and Drill Method on the Number of Leaves per Plant at 26 d.a.s., and the Number of Tillers per Plant and Skewness of Tiller Number and T X L index at 43 and 145 d.a.s.

d.a.s. (Month)	26 (May)		43 (May)			145 (Sep)		
Characteristic	Leaf No	Skew Leaf	Tiller Number	Skew Tillers	Skew T X L †	Tiller Number	Skew Tillers	Skew T X L
Fescue	1.96	-0.315	1.6	0.067	0.089	4.4	0.034	0.04
Ryegrass	2.92	-0.274	2.6	0.006	0.010	7.7	0.157	0.178
S.E.D. ±	0.115	0.1329	0.10	0.028	0.048	0.30	0.019	0.037
Significance	* *	n.s.	* * *	n.s.	n.s.	* * *	* * *	*
High	2.46	-0.277	2.0	0.062	0.050	5.2	0.090	0.107
Low	2.42	-0.312	2.1	0.011	0.048	6.8	0.100	0.111
S.E.D. ±	0.138	-0.098	0.06	0.080	0.048	0.27	0.048	0.037
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	* * *	n.s.	n.s.
75 mm row	2.48	-0.319	2.1	-0.019	0.043	6.2	0.094	0.066
Cross drill	2.55	-0.287	2.1	0.057	0.054	6.0	0.080	0.105
150 mm row	2.28	0.287	2.0	0.050	0.047	5.9	0.126	0.159
S.E.D. ±	0.168	0.120	0.08	0.098	0.059	0.08	0.058	0.046
Significance	n s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

- † T X L size index represents the product of tiller and leaf number

Ryegrass plants clearly had more leaves and tillers per plant than fescue at every measurement time. Fescue tiller accumulation rate was only half that of ryegrass for the two periods described, illustrating the faster establishment rate of ryegrass. On average one extra ryegrass tiller accumulated every 19 days from 0 to 145 d.a.s., whereas fescue accumulated one extra tiller every 32 days.

Plants sown at the high seeding rate had fewer tillers than those sown at the low rate. The influence of seeding rate on tiller number was not significant at 43 d.a.s., indicating that intra-row plant competition did not influence tiller number until after that time. Although the trend was apparent, the difference was only significant at 145 d.a.s.. At 43 and 145 d.a.s., those plants sown at the low rate had more leaves than those sown at the high rate (Table A1.23, Appendix 1). Competition between plants was initially reflected by leaf number, and subsequently by tiller number. Although the absolute increase in leaf number at low seeding rate was the same for both species (0.4 leaves) as compared with high seeding rate at 43 d.a.s., the S.E.D. was higher for ryegrass so the effect was significant for fescue but not for ryegrass (Table A1.23, Appendix 1). At 43 d.a.s., fescue and ryegrass plants had either 2 or 3 leaves per tiller (average 2.4 and 2.7 leaves/tiller for fescue and ryegrass, respectively).

There were no significant drilling method effects on leaf number at 26 d.a.s. or tiller number at

43 and 145 d.a.s..

Distribution of leaf number was negatively skewed at 26 d.a.s. (Table 4.1.3.1). The distribution of tiller number was positively skewed (ie. skewed to the left) at 43 and 145 d.a.s. indicating a preponderance of small units in the population at those times. There were no significant treatment effects on skewness at 26 or 43 d.a.s.. By 145 d.a.s., the faster growth rate of ryegrass and consequent higher level of stress was reflected by a more positively skewed plant size distribution recorded for ryegrass tiller number and T X L index as compared with fescue. Although plant tiller number and size index was reduced for both species at high seeding rate by 145 d.a.s., apparently by increased competition (stress), overall skewness did not reflect this. This anomaly is addressed in the following section.

4.1.3.2.2 Interactive Effect of Species and Sowing Rate

Table 4.1.3.2 describes the effect of seeding rate for fescue and ryegrass on the skewness coefficient. There was a significant interaction between the effect of species and seeding rate at both 43 d.a.s. and 145 d.a.s..

Table 4.1.3.2 Effect of Seeding rate on the Skewness Coefficient of Tiller and Leaf Number and Plant Tiller by Leaf Size Index for Ryegrass and Fescue at 43 and 145 d.a.s.

d.a.s. (Month)		43 (May)			145 (September)		
Characteristic		Skew Tiller	Skew Leaves	Tiller X Leaf	Skew Tiller	Skew Leaves	Tiller X Leaf
Fescue	**High**	0.127	0.210	0.242	-0.029	-0.028	0.091
	Low	0.007	0.044	0.082	0.096	0.041	0.175
S.E.D. ±		0.124	0.091	0.094	0.080.	0.066	0.069
Significance		n.s.	(*)	(*)	n.s.	n.s.	n.s.
Ryegrass	**High**	-0.004	0.043	0.132	0.209	0.180	0.303
	Low	-0.015	0.093	0.121	0.104	0.053	0.174
S.E.D. ±		0.105	0.054.	0.0726	0.052	0.056	0.051
Significance		n.s.	n.s.	n.s.	*	*	*
Species X Rate	S.E.D. ±	0.103	0.059	0.072	0.051	0.057	0.045
Interaction	Significance	n.s	*	n.s.	*	*	*

At 43 d.a.s., seeding rate had a significant ($P \leq 0.1$) effect on the skewness of the fescue population but no effect on the skewness of the ryegrass population. The distribution of fescue leaf number and T X L index was more positively skewed at high seeding rate than it was at low seeding rate. Although not significant, tiller number was consistent with leaf number. The interaction for skewness of leaf number at 43 d.a.s. indicated that high seeding rate fescue was more positively skewed than ryegrass at either seeding rate, and was consistent with results for tiller number and T X L index. The results suggest that fescue sown at the high rate had relatively more plants with fewer leaves and tillers as compared with plants sown at the low rate at 43 d.a.s. and is consistent with the fact that leaf number was significantly reduced at high seeding rate at that time. The plant size distribution of ryegrass was not significantly skewed at that stage.

At 145 d.a.s., seeding rate had a significant effect on the skewness of tiller and leaf number and T X L index of ryegrass in the same manner as for fescue at 43 d.a.s., but the plant size distribution of fescue at that time was not influenced by seeding rate.

The trend for a positive relationship between skewness and seeding rate is consistent in that crowding accentuates and accelerates progress toward skewness (Koyama and Kira, 1956). However, the results were not consistent over time or species. Although seeding rate did significantly affect the skewness coefficient for each species, the overall effect of seeding rate was not significant (Table 4.1.3.1) because the contrasting effects occurring in fescue and ryegrass at each time effectively cancelled out the overall seeding rate effect. The discussion following these results pursues this line of investigation (Section 4.1.4.3).

4.1.3.2.3 Effect of Plant Position

Table 4.1.3.3 describes the effect of plant position on leaf and tiller number and skewness of leaf and tiller number and T X L index at 43 and 145 d.a.s.. Leaf number was included as that characteristic showed greater sensitivity to position than tiller number. The results were the same for both species so the combined results are shown. As with the seeding rate, increasing plant density had no significant effect on tiller number at 43 d.a.s., but unlike the seeding rate effect, leaf number was also unaffected by position. The position effect was significant at 145 d.a.s. at which time plants at the intersections of cross drilled rows had significantly less tillers per plant than those in 75 mm rows or between the intersection of cross drilled rows.

At 145 d.a.s., plants located at either the Angle or Straight (the 'Between' position) had significantly more leaves than those in 150mm rows. Tiller number was consistent with leaf number in this respect but was significant only at the lower order of probability ($P \leq 0.1$) . This result reflects the lower in-row population and lower level of intra-row competition as plants for both treatments (150mm and 'Between') occurred in rows at the same spacing. However, plants in 75 mm rows, although they occurred at the same in-row population as 'Between' plants, were not significantly different from those in 150mm rows, indicating that competition for resources was not only occurring at the intra-row level, but also at the inter-row level, between plants in adjacent rows.

Table 4.1.3.3 Effect of Position on the Number of Tillers, Distribution of Tiller Number and of Tiller by Leaf Index (Combined Species)

d.a.s. (month	43 (May)					145 (September)				
Characteristic	Leaf Number	Skew Leaf	Tiller Number	Skew Tillers	Skew T X L	Leaf Number	Skew Leaf	Tiller Number	Skew Tillers	Skew T X L
Intersection	5.556	0.169 a	2.111	0.150	0.229 a	9.9 a	0.012	5.33 a ‡	0.043	0.148
Between	5.563	0.033 b	2.153	-0.035	0.083 b	12.4 c	0.095	6.58 b	0.117	0.063
75mm	5.625	0.090 ab	2.111	-0.019	0.104 b	11.8 cb	0.037	6.25 cb	0.094	0.066
150mm	5.347	0.100 ab	2.014	0.05	0.162 ab	10.8 ab	0.101	5.92 ca	0.126	0.159
S.E.D. ±	0.2279	0.059	0.093	0.161	0.042	0.67	0.061	0.377	0.067	0.037
Significance	n s	(*)	n.s.	n.s.	(*)	* * *	n.s.	* * *	n.s.	n.s.
		Fpr= 0.078			Fpr= 0.085					

- ‡ Least significant difference (L.S.D.) 0.05 = 0.752 and L.S.D 0.1 = 0.628

The skewness of leaf number was consistent with skewness of tiller number X leaf number index, which indicated that the population occurring at the intersection of cross drilled rows was more positively skewed than that which occurred between the intersections of drill rows at 43 d.a.s. but was not significantly different from that of 150mm rows. Tiller X Leaf number index also indicated that the plant size distribution of the population in 75mm rows was less positively skewed than at the intersection of cross drilled rows. However, there was no significant difference between the tiller number of plants at any position at that stage. Here, plant size distribution, as described by skewness, reflected the higher level of competitive stress which occurred at the intersection of cross drilled rows compared with plants at other positions in drill rows before that stress was manifested as a difference in tiller or leaf number.

Comparison of T X L index with Tiller and Leaf Number

Analysis of variance of plant size indices largely mirrored that for individual plant characteristics. However, there were two differences. Table A1.31, Appendix 1, lists the significance of treatment effects on individual plant characteristics, leaf and tiller number and plant height and Table A1.32, Appendix 1, lists the significance of treatment effects on plant size indices.

Comparison of those tables shows that analysis of variance of plant size indices (eg. T X L), indicated a species by position effect at 145 d.a.s. which was not apparent from analysis of variance of individual plant characteristics. The result, located in Table A1.14, Appendix 1., showed that the 'position' effect was more marked for ryegrass than for fescue, which is consistent with the overall effect of density on species. On the other hand, individual plant characteristics (height) indicated a drill x species effect at 145 d.a.s. which was not indicated by plant size indices. That result is presented later in section 4.1.4. Thus size index did not necessarily reflect plant treatment responses any better than individual plant characteristics.

There was no significant interaction between position and species or position and seeding rate for tiller number at 43 or 145 d.a.s., and no interactions between species and drilling methods on the number of leaves per plant at 26, or tillers per plant at 43 and 145 d.a.s..

4.1.3.2.4 The Effect of Population

Species, seeding rate and to a lesser extent drilling method affected the number of tillers per plant and plant size distribution. In order to more closely assess the effects on those parameters of plant populations on an in-row and area basis, linear regression analyses of the individual plant characteristics, their skewness and the skewness of indices for each as a function of either plants m^{-1} row or plants m^{-2} which were present at the beginning of the trial was carried out. The population was not fully recorded at 26 d.a.s., therefore analysis was carried out for 43 and 145 d.a.s.. Plot means were used for both population and leaf number. Species were analysed separately and data were pooled from all seeding rate and drilling method treatments. The in-row plant population at the point where the drill rows crossed was not known. Therefore only the data from the plants which occurred between the intersections of the cross drilled rows were included for analysis. Thus the analysis for each species was based on data from 200-250 plants.

In all cases the association for plants m^{-2} was similar to that for plants m^{-1} row but less clear (lower r^2). Therefore the effect of in-row population is presented here (Table 4.1.3.4). The equivalent data for the relationships between plant population on an area basis and; tiller number (Table A1.30); leaf number (Table A1.24); skewness of tiller number (Table A1.35); and skewness of plant size indices (Table A1.37); can be found in Appendix 1.

Table 4.1.3.4 Effect of In-row Population on Tiller Number and Skewness of Tiller Number and Tiller X Leaf Index for both Fescue and Ryegrass.

	Fescue						Ryegrass					
d.a.s.	43			145			43			145		
Characteristic/ Size Index	Tiller Number	Skew Tillers	Skew T X L	Tiller Number	Skew Tillers	Skew T X L	Tiller Number	Skew Tillers	Skew T X L	Tiller Number	Skew Tillers	Skew T X L
mean	1.60	0.033	0.11	4.5	0.063	0.167	2.60	-0.028	0.012	7.96	0.16	0.24
slope of regression line	-0.0013	0.004	0.0045	-0.0082	-0.0006	-0.0002	-0.0040	0.00006	-0.0005	-0.0334	0.001	0.0025
S.E.D. ±	0.0016	0.002	0.002	0.0074	0.002	0.0002	0.0025	0.002	0.001	0.012	0.001	0.001
significance	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	*
r^2	0.02	0.06	0.12	0.03	0.003	0.03	0.07	0.05	0.02	0.17	0.04	0.11

Table 4.1.3.4 compares the effect of variation in in-row population on the tiller number, and skewness of tiller number and T X L index for fescue and ryegrass at 43 and 145 d.a.s..

Means, along with the slope of the regression line and its standard error, (r^2) and the level of probability are also listed. Although not always significant, the slope of the regression line for tiller number was negative on each occasion for both species. The slope was only significantly different from zero on one occasion and only in ryegrass at 145 d.a.s..

The correlation coefficients for tiller number were poor but trends were consistent. Variation of in-row population accounted for up to 17 % (r^2) of the variation in tillering in ryegrass but less than 3% in fescue. The relationship between leaf number and population was better. Twenty five percent of the variation of leaf number of ryegrass was attributable to in-row population as compared with 6% for fescue at 145 d.a.s. (Table A1.15, Appendix 1). As with tiller number the slope of the regression line for leaf number were always negative but not always significant.

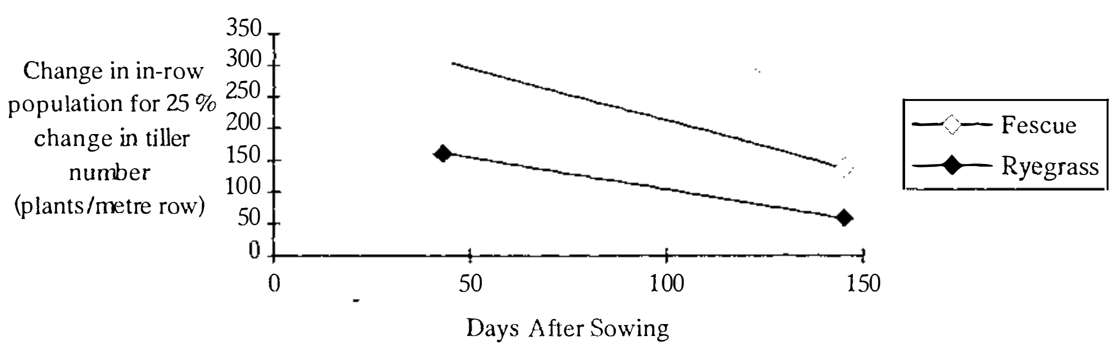
There was a firm trend indicating a negative relationship between tiller number and in-row plant population. As in-row population increased, tiller number decreased. Ryegrass tiller number was more sensitive to in-row population than fescue tiller number.

Figure 4.1.3.2 shows the change in in-row population required to effect a 25 % change in tiller number. Data for the Figure 4.1.3.2 was calculated using the following equation:

$$\frac{\text{(Average tillers/plant x 0.25)}}{\text{Slope of the regression line}} = \text{change in in-row population (plants m}^{-1}\text{ row) to effect a 25 \% change in plant tiller number (tillers/plant)}$$

Fescue required a greater increase in in-row population than ryegrass to effect a 25 % decrease in the number of tillers per plant at 43 and 145 d.a.s..

Figure 4.1.3.2 Change in In-row Population Required for a 25 % Change in the Number of Tillers/plant



Plant density had no significant effect on the size frequency distribution (skewness) of plant tiller number or leaf number at either 43 or 145 d.a.s. (Tables 4.1.3.4 and A1.34 Appendix 1, respectively). However, the size frequency distribution curve for T X L index showed that there was a positive correlation between plants m^{-1} row and skewness for fescue at 43 d.a.s.

and for ryegrass at 145 d.a.s.. The effect was more obvious for ryegrass than fescue as indicated by the higher level of probability and r^2 for ryegrass. This result coincides with the expected pattern of plant size variation where interference between plants has occurred, and the suggestion that interference was more severe at higher populations as compared with lower populations (Weiner 1985, Ford and Diggle 1981).

At 43 d.a.s., 12% of the variation in the skewness of tiller X leaf index for fescue was attributable to variation of in-row population. There were no significant in-row population effects recorded for skewness of ryegrass plant indices at that time. At 145 d.a.s. up to 21% of the variation in skewness coefficient of the plant size distributions for ryegrass plants was caused by variation in in-row population. At 145 d.a.s. fescue was actually showing the opposite trend to ryegrass, that being a decrease in skewness at higher in-row populations but at a lower level of probability (Table 4.5.1.6). In-row population effect is consistent with the interactions between seeding rate and species which occurred at those times (Table 4.1.3.2).

There were no significant drill by species interactive effect on tiller number or skewness of tiller number or T X L index at 43 or 145 d.a.s..

4.1.3.2.5 Interactions Between Drill Method and Seeding Rate for Fescue

There was a statistically significant drill by seeding rate interaction for fescue at 43 d.a.s. as indicated by both leaf and tiller number, but no interaction was recorded for ryegrass (Table 4.1.3.5). Unlike cross drilled fescue plants and those sown in 150mm rows, plants at 75mm row spacing showed the reverse of the overall of seeding rate effect. Drilling method effects for ryegrass were consistent with fescue sown in 150mm rows and cross drilled but fescue sown in 75mm rows was not. Given that the fescue data were not consistent with ryegrass data, that ryegrass has been shown to reflect plant density variation more closely than fescue, and that the range in plant tiller and leaf number was very small anyway (0.25 tillers and 0.5 leaves, 12 to 15%, respectively), the interactive effect was not considered important.

Table 4.1.3.5 Effect of Drill Method on Tiller and Leaf Number at High and Low Seeding Rate at 43 d.a.s. for Fescue and Ryegrass

		LEAF NUMBER		TILLER NUMBER	
SEEDING RATE	*DRILL METHOD*	**Ryegrass**	**Fescue**	**Ryegrass**	**Fescue**
LOW	75mm (L75)	7.28	3.69 ab	2.64	1.47 a
	Cross (LX)	7.26	4.51 c	2.72	1.74 c
	150mm (L150)	7.14	4.08 bc	2.53	1.64 a
HIGH	75mm (H75)	7.31	4.22 cb	2.58	1.75 bc
	Cross (HX)	6.69	3.79 a	2.53	1.54 ab
	150mm (H150)	6.61	3.56 a	2.42	1.47 a
S.E.D. ±	Comparison †				
	Cross with Cross	0.41	0.20	0.16	0.10
	Cross with 75 or 150	0.50	0.24	0.19	0.12
	75 with 150	0.58	0.28	0.22	0.14
Significance for interaction		n.s.	* *	n.s.	*

† Comparisons of cross drill with 75 or 150mm data is associated with a lower S.E.D. because the data for cross drilled plot is a mean of 12 plants (intersection and between plants cf 6 plants for the other drill treatments).

4.1.3.2.6 Overall Effect of Species, Seeding Rate and Drill Method on Tiller Weight

Table 4.1.3.6 compares the effect of species, seeding rate and drill method on tiller weight. Ryegrass tiller weight was greater than fescue at 49 d.a.s. but was similar at 135 d.a.s.. The seeding rate did not influence tiller weight at 49 d.a.s. but tillers from plants sown at the high rate were lighter than those sown at the low rate at 135 d.a.s.. Drill method did not affect tiller weight at either time.

Table 4.1.3.6 Effect of Species, Seeding Rate and Drill Method on Tiller Weight up to 135 Days After Sowing (mg/tiller)

	Days After Sowing	49	135
SPECIES	**Fescue**	8.19	38.6
	Ryegrass	11.88	36.1
	S.E.D. ±	0.91	1.46
	Significance	(*) Fpr = 0.056	n.s.
SEEDING RATE	**High**	9.63	33.6
	Low	10.45	41.2
	S.E.D. ±	0.91	3.4
	Significance	n.s.	*
DRILLING METHOD	**75 mm row**	9.38	39.0
	150 mm row	10.69	35.7
	S.E.D. ±	0.86	3.2
	Significance	n.s.	n.s.

Table 4.1.3.7 describes the effect of seeding rate and drill method on tiller weight for ryegrass and fescue. The seeding rate effect was consistent for both species but significant only for ryegrass at 135 d.a.s.. No significant drilling method effect on tiller weight was recorded, although it is worth noting that the magnitude of the difference between the means of fescue sown at high and low seeding rates was similar to the difference between drill methods at 135 d.a.s..

Table 4.1.3.7 Effect of Seeding Rate and Drilling Method on Fescue and Ryegrass Tiller Weight at 49 and 135 d.a.s. (mg/tiller)

		FESCUE		RYEGRASS	
	d.a.s	49	135	49	135
SEEDING RATE	**High**	8.38	35.6	10.87	31.5
	Low	8.01	41.6	12.89	40.7
	S.E.D. ±	1.14	5.5	1.43	4.01
	Significance	n.s.	n.s.	n.s.	*
DRILLING METHOD	**75 mm**	7.89	41.5	10.87	36.5
	150 mm	8.50	35.7	12.88	35.7
	S.E.D. ±	1.08	5.2	1.35	3.8
	Significance	n.s.	n.s.	n.s.	n.s.

There were no interactions between the effects of main treatments on tiller weight at either 49 or 135 d.a.s. Seeding rate and drilling method comparisons for each species are shown in Table A1.45, Appendix 1. Regression analysis showed that in-row population had no significant effect on tiller weight of ryegrass or fescue at either time (Table A1.47, Appendix 1). The r^2 values were low (4-7%) but the slope tended to be negative at 135 d.a.s. for both species.

4.1.3.3 Discussion

Results are discussed under main treatment headings.

Species

The contrast in the rate of growth of tall fescue and perennial ryegrass was a dominant feature during early establishment. Perennial ryegrass had up to 100 % more leaves and 60 to 80 % more tillers per plant than tall fescue during the first 145 days after sowing. Tiller dry weight was, however, similar for the two species.

Previous comparative studies of seedling growth and establishment of these two species have shown similar results in both glasshouse experiments (Ryle, 1964; Rhodes, 1968b; Brock et al., 1982) and field experiments (Brock, 1973). Brock (1973) concluded that "establishment rates of tall fescue varieties were approximately 50 % slower than those of ryegrass". Establishment method in those studies was essentially conventional cultivation. This study demonstrated that similar differences in establishment for these two species held true for direct drilling.

Seed size has a major influence on seedling vigour and emergence (Erikson, 1946) and seedling growth (Arnott, 1969; Evans, 1973; Hill et al., 1985; Hampton, 1986). Results from the current field trial showed that the size of the endosperm (seed) was not related to seedling emergence (Section 4.1). It has also shown that seed size was not related to growth rate during establishment, confirming the conclusion of Wright (1971) who suggested there was little or no positive correlation between seed size and vigour between species.

Few pasture establishment trials actually list individual plant size. Information from other trials, carried out in close proximity (within 0.5 km) to the current trial provide some useful comparisons and suggest that growth of seedlings in the current trial was similar to other trials (Brougham, 1954a; Brock, 1973; Brock et al., 1982; Inwood, 1990) The tiller number of perennial ryegrass plants in the current trial was similar to that recorded by Brougham (1954a) for short rotation ryegrass (*Lolium perenne* L. *X L. multiflorum* L.) cv 'Manawa' from an autumn sown trial, established by conventional cultivation. Ryegrass plants, sown at a rate of 17kg ha^{-1}, had approximately 7.3 tillers/plant and tillers weighed 29mg at 136 d.a.s. compared with an average of 7.7 tillers/plant and 36 mg/tiller for the current trial at 145 d.a.s.. Tiller weights of the current trial were also similar to another trial previously conducted nearby by Brock (1973) and similar to tiller weight reported by Holliday (1953) from the United Kingdom.

Tall fescue cv 'Aberystwyth S170', also established in Brock's (loc cit) trial, had 1.65 tillers, with a weight of 13.9 mg and had 4.8 leaves/plant at 56 d.a.s.. In the current trial, at 49 d.a.s., fescue had 1.8 tillers which weighed 8.2 mg and had 4.3 leaves. Fescue plants in the current trial were larger than those for another of Brock's trials carried out on a higher fertility soil within 20 km of the current site. At 60 d.a.s. 'Grassland Roa' had 1.4 tillers which weighed 7mg and had 3.1 leaves (Brock, 1982). Some of the advantage of fescue plants in the current trial over Brock's trial may have been due to a cultivar difference. 'AU Triumph' has been shown to be consistently more vigorous at establishment than 'Grasslands Roa' (Easton and Pennell, 1993; Anon, 1993). No comparable measurements for tall fescue are available beyond about 60 d.a.s. for autumn sown fescue in the Manawatu, though Ryle (1964) recorded 4.6 tillers/plant for 'S170' at 95 d.a.s. in a glasshouse experiment, these values not unexpectedly being higher than those from the current trial.

Differences in tiller and leaf number between ryegrass and tall fescue found in the current trial were similar to that reported by Brock et al. (1982) from a glasshouse experiment, but plant size in general was larger in the latter. 'Grasslands Ruanui' perennial ryegrass grown in pots of low-medium fertility silt loam had a 70 % advantage in leaf and tiller number over several tall fescue cultivars including 'Aberystwyth S170' and 'Grasslands Roa'. In another glasshouse experiment carried out at the same time (sown mid July) using a relatively higher fertility potting medium, shoot weight at 37 d.a.s. was the same for 'Grasslands Ariki' ryegrass, S170 Roa and wild type tall fescue cultivars at around 28 to 37 mg/plant, but ryegrass had a faster leaf appearance rate and showed much greater recovery from defoliation than tall fescue. Similarly, Ryle (1964) also reported a narrower margin between ryegrass and fescue under medium to high fertility conditions in the glasshouse. Perennial ryegrass 'S24' had 20% more leaves (9.8/plant) at 95 d.a.s. than 'S170' tall fescue. As expansion of tillers in those varieties was limited to sites in the axils of mature leaves, ryegrass had accumulated 50% more tillers (6.8) than fescue (4.6).

Greater variation of environmental factors such as soil moisture content, temperature, sowing depth and crust strength along with insect predation and fungal pathogen attack occur in the field as compared with the more stable environment of a glasshouse. These factors all mitigate against those species such as tall fescue which are less vigorous at establishment. This results in an accentuation of the difference in relative speed of establishment and comparative size of fescue and ryegrass in field trials as compared with glasshouse trials.

Brock et al. (1982) suggested that the main factor causing very slow seedling growth of tall fescue was slower root development in comparison with ryegrass. They showed that Roa root appearance was later and root elongation slower than Ruanui ryegrass at 10 d.a.s., although root weight was the same. Rhodes (1968b) found the number and elongation rate of both seminal and nodal roots of tall fescue were much lower than for hybrid ryegrass cv 'Manawa' (*Lolium perenne* L. X *L. multiflorum* L.). Hayes (1976) also reported similar variation in root elongation between the species. At 14 days after germination seminal root lengths of S24 ryegrass were longer and emerged earlier than S170 tall fescue despite similar shoot lengths.

From their glasshouse experiments, Brock et al. (1982) suggested that the poorer root growth of tall fescue was reflected in the relatively greater difference between ryegrass and fescue shoot weights in a low-medium fertility silt loam (low soil nitrogen (N) availability) compared with those grown in a high fertility potting mix (high soil N availability). Less root elongation by fescue was thought to reduce root exploration and root/soil contact area, limiting the opportunity for nutrient uptake in comparison with ryegrass, which amplified the difference in seedling growth between the species in conditions of low soil N availability. This supported earlier suggestions (Allo and Southon, 1967) that tall fescue may be less suitable for low fertility soils.

Nitrogen fertility is likely to have contributed to the difference in size between fescue and ryegrass in the current trial, as no nitrogen was applied during early establishment. The soil type in the trial area has been described as medium to high fertility with potentially low to medium soil N availability (Sears, 1953). Soil nitrogen was likely to have been limiting because there is generally less soil N available during establishment by direct drilling as compared with conventional cultivation, because of reduced mineralisation (Francis et al., 1987; Haynes and Knight, 1989) and competition for nitrogen from micro-organisms which actively break down dead surface vegetation (Ludeke, 1979). However, the reduction in nutrient mineralisation is not always manifested by a reduction in plant size where early establishment by direct drilling and conventional cultivation are compared directly (Inwood, 1990).

Hill et al. (1985) reported three- to four-fold differences in the shoot weight at 42 d.a.s. of tall fescue cv 'Demeter' as compared with Italian ryegrass (*Lolium multiflorum* L.) cv 'Grasslands Tama' from a field sowing at day temperatures in the range 15 to 24ºC. Italian ryegrass is more vigorous than perennial ryegrass during establishment (Mitchell, 1953b), and larger differences would not be unexpected between tall fescue and Italian ryegrass as compared with the difference between tall fescue and perennial ryegrass found in the current trial.

Bellotti (1984) also found a large difference in speed of establishment for fescue and ryegrass. Ryegrass direct drilled in the late autumn had 50% more leaves at 50 and 100 d.a.s., and 50% more tillers at 100 and 150 d.a.s., than tall fescue. Nutrient status of the soil used in Bellotti's trial was similar to that used for this trial but plants were much smaller in his trial due to the comparatively dry conditions.

The contrast between initial growth rates of ryegrass and tall fescue has been firmly established and provides a basis on which to compare the relative effects of plant density and arrangement on individual plant development for perennial grass plants with contrasting rates of growth.

Seeding Rate

Moisture, nutrients and light are commonly deficient in an establishing sward and competition may occur amongst plants for these factors (Donald, 1963). Over a wide range of densities and after a sufficient period of growth, the effects of high density, termed the "Competition-Density" (C-D) effect (Westoby, 1984), are represented by a reduction in average plant size due to competition, but without plant death having occurred. Competition in a sward may increase to a point where plant mortality occurs and the plant size/density relationship conforms to the $-\frac{3}{2}$ power rule, described as the 'self thinning rule' (loc cit). The results of this trial suggested that the C-D effect had occurred but there was no evidence of plant mortality by 145 d.a.s.. Plant loss was negligible between 43 and 145 d.a.s. (Table 4.2.1.6).

Donald (1963) stated that crops or pastures in the establishment phase of growth were an exception to the general occurrence of competition or interference between plants in a community. In Donald's review little or no competition occurred during the seed or seedling stage because seedlings were a few centimetres away from each other. That may be so in a broadcast sown pasture or precision sown large seeded cereal crop. However, where grass seeds are placed in a row by a standard drill which does not have the capability to manipulate seeds individually and/or to place them at pre-determined spaces within a seed groove, seed distribution is irregular and seeds may be placed in close proximity to each other. Results from the current trial indicate competition between seedlings may have occurred as early as 21 d.a.s. because seedlings emerged more slowly from higher in-row densities than from lower densities, and emergence percentage was depressed at higher seed densities.

Seed distribution along rows was irregular. The seed metering mechanism of the Aitchison drill used for the trial was a foam pad seeder, and seed rate was governed by the speed of rotation of the foam pads. Periodicity of seed distribution for this drill (especially at low seeding rates) was noted by Inwood (1990) but no measurements were taken. There was also graphic evidence of periodicity from an earlier trial where a crop of rape (*Brassica napus*) cv 'Emerald' was sown at very low rates (3kgha^{-1}) with the same drill used for the current trial (Praat and Krishna, unpublished data). Periodicity was thought to have been caused by the irregular drive given by the variable speed gearbox to the seed distributors (C.D. Kernohan pers. com. 1990) and resulted in emissions of bursts of seed from the metering mechanism rather than a constant flow. The effect was more obvious at low rates (3-15 kg ha^{-1}) than higher rates because at low rates the drive mechanism rotated slowly.

Data from population counts confirmed earlier observations. Plant population was recorded for 36, 0.4m row sections of 75 and 150mm row spacing, 14.4m of row, for each of eight treatments. The distribution of those seedlings provided a good indication of the variation in the distribution of seeds along a row. Table 4.1.3.8 lists the plants m^{-1} row, the average, maximum and minimum distances between seedlings along a row and the standard deviation and coefficient of variation of those distances. Three ryegrass treatments were used as an example of seedling distribution.

Table 4.1.3.8 Variation in Distance Between Ryegrass Seedlings Along A Row

Treatment	Low Seed Rate 75mm row	High Seed Rate 75mm row	High Seed Rate 150mm row
Spot Drill Output (kg ha^{-1})	6.3	11.2	23.6
Seedlings m^{-1} row	39 (25.6)¥	57 (17)	107 (9)
maximum distance (mm)	100	40	19
minimum distance (mm)	11	10	6
Std Dev	18	8	3
Coefficient of Variation (%)	71	48	32

¥ - figure in parenthesis = average distance between seedlings (mm)

Variation in seedling distribution was most obvious with low seed output from the foam pad seed metering unit, indicating periodicity in the distribution of seeds from the drill. The actual seed output used to achieve a seed rate of 12.6kg ha^{-1} in 75mm rows was a seed metering unit spot output of 6.3kg ha^{-1} for each of the two drill passes at the low seeding rate. Variation in inter-seedling distance was progressively reduced from a ten-fold difference at an output of 6.3kg ha^{-1} where seeds were sown at the low rate in 75mm rows, to a three-fold difference at 23.6kg ha^{-1} where seeds were sown at the high rate in 150mm rows. Coefficients of variation of the distance between seedlings along a row were high in comparison with a precision planter which may be used to sow a crop such as maize (*Zea mays*). Calculations from a trial reported by Ritchie (1982) showed that where subterranean clover (*Trifolium subterranean*) was sown with a precision vacuum-operated seed metering unit 'Nodet Goudis Seeder', at a target distance of 50mm between seeds (20 plants m^{-1} row), the coefficient of variation for the distance between seeds was 44%. In the current trial the coefficient of variation determined for the distance between seedlings (Table 4.1.3.8) probably underestimated of the coefficient of variation for distance between seeds because the distance between seedlings was averaged over 0.4m row length as compared with Ritchie's data, which was based on measurements between individual seeds dropped in a tray. Also seeds in the current trial had been through the germination and emergence 'filters' by the time they were assessed, possibly smoothing out differences in seed spacing.

The average distance between seedlings in 150mm rows sown at the high rate (9mm), would be less than if the seedlings had been broadcast sown at the same rate (average distance 31.3mm) and was certainly less than the 25 to 50mm which Donald (1963) assumed for a field crop. This may explain the earlier onset of inter-plant competition found in the current trial than suggested by Donald (1963).

The plant size/density relationship of the current trial followed the same trend as that shown in other trials with grasses (Williams, 1947; Holliday, 1953; Brougham, 1954a,b,d; Kays and

Harper, 1974; Harris, 1971; Robinson and Whalley, 1988). Density had a major effect on the growth and development of individuals, the general relationship between plant size and density conforming to the following pattern: Competition first became operative at the highest densities and then progressively with advancing stages of growth at lower densities. This pattern of development has been demonstrated over a wide range of densities by the above authors. Typically for seeding rates from around 5-10kg ha^{-1} up to 40-70 kg ha^{-1} of short rotation ryegrass and perennial ryegrass (Brougham, 1954a,b,d; Harris et al., 1973; Colvill and Marshall, 1981; Robinson and Whalley, 1988) and up to as much as 140kg ha^{-1} of perennial ryegrass (Holliday, 1953; Kays and Harper, 1974; Simon and Lemaire, 1987). These studies represents a range of ryegrass plant densities from 2-300 up to over 10,000 plants m^{-2}.

The current trial demonstrated that after the initial phase of seedling establishment, increasing population in the range 500 to 800 plants m^{-2} reduced individual plant size. The effect was indicated by leaf number as early as 43 d.a.s. but was not significant for tiller number until 145 d.a.s. (Table 4.1.3.1) or tiller weight until 135 d.a.s. (Table 4.1.3.6). Plants sown at the high seeding rate with a resultant plant density of around 800 plants m^{-2} had 29% less tillers and 24% less leaves at 145 d.a.s., and tillers were 22% lighter at 135 d.a.s. than those sown at the low rate (500 plants m^{-2}).

Competition reduced leaf number at 43 d.a.s.. The effect was significant for fescue but not for ryegrass even though ryegrass had almost twice as many leaves/seedling at that stage (3.9 cf 7.1 leaves). The absolute difference in leaf number was similar but the variance was higher for ryegrass (Table A1.23, Appendix 1). Subsequent measurements revealed that population effects on leaf number were more clearly defined for ryegrass than for fescue (Table A1.15, Appendix 1).

Few reports which compared seeding rate effects on perennial grass establishment in the field have included detail of individual plant size. The most notable was a series of studies carried out by Brougham (1954a,c,d). Some have used a wide range in rates in order to understand the general principles of density effects (Holliday, 1953; Kays and Harper, 1974; Simon and Lemaire, 1987). Most studies were carried out pre-1970 so ryegrass was generally used as the bioassay. There has been few detailed studies of tall fescue establishment in New Zealand. This is probably because it is only in the last 20 years some of the problems associated with fescue in terms of slow establishment (Brock, 1973; Lancashire and Brock 1983; Thomson et al. 1988)) and toxicity (Anderšon 1982) have been understood to a point where tall fescue is now becoming more popular with farmers as a replacement for perennial ryegrass in areas prone to droughts and pest attacks (Milne and Fraser, 1990). There are few reports of seeding rate effects on plant size under direct drilling. Ryan et al. (1979) compared the effect of seeding rate on perennial ryegrass with this method of establishment but no plant size measurements were reported.

No comparable reports for seeding rate effects on tall fescue under conventional cultivation or direct drilling, which detailed plant size, have been found. Frame and Hunt, (1964) and Keane (1980) reported only annual tiller densities and yields for tall fescue established from a range of seeding rates from 11 to 56kg ha^{-1}. In the absence of comparable data, the results from the current trial are compared with trials established by conventional cultivation in which seeds were in most cases broadcast (Holliday, 1963; Brougham, 1954a,c,d) although some were stated to have been in rows (Hallgren, 1976b). Some reports make no clear distinction of the plant arrangement (Frame and Hunt, 1964; Keane, 1980).

Comparison of results for the current trial with that of Brougham (1954a) suggest that the seeding rate effect on plant size occurred earlier where seedlings were concentrated in rows as compared with those broadcast sown. The difference in population for the current trial was around 300 plants m^{-2} (500 to 800 plants m^{-2}) between seeding rate treatments. Brougham recorded no significant difference in tiller weight for a similar increase in population at either 136 or 207 d.a.s. (367 to 673 plants m^{-2}). Tiller weights from Brougham's trial were similar (average 29 and 52mg/tiller at 136 or 207 d.a.s., respectively) to ryegrass tiller weight in the current trial (36 mg/tiller at 145 d.a.s., Table 4.1.3.6). The exact population at that stage of establishment (136-207 d.a.s.) was not known for either the current or Brougham's trial, but plant mortality was not likely to have been significant as shown by the low death rate for the current trial between 43 to 145 d.a.s..

Brougham (1954a) proposed that competition for light and nitrogen were the main factors causing a reduction in plant size at higher densities and that the increased competition for nitrogen at higher grass seeding rates was compounded by poor companion clover growth. Colvill and Marshall (1981) showed that after the initial establishment phase of seedling growth, plants at high density assimilated less carbon and had longer leaves, at least initially, than plants at lower densities. Plants at higher density produced fewer and lighter second and third order tillers. They proposed that the overall changes in plant morphology reflected the difference in light relationships within miniswards. That may hold where fertility is high and there is no restriction in moisture availability, as was the case for the glasshouse experiment reported, and while leaf length was longer at high density, (up until 6 leaves were on the main shoot) but it does not hold for the period when leaves were shorter at high density toward the end of their 12 week experiment.

Analysis of variance of the raw tiller and leaf number data at 145 d.a.s. indicated an interaction between species and seeding rate which suggests that seeding rate had more of an effect on ryegrass than on fescue. Fescue plants had 0.94 extra tillers at low seeding rate compared with high seeding rate whereas ryegrass had 2.17 extra tillers (Table A1.23, Appendix 1). However, analysis of $\log_{10}$ transformed data showed no interaction. This indicated that the seeding rate effect was multiplicative or proportional rather than additive. Both species responded similarly to a similar change in plants m^{-2} and had approximately 30 % more leaves per plant at low sowing rates as compared with high seeding rate at that time (Table A1.23, Appendix 1).

The treatments of the current trial were designed in such a way as to contrast the effect of population variation on both an area basis and an in-row basis, along with row arrangement, to determine the relative importance of those changes to plant and sward development. Besides the obvious difference between fescue and ryegrass, seeding rate also had an influence on plant development.

Leaf number was more responsive to treatments than either tiller weight or tiller number. Leaf number reflected the effect of higher seeding rates before tiller number or tiller weight, and the 'position' effect at 145 d.a.s. was more clearly defined by leaf number than tiller number (Table 4.1.3.3).

Drilling Method

Varying the population of grass plants on an area basis by adjusting seeding rate clearly affected plant size by 145 d.a.s., but variation in the arrangement of those plants had minimal influence on tiller and leaf number per plant. By reducing row spacing from 150mm to 75mm, the distance between plants in a row at given seeding rate was effectively doubled (11.6 to 20.4mm on average) and was expected to result in a significant increase in plant size. However, the concomitant reduction in the distance between rows diminished the advantage brought about by a reduction in in-row population. Cross-drilling also increased the average distance between plants by doubling the number of drill row metres per square metre of ground compared with one-pass drilling at 150mm row spacing. However, the plants which occurred at the intersection of cross drilled rows were considerably smaller than plants between the intersections of rows, reflecting the increase in competition occurring where plants were in closer contact.

Cross-drilling offered no advantage to leaf or tiller number over 150mm row spacing (Table 4.1.3.5, Table A1.29, Appendix 1) for both species despite the reduction in in-row population . However, leaf and tiller number data for the cross drilled treatment may have had a downward bias due to the plants at the intersection of cross drilled rows. Although plants at the intersection did contribute to the sward, they only occurred every 260 mm along a row or 4 times in a metre and only accounted for a small proportion of the plants on an area basis. For example at in-row populations of 38 to 68 plants m^{-1} row, only 6 to 10 % of plants will occur at the intersection. Thus leaf and tiller number from plants at the intersection accounted for 50% of the cross drill data but only approximately 6 to 10 % of in-row population in question, so would have tended to come from a population with closer resemblance to 150mm rows than 75mm rows. In any case, the advantage from increasing intra-row plant spacing by using a second pass of the drill, in terms of reducing competition between plants in a row, appears to be offset by the increased competition which occurs at the intersection of drill rows. Specific results for comparison of plants which occurred at the various plant positions support this suggestion.

Comparison of the section of row in the cross drilled plots described as the 'between' position which could be thought of as unimpaired by the second pass of the drill, and similar to other drill treatments, provides an insight into the competition operating on both intra-row and inter-row levels. Plants at the 'between' (angle or straight) position of cross-drilled rows, had more leaves and tillers at 52 plants m^{-1} row than those plants sown at the same inter-row spacing (150mm) where the same rate of seeds per square metre were sown, reflecting the higher in-row population (86 plants m^{-1} row) of 150mm rows (Table 4.1.3.3). Plants 'between' intersecting rows were not significantly different from those at the same in-row population but narrow row spacing (75mm row spacing). Plants in 75mm rows, at a lower in-row population (49 plants m^{-1} row) had the same leaf and tiller number as those at a wider inter-row spacing (150mm) where in-row population had increased to 86 plants m^{-1} row. A reduction in in-row population increased tiller number where inter-row spacing was held constant (between vs 150mm) ie. where there was a reduction in plants m^{-2}. However, when in-row population was reduced along with a reduction in inter-row spacing (75mm vs 150mm), plants sown at lower in-row population did not gain a significant advantage in terms of tiller and leaf number, indicating that competition was operating on an inter-row basis as well as a intra-row level. Analysis of variance of T X L index indicated that the above effect was more marked for ryegrass than fescue (Table A1.14, Appendix 1).

A more complete discussion of drill method effects on plant tiller and leaf number, specifically 75mm vs 150mm rows, is included in section 4.1.4 along with shoot weight and extended height.

Skewness

The skewness coefficient for tiller and leaf number and T X L size index were calculated to determine the size hierarchy of the populations for the various treatments and were expected to ascertain the relative levels of competition operating within a population. However, comparisons of these factors were not always consistent with the observed difference between treatment means, caused by the 'C-D' effect eg. overall seeding rate comparisons.

Comparison of leaf number at 26 d.a.s. suggested that the populations of both fescue and ryegrass were negatively skewed to a similar extent (Table 4.1.3.1). Plants at that stage of growth had only 2, 3 or 4 leaves. Such a distribution of leaf number indicated a preponderance of plants with 2 leaves rather than one, for example in the case of fescue at 26 d.a.s.. This effect may be a function of timing, as only 17 days later the distribution of fescue and ryegrass populations was positively skewed (Table A1.13, Appendix 1). Alternatively it may be representative of a mutually beneficial 'cooperative effect' between organisms noted by Donald (1963). This possibility is further explored in the discussion regarding plant weight and extended height in the next section (Section 4.1.4.3).

Harris (1971) examined the distribution of growth characteristics other than plant yield. He found that tiller length in a population of ryegrass seedlings was less skewed than tiller number which in turn was less skewed than plant yield where the 'C-D' effect was operating. Thus, some growth characteristics may better reflect the 'C-D' effect as measured by skewness than others. In the current trial only the average weight of plants was available and seedling growth was assessed non-destructively from the tagged seedlings monitored for survival. Harris and Sedcole (1974) measured growth characteristics combined into a size index which was sensitive to competition induced stress as indicated by skewness.

In the current trial a significant relationship was found between the variation of skewness of T X L size index for ryegrass and in-row population at 145 d.a.s. (Table 4.1.3.4). In-row population was not related to the skewness of tiller or leaf number at that time (Table 4.1.3.4 and Table A1.34, Appendix 1, respectively). The result is consistent with the prediction of Harris and Sedcole (1974) that size index is more sensitive to competition-induced stress (the 'C-D' effect) than individual parameters of plant size and is consistent with the concept of plant 'space' developed by de Wit (1960) who used the term "space" encompassing growth factors or requisites namely water, minerals and light.

At 145 d.a.s., tiller and leaf number accounted for 60% and 50% of the variation in ryegrass shoot weight, respectively, but there was no significant relationship between fescue shoot weight and tiller or leaf number (Table A1.17, Appendix 1).

A higher level of competitive stress was operating in the ryegrass sward at a given time than in the fescue sward as indicated by the significant difference in skewness of tiller number and T X L index (Table 4.1.3.1) and supported by several of the results for treatment effects, Specifically:

1. A significant inverse relationship was found between tiller number and in-row population for ryegrass but fescue tiller number was not related to in-row population (Table 4.1.3.4).

2. Fescue required a greater change in in-row population than ryegrass to effect a given change in tiller number (Figure 4.1.3.2)

3 A positive relationship between skewness and in-row population was found for ryegrass but not for fescue (Table 4.1.3.4).

4. Ryegrass sown at the high rate was significantly more skewed than when sown at the low rate but fescue population was not skewed (Table 4.1.3.2)

5. Position effect was more marked for ryegrass than fescue (Table A1.14, Appendix 1)

Despite the evidence at 145 d.a.s., ryegrass was not unequivocally more skewed than fescue . The skewness of fescue at 43 d.a.s. was actually similar to that of ryegrass at 145 d.a.s.. Skewness faithfully reflected the difference in treatment means for seeding rate comparisons with ryegrass at 145 d.a.s. but that was not the case for fescue. Fescue tiller number was actually different for the two seeding rates at 145 d.a.s., presumably because of competitive stress reducing the tiller number at the high seeding rate. The skewness coefficient did not reflect this, which raises a question about its usefulness in predicting or portraying competitive stress operating in a plant community. However, skewness coefficient was a good predictor/indicator of stress where the contrast in position was examined.

The most consistent result for skewness was that for the comparison of plants at contrasting positions at 43 d.a.s.. A known increase in competition-induced stress, as shown by subsequent differences for means, was reflected by a more positively skewed plant size distribution curve (Table 4.1.3.3). This difference in skewness between populations at various positions was detected before the actual differences in means were apparent (Table 4.1.3.3).

No significant differences in skewness for drilling methods were recorded although there was a trend in the data which suggested that plants in 150mm rows were more skewed than those in 75mm rows (Table 4.1.3.1). This coincides with the general relationship for an increase in skewness with increasing in-row population (Table 4.1.3.4).

Bellotti (1984) successfully demonstrated the contrast in size frequency distribution of derived seedling size index by comparing relative skewness of ryegrass and fescue seedlings established by direct drilling, either with or without herbicide. The variation in distribution was much wider than that found here. For example, fescue population established without herbicide in the disc drill treatment of Bellotti (loc cit) had become highly skewed towards smaller plants by 150 d.a.s., so much so that there were no surviving seedlings from this treatment by 250 d.a.s., whereas fescue plants established with herbicide had 2 tillers at that time. Despite the fact that populations were much higher for the current trial than reported for Bellotti's trial (640 cf 75-50 plants m^{-2}), the competitive stress operating between plants in the current trial never reached a level sufficient to result in plant mortality by 145 d.a.s. when fescue had 7 tillers. Growth rates were much slower in Bellotti's trial because of lower temperatures and moisture availability, and plants would have been competing for a smaller pool of resources which resulted in sufficient competition to cause plant mortality.

Coefficient of Variation

Donald (1963) suggested that the coefficient of variation of a data set increases with higher densities because variation in growth rate is greatest at high densities. This was recently demonstrated by Inwood (1990). He found that the coefficient of variation for the weight of tillers from 150mm rows was greater than that for tillers from the broadcast sown treatment in a cultivated seedbed at 101 d.a.s., presumably because of increased competition between plants at similar populations on an area basis being confined to a row with a resulting reduction in distance between neighbouring plants. However, at that time there was no significant difference in plant or tiller weight or nodal roots per plant between those treatments. No subsequent measurements were taken in that trial. Inwood (loc cit) also calculated skewness of tiller weight but no significant differences were found, which suggested that coefficient of variation was a more sensitive indicator of stress than skewness.

Coefficients of variation for treatment means were compared in the current trial. There were few significant differences between the coefficients of variation for various treatments (Table A1.18, Appendix 1). The major effect was a difference in coefficient of variation between species (Table A1.19, Appendix 1). Ryegrass had a higher coefficient of variation than fescue.

Comparison of coefficient of variation for 'position' effect at 43 d.a.s. was consistent with skewness (Table A1.20, Appendix 1). Thus coefficient of variation also indicated competitive stress in a population before that stress induced a noticeable difference in plant size as measured by tiller and leaf number (43 d.a.s.). However, once the populations were differentiated in terms of plant size (145 d.a.s.), as for skewness, the coefficients of variation of treatment means were not significantly different.

The increased sensitivity of ryegrass plant size to density at a given time was a result of its faster growth rate and larger physical size (Donald, 1963) which resulted in a higher level of competitive stress operating in the ryegrass sward as evidenced by higher skewness (Harris, 1971; Westoby, 1984; Bellotti and Blair, 1989c). Larger plants with higher growth rates require comparatively higher levels of plant available nutrients where they occur at similar densities. Where comparisons of species were made on the basis of the stage of growth of the plant and as a proportion of plant size, differences were less obvious.

4.1.4 Treatment Effects on Seedling Weight, Extended Height and Plant Size Indices

4.1.4.1 Introduction

The previous section dealt with plant size as either leaf number or tiller number. A third, non-destructive measurement was recorded for 'tagged' plants. The distance from the base of the plant to the extended tip of the longest leaf was measured at 26, 43 and 145 d.a.s. and is referred to as extended height for the remainder of this thesis. The average shoot weight of 10 whole seedlings/plot was taken at 26, 49, 85 and 135 d.a.s.. Thus non-destructive plant measurements could be compared with shoot weight data for individual plants.

Plant size indices were derived in the same manner as Bellotti (1984) on the basis that relating changes in the distribution of plant size to density stress was developed from a simple geometrical observation that plant weight was proportional to the volume it occupied (Yoda et al., cited by White and Harper, 1970), and consequently most studies of the distribution of individual growth in plant populations have examined plant weight. Tagged plants were required to monitor plant survival under grazing so only non-destructive measurements were possible on those plants which were under closest scrutiny. The extended height measurement, in combination with leaf and tiller number, was used to derive a number of plant size indices which provided a representation of the plant volume and mass (Harris and Sedcole, 1974; Bellotti and Blair, 1987; Seager, 1987; Dodd, 1989). Skewness of the distribution of plant size index has been suggested as providing a better indicator of stress in a population than the skewness of individual plant parameters (Harris, 1971; Bellotti and Blair, 1987). To some extent, the results from this study are consistent with that suggestion. The skewness of T X L index was found to be more closely related to in-row population than the skewness of tiller or leaf number at 145 d.a.s. (Table 4.1.3.4).

Tiller by Leaf number index has been previously described in section 4.1.3.

The following additional plant indices were calculated:

At 26 d.a.s.	Leaf number X Extended height	Lf X Hgt
At 43 and 145 d.a.s.	Leaf number X Extended height	Lf X Hgt
	Tiller number X Extended height	Till X Hgt

Leaf number by extended height was used at 26 d.a.s. as plants had only one tiller at that stage. Results (Section 4.1.3) indicated that leaf number was more sensitive to competition in the current trial than tiller number and results of analysis of variance were similar for Till X Hgt as for Lf X Hgt, so only the latter is presented along with extended height means and the skewness of extended height.

Seedling weight is presented first in this section, followed by plant height and size index data and their skewness.

4.1.4.2 Results

4.1.4.2.1 Treatment Effects on Seedling Weight

4.1.4.2.1.1 Overall Effect of Species, Seeding Rate and Drill Methods

Table 4.1.4.1 compares the effects of species, seeding rates and drilling methods on seedling weight at 26, 49, 85 and 135 d.a.s.. On average, the shoot weight of ryegrass seedlings was twice that of fescue plants which illustrates the difference in the vigour of establishment of ryegrass and fescue plants.

Plants sown at the high seeding rate were significantly heavier than those sown at the low rate at 26 d.a.s.. At 49 d.a.s., the shoot weight from both sowing rates was the same, and at 85 and 135 d.a.s. was greater for low than high seeding rate .

Table 4.1.4.1 Effect of Species, Seeding Rate and Drill Method on Shoot Weight up to 135 Days After Sowing (mg/plant)

	Days After Sowing			
SPECIES	26	49	85	135
Fescue	3.07	14.2	71	143
Ryegrass	4.93	35.1	142	255
S.E.D. ±	0.146	0.76	8.5	10.0
Significance	***	***	***	***
Fescue as % of Rye	62	41	50	54
SEEDING RATE				
High	4.04	22.7	94	184
Low	3.74	21.9	108	223
S.E.D. ±	0.136	1.60	5.3	13.4
Significance	*	n.s.	**	***
DRILLING METHOD				
75 mm row	4.25 a	20.4 a	103 ac	198
Cross drill	3.85 b	24.5 b	108 a	198
150 mm row	3.60 b	22.4 ab	92 bc	177
S.E.D. ±	0.169	2.01	6.5	16.5
Significance	**	n.s.	*	n.s.

Unlike the effects on leaf and tiller number, shoot weight was influenced by drilling method. Drilling method had a significant effect on shoot weight at 26 and 85 d.a.s. (Table 4.1.4.1). At 26 days after sowing, plants from the 75mm drill rows were significantly heavier than those from the 150mm or cross drilled. The latter two treatments were not significantly different from one another. However, at 85 d.a.s., seedlings which were sown in 150mm rows were by then significantly lighter than those sown by cross-drilling but were not significantly different from those sown in 75mm rows. The latter two treatments were not different from each other. No significant differences were detected at 47 d.a.s. or 135 d.a.s.. Thus plants in the 150 mm drill rows were smaller than one or other of the drill treatments at 26 and 85 d.a.s..

4.1.4.2.1.2 Effect of Seeding Rate on Fescue and Ryegrass on Shoot Weight

No interaction between species and seeding rate was indicated from combined species analysis of variance, but comparison of individual species analyses suggested that the seeding rate effect was similar for both species but more obvious for ryegrass than fescue. Table 4.1.4.2 describes the effect of seeding rate on fescue and ryegrass. The results are included here as they illustrate the contrast in response of each species to increasing population density in terms of the severity and timing of competition effects.

Table 4.1.4.2 Effect of Seeding Rate on Fescue and Ryegrass Shoot Weight (mg/plant)

	FESCUE				RYEGRASS			
Days After Sowing	26	49	85	135	26	49	85	135
High	3.16	15.44	69	130	5.31	35.2	136.3	224
Low	3.06	14.22	78	172	4.70	37.2	156.9	326
S.E.D. ±	0.141	1.538	5.9	13.5	0.27	2.81	8.8	32.1
Significance	n.s.	n.s.	n.s.	**	*	n.s.	*	***

4.1.4.2.1.3 Overall Effect of Species, Seeding Rate and Drill Method on Mean Relative Seedling Growth Rate

Table 4.1.4.3 compares the effect of species, seeding rate and drill method on mean relative seedling growth rate ($\log_{10}$ transformed data). Relative growth rate from 0 to 26 d.a.s. was calculated from the shoot weight minus seed weight divided by 26 days. Ryegrass relative growth rate was superior to fescue from 0 to 85 d.a.s., after which time both species were the same and had comparatively slower relative growth rates, presumably because they were reaching the top of the growth curve (Hunt 1982). Shoots of seedlings sown at the high seeding rate grew faster than those at the low rate from 0 to 26 d.a.s. through increased competition for light, but relative growth rates were the same between 26 and 49 d.a.s., after which time plants sown at the low seeding rate always grew faster than those sown at the high rate. The effect of seeding rate was consistent with increasing competition reducing relative growth rate after 49 d.a.s..

Table 4.1.4.3 Effect of Species, Drill Method and Seeding Rate on the Mean Relative Growth Rate of Fescue and Ryegrass up to 135 Days After Sowing ([mg mg-1] day^{-1})

	Growth Period (d.a.s.)			
SPECIES	0 - 26	26 - 49	49 - 85	85 - 135
Fescue	- 2.18†	28.9	19.5	6.07
Ryegrass	7.05	37.1	16.9	5.03
S.E.D. ±	0.06	1.048	0.734	0.752
Significance	***	***	*	n.s.
SEEDING RATE				
High	3.06	32.6	17.1	4.79
Low	1.81	33.3	19.2	6.30
S.E.D. ±	0.575	1.38	0.99	0.697
Significance	*	n.s.	*	*
DRILL METHOD				
75 mm row	3.94 a	29.6 a	19.6 a	5.61
Cross drill	2.27 b	34.8 b	17.9 ab	5.30
150 mm row	1.10 b	34.6 b	17.0 b	5.73
S.E.D. ±	0.07	1.70	1.21	0.854
Significance	**	**	*	n.s.

† all values transformed data ($\log_{10}$) multiplied by 10^3

From 0 to 26 d.a.s., plants in 75mm rows had a higher relative growth rate than cross drilled plants or those in 150mm rows. Plants sown at 75mm row spacing then had a significantly slower relative growth rate than those sown in cross drilled or 150mm rows from 26 to 49 d.a.s.. During the period 49 to 85 d.a.s. plants in 75mm rows showed higher relative growth than those in 150mm rows. Relative growth rate of cross drilled plants was not significantly different from plants in other drilling treatments. From 85 to 135 d.a.s. relative growth rates were the same for all treatments.

There were no significant interactions between any of the main effects. Individual species analysis showed that the seeding rate effect on relative growth rate was consistent for both species but was not significant for either species from 49 to 135 d.a.s., Results were only significant for combined species (Table A1.21, Appendix 1).

4.1.4.2.1.4 Effect of Population

Assessing the relationship between plant population and shoot weight on both an in-row population and plants m^{-2} basis, avoids the confounding effect of seeding rate when interpreting the effect of drilling method on shoot weight. However, it does not account for variations in shoot weight caused by adjusting spacing between rows.

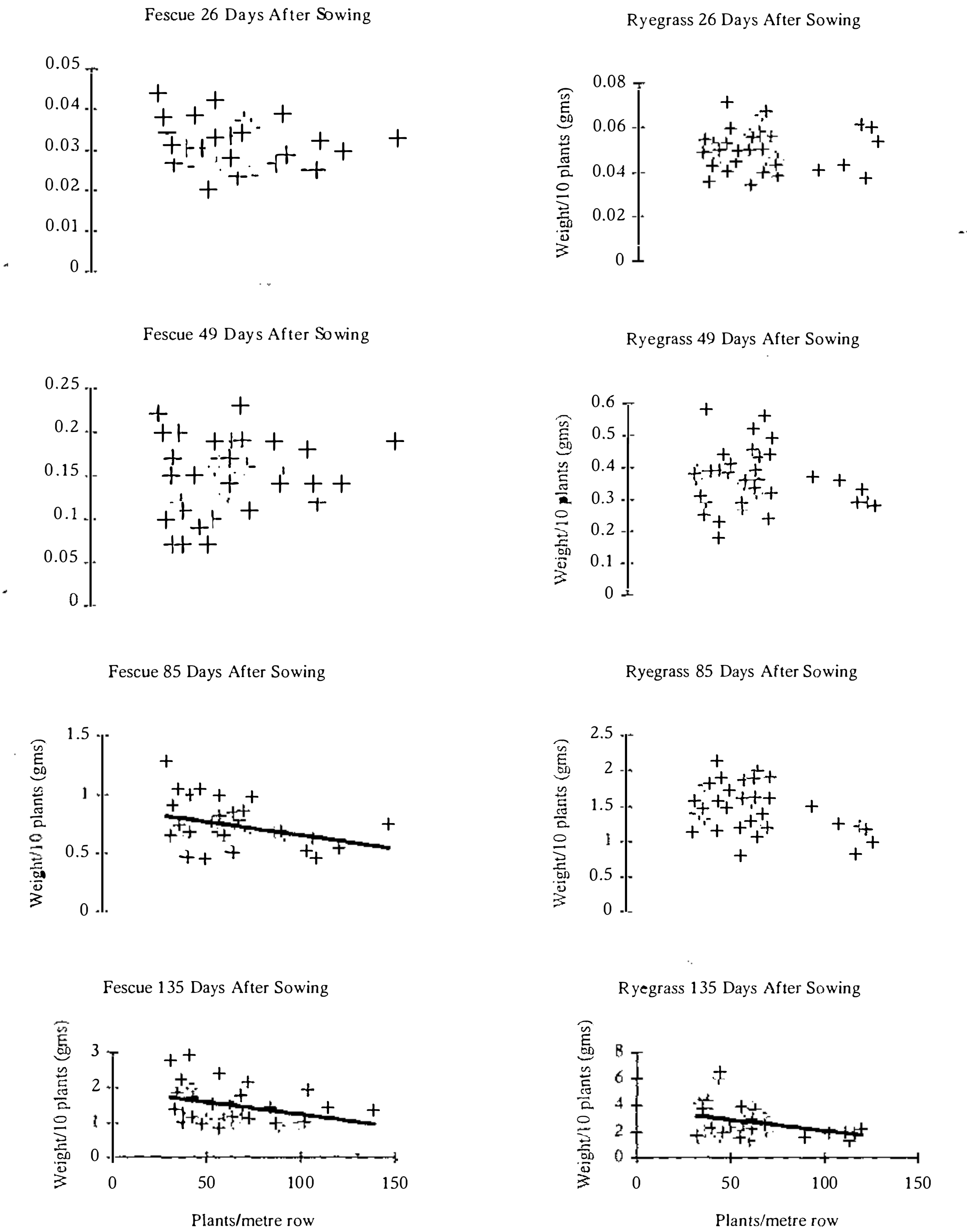
Linear regression analyses of the shoot weights of 10 plants at 26, 49, 85 and 135 d.a.s. as a function of plants m^{-1} row and plants m^{-2} (which was determined at 42 d.a.s.) were carried out. Each species was analysed separately and data were pooled from all drilling method and seeding rate combinations. The relationship with ^{1}/shoot weight was also tested as suggested by Donald (1963) but did not provide a better fit to the data.

As for tiller and leaf number (Section 4.1.3), the association between plants m^{-2} and shoot weights was weaker than between plants m^{-1} row and shoot weights. Results for the former regression analysis can be found in Table A1.42, Appendix 1. Results for the latter analysis are presented below.

Figure 4.1.4.1 shows the relationship between shoot weight and in-row plant population for both fescue and ryegrass. Details are given Table A1.43 in Appendix 1. Regression lines are shown only on the Figures where slopes were significantly different from zero. In-row population did not affect the shoot weight of fescue plants until after 49 d.a.s. or ryegrass plants until after 85 d.a.s.. The regression lines for fescue at 85 and 135 d.a.s. and ryegrass at 135 d.a.s. had negative slopes, which indicated that as in-row plant population increased shoot weight was reduced.

Overall there was a weak but consistent relationship between the above-ground weight of plants from 85 to 135 d.a.s. and the in-row population recorded at 42 d.a.s.. Eleven percent (r^2) of the variation in fescue plant weight was attributable to variation in in-row population at 85 d.a.s. when the effects were negligible for ryegrass. A similar change in in-row population was required to effect a 25% change in shoot weight for both species by 135 d.a.s. (Table A1.43, Appendix 1), indicating that in-row population had a similar effect on fescue and ryegrass.

Figure 4.1.4.1 Effect of In-row Plant Population on Ryegrass and Fescue Shoot Weight.

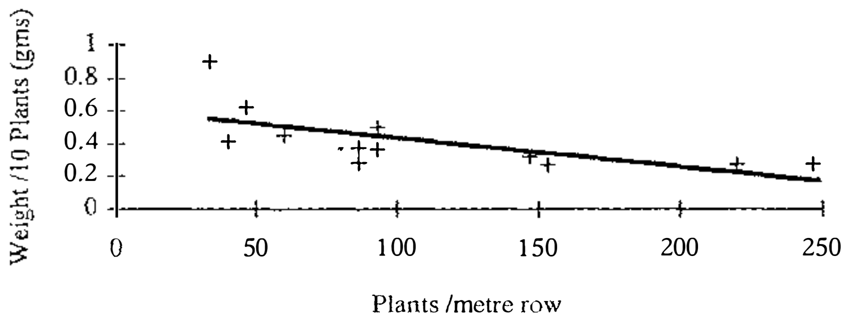


4.1.4.2.1.5 Effect of In-row Population on Root Weight

Fescue appeared to be more sensitive to in-row plant population at 85 d.a.s. than ryegrass, despite the fact that fescue had only half the above-ground weight of ryegrass plants. This suggests that the absolute weight of the above ground portion of the plants may not have been directly involved in the competition effect which reduced plant size at higher in-row population densities. Competition for below-ground resources (nutrients, moisture) may have more important. A brief investigation of root size was carried out at 54 d.a.s.. The results are reported below.

Regression analysis of root weight as a function of plants m^{-1} row was carried out. Data were pooled from all treatments and blocks. Data from 101 plants were collected from 12 samples and were used in the regression analysis of root weights on plants m^{-1} row. Figure 4.1.4.2 describes the relationship between the root weight of 10 sample ryegrass plants and the in-row population of that sample at 54 d.a.s.. Note that the maximum in-row population shown in Figure 4.1.4.2 (250 plants m^{-1} row) is higher than the highest average in-row population listed in Table 4.1.1.4 (109 plants m^{-1} row). This is a function of the length of row taken as a sample and the large variation in in-row population. Variations in in-row population for the sample used here were large (coefficient of variation 32-71 %, Table 4.1.3.8). The discrepancy between the populations listed for 150mm long row samples taken for root weight determination and the populations listed for the 0.4 m row samples taken to determine established seedling populations shows this. As in-row population increased, root weight decreased. Forty two percent (r^2) of variation in root weight was attributable to in-row population. Regression of shoot weight on in-row population for ryegrass plants from the same treatments as those from which the root weight had been sampled (ie. H 150 and L75 treatments) showed no significant relationship at 49 d.a.s.. Consequently, it is concluded that in-row population had a clear effect on root weight but no effect on shoot weight at this time.

Figure 4.1.4.2 Effect of In-row Population on Root Weight of Ryegrass at 54 Days After Sowing.



4.1.4.2.1.6 Effect of In-row Population on Other Plant Characteristics

The number of tillers, main roots, and daughter roots were measured from the 12 samples. Regression analyses of tillers/plant and the number of roots in the primary root system (main roots/plant and roots arising from main roots or daughter roots) as a function of plants m^{-1} row were also carried out. Table 4.1.4.4 describes the relationships between tillers/plant, main roots/plant and roots arising from main roots (daughter roots/plant) and in-row population.

Table 4.1.4.4 Effect of In-row Population on Root Weight, Tiller number, Main roots and Daughter Roots at 54 d.a.s..

	Characteristic			
	Weight of roots/10 Plants	Tiller number	Main Roots per plant	Daughter Roots per plant
Mean	0.418	5.5	12.5	7.7
Slope	-0.00176	-0.0135	0.0071	-0.0282
S.E.D. ±	0.0006	0.0044	0.0065	0.01
level of significance for slope of regression line	2 %	1 %	n.s.	2 %
coefficient of correlation (r^2)	0.42	0.47	0.09	0.45
plants m^{-1} row required to effect a 25 % change §	59	101	0	68

§ Average #*x 0.25 / Slope of the regression line = change in in-row population (plants m^{-1} row) to effect a 25 % change in plant characteristic

As the in-row population increased, the weight of plant roots, tiller number and the number of daughter roots per plant decreased. The slope of the regression line was negative and significantly different from zero at the 2% level of probability or less for each characteristic which described plant size, except the number of main roots/plant. The number of main roots/plant was not affected by in-row population. The data for the number of main roots, in effect, provided a historical record of intra-row root competition and indicates that main root formation was not affected by in-row population. On the other hand, daughter root numbers provided an indicator of contemporary root competition which had developed by the time of sampling. Root growth was affected by in-row plant population at an earlier stage than the above-ground portion of the plants.

Even though root weight per plant decreased as in-row population increased, no upper limit on root weight had been reached by 54 d.a.s.. Regression analysis of root weight m^{-1} row as a function of plants m^{-1} row was carried out. The result showed that root weight m^{-1}row was highly and positively correlated with in-row population (r=0.91). As in-row population increased the weight of roots per unit row length also increased.

4.1.4.2.2 Treatment Effects on Extended Height and Plant Size Index

4.1.4.2.2.1 Overall Effect of Species Seeding Rate and Drill Method

Table 4.1.4.5 describes the overall effect of species on extended height and skewness of extended height and Lf X Hgt index at 26, 43 and 145 d.a.s.. In general, ryegrass had longer leaves than fescue. At 26 d.a.s. plants sown at the high rate had significantly longer leaves than those sown at the low rate. At that stage the effect was significant for fescue but not for ryegrass, although ryegrass exhibited the same trend as fescue (Table A1.26, Appendix 1). At 43 d.a.s. plants from both sowing rates had the same extended height and by 145 d.a.s., in contrast to measurements taken at 26 d.a.s., plants sown at the low rate then had longer leaves than those from the high rate. This result is consistent with the results for shoot weight during that period (Table 4.1.4.1) and indicates competition for light amongst seedlings (Colvill and Marshall, 1981).

Drill method had no significant effect on extended height at 26, 43 or 145 d.a.s.. The raw data are shown in Appendix 1 (Table A1.26). Unlike the plant position effects on leaf and tiller number, there were no significant position effects on extended height (Table A1.28, Appendix 1) or the skewness of extended height or skewness of Lf X Hgt index.

Skewness of extended height did not reflect the higher level of stress operating in the ryegrass at 145 d.a.s. as indicated by leaf and tiller number (Table 4.1.3.1) as compared with the fescue.

Table 4.1.4.5 Effect of Species and Seeding Rate on Extended Height and Skewness of Extended Height and Leaf by Extended Height Index at 26, 43 and 145 d.a.s.

d.a.s. (Month)	26 (May)			43 (May)			145 (September)		
Characteristic	Extended Height	Skew Ext Hgt	Skew Lf X Hgt	Extended Height	Skew Ext Hgt	Skew Lf X Hgt	Extended Height	Skew Ext Hgt	Skew Lf X Hgt
Fescue	60 ‡	-0.03	-0.023	66	-0.052	0.095	131	0.018	0.053
Rye	65	-0.064	-0.018	89	-0.037	0.076	178	0.086	0.184
S.E.D. ±	1.5	0.053	0.05	1.2	0.076	0.06	12.1	0.044	0.036
Significance	*	n.s.	n.s.	***	n.s.	n.s.	***	n.s.	*
High	64	-0.050	-0.001	78	-.076	0.105	148	0.036	0.106
Low	61	-0.045	-0.041	78	-0.013	0.066	160	0.068	0.103
S.E.D. ±	1.2	0.043	0.052	1.4	0.051	0.042	5.0	0.042	0.039
Significance	*	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.

‡ Extended Height = length of longest leaf from base of plant to extended tip (mm)

4.1.4.2.2.2 Interactive Effect of Species and Drill Method

Table 4.1.4.6 compares the effect of drill method on extended height for fescue and ryegrass. There was an interaction between species and drill method at 145 d.a.s. on extended height but there was no interaction for skewness of either height or Lf X Hgt index so those results are not presented here.

Fescue plants in 75mm rows had longer leaves than cross drilled plants or those in 150mm rows, but there were no differences amongst drill methods for ryegrass. The effect was consistent with the overall effect in that higher populations generally had shorter plants, but is not altogether consistent in that cross drilled plants were also shorter than plants in 75mm rows and a similar size as those in 150mm rows which were at a higher in-row population. .

There were no significant interactions between drill method and seeding rate for extended height, skewness of extended height or skewness of Lf X Hgt.

Table 4.1.4.6 Effect of Drill Method on Extended height of Fescue and Ryegrass Plants

		d.a.s. (month)		
	DRILL METHOD	26 (May)	43 (May)	145 (Sep)
RYEGRASS	75 mm row	6.777	87	171
	Cross drill	6.371	89	182
	150 mm row	6.497	89	175
S.E.D. ±		0.160	2.5	13.0
Significance		n s	n.s.	n.s.
FESCUE	75 mm	6.042	68	148 b
	Cross	5.959	67	124 a
	150 mm	6.155	64	128 a
S.E.D. ±		0.241	2.55	8.23
Significance		n.s.	n.s.	*

4.1.4.2.2.3 Interactive Effect of Species and Seeding Rate on Plant Size Distribution

Table 4.1.4.7 describes the effect of seeding rate on the skewness of leaf number, extended height and Lf X Hgt for fescue and ryegrass at 43 and 145 d.a.s.. The interaction was similar to that for tiller number and leaf number (Table 4.1.3.2). Skewness of extended height did not reflect that interactive effect but there was a significant interaction between species and seeding rate effects on the skewness of Lf X Hgt at 43 d.a.s. and 145 d.a.s..

At 43 d.a.s., the distribution of fescue leaf number was more positively skewed at high seeding rate than it was at low seeding rate and it was more positively skewed than ryegrass at either seeding rate, which was consistent with tiller number (Table 4.1.3.2). However, the skewness of Lf X Hgt index indicated that fescue at the high rate was more positively skewed than at the low rate but was not more skewed than ryegrass at either rate. Skewness of Lf X Hgt was consistent with the general trend which saw fescue become more positively skewed as population increased at 43 d.a.s. (Tables 4.1.3.4 and 4.1.3.2) whereas ryegrass was not significantly skewed.

Table 4.1.4.7 Effect of Seeding rate on Skewness of Extended Height and Leaf by Extended Height Index for Ryegrass and Fescue at 43 and 145 d.a.s.

d.a.s. (Month)		43 (May)			145 (September)		
Characteristic		Skew Leaves	Skew Ext Hgt	Skew Lf X Hgt	Skew Leaves	Skew Ext Hgt	Skew Lf X Hgt
Fescue	**High**	0.210	-0.074	0.161	-0.028	0.009	-0.013
	Low	0.044	-0.029	0.03	0.041	0.027	0.119
S.E.D. ±.		0.091	0.070	0.065	0.066	0.057	0.063
Significance		(*)	n.s.	*	n.s.	n.s.	*
Ryegrass	**High**	0.043	-0.077	0.050	0.180	0.063	0.225
	Low	0.093	0.003	0.101	0.053	0.108	0.142
S.E.D. ±		0.054	0.074	0.055	0.056	0.060	0.43
Significance		n.s.	n.s.	n.s.	*	n.s.	(*)
Species X	S.E.D. ±	0.059	0.091	0.074	0.057	0.061	0.053
Rate Interaction	Significance	*	n.s.	*	*	n.s.	* *

There was also an interaction at 145 d.a.s.. As previously shown, the population of ryegrass leaves were more positively skewed at high seeding rate as compared with the low rate at 145 d.a.s. (Table 4.1.3.2) but the skewness of extended height did not reflect this. Neither the skewness of leaf number nor extended height indicated that the size distribution of fescue was significantly affected by seeding rate at 145 d.a.s. but Lf X Hgt indicated that fescue was more positively skewed at the low as compared with the high rate. Interaction between species and seeding rate was reflected by Lf X Hgt but not by height. The plant size index (Lf X Hgt) indicated the interactive effect at a higher level of probability than skewness of tiller or leaf number, extended height or T X L index and confirms the general observation that seeding rate had a contrasting influence on the skewness of ryegrass and fescue at 145 d.a.s.

4.1.4.2.2.4 Effect of Population

Regression analyses of extended height, skewness of height and skewness of Lf X Hgt index as a function of plants m^{-1} row and plants m^{-2} was carried out in the same manner as for previous analyses for the effects of population variation on plant parameters and skewness. Table 4.1.4.8 describes these results.

As previously described, population on an area basis showed less association with plant characteristics and their skewness than plants m^{-1} row. The equivalent data for the relationships between plant m^{-2} and extended height, skewness of extended height (Table A1.35) and skewness of Lf X Hgt index (Table A1.37) can be found in Appendix 1.

Table 4.1.4.8 Effect of In-row Population on Extended Height and Skewness of Extended Height and Leaf X Extended Height Index for both Fescue and Ryegrass.

	Fescue						Ryegrass					
d.a.s.	43			145			43			145		
Size Index	Ext'd Height	Skew Ext Hgt	Skew Lf X Hgt	Ext'd Height	Skew Ext Hgt	Skew Lf X Hgt	Ext'd Height	Skew Ext Hgt	Skew Lf X Hgt	Ext'd Height	Skew Ext Hgt	Skew Lf X Hgt
mean	66	-0.05	0.09	0.04	131	0.06	89	-0.046	0.11	178	0.1	0.2
slope of regression line	-0.096	-0.0006	0.0012	-0.0007	-0.075	-0.0003	0.048	-0.001	-0.0001	-0.24	0.003	0.003
S.E.D. ±	0.045	0.001	0.001	0.001	0.24	0.002	0.047	0.0017	0.001	0.27	0.001	0.001
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**
r^2	0.07	0.005	0.02	0.007	0.03	0.004	0.02	0.016	0.	0.002	0.09	0.21

Neither the skewness of leaf number (Table A1.34, Appendix 1) nor extended height (Table 4.1.4.8) were related to in-row population. However, the skewness of Lf X Hgt index for ryegrass increased as in-row population increased (Table 4.1.4.8).

4.1.4.2.3 Drill Method and Seeding Rate Effects on Plant Size Characteristics

Table 4.1.4.9 summarises the effects of drilling method on leaf and tiller number, extended height and shoot and tiller dry weights at both high and low seeding rates at 145 d.a.s. for combined species and lists both the in-row and area population. Presentation of combined results is appropriate as there were no interactions between drill methods and species or between species, drill method and seeding rate, except for extended height of fescue. Results are presented here for the purposes of later discussion. Individual species data are listed in Table A1.45, Appendix 1.

Table 4.1.4.9 Effect of Drill Method on Tiller and Leaf Number at 145 d.a.s. and Shoot and Tiller Weight at 135 d.a.s. at High and Low Seeding Rate (Combined Species Results)

SEEDING RATE	*DRILL METHOD*	**Plants m^{-1} row**	**Plants m^{-2}**	**SHOOT weight (mg/plant**	**TILLER weight (mg/tiller)**	**Extended Height (mm)**	**LEAF NUMBER**	**TILLER NUMBER**
HIGH	75mm (H75)	59 a	786 ab	157 a	28.7 ab	153	10.46 a	5.47 ab
	Cross (HX)	65 a	866 a	186 ab	N/A §	146	9.52 a	5.05 a
	150mm (H150)	108 b	720 b	149 a	27.6 a	146	9.67 a	5.40 ab
LOW	75mm (L75)	39 c	523 c	248 c	35.3 b	166	13.20 b	7.03 c
	Cross (LX)	38 c	507 c	210 bc	N/A	159	12.74 b	6.86 c
	150mm (L150)	64 a	425 c	217 bc	33.7 ab	156	11.94 b	6.44 cb
	Comparison	SED 3.6	SED 46	SED 23	SED 4.7			
S.E.D. ±	Cross with Cross					7.09	0.670	0.377
	Cross with 75 or 150					8.68	0.822	0.462
	75 with 150					10.02	0.949	0.533

- Unlike letters in a column denote significant differences
- § N/A indicates not assessed (plant weight was not recorded for plants at the intersection of cross drilled rows)

4.1.4.3 Discussion

Species

Perennial ryegrass had up to 100 % more dry weight per plant, and up to 35 % greater extended height than tall fescue during the first 145 days after sowing, which is consistent with previous comparative studies (Ryle, 1964; Rhodes, 1968b; Brock, 1973; Brock et al., 1982).

Shoot weight of fescue and ryegrass at 49 d.a.s. in the current trial was higher than that reported by Brock et al. (1982) for a low-medium fertility silt loam in the glasshouse at 42 d.a.s.. This was more so than would be expected for the difference in d.a.s.. However, shoot weight in the current trial was less than that reported for the Brock et al. (loc cit) high fertility glasshouse experiment. Shoot weight of ryegrass and tall fescue at 49 d.a.s. in the current trial was similar to that reported from a field trial carried out on the same soil type within 0.5 km of the current site and which was also sown in mid April using conventional cultivation (Brock, 1973). No comparative shoot weight data are available for tall fescue after 56 d.a.s., but shoot weight for short rotation ryegrass at 136 d.a.s. was recorded by Brougham (1954a) and was slightly lower than that for perennial ryegrass plants in the current trial at 135 d.a.s. (188 cf. 275mg/plant) and similar to that reported by Inwood (1990).

Seeding Rate

Inter-plant competition at high seeding rate reduced shoot weight, leaf length and leaf and tiller number for both fescue and ryegrass as compared with low seeding rate. However, the 'C-D' effect (Westoby 1984) was not sufficient to cause plant mortality. Whether or not plants are sufficiently stressed to cause mortality, according to the $-\frac{3}{2}$ thinning rule, can be tested by dividing the difference of the logarithms of shoot weights between two densities by the difference of the logarithms of the densities (Robinson and Whalley, 1988). If that ratio is greater than 1.5 then density-related plant mortality is likely to occur. Robinson and Whalley (loc cit) actually described the ratio incorrectly in their text as the "logarithm of the difference" between weights and populations, when in fact the calculation is of the "difference in the logarithms" of weight and population. Calculations for the current trial showed that the ratio between the change in log shoot weight and change in the log population was less than 1 for both species at 135 d.a.s. (Table A1.46, Appendix 1), confirming that competition was not sufficient to cause plant mortality.

Nutrients and light are the most likely factors for which plants compete (Brougham, 1954a; Donald, 1963). Moisture was not likely to have been limiting in the current trial as soil water holding capacity remained fully charged for most of the early establishment period (Figure A1.2, Appendix 1). The current trial was not designed to specifically identify the relative importance of above and below ground competition, but the shift in the pattern of plant development for the two seeding rates did indicate changes in factors limiting plant growth.

Results from this trial would suggest that there was competition between newly emerged seedlings as early as 26 d.a.s., even before all plants had emerged, which was earlier than predicted by Donald (1963). Extended height (Table 4.1.4.5), shoot weight (Table 4.1.4.1) and relative growth rates (Table 4.1.4.3) were greater for seedlings at higher population densities (800 plants m^{-2}) than those at lower densities (425 plants m^{-2}) and is consistent with plant responses to shading (Ludlow, 1978). Comparable field seeding rate trials have not measured plant height. Where shoot and root competition of transplanted ryegrass plants had been isolated from surrounding pasture (Seager et al., 1992), plant height, measured as the height of the ligules of the youngest leaves of the 3 highest tillers above soil surface (Seager, 1987), was greatest for shoot competition only as compared with no, full or root-only competition. A similar effect was found with ryegrass tillers (pre-grazing) surrounded by unclipped compared with clipped herbage (Thom et al., 1986c). The increased competition for light at higher plant density was consistent with results from Colvill and Marshall (1981). From a glasshouse experiment, they recorded an increase in the length for each of the first six successive perennial ryegrass leaves (cv S23) which formed on the main shoot when sown at 5000 seeds m^{-2} as compared with plants sown at 500 seeds m^{-2}. The length for subsequent leaves was shorter at the higher density. Leaf length in Colvill and Marshall's experiment was synonymous with extended height in the current trial. In the current trial, the growth stage of perennial ryegrass (7.1 leaves) and inter-plant distance (14 mm) were similar to those of Colvill and Marshall

(1981), when those plants at the high density no longer had a length advantage.

Interrelationships between organisms may be mutually harmful and competitive, or mutually beneficial and cooperative (Donald, 1963). An expression of cooperation is the effect of density on height. As density increases and competition for light is intensified, plant height may be substantially increased which may be seen as mutually beneficial since height gives competitive advantage by enabling the shading of neighbours, in this case perhaps neighbouring weeds.

Plants had the same extended height and were the same weight at 43 and 49 d.a.s. irrespective of seeding rate (Tables 4.1.4.1 and 4.1.4.5, respectively). However, extended height of plants by 145 d.a.s. was actually less at high seeding rate and plants were lighter at 135 d.a.s. than those sown at the low seeding rate. Root competition was apparently more severe on transplanted perennial ryegrass seedlings than shoot competition, but plant growth and development were affected by both (Seager, 1987). The results of Seager (1987) were in line with earlier work by Cook and Ratcliff (1984) and Cook (1985). In the experiments of Cook and Ratcliff (1984), Cook (1985) and Seager (1987), root competition between transplanted and resident pasture plants decreased shoot weight and plant height, and shoot competition increased plant height and shoot weight.

Results from the current trial suggest that competition for light at 26 d.a.s. switched to competition for edaphic factors, most probably nutrients, between 26 and 43 d.a.s. after which time root competition may have been more important than shoot competition. Interrelationships between seedlings changed from a cooperative effect of plant density on height to a competitive effect on plant height. The effect was consistent for both perennial ryegrass and tall fescue. This may explain why distribution of leaf number was negative at 26 d.a.s.. Early competition for light may not only have encouraged growth (height and weight) in seedlings sown at a high seeding rate but may also have encouraged general leaf production. If root competition for nutrients was the main determinant of extended height then the cooperation effect may have lasted longer if nutrients had been more abundant.

Seager (1987) also found that root:shoot ratio increased in plants with root only or full (root plus shoot) competition as compared with shoot or no competition. Lower root:shoot ratios have been reported for plants sown at higher densities (Harper, 1977). As the extended height of seedlings sown at the high seeding rate in the current trial increased, relative to those sown at the low rate, root growth was likely to have decreased, placing those seedlings at a disadvantage later in terms of soil exploration for nutrients.

The effect of density on seedling height has been found in an earlier field trial. From an autumn sown trial, conducted in close proximity to this trial, Brougham (1954a) noted that short rotation ryegrass seedlings in lower sowing rate plots adopted a more prostrate habit of growth. Herbage height at the first grazing was 50-75mm at a seed rate of 11.3kg ha^{-1} compared with 75-100mm for plots sown at up to 68kg ha^{-1}. Brougham measured undisturbed sward height rather than extended leaf length, but the trend indicated would seem comparable on the basis that in the current trial, tall fescue, a more erect plant than perennial ryegrass, exhibited a height increase at high seeding rate and extended height would have been similar to resting height (Table A1.26, Appendix 1).

After the brief period where higher density increased seedling growth, the plant size/density relationship followed the same trend as that shown in other trials with grasses (Williams, 1947; Holliday, 1953; Brougham, 1954a,b,d; Kays and Harper, 1974; Harris, 1971; Robinson and Whalley, 1988). Density had a major effect on the growth and development of individuals. The current trial demonstrated that after the initial phase of seedling establishment, increasing population from 500 to 800 plants m^{-2} reduced extended height by 11% at 145 d.a.s., and reduced shoot weight by 12 and 40% at 85 and 135 d.a.s., respectively.

The effect of seeding rate on shoot weight was not apparent for either species until average shoot weight was 140 to 150mg/shoot, and was apparent for ryegrass sooner than fescue (Table 4.1.4.2). Colvill and Marshall (1981) showed that the effect of density on plant size occurred at an earlier stage of growth where plant density of perennial ryegrass was higher. Their experiment, which contrasted perennial ryegrass densities of 500 and 5000 plants m^{-2}, demonstrated a reduction in plant size at the high density where plants were sown equidistantly before shoot weight reached 70mg/plant. Therefore, the effect of density conforms to the expected pattern in that competition first becomes operative at the highest densities, and then progressively with advancing stage of growth at lower densities.

Brougham (1954a) proposed that competition for light and nitrogen were the main factors causing a reduction in plant size at higher densities and that increased competition for nitrogen at higher grass seeding rates was compounded by poor clover growth. Colvill and Marshall (1981) showed that after the initial establishment phase of seedling growth, plants at high density assimilated less carbon and initially had longer leaves than plants at lower densities. Plants at higher density produced fewer and lighter second and third order tillers. They proposed that the overall changes in plant morphology reflected the difference in light relationships within miniswards. That may hold where fertility is high and there is no restriction in moisture availability (as was the case for that glasshouse experiment) and while leaf length was greater at high density, but it does not hold for the period when leaf length became shorter at high density toward the end of their 12 week experiment.

The brief investigation of root weight indicated that below-ground competition was important in determining plant size in the current trial during early establishment (54 d.a.s.). However, competition for light would also have occurred. Donald (1963) considered solar radiation to be the major factor limiting plant growth, since competition for light (inter- and intra-plant shading) occurred irrespective of the soil nutrient or water status. He further speculated that with the increased use of fertilisers and irrigation, light would become the sole limiting factor to production. Light intensity is implicated in control over tiller and leaf appearance and death

(Langer, 1963; Jewiss, 1972). Artificial shading of plants, relative to unshaded conditions, was shown by Mitchell (1953a) and Mitchell and Coles (1955) to result in fewer tillers and leaves per plant.

Tiller weight of ryegrass was significantly reduced at high seeding rate in the current trial at 135 d.a.s. (Table 4.1.3.7). The effect was not significant for fescue but was significant for combined species results (Table 4.1.3.6). Seeding rate had no affect on the average number of leaves per tiller of either species (1.6 and 1.9 leaves/tiller for fescue and ryegrass, respectively (Table A1.23, Appendix 1), so leaves must have been lighter at high seeding rates as compared with low seeding rates. A reduction in leaf weight is consistent with reduced extended height recorded at 145 d.a.s. (Table 4.1.4.5) for both species. Mitchell (1954) showed that where shading slowed down tillering of short rotation and perennial ryegrass, there was a lower proportion of newly formed, small tillers on the plant. The average tiller weight increased and it was that tendency, rather than an increase in weight of individual leaves, which was responsible for tiller weight of shaded plants being approximately equal to or greater than that of plants in full light. Therefore if shading had reduced tiller number in the current trial, then tiller weight might have been similar, with only a difference in tiller number. However, tiller weight was reduced at high seeding rate so it is unlikely that competition for light caused the reduction in tiller number in the current study. Ryegrass shoot weight showed a larger proportional response to seeding rate reduction at 135 d.a.s than leaf number at 145 d.a.s. (Table 4.1.4.9) which is consistent with a reduction in leaf weight and height rather than leaf number at higher seeding rate.

The effect of seeding rate was more marked for ryegrass than fescue for every measurement except for leaf number at 43 d.a.s. (Table 4.1.4.2, Table A1.23, Appendix 1`). This reflects the increased competition between ryegrass plants in comparison with fescue as shown by a more positive skewness for plant tiller number and leaf number distribution at 145 d.a.s. (Table 4.1.3.1) (Harris, 1971; Westoby, 1984; Bellotti and Blair, 1989c). The increased sensitivity of ryegrass plant size to density at a given time was a result of faster growth rate and larger physical size (Donald, 1963). Larger plants with higher growth rates require comparatively higher levels of plant available nutrients where they occur at similar densities. In all cases fescue results followed the same trend as ryegrass (Table 4.1.4.9). Table 4.1.4.9 summarises the proportional increase in plant size for the reduction in seeding rate and the relationship between population variation and plant size. The association between in-row population and plant size was greater than that between plants m^{-2} and plant size for each of the plant parameters measured, hence in-row population relationships are presented here.

The correlation coefficient with plants m^{-1} row was generally higher for ryegrass than fescue for leaf and tiller number, but the relationship between shoot weight and in-row population was more obvious with fescue than ryegrass at 85 d.a.s. although overall it was poorly related (r^2 = 0.11). Despite this, seeding rate effect was not significant for fescue at that time but was for ryegrass (Table 4.1.4.2). The results indicate that row spacing (in-row density) had more influence over shoot weight of fescue than plant population on an area basis. Row arrangement/spacing has more influence over light interception than seeding rate at least, in the early stages of establishment (Holliday, 1963; Donald, 1963; Hallgren, 1976b), because of improved ground cover associated with reduced row spacing. This was demonstrated by the reduced transmission of photosynthetically active radiation (PAR) between 75mm as compared with 150mm rows (Table A1.10, Appendix 1). It would appear that fescue benefited more from the improved light interception than ryegrass.

By 145 d.a.s. in-row population had a comparable effect on shoot weight for both species. Correlation coefficients were low and fescue leaf and tiller number was not related to in-row population at 145 d.a.s.. Thus in-row population had more influence on leaf number and tiller number of ryegrass than fescue. Ryegrass and fescue plants at the vegetative stage of growth comprise a main shoot, tillers, and leaves on the main shoot and on tillers (Hunt and Field, 1979). Their combined weight is the shoot weight. Tiller number and leaf number largely determined shoot weight in ryegrass but extended height did not. Fescue shoot weight was not related to any of those characteristics (Table A1.17, Appendix 1). This would explain why in-row population was found to have had little influence on tiller or leaf number of fescue. However, leaf number of fescue was the earliest indicator of the seeding rate effect and leaf number was related to in-row population at that stage, but at a lower level of probability (Table A1.49, Appendix 1). The effect of seeding rate on leaf number of fescue at 43 d.a.s. was an atypical result in that the effect was significant for fescue and not ryegrass, and the effect of position on leaf number was not significant for either species at that stage. Position (intersection vs between) was subsequently found to provide a larger contrast in plant size at 145 d.a.s. than seeding rate, and the effect was more obvious for ryegrass than fescue (Table A1.14, Appendix 1).

Extended height reflected main treatment effects (species, seeding rate and drilling method) but in contrast to other studies, (Harris, 1971; Harris and Sedcole, 1974; Bellotti, 1984; Bellotti and Blair, 1989c and Seager, 1987) did not predict plant size in the current trial for either species. Extended height was not related to shoot weight or in-row population at any time during early establishment. The above authors found that between 50 and 80% of individual plant weight was attributable to plant height. Therefore they considered plant height to be a good predictor of plant size. The discrepancy between those results and the current trial may in part be due to the fact that those authors measured height and weight of the same tillers whereas different samples were measured for the respective measurements in the current trial so a lower coefficient of correlation was likely. However, this is unlikely to be the major cause of the discrepancy because tiller and leaf number of tagged ryegrass plants was found to be related to shoot weight despite the limitations imposed by the sampling technique used. The discrepancy is more likely to be a result of the contrasting situations in which plants occurred. Plants in the current trial were concentrated in rows and so were in close proximity to one another (average 16mm to nearest neighbour, 62 plants m^{-1} row) whereas plants in other trials were either very small and at low populations (50 to 75 plants m^{-2}, Bellotti and Blair, 1989c), widely spaced in plots (250mm Harris, 1971; 90mm, Harris and Sedcole, 1974), or in pots (4 to a planter bag, Bellotti, 1984). Absolute differences for seeding rate effects tended to be smaller in the current trial (eg. 12mm between plants at 145 d.a.s., Table 4.1.4.5) than for treatment differences recorded in other trials (eg Seager, (1987) 118mm, Bellotti, (1984) 180mm).

Plant Size Distribution

Skewness of tiller and leaf number and T X L index indicated that the distribution of ryegrass was more skewed than fescue at 145 d.a.s.. This was not reflected by skewness of extended height (Table 4.1.4.5). However, skewness of Lf X Hgt was consistent with that effect because of the inclusion of leaf number as a factor in its derivation (Table A1.32, Appendix 1).

Where plant size was reduced by a treatment, skewness should have become more positive as a reflection of the 'C-D' effect in the population. This was clearly the case with ryegrass at 145 d.a.s. (Tables 4.1.3.2 and 4.1.4.8). However, skewness did not reflect the obvious overall effect of high seeding rate in reducing leaf number, tiller number, extended height and shoot weight at 135 and 145 d.a.s.. This was the result of contrasting skewness for fescue and ryegrass populations for high and low seeding rate comparisons (Tables 4.1.3.2 and 4.1.4.8), effectively cancelling out the overall effect when results for species were combined (Tables 4.1.3.1 and 4.1.4.5). Thus skewness of fescue was not consistent with the variation in means. It is unclear why this may have occurred but the finding is consistent with the fact that fescue tiller number, leaf number and extended height (Table A1.49, Appendix 1) or the skewness of those characteristics (Tables 4.1.3.4 and 4.1.4.8), did not show any significant association with in-row population at 145 d.a.s.. On the other hand, those relationships, with the exception of extended height, were significant for ryegrass. It may be that the skewness of plant size distribution based on non-destructive measurements of tiller and leaf number of plants in the early stages of growth, in this case 1 to 4.4 tiller/plant, was unreliable, although Bellotti (1984) did obtain reliable results for skewness of plant size index (tiller X height) with fescue plants of similar size but where growth rate was slower (eg. 1.83 tillers per fescue plant at 250 d.a.s., Table 2 Bellotti and Blair 1989c) and contrast between competition effects on plant size was greater (eg. overdrilling vs direct drilling). White and Harper (1970) reported a spread of skewness for individual plant weight of *Brassica napus* and *Raphinus sativus* which was "not accounted for" during establishment. There was a more consistent skewness value for each species just before the onset of plant mortality. It would seem that skewness may vary during the early stages of growth.

The skewness of Lf X Hgt size index was more sensitive to competition induced stress (the 'C-D' effect) than skewness of individual parameters (Tables A1.34, Appendix 1. and 4.1.4.8). Skewness of ryegrass Lf X Hgt index became more positive as in-row population increased, consistent with T X L index (Table 4.1.3.4). The measurement of extended height added little to the results obtained from T X L index and certainly was of no value on its own in terms of reflecting the size frequency distribution of ryegrass and fescue populations. However, extended height was useful in signifying the relative importance of root and shoot competition.

Drilling Method

Despite the range in distances between seeds and seedlings along a row, and unlike seeding rate, variations in drill method did not provide sufficient contrast in light competition at 26 d.a.s. to effect extended height. Trends were not consistent with the seeding rate effect (Table A1.27, Appendix 1). The difference in in-row population was similar for drill method and seeding rate comparisons (49/52 vs 86 plants m^{-1} row for 75mm/cross drill vs 150mm rows compared with 47 vs 77 plants m^{-1} row for low vs high seeding rate, respectively). However, population difference on an area basis provided less divergence in population for drill method than seeding rate comparisons (659/690 vs 573 for 75mm/cross drill vs 150mm rows and 795 vs 487 plants m^{-2} for low vs high seeding rate, respectively) which would suggest that competition for light was operating at a inter-row level rather than a intra-row level.

Tiller weight, shoot weight, leaf number and tiller number were not influenced by drilling method at the same seeding rate but each of those plant parameters was affected by seed rate within a drilling method. Thus, where population on an area basis was held relatively constant (within a seeding rate) but in-row population was altered, plants did not benefit from the reduction in intra-row plant density. This suggests that variations in the number of plants m^{-2} within the range tested was the dominant effect on plant size rather than variation of plants m^{-1} row.

As previously mentioned, the relationship between in-row population and plant size was generally weak (maximum r^2 =0.25, average r^2 to the end of the early establishment period for fescue = 0.05 and for ryegrass = 0.12, Table A1.49, Appendix 1) and was lower than expected considering that there was a three-fold variation in the distance between nearest neighbour plants (9 to 26 mm at 109 to 38 plants m^{-1} row, respectively). The variation in in-row density was tempered by the variation in row spacing and row arrangement. Where comparisons of variation in in-row density at a constant row spacing are made (eg. 'between' vs 150mm or Low 150mm vs High 150mm; Tables 4.1.3.3 and 4.1.4.9, respectively) plant size is more strongly related to in-row population. The r^2 value for ryegrass weight as a function of in-row population within the 150mm row spacing treatment is 0.54 (Table A1.22, Appendix 1) which confirms that seeding rate had more influence over plant size than row spacing. The correlations between in-row population and plant size were consistently higher for all plant size measurements than those between plants m^{-2} and plant size. A reduction in plants m^{-2} was inter-related with a reduction in plants m^{-1} row. The variation in in-row spacing brought only a reduction in in-row population which was not sufficient to significantly improve individual shoot weight at 145 d.a.s.. Competition or the 'C-D' effect was operating at both inter-row and intra-row levels and the two appeared to be of similar importance in terms of determining plant size.

Plants in 75mm rows were consistently, but not significantly larger than those in 150mm rows. However there were some significant differences in shoot weight at the early stages of sward development (0-85 d.a.s., Table 4.1.4.1). Plants in 75mm rows had an early growth advantage (0-26 d.a.s.) over those in 150mm and cross drilled rows (Table 4.1.4.1). Initially, plants sown at high density (150mm rows) had a lower relative growth rate than those at lower density (75mm rows) possibly because of increased intra-row competition between the time of seed germination and seedling emergence (Table 4.1.4.3). The contrast in relative growth rate found between 26 and 49 d.a.s. with respect to row spacing has not been described elsewhere but is consistent with the observation that proportionately less of the eventual population for the 150mm rows had emerged by 21 d.a.s. as compared with 75mm rows (Table A1.4, Appendix 1). There was no difference between the proportion of plants which emerged from the contrasting seeding rates at that time, which suggests that in-row population was more important than population on an area basis, at least during emergence. After 26 d.a.s., plants sown at lower density (75mm row) suffered a check in growth rate as some factor became limiting, most likely nitrogen. This allowed those sown at higher densities to catch up, as evidenced by the lower growth rate of plants in 75mm rows as compared to those in 150mm rows during that time. After that time, plants in 75mm rows regained the advantage in relative growth rate over 150mm rows and equalled cross drilled plants between 49 and 85 d.a.s. (Table 4.1.4.3), once again reflecting the overall effect of variation in plant density on shoot weight.

Plants in 75mm rows grew faster than those in 150mm rows at some stages during early establishment but cross drilled plants, which occurred at the same in-row population as plants in 75mm rows (except where rows crossed) never grew faster than 150mm row spacing but did weigh more than plants in 150mm rows at 85 d.a.s. (Table 4.1.4.1). Leaf and tiller number and extended height (Tables A1.12, Appendix 1, 4.1.3.1 and 4.1.4.6, respectively) also showed no advantage for cross drilled plants from a reduction in in-row population over 150mm row spacing.

Plants in the cross drilled treatment had similar in-row populations as 75mm rows but did not follow the same pattern of growth as those from 75mm rows. There was, however, more variation in population density in the cross drilled treatment than in 75 or 150mm rows. Seedlings were removed at random for weight determination for all drilling treatments and cross drilled seedlings may have come from a high or low population depending on proximity to an intersection between rows. This may explain why the growth rate of cross drilled plants did not follow a pattern similar to the other two.

The advantage from increasing intra-row plant spacing by using a second pass of the drill, in terms of reducing competition between plants in a row, appears to be offset by the increased competition which occurs at the intersection of drill rows. However, reducing row spacing from 150mm to 75mm did benefit plant growth rate during early establishment. Extended height at 145 d.a.s. would suggest that the advantage may have persisted for fescue but not ryegrass.

The influence of variation in in-row population was shown clearly by the data for root weight, daughter root number and tiller number, collected from the ryegrass plants at 52 d.a.s. (Table 4.1.4.4). Forty seven percent of the variation in root weight was attributable to in-row population at that time, which was far higher than any other correlation coefficient for any other plant parameter during 0 to 145 d.a.s.. However, shoot weight for ryegrass plants from those plots indicated there was no relationship between in-row population and shoot weight at that time (Figure 4.1.3.1). The former was the only data set where measurements of plant size were used as a covariate with a known in-row population. Those data were taken from very short sections of row (150mm long) and showed that density did indeed vary widely (33 to 250 plants m^{-1} row, Figure 4.1.4.2). This was a greater range than that indicated by plant counts at 42 d.a.s. (38 up to 109 plants m^{-1} row, Table 4.1.1.4) which were taken from longer sections of row (400mm). The longer the section of row sampled, the lower the variation in plant number is likely to be as the peaks and troughs of distribution are smoothed out. All other regressions of plant size as a function of population, including that for shoot weight, were carried out using plot means and as a consequence those results effectively compared the in-row population density for ryegrass in the range 38 to 109 plants m^{-1} row. Much lower correlation coefficients were obtained. This suggests that where in-row population varies between 38 and 109 plants m^{-1} row as a result of manipulating seeding rate, with resultant populations in the range of 500 to 800 plants m^{-2} and row spacing from 75 to 150mm, less than 25% (average r^2 9% , Tables A1.15 and A1.43, Appendix 1) of the variation in plant size (tiller and leaf number and shoot weight) is attributable to variation in in-row population. A wider contrast in in-row population was required. Competition between plants along a row influenced above and below ground plant characteristics where in-row population varied from 33 to 250 plants m^{-1} row at 52 d.a.s. but was not apparent for above ground plant characteristics where in-row population varied from 38 to 109 plants m^{-1} row at that time. The effect of in-row population on shoot weight did not become apparent until 85 d.a.s. for fescue and 135 d.a.s. for ryegrass.

Plants at similar densities were of a similar size regardless of plant arrangement. Because the 75mm rows and cross drilled rows resembled a square planting pattern, plants would have been better placed to intercept incoming light than where they were sown in 150mm rows, as ground cover was more complete for a given time during establishment. Despite this the plants were unable to capitalise on their better positioning and were not significantly larger than their counterparts in 150mm rows. This would suggest competition for something other than light was the limiting factor for plant growth. If water and nutrients are available in adequate supply, so that competition for these factors ceases, then light becomes the sole limiting factor to production. On the other hand, where there is a shortage of water or nutrients, light would not be the sole limiting factor (Donald, 1963). In view of several other studies where establishing grass species have been grown in close association and which have clearly demonstrated that root competition had more influence on plant growth than competition for light (Rhodes, 1968a; Eagles, 1972; Cook and Ratcliff, 1984; Seager et al., 1992), it would seem that in the current trial, root competition for nutrients was most likely the limiting factor for plant growth. This was indicated by the apparent shift in the relative height of plants from contrasting seeding rates during early establishment and the lack of response in terms of plant size to the improvement in light interception opportunities offered by 75mm rows and cross-drilling. Nitrogen is commonly thought to be the mineral for which competition is most intense (Brougham, 1954a; Donald, 1963). Pasture in New Zealand is always under some from of nitrogen deficiency as a rapid growth response from nitrogen application is expected where temperature is above 12ºC and moisture is adequate (Harris et al., 1973).

Donald (1963) cited work by Sprague and Ferris (1931) and by Smith (1937), both of whom apparently demonstrated that there was a strong negative correlation between the yield of wheat per unit row length and the number of plants in the adjacent rows, indicating that inter-row competition had an important influence on individual plant yield. Striking differences in patterns of root distribution at various plant spacings have been examined by Haynes and Sayre (1956) for corn in Ohio, United States of America. The density varied from 25mm to 1.6m spacing along rows 2.15 m apart, which presumably were free from lateral competition. Widely spaced plants had more or less a circular distribution of roots of about 750mm radius. However, lateral penetration of roots of closely crowded plants (25mm spacing) increased by 36% from the row and decreased by 50% along the row as compared with widely spaced plants. Increased in-row competition for water or nutrients changed the distribution of the root system such that roots grew further out from rows at higher density.

The root systems of individual plants at 75mm row spacings and those which were cross-drilled in the current trial presumably came into contact with each other and would have been competing for nutrients sooner than those at 150mm, which themselves may have had a slightly wider lateral spread than plants at the lower in-row population. This suggestion is supported by measurements taken by Inwood (1990). He reported no differences in the amount of new plant root (km m^{-2}) found at central spots between 75mm rows in a cultivated seedbed and 150mm direct drilled rows at 105 d.a.s..

The analysis of both root and shoot portions of plants proved fruitful, even where only a brief investigation was carried out. Further measurements of root growth in terms of mass and spread would have complemented the extensive measurements of shoot growth and also would have more fully explained interactions between species, row spacings and seeding rates. However, time constraints were such that no further investigation was possible.

4.1.5 Herbage Composition and Mass

4.1.5.1 Introduction

Ryegrass was grazed twice during the early establishment period, at 55 d.a.s. (6-6-90) and 150 d.a.s. (9-9-90), and fescue was grazed once at 150 d.a.s.. Despite the large differences in growth rate between species, seeding rate and drilling method, treatment effects were consistent so generally combined results are presented. Where a significant interaction between species and seeding rate and drilling methods occurred, results for individual species are presented.

Botanical composition, hereafter referred to as 'composition' is expressed as a proportion of live herbage mass. Herbage mass is expressed throughout as kilograms of dry matter per hectare (kgDM ha^{-1}). The category 'Unsown' represents all unsown species and is the combination of broadleaf weeds, grass weeds and prairie grass. The proportion and mass of the components of unsown species are located in the appendices. Spots where cattle had urinated during the first grazing were very distinct at the second grazing of ryegrass. Those patches were not included in the area from which quadrats were cut at the second grazing.

4.1.5.2 Results

4.1.5.2.1 Seeding Rate and Drilling Method Effects on Ryegrass at 55 d.a.s.

Table 4.1.5.1 lists the effect of seeding rate and drilling method on the proportions and mass of sown species, clover and unsown species on ryegrass plots at 55 d.a.s.. The mass of sown species (ryegrass) and the total herbage mass of live herbage increased in swards sown at the high seeding rate as compared with those sown at the low rate. There was an indication that the proportion of unsown species may have been higher at low seeding rate, although the difference was only significant at Fpr=0.086. Corresponding broadleaf and grass weed mass and the amount of dead matter are shown in Table A1.51, Appendix 1. The amount of dead material was the same for all treatments (approximately 120kgDM ha^{-1}) and consisted almost entirely of the vegetation resident before drilling which was killed almost 3 months previously with herbicide. Clover mass was not significantly influenced by seeding rate at that stage.

Drilling method did not significantly influence sward composition or herbage mass at 55 d.a.s..

Table 4.1.5.1 Effect of Drill Method and Seeding Rate on the Herbage Composition and Mass of Ryegrass at 55 d.a.s. (6-6-90)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total Live Herbage
High	79	4	18	274	12	57	344
Low	74	3	23	208	8	68	284
Standard Error ±	2.8	0.7	3.1	21	2.6	9	23
Significance	n.s.	n.s.	(*)	**	n.s.	n.s.	*
75 mm row	74	4	22	240	13	68	322
Cross drill	80	2	18	249	8	57	314
150 mm row	76	3	21	234	9	63	306
Standard Error ±	3.4	0.9	3.8	26	3.2	11	28
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

4.1.5.2.2 Overall Species, Seeding Rate and Drilling Method Effects at 150 d.a.s.

Table 4.1.5.2 lists the overall species, seeding rate and drilling method effects on the proportions and mass of sown species, clover and unsown species at 150 d.a.s.. Herbage mass of ryegrass and fescue at 150 d.a.s. was not different but the contribution of the sown species component of the fescue sward was lower than for the ryegrass sward. An increase in unsown species, mostly broadleaf weeds, commensurate with the decrease in sown species was apparent in the fescue sward. The components of unsown species are listed in Table A1.52, Appendix 1.

Seeding rate had no significant effect on the overall herbage composition or mass. Drilling method had a significant effect on the mass of unsown species. Cross drilled plots had significantly higher mass of unsown species than those sown at either 75 or 150mm row spacing, but the overall mass of the sown grass component was not significantly different. Commensurate with that was a significant decrease in the proportion of sown species in the cross drilled swards as compared with the other drilling methods. Herbage from cross drilled swards contained comparatively more unsown species than swards with 75mm row spacing. The proportion of unsown species in plots with 150mm row spacing was the same as the other drilling methods. Fescue plots contained three times more clover than ryegrass percentage basis and 2.4 times more on a herbage mass basis. Seeding rates and drilling method did not influence the mass or proportion of clover in the sward.

Table 4.1.5.2 Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 150 d.a.s. (9-9-90)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	40	9	51	570	111	708	1389
Ryegrass	66	3	31	962	46	459	1467
S.E.D ±	2.3	1.2	1.6	92	15	42	112
Significance	* * *	* * *	* * *	**	* *	* * *	n.s.
High	53	6	41	784	78	587	1450
Low	52	6	42	748	78	581	1407
S.E.D ±	2.3	1.1	2.1	48	15	36	53
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm row	57 a	5	37 a	834	68	531 a	1433
Cross drill	48 b	6	46 b	710	86	675 b	1471
150 mm row	54 a	6	40 ab	754	81	545 a	1380
S.E.D ±	2.8	1.4	2.6	59	18	45	124
Significance	*	n.s.	* *	n.s.	n.s.	* *	n.s.

4.1.5.2.3 Interactive Effect of Species and Drilling Method

Table 4.1.5.3 compares the effects of drilling method on the composition and herbage mass of fescue and ryegrass at 150 d.a.s.. There was a significant interaction between species and drilling method effects on the mass of sown species and of live herbage.

Drilling method had a significant effect on the mass of sown species in the fescue sward but had no such effect in the ryegrass sward. The mass of sown species in the fescue sward sown in 75mm rows was greater than that for 150mm rows or cross-drilling and the proportion of sown fescue in the sward was significantly less for cross-drilling than for 75 or 150mm rows, but mass of total live herbage was the same. There was a substitution of sown species in cross drilled fescue for unsown species. The opposite effect occurred in the sward sown at 75mm row spacings. The increase in the mass of unsown species was mainly from broadleaf weeds (Table A1.54, Appendix 1). In both fescue and ryegrass, the mass and proportion of unsown species was increased with cross-drilling as compared with 75mm rows, but the difference was only significant at a lower level of probability for ryegrass (Fpr=0.1). Instead of a substitution effect in ryegrass, it was the extra mass of unsown species, again mainly broadleaf weeds, which lifted total mass of live herbage for the cross drilled treatment while the mass of sown species was the same for all three drilling methods (Table 4.1.5.3). It appears there was an increase in the growth of broadleaf weeds with cross-drilling as compared with 75mm or 150mm row spacing with both species, which had no effect on the growth of the faster establishing ryegrass but reduced the growth of fescue.

There was an interaction between species and drilling effects on the mass of live herbage. The ranking of drill treatments, in terms of the mass of live herbage accumulated, differed for each species. For fescue the ranking was 75mm row spacing highest followed by cross-drilling then 150mm row spacing, whereas for ryegrass, cross-drilling accumulated more than 150mm row spacing which in turn had accumulated more than 75mm row spacing. The change in the ranking is the result of the common effect for the two species which reflected higher broadleaf weed mass in the cross-drilled swards as compared with the other drilling treatments and the comparative advantage of fescue sown in 75mm rows over both cross-drilling and 150mm rows.

Table 4.1.5.3 Effect of Drill Method on Herbage Composition and Mass of Fescue and Ryegrass 150 d.a.s. (9-9-90)

		Proportion of Live Herbage		Yield (kgDM ha^{-1})		
		% Sown	% Unsown	Sown	Unsown	Total live
FESCUE	75 mm row	47 a	46 a	728 a	668 a	1490
	Cross drill	33 b	58 b	462 b	825 b	1409
	150 mm row	41 a	50 a	520 b	631 a	1269
S.E.D. ±		3.5	2.9	84	69	112
Significance		**	**	**	*	n.s.
RYEGRASS	75 mm row	68	29	940	395	1377
	Cross drill	63	34	958	525	1533
	150 mm row	66	31	989	459	1491
S.E.D. ±		4.4	3.8	83	83	69
Significance		n.s.	n.s.	n.s.	(*)	(*)
Species X Drill	S.E.D. ±	3.9	3.4	114	67	136
Interaction	Significance	n.s.	n.s.	*	n.s.	*

4.1.5.2.4 Interactive Effect of Seeding Rate and Drilling Method

There was a significant interaction between seeding rate and drilling method effects on the proportion of sown and unsown species in the sward and on the mass of unsown species and live herbage (Table A1.54, Appendix 1). Only the proportion of sown species was affected by the interaction, not the mass of sown species. The mass of sown species is of primary concern, however the interactive effects of drilling method and seeding rate in terms of the growth of unsown species and mass of live herbage are also important.

The most obvious interactive effect was that for drill method and seeding rate on the mass of unsown species (Fpr = 0.007). Other interactions at the time occurred at a probability level of 5% or more. Where a significant interaction occurs, it is sometimes difficult to identify which treatment is not consistent with the others. Figures 4.1.5.1 and 4.1.5.2 provide a graphical presentation of the data from Table A1.54. located in Appendix 1. If there were no interactions between drilling treatments and seeding rates then the two columns on the graphs should be roughly equal. The mass of unsown species was significantly higher for the cross drilled treatment sown at the high seeding rate than for other seeding rate and drill combinations (Table A1.54). From Figure 4.1.5.1 it is clear that the unsown species mass for that treatment resulted in the comparatively higher mass of live herbage for that treatment (Figure 4.1.5.2). Unlike drill comparisons between species, all three components (broadleaf and grass weeds, and prairie grass) contributed equally to the increase in mass of unsown species (Table A1.55, Appendix 1).

Figure 4.1.5.1 Effect of Drilling Method at Two Seeding Rates on Mass of Unsown Species at 150 d.a.s.

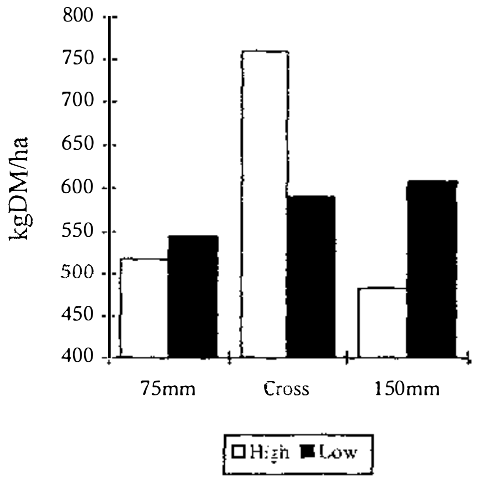
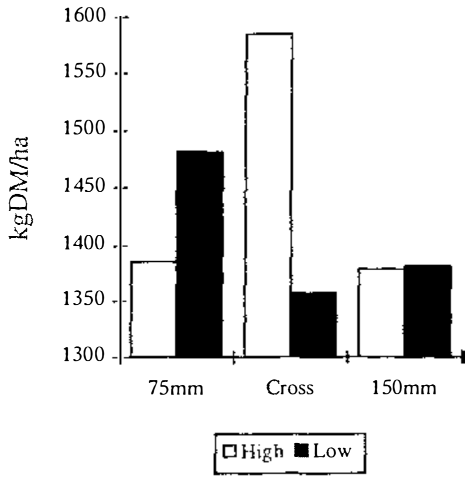


Figure 4.1.5.2 Effect of Drilling Method at Two Seeding Rates on Live Herbage Mass at 150 d.a.s.



4.1.5.3 Discussion

The discussion of botanical composition and mass initially covers grazing in general, and then focuses on main treatment effects.

An attempt was made to graze as soon as ryegrass seedlings were sufficiently anchored to resist pulling out by hand plucking (Thom et al., 1987b). In the current trial this occurred at 55 d.a.s., but, grazing was not successful. Pre-grazing height was within the range recommended (100-150mm, Ritchie, 1986b; Thom et al., 1987a), though little herbage was removed during 8½ hours because of low herbage mass (approximately 300kgDM ha^{-1} live herbage). Cattle had to be removed from the ryegrass plots before target residual pasture height was reached due to persistent rain (14mm rainfall). Pasture became soiled when the rain started so grazing was not recommenced at that stage (Figure 4.1.5.3). No attempt was made to graze fescue plots at that stage since plants were considerably smaller (extended height 66mm and 1.6 tillers per plant at 43 d.a.s., Tables 4.1.4.5 and 4.1.3.1, respectively)

Figure 4.1.5.3 The First Grazing of Ryegrass (55 d.a.s., 6-6-90)

At 150 d.a.s. grazing pressure was imposed at the equivalent of 909, 15 month yearling heifers ha^{-1} and sufficient herbage was on offer (1400kg $DMha^{-1}$), so grazing was successful in terms of achieving a close defoliation over a short period (residual height (visually assessed) 40-70mm in 8 to 12 hours Figure 4.1.5.3). This level of herbage mass is similar to that recommended by Thom et al. (1987a) for initial grazings of direct drilled pasture. Initially, younger stock were used for grazing (622, 150kg weaner heifers ha^{-1} equivalent) but this class of stock could not be successfully controlled by electric fences at the high stocking rates necessary. Older cattle were more easily controlled and found to do a better job of grazing.

Figure 4.1.5.4 Whole Trial Grazing 150 d.a.s. (9-9-90)

Species

Total live herbage produced to 150 d.a.s. from swards sown with either fescue or ryegrass was the same, but the mass of fescue was 60% that of the ryegrass mass. Tiller weight for fescue and ryegrass was the same. The higher mass of ryegrass was a consequence of higher tiller number per unit area, reflecting the higher tillering capacity of perennial ryegrass as compared with tall fescue (Table 4.1.3.1). Consequently fescue contributed proportionately less (40%) to herbage mass than ryegrass (66%) (Table 4.1.5.2). The mass of unsown species and white clover was greater in fescue as compared with ryegrass. The mass of grass weeds (mainly annual poa and prairie grass) although greater in fescue, was not significantly different for ryegrass and fescue swards but there were more broadleaf weeds in the fescue (Table A1.52, Appendix 1). Clover mass in fescue was double that in ryegrass. These results reflect the slower establishment of fescue compared with ryegrass and the resultant reduction in suppressive effect of fescue on unsown species (Harris et al., 1977). Broadleaf (dicotyledonous) weeds benefited more from reduced competition from the sown component of the sward at that stage than annual poa and prairie grass. Mouse eared chickweed and speedwell were the dominant broadleaf weeds. These species are described as "early establishing dicotyledonous annuals associated with cultivation" (Harris et al., loc cit).

The results for ryegrass were similar to those reported by Inwood (1990) for direct drilling, although the proportion of ryegrass was slightly less (59%) and clover was higher (17%) from his trial on a soil with high natural fertility as indicated by the fact that overall mass was 85% higher than for the current trial at a corresponding time (150 d.a.s.). A slightly higher proportion of sown species (72%) and less unsown species (13%) were reported by Brougham (1954a) for short rotation ryegrass sown by conventional cultivation to 170 d.a.s., which reflected the more vigorous growth of the hybrid ryegrass as compared with the perennial ryegrass used in the current trial (Brougham, 1954d; Cullen, 1958) and higher fertility levels. Broughams' trial was also closely grazed with sheep several times before measurements were taken, which would have improved the proportion of sown ryegrass and clover relative to the current trial through the encouragement of tillering and improving light relations in the sward (Brougham, 1960). Although desirable, earlier grazing was not possible in the current trial because only dairy cattle were available. This reduced the flexibility in grazing management relative to sheep grazing, because increased herbage allowance was required for grazing to be effective and there was a greater risk of treading damage in wet conditions from the heavier stock. High stock pressure was required to reduce herbage height to target levels so stock were confined to small areas (0.144 ha). Six days of continuous dry weather conditions were required to ensure all plots were grazed similarly. Persistent wet weather during the early establishment period delayed grazing.

The results from fescue are similar to those reported by Brock (1982) from a trial established by conventional cultivation. Fescue contributed 40% of the mass of live herbage harvested in the first spring after sowing. Unsown species made up the remainder of the herbage mass and clover mass was negligible. However, in contrast to the current trial, unsown species consisted almost entirely of volunteer grass species (brown top, (*Agrostis tenuis),* Yorkshire fog, *(Holcus lanatus)* and annual poa. These species were present as mainly regrowth from the previous sward as ploughing failed to effectively control resident vegetation (Brock, 1982). Poorer weed suppression by establishing fescue as compared with ryegrass is a common occurrence (Harris et al., 1973; Hallgren, 1976a, b).

Fescue and ryegrass swards had similar populations of broadleaf and grass weeds at 37 d.a.s. (Table 4.1.2.1). At that stage there was almost twice the number of broadleaf weeds as there was grass weeds present. However, by 150 d.a.s. the proportion of broadleaf weeds had diminished to about half and two thirds of the unsown species in fescue and ryegrass swards, respectively (Table A1.52, Appendix 1). This follows the same sequence of succession for weed species in an establishing grass-legume mixture as described by Harris et al., (1977).

Seeding Rate

Increasing the seeding rate from 12 to 22.5kg ha^{-1} for ryegrass and from 17 to 30kg ha^{-1} for fescue, with the resultant 60% increase in sown grass population, did not increase dry matter production of sown species to 150 d.a.s. (Table 4.1.5.2). Mass of sown species (kgDM ha^{-1}) is the product of plant population and plant weight. At 49 d.a.s. shoot weight was the same for both seeding rates (Table 4.1.4.1). Therefore mass per unit area increased in proportion to the increase in plant population (seeding rate), very early in the life of the sward. The effect was consistent for both fescue and ryegrass and was reflected in the increase in sown species mass recorded at 55 d.a.s. from ryegrass sown at high seeding rate (Table 4.1.5.1). By as early as 85 d.a.s. in ryegrass and 135 d.a.s. in fescue, shoot weight decreased as seeding rate increased (Table 4.1.4.2) and tiller number and weight, and extended height were all reduced at high seeding rate (Tables 4.1.3.1, 4.1.3.6 and 4.1.4.5, respectively). The increase in plant size at low seeding rate compensated for the initial reduction in density.

There was a linear decrease in shoot weight, tiller number and leaf number with increasing in-row population (Table A1.49, Appendix 1) within the range used for this trial. Similar results have been reported elsewhere with respect to population on an area basis but for a wider range of seeding rates of ryegrass (11 to 68+ kg ha^{-1}) (Brougham 1954a; Holliday 1953; Donald, 1963). In the current trial there was poorer correlation between the various measures of plant size and plants m^{-2} than between plant size and plants m^{-1} row, indicating that intra-row competition was more important than inter- row competition.

The results of the current trial contrast with previous work in terms of the timing at which competition reduced the size of plants at higher seeding rate to a level where mass for both high and low seeding rates was equal. The disparity is likely to have been due to the variation in plant arrangement. Under cultivation, where seeds were broadcast sown, total dry matter increased linearly with an increase in seeding rate of perennial or short rotation ryegrass during the initial stages of pasture establishment (91 d.a.s. Holliday (1953); 170 d.a.s. Brougham, 1954a). That is, the curve depicting herbage mass showed a substantial upward trend with seeding rate, but as swards developed the curve levelled off and became a horizontal line. Where similar seeding rates from those previous trials are compared with those of the current trial, the mass of sown species was still related to seeding rate at 275 d.a.s. (Brougham, 1954a, short rotation ryegrass) and to 210 d.a.s. (Holliday, 1953, perennial ryegrass) ie. individual plant size was not influenced by seeding rate in the 11 to 22kg ha^{-1} range even at those later stages of establishment. Holliday (1953) did not specify plant population but the results quoted from Brougham (1954a) were for 348 vs 658 plants m^{-2}, very similar in terms of absolute increase in population (approximately 300 plants m^{-2} increase) but larger in terms of a proportional increase (90% increase) compared with 60% for the current trial (500 to 800 plants m^{-2}). In both cases overall herbage mass was higher than the current trial for a similar period of growth, which suggests that sward development would have been relatively more advanced in those trials than for a corresponding time after sowing for the current trial. Culleton et al. (1986) reported less production in the first year after sowing from perennial ryegrass conventionally sown at 11kg ha^{-1} as compared with 22kg ha^{-1}. Sowing method was not stated but on the basis of other work (Culleton and Murphy, 1987) was most likely broadcast sown onto cultivated soil. Herbage mass of pastures sown at lower rates is usually initially less than that where higher sowing rates are used, but tends to become more similar as the season progresses. Results from the current trial show that the curve for herbage mass flattened out much sooner in terms of growth stage (kgDM ha^{-1}) and calendar time where plants were confined to rows, as compared to broadcast sown swards which had equidistantly spaced plants.

Increased tillering at lower seeding rates makes up for the initial deficiency in plant number. This capacity of grass plants to react to competitive stress by means of phenotypic plasticity has been shown in a large number of experimental investigations (White and Harper, 1970; Westoby, 1984). Results of the current trial indicate that this process is faster where plants are confined to rows, as compared with broadcast sown swards, because distance to nearest neighbours is drastically reduced. This explanation is an extension of the description given by Donald, (1963) of how competition operates in plant communities with contrasting plant densities. "Competition first becomes operative at the highest densities and then progressively with advancing stage of growth at lower and lower densities". In confining plants to rows, plant space is reduced to a greater extent as compared with evenly spaced plants. The process can be explained in terms of ceiling yield (Donald, 1963).

Initially, yield is proportional to plant density but, as time progresses and plants at lower densities become relatively larger, herbage mass for all densities reaches a common or ceiling level (Donald, 1963). This was demonstrated in an extreme result by Culleton and Murphy (1987). No increase in DM production was recorded for the first harvest of broadcast sown Italian ryegrass at seeding rates ranging from 11 to 88kg ha^{-1} (237 to 1896 seeds m^{-2}). The first cut was not taken until 210 days after an autumn sowing, by which time 7000kgDM ha^{-1} had accumulated, and it was thought that the crop had reached its full growth rate potential and all incoming light had been intercepted for some time. The result demonstrates the relationship between density and time; the population required to give maximum herbage mass depends on the date of harvest (Donald, 1963).

The seeding rate effect on fescue was similar to that for ryegrass, but compensatory growth for fescue plants sown at the low rate occurred later than for ryegrass (85 d.a.s. cf 135 d.a.s., Table 4.1.4.2). No comparative data were found for the effect of seeding rate on tall fescue production for a similar stage of establishment, but the delay in competition effect was consistent with the slower establishment rate of tall fescue (Brock, 1973; Brock, 1982; Brock et al., 1982). Two trials which reported annual production of tall fescue without plant population information and only annual dry matter production data, suggested that herbage mass in the first year was not influenced by seeding rates of tall fescue in the range 11 to 56kg ha^{-1} (Frame and Hunt, 1964; Keane, 1980).

The mass of clover and unsown species was not influenced by seeding rate, so although increasing seeding rate has been shown to reduce the mass of clover and unsown species in pastures established by conventional cultivation (Brougham, 1954a,d; Cullen 1958; 1964; Culleton and Murphy, 1987) and in grass turf establishment (Parr, 1985), this was not the case in the current trial. Where suppression of unsown species has been demonstrated with ryegrass, seeding rate comparisons were usually wider than those of the current trial (11 to 50+ kg ha^{-1}) and were usually associated with an increase in sown species production. In the current trial, the mass and proportion of sown species, clover and unsown species was remarkably similar in the ryegrass swards sown at either high or low seeding rate at 150 d.a.s. (eg. 974 and 951 kgDM ha^{-1} sown species at high and low seeding rates, respectively Table A1.56, Appendix 1) despite a 60% increase in population of sown species. A similar result occurred in the fescue sward. If seeding rate of ryegrass had been increased in the current trial to 50kg ha^{-1} it is unlikely that significant unsown species or clover suppression would have occurred because sown species mass appeared to have reached a plateau at the higher seeding rate anyway.

Drilling Method

Variation in plant arrangement, as a function of drilling method, had no influence on the mass of ryegrass but did effect the mass of fescue at 150 d.a.s. (Table 4.1.5.3). Ryegrass results are discussed first, then fescue.

Ryegrass

Herbage mass produced from the ryegrass sward was not increased by reducing row spacing or cross-drilling at 150mm row centres as compared with traditional single pass drilling at 150mm row spacings. Similar results are reported from a trial carried out simultaneously within 1 km and at a seeding rate equivalent to the "low" rate in the current trial (Inwood, 1990) who also demonstrated no advantage in herbage mass for perennial ryegrass cross drilled at 90° (ie. square drilling pattern) compared with single pass drilling at 150mm row spacing. The results for ryegrass from the current trial are at odds with Hallgren (1976b) who showed that herbage mass of perennial ryegrass was higher at narrower row spacings (range 50 to 400mm). However, the absolute herbage mass of sown species in 60mm to 125mm row spacing at 130 days after a spring sowing in Hallgren's trial was much higher than in the current trial (3000 to 3560kgDM ha^{-1}). This is likely to have been due to higher fertility (90 kgN ha^{-1}applied) which may have altered the relative importance of shoot and root competition.

As the resources of light, moisture and plant nutrients are available to the individual plant on an area basis (assuming a constant root depth penetration of the soil profile), it would be expected that narrower row spacings which bring the plant spatial arrangement closer to a square rather than a rectangular arrangement would improve efficiency of utilisation of these resources (Holliday, 1963). In a review of the effects of plant spatial arrangements on grain crop yield Dungan et al. (1958) suggested that where population was the same per unit area, under favourable conditions (high yield potential), uniform spacing gives a greater yield. However, where conditions are adverse (eg., dry weather) then the advantage of uniform distribution may disappear. The advantage of uniform distribution may lie in the reduction of competition for light, but when moisture supply is restricted this supersedes light as the prime limiting factor and reduces each planting system to a common yield. In Hallgren's trial (1976b) light was probably more important than nutrients in terms of limiting herbage mass, so an increase in ground cover improved herbage mass. However, in the current trial the most likely limiting factor for ryegrass was not light or moisture but nitrogen (Brougham 1954a,d; Sears 1953; Harris et al., 1973), as shown by the lack of response to variation in plant arrangement. Nitrogen is a mobile nutrient in the soil (Holliday, 1963) and it is likely that the roots of grass plants would have fully explored the soil between rows of the current trial (Inwood, 1990). Work with cereals also suggests that even where nitrogen is added as broadcast fertiliser there was very little growth advantage for different row widths (75mm cf 150mm) (Holliday, 1963) supporting the idea that, in terms of nitrogen use, there is no advantage to closer row spacing.

The work of Hallgren (1976b) is the only example apparent in the literature of comparisons of the effects of row spacing on the herbage mass of pasture species. Unfortunately the data from his trial were presented as relative yield with no error terms. Although it is obvious from his work that narrower row spacings increased herbage mass in general terms, it is difficult to ascertain whether or not 50mm row spacing produced more herbage than 75mm, 100mm or 150mm row spacings. Data from Hallgren's dissertation (Hallgren, 1974) show that plant population at 50mm was double that at 100mm spacings (300 vs 150 plants m^{-2} for perennial ryegrass at approximately 130-140 d.a.s.), despite having being sown at a constant seed rate per unit area (over 1300 seeds m^{-2}). Herbage mass at 90 d.a.s. was 2000-3000 kgDM ha^{-1} and showed a strong relationship with population in the range of 50 to 200mm row spacing for ryegrass (Figure 3, Hallgren, 1976b). So herbage mass was proportional to seed rate (plant population). On the basis of plant survival information from the current trial (Section 4.2.1.2.3), and the fact that the difference in herbage mass apparent at around 90 d.a.s. was virtually identical to the difference in herbage mass at 130 d.a.s. for 50 and 100mm row treatments in Hallgren's trial, it is unlikely that much plant mortality occurred between when he made the first cut at 90 d.a.s. and when population was measured (130-140 d.a.s.). It is also likely that differences in herbage mass which Hallgren attributed to row spacing in the range comparable to the current trial (75-150 mm) reflected differences in plant population rather than row spacing as such. In the current trial perennial ryegrass did not produce more with narrow row spacing with constant populations of either 485 or 778 plants m^{-2}.

Fescue

Fescue sown in 75mm rows had a higher mass of sown species than where it was sown by cross-drilling or in 150mm rows (Table 4.1.5.3). However, there was no increase in the mass of sown fescue as a result of cross-drilling compared with 150mm rows. This was most likely because of the increased broadleaf weed growth associated with cross-drilling.

The contrast in the response of fescue and ryegrass at 150 d.a.s. to drilling method highlights their different growth patterns and the relative importance of different growth factors for each species. While nitrogen appeared to be the limiting factor for ryegrass, a combination of light and nitrogen were probably the limiting factors for tall fescue. Moisture was not limiting in the current trial. The rapid growth of ryegrass in comparison with fescue would have placed a heavier demand on nutrients, although fescue shoot weight was reduced at the high seeding rate. While this was most likely due to intra-row competition for nitrogen, there was also a competitive interaction with the unsown component of the sward which was more likely related to competition for light.

There was an overall increase in the mass of unsown species with cross-drilling as compared with 75mm and 150mm row spacings (4.1.5.2) and the effect was apparent for both species (Table 4.1.5.3). The increase in mass was attributable to a higher mass of the early establishing broadleaf weeds, predominantly dicotyledonous annuals, rather than grass weeds (Table A1.52 and A1.53, Appendix 1). Competition for light is often suggested as an important determinant of unsown species growth in establishing swards (Cullen, 1958; Hallgren, 1976a,b; Culleton and Murphy, 1987) and indeed clover growth (Brougham, 1954a,d, 1960). Common practice accepts that an increase in ground cover by sown species reduces the occurrence of weed ingression and to some extent is the basis for recommending higher seeding rates (Cullen, 1958; Cullen and Meeklah, 1959; Culleton and Murphy, 1987; Robinson and Whalley, 1988). This is also a justification for cross-drilling (Ritchie, 1986b, Thom and Ritchie, 1987) but the results of the current trial suggest that neither assumption holds true for pasture established by direct drilling in autumn.

The quantity of photosynthetically active radiation (PAR) penetrating to 30mm above the surface at 65 d.a.s. was the same for cross drilled and 150mm treatments (Table A1.10, Appendix 1). The measurements were taken at the midpoint between drill rows, and so overestimate the average light penetration between cross drilled rows. However, it does suggest that the increase in ground cover may not be particularly important and light relations do not explain the difference in mass of unsown species in cross drilled as compared with 150mm spaced rows.

All drilling treatments had the same population of broadleaf weeds at 37 d.a.s. (Table 4.1.2.1). The increase in the broadleaf component at 150 d.a.s. in cross drilled plots was probably not a result of increased growth of those seedlings present at 37 d.a.s., because the mass of unsown species was less for 150mm rows where sown species were likely to have provided similar, if not less competition to broadleaf plants and other unsown species (Table 4.1.5.2). The increase is more likely to be the result of an increased number of broadleaf weeds which emerged after 37 d.a.s. because they feature more with increasing soil disturbance as compared with volunteer grasses (Froud-Williams, 1988; Inwood, 1990).

The increased opportunity for broadleaf weed growth in the cross drilled treatment was such that it suppressed sown species growth in the fescue sward. A similar amount of soil disturbance occurred with 75mm rows and cross drilled treatments but broadleaf weeds were suppressed, presumably because of the increased cover afforded by narrow row spacing. This is in line with the reduction in PAR penetration recorded at 65 d.a.s. (Table A1.10, Appendix 1) in comparison with 150mm or cross drilled rows. Extended height of cross drilled fescue at 150 d.a.s. should have been similar to plants in 75mm rows because in-row population was similar, but it was similar to plants in 150mm rows most likely because of competition from unsown species.

The increased mass of fescue sown at 75mm row spacing, as compared with 150mm row spacing was not related to an increase in broadleaf weed growth at 150mm row spacings (Table A1.53, Appendix 1). It was more likely the result of fescue being able to capitalise on the increased ground cover commensurate with narrower row spacings. Although not always significant, differences in shoot weight for fescue in 75mm rows as compared with 150mm rows was related to mass of sown species. Table 4.1.5.5 summarises those comparisons. This table combines results recorded for plant size and herbage mass from previous sections for fescue and ryegrass. Extended height and mass of fescue in 75mm rows was significantly greater than in 150mm rows, consistent with variations in shoot weight and tiller weight. On the other hand shoot weight, tiller weight and extended height were virtually identical for 75 and 150mm row spacing for ryegrass which was also consistent with mass of sown species.

Table 4.1.5.5 Effect of Drill Method on Fescue and Ryegrass Shoot Weight, Tiller Weight and Extended Height and Mass at 135 d.a.s.

		Shoot Weight mg/plant	Tiller Weight (mg/tiller)	Extended Height (mm)	Sown Species (kgDM ha^{-1})
FESCUE	75mm rows	155	41	148	728
	150 mm row	136	36	124	520
	S.E.D. ±	15	5	8.2	84
	Significance	n.s.	n.s.	*	*
RYEGRASS	75mm rows	251	36	171	940
	150 mm row	232	36	175	989
	S.E.D. ±	35	4	13	83
	Significance	n.s.	n.s.	n.s.	n.s.

It appears that the recorded overall increase in relative growth rate for 75mm row spacing as compared with 150mm row spacing from 0 to 26 and 49 to 85 d.a.s. in the current trial (Table 4.1.4.3) improved the mass of fescue, but was no advantage for ryegrass. Hallgren (1976a) also tested the effect of row width on meadow fescue (*Festuca pratensis*), a less robust and finer version of tall fescue with similar low vigour at establishment (Langer and Hill, 1982). In contrast to the current trial, no herbage mass difference was obvious for meadow fescue sown at 75mm and 125mm row spacings, but there was a substantial difference between 125mm and 225mm row spacings. The work of Hallgren (1976b) was confounded by the fact that population at 50mm was double that at 100mm spacings (400 vs 200 plants m^{-2} for meadow fescue). The overall low population of Hallgren's trial (average less than 150 plants m^{-2}) may have also favoured narrow row spacing. Results from the current trial suggest that for fescue, although no significant interaction was indicated from analysis of variance, individual shoot weights and herbage mass were more likely increased with narrow row spacing at lower seed rates than at higher seed rates (Table A1.50, Appendix 1).

4.1.6 Summary

The treatments of the current trial were designed in such a way as to contrast the effect of population variation on both an area basis and on an in-row basis together with row arrangement to determine the relative importance of those changes to plant and sward development and to provide a pointer for non-tillage seed drill design. The measurements of individual plants throughout early establishment expand our thinking to consider individual yield components of a sward in order to understand how an end result in terms of herbage mass and sward composition was arrived at. The relationship between early establishment yield and plant population has been clarified in relation to row spacing, plant arrangement and plant vigour.

A reduction in seeding rate brought about a reduction in population on an area basis from 795 to 487 plants m^{-2} and a concomitant reduction in in-row population from 77 to 47 plants m^{-1} row. Thus the two factors, plants m^{-2} and plants m^{-1} row, were inter-related and difficult to distinguish between. However, the influence of plant population on an area basis had a larger impact than in-row population on plant size because the effect of seeding rate was obvious but drill method effects were not.

Increasing seeding rate in the range 500 to 950 viable seeds m^{-2} did not increase yield at 147 d.a.s. for fescue or ryegrass, and was of no value in terms of reducing the growth of unsown species . Clover growth was not affected by the seeding rate of sown grass species, but was doubled in the fescue sward compared with the ryegrass sward. Seedling emergence was slower where in-row populations were increased.

These results indicate that there was no agronomic gain to be had from increasing seeding rate of direct drilled perennial pasture for dairy cattle grazing, above that necessary to establish around 450 to 500 plants m^{-2}. There may in fact be some disadvantages in terms of percentage emergence and reduced plant size with high seeding rates. This is not an unusual result in itself except that drilling perennial pasture in rows as opposed to broadcast sowing seemed to have accelerated the process whereby populations at higher density reach a ceiling yield. The effect of individual plant size adjustment (increased tiller number and weight, or ramet number and size (Westoby, 1984)) at lower population density compensates for reduced plant or genet number at establishment.

Tall fescue was less vigorous during establishment than perennial ryegrass, which resulted in an increase of unsown species and clover growth with fescue as compared with ryegrass, though total yields were similar. This suggests a substitution of sown species for unsown species and clover in the establishing fescue sward. Higher tiller number, rather than increased tiller size, was responsible for the higher yield of ryegrass.

A decrease in row spacing improved the yield of sown species in the fescue sward but was not an advantage for ryegrass. Cross drilling did not benefit either species regardless of seeding rate within the range commercially sown (11 to 22 $kgha^{-1}$ for ryegrass and 17 to 32 kgha-1 for fescue) and seemed to enhance the yield of unsown species in both fescue and ryegrass, despite the fact that doubling the scarification/disturbance on the soil surface did not significantly increase the population of weeds which established after drilling. In the fescue sward, the increase in unsown species with cross drilling was at the expense of sown species but the yield of ryegrass was unaffected by the increase in growth of unsown species associated with cross drilling probably because of its more vigorous growth during establishment with the resultant better suppression of unsown species. Tiller number was very similar for all drilling methods (variation of 13 and 4% for ryegrass and fescue respectively at 145 d.a.s.). Reducing row spacing improved the yield of fescue by an increase in tiller weight rather than tiller number. This is an important result as it indicates that there may be an advantage in sowing slower establishing species such as tall fescue in 75mm rows, but cross drilling did not improve success in an establishing sward compared with 150mm row spacing.

Non-destructive measurements of fescue tiller and leaf number and extended height were not related to shoot weight at 145 d.a.s.. The size frequency distribution of plant characteristics was not always consistent with the variation in treatment means. The skewness of size distribution of T X L and Lf X Hgt index for ryegrass was consistent with the 'C-D' effect of seeding rate on plant size. Unlike other studies, extended height was of no value as a predictor of plant size, most likely because differences were small and plants in the current trial were in closer proximity to one another in comparison to many other studies.

4.2 Late Establishment

4.2.1 Plant Size and Survival from 145 to 313 d.a.s.

4.2.1.1 Introduction

Row spacing and plant spatial arrangement, which were determined by drill configuration, drilling method and seeding rate, affected plant size (shoot weight, tiller and leaf number and extended height) during early establishment (0-145 d.a.s.). However, the most important aspect in determining drill design criteria/boundaries is how plant size and plant spatial arrangement affect sward development and plant persistence.

Tiller number, leaf number and extended height measurements were continued until 244 d.a.s. after which time only tiller number was recorded. Leaf counts were not continued because of the excessive time demand of counting large numbers of leaves. Measurements of extended tiller height were discontinued because the random variation of height, caused by grazing, dominated treatment effects. Less value was placed on those results.

Generally, tiller number, rather than leaf number, are presented because leaf number was consistent with tiller number and tiller counts were continued for longer than leaf counts. Results for leaf number are presented where a discrepancy between treatment effects on leaf and tiller number arose. Results for extended height are also included where their response to the various treatments differed from the response of tiller number.

Skewness of the distribution of tiller, leaf, extended height, tiller x leaf, tiller x height and leaf x extended height indices were calculated and are presented along with plant survival data (Section 4.2.1.2.2) following tiller, leaf and extended height data.

4.2.1.2 Results

4.2.1.2.1 Tillering Activity

Table 4.2.1.1 describes the occurrence of significant main treatment effects on tiller number per plant for combined species, and for fescue and for ryegrass separately, during the period October to February (178 to 313 d.a.s.). Apart from the obvious species difference, seeding rate and position had the most consistent effects on tiller number. Interactive effects on tiller number per plant were limited to a rate x drill effect on ryegrass at 275 and 313 d.a.s. which was related to a rate x drill x species effect at 313 d.a.s. (Section 4.2.1.2.1.5).

Table 4.2.1.1 Time and Level of Probability for Main Treatment Effects on Tiller Number per Plant for Combined Species and for Fescue and Ryegrass from 178 to 313 d.a.s.

d.a.s. (Month)		MAIN EFFECTS Rate	Species	Drill	Position
178 (October)	Combined Species	⊙ ⊙ ⊙ ‡	⊙ ⊙ ⊙		⊙
	Ryegrass	✧ ✧			✧
	Fescue	★ ★ ★			
217 (November)	Combined Species	⊙ ⊙ ⊙	⊙ ⊙ ⊙	⊙ ⊙	⊙
	Ryegrass	✧ ✧ ✧		✧ ✧	★
	Fescue	★ ★ ★			
244 (December)	Combined Species	⊙ ⊙ ⊙	⊙ ⊙ ⊙		⊙
	Ryegrass	✧ ✧			
	Fescue	★			
275 (January)	Combined Species	⊙ ⊙ ⊙	⊙ ⊙ ⊙		⊙
	Ryegrass	✧			✧
	Fescue	★			★
313 (February)	Combined Species	⊙	⊙ ⊙ ⊙		⊙
	Ryegrass				✧
	Fescue				★ ★ ★

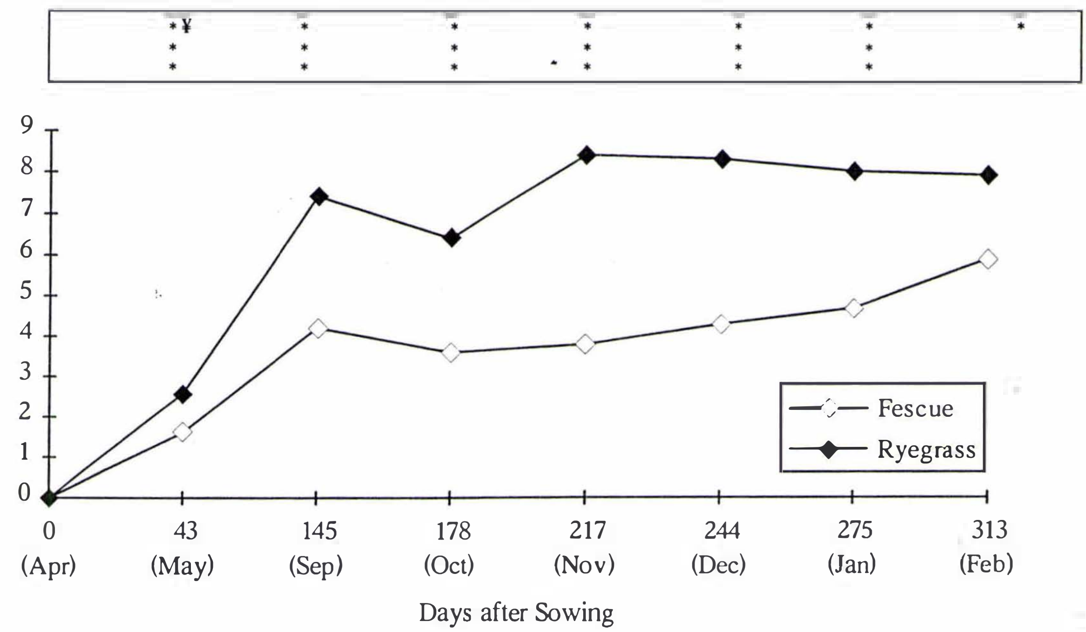
Key
- ⊙ is the symbol indicating significant effect for combined species (**overall**)
- ✧ is the symbol indicating significant effect for **ryegrass**
- ★ is the symbol indicating significant effect for **fescue**
- ‡ Nomenclature for level of Probability symbol in parenthesis = 10%, one symbol = 5% , two symbols = 1%, three symbols = 0.1%

4.2.1.2.1.1 Species Effects

Figure 4.2.1.1 describes the tiller number for both fescue and ryegrass during the first 10 months of the trial. The data from which Figure 4.2.1.1 is shown in Appendix Two, Table A2.1.

Overall increase in tiller number was very slow after 145 d.a.s.. Ryegrass plants clearly had more tillers per plant than fescue at every measurement time. It appears that fescue had a slower rate of tiller accumulation than ryegrass in the early stages (0 to 145 d.a.s.). Tiller number of both fescue and ryegrass plants appeared to be reduced after the grazing which occurred at 150 d.a.s. and increased again in ryegrass after 178 d.a.s.. Fescue tiller number showed only a marginal increase after 217 d.a.s. which was most likely related to infestation by Argentine stem weevil (*Listronotus bonariensis*) at 217 d.a.s..

Figure 4.2.1.1 Effect of Species on Tiller Number per Plant



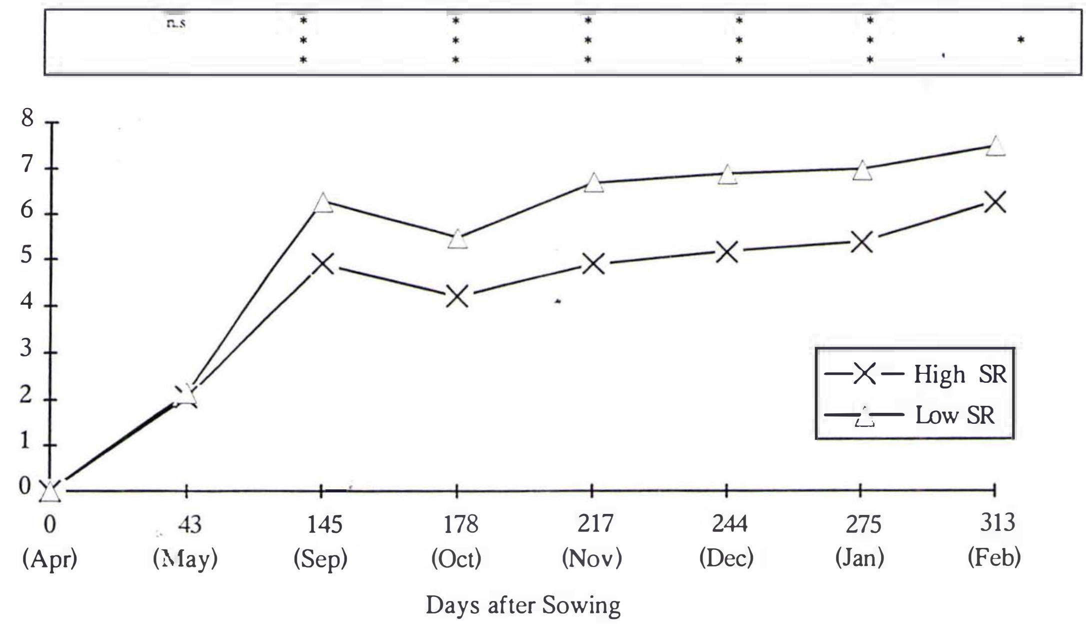
Note - ¥ level of probability for significance

Tiller accumulation in ryegrass plants effectively ceased in November after 217 d.a.s., coinciding with the reproductive phase of growth. Tiller production of fescue plants appeared to recommence after 217 d.a.s.. This was the post reproductive phase, after Argentine stem weevil had been controlled. The reproductive phase of fescue occurred earlier, from late September until mid to late October.

4.2.1.2.1.2 Overall Seeding Rate Effects

Figure 4.2.1.2 describes the effects of seeding rate on tiller number. Plants sown at the higher seeding rate had less tillers than those at the low rate although once the difference between tiller number of plants sown at high and low rates was established (145 d.a.s.) the difference remained relatively consistent at between 1.2 and 1.9 tillers/plant (Table A2.1, Appendix 2). There were no interactions between the effects of species and seeding rate on tiller number at any measurement during the late establishment period.

Figure 4.2.1.2 Effect of Seeding Rate on Tiller Number per Plant

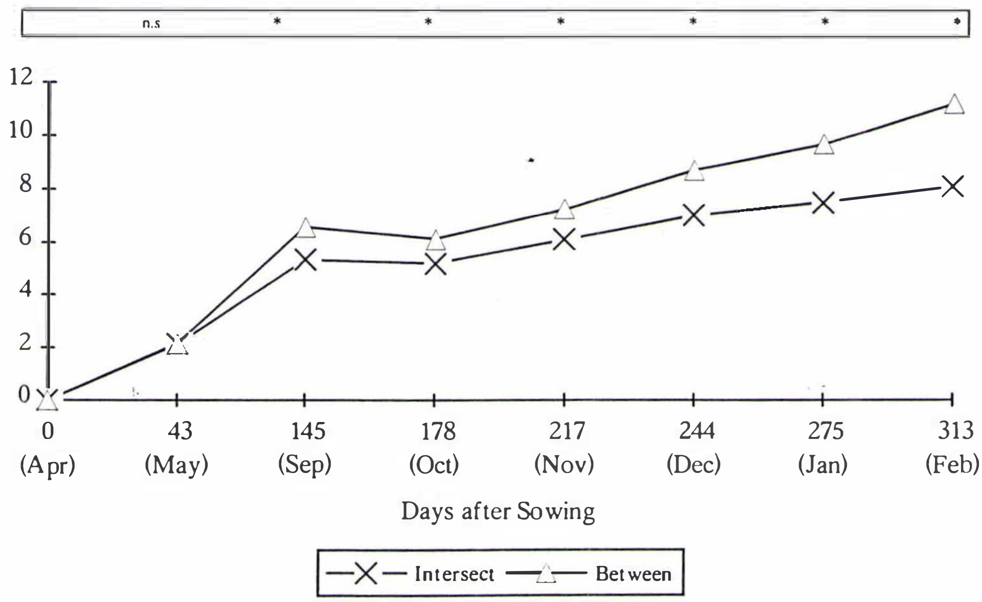


4.2.1.2.1.3 Overall Drill Method and Position Effect

Drill method had a significant effect on tiller number on only one occasion (217 d.a.s.) when plants sown by cross-drilling had less tillers than those sown in 75mm rows (Table A2.1, Appendix 2). The average tiller number for cross drilled plants, the mean of plants at the intersection and between positions, is probably an underestimate of the actual average number of tillers per plant for that treatment for reasons outlined in Section 4.1.3.3 under '*Drilling Method*', so the actual average tiller number of cross-drilled plants was probably not significantly different from plants in 75mm rows. The effect was significant for ryegrass only but no interaction between species and drill method was apparent. Tiller number of plants in 150mm rows were never significantly different from cross-drilled plants or those in 75mm rows at any stage of the tiller measurement period. A comparison of drill method effects for each species is presented for completeness in the next section.

Figure 4.2.1.3 shows the tiller number of cross drilled plants which occurred at either the "intersection" or "between" positions. Plants which occurred between the intersection of the rows in the cross-drilling treatment had more tillers than those which occurred at the intersection (Table A2.5, Appendix 2). That effect was similar to the seeding rate effect on tiller number but with one important difference. The absolute difference in tiller number between plants from the intersection and between positions increased with time and the difference became significant at a more exacting level of probability as time progressed. In contrast, the corresponding difference between plants sown at high and low rates remained constant as time progressed and the level of probability for significance became less exacting.

Figure 4.2.1.3 Effect of Position on the Tiller Number of Plants Sown by Cross-drilling

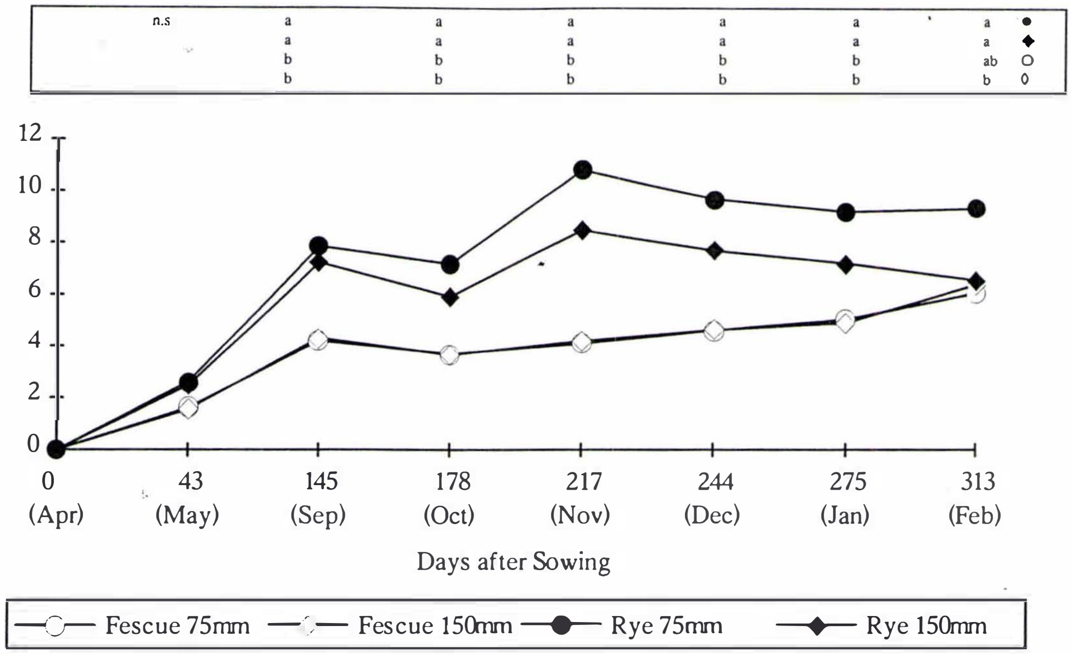


4.2.1.2.1.4 Drill Method Effect on Fescue and Ryegrass

One of the reasons for cross-drilling is to increase intra-row plant spacing in the expectation of better individual plant performance (Thom and Ritchie, 1987). The tiller number of plants in the cross drilled rows tended to be underestimated in the current trial so in order to see how variation in intra-row plant spacing affected tiller number, the data for plants in either 75mm or 150mm row spacing are presented. Data for cross drilled plants are excluded to avoid the confounding position effect on tiller number. Figure 4.2.1.4 describes the tiller numbers of fescue and ryegrass plants which occurred in 75mm or 150mm rows.

Fescue tiller number showed no response to drill method and with ryegrass, although plants in 75mm rows appeared on average to have more tillers than those in 150mm rows, the difference was never significant (Table A2.3, Appendix 2).

Figure 4.2.1.4 *Effect of Drilling Method on Tiller Number for Fescue and Ryegrass Plants*



4.2.1.2.1.5 Interactive Effect of Seeding Rate and Drill Method for Ryegrass

There was a seeding rate x drill method interaction on tiller number for ryegrass at 275 and 313 d.a.s.. This interaction, which was more obvious at 313 than 275 d.a.s., was associated with the three way interaction of seeding rate x drill method x species on tiller number indicated at 313 d.a.s. in that a significant seeding rate x drill method interaction occurred in ryegrass but not fescue.

Figures 4.2.1.5 and 6 show the effect of drill method on tiller number for ryegrass and fescue at both high and low seeding rate. The data from which Figures 4.2.1.5 and 6 were drawn are located in Table A2.7, Appendix 2. The overall seeding rate effect became weaker as time progressed (Figure 4.2.1.2). By 313 d.a.s., seeding rate did not have a significant effect on fescue tiller number and the effect was significant for ryegrass only at the lower order of probability (10%), and for combined species at less than 5% (Table A2.2, Appendix 2). With respect to drill method effects, seeding rate appeared to have little impact on ryegrass except where it was cross drilled. Plants at the high seeding rate in the cross drilled plots had less tillers than those sown at the low rate (6.0 compared with 10.7 tillers). However, ryegrass plants in 75mm and 150mm rows were not influenced by seeding rate. With fescue, cross drilled plants and those in 75mm rows were not influenced by seeding rate, and although plants in 150mm rows appeared to be affected by seeding rate the difference in tiller number was not significant.

Figure 4.2.1.5 *Effect of Drill Method at High and Low Seeding Rate on Tillers per Plant in Fescue at 313 d.a.s.*

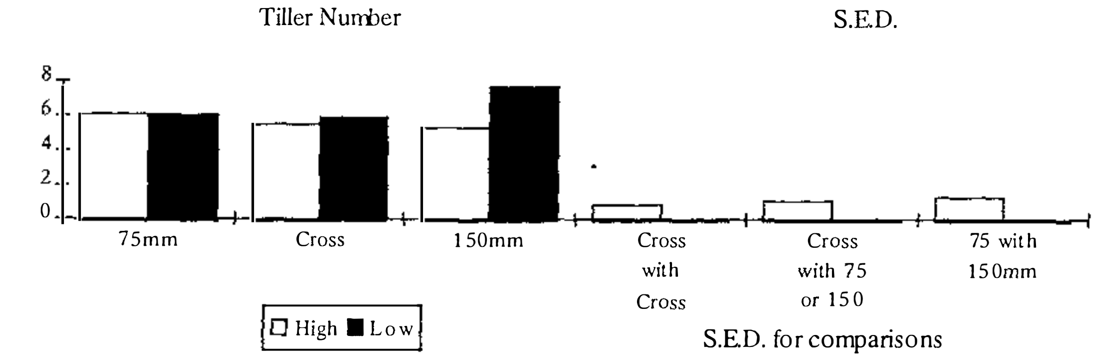
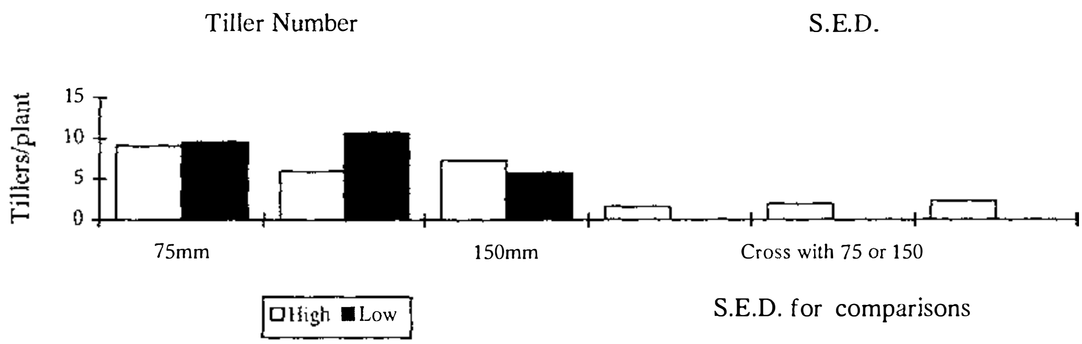


Figure 4.2.1.6 *Effect off Drill Method at High and Low Seeding Rate on Tillers per Plant in Ryegrass at 313 d.a.s.*



4.2.1.2.1.6 Effect of In-row Population

The relationship between tiller number and in-row population for late establishment was consistent with that for early establishment. Regression analysis of tiller number was carried out as described in Section 4.1.3.2.4. Table 4.2.1.2 compares the results of the regression analysis for both fescue and ryegrass and also shows the average tiller number for the period 178 to 313 d.a.s.. Although the slope of the regression line tended to be negative on each occasion for both species it was only significantly so in the early stages with ryegrass (178 and 217 d.a.s.).

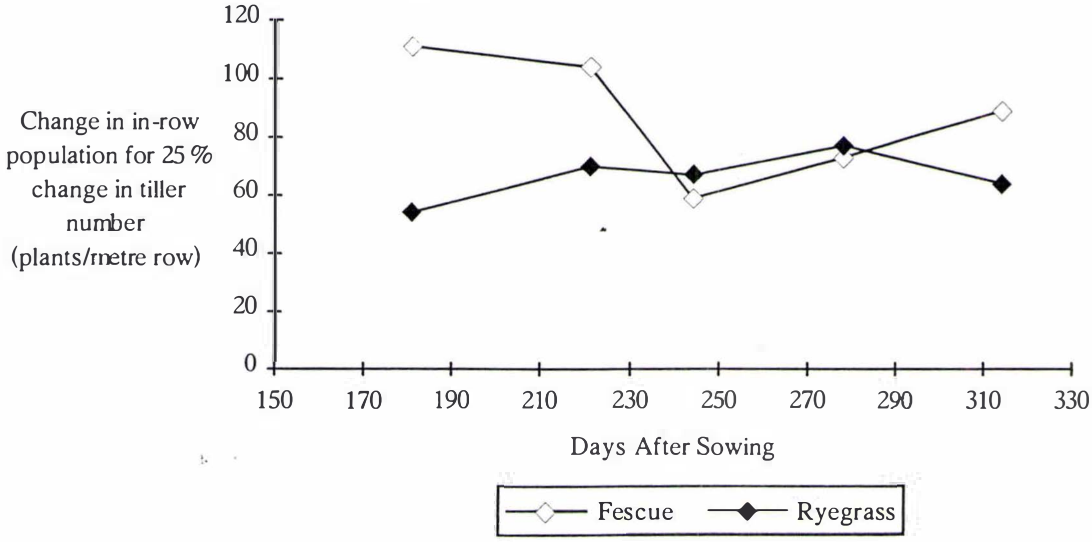
Table 4.2.1.2 Effect of In-row Population on Tiller Number of Fescue and Ryegrass Plants.

d.a.s.	178	217	224	275	313
Fescue Tiller number	3.6	3.8	4.3	4.7	5.9
slope of regression line	-0.0098	-0.0115	-0.0239	-0.0219	-0.0223
S.E.D. ±	0.008	0.01	0.01	0.01	0.02
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
r^2	0.04	0.03	0.06	0.05	0.04
Ryegrass Tiller number	6.4	8.4	8.3	8.0	7.9
Slope of regression line	-0.0356	-0.0396	-0.0404	-0.0352	-0.0467
S.E.D. ±	0.01	0.02	0.02	0.02	0.03
Significance	* *	(*)	n.s.	n.s.	n.s.
r^2	0.17	0.09	0.07	0.06	0.06

For fescue, tiller number decreased by between 0.8 and 4.2 % for every 10 plant m^{-1} row increase in in-row population. The coefficients of correlation for the data were weak (Table 4.2.1.2). Variation in in-row population accounted for up to 17 % of the control over tillering in ryegrass but up to only 6 % control in fescue. Those differences in response to in-row population occurred in the early stages of sward establishment (145 d.a.s.) but disappeared later (244 to 313 d.a.s.). At the later stages in-row population had no influence on tiller number.

Figure 4.2.1.7 shows the change in in-row population required to effect a 25 % change in tiller number. Data for Figure 4.2.1.7 were calculated using the equation described in Section 4.1.3.2.4.

Figure 4.2.1.7 *Change in In-row population Required for a 25 % Change in the Number of Tillers per plant.*



Fescue required a greater increase in in-row population than ryegrass to effect a 25 % decrease in tiller number until 217 d.a.s. after which time both species were similar in their response to in-row population change.

From 145 to 217 d.a.s. an increase of 55 to 70 plants m^{-1} row was required to reduce tiller number of ryegrass by 25 %. Ryegrass plants at that stage had at least 6.4 tillers per plant (Table 4.2.1.2). Fescue on the other hand had only 3.6 to 3.8 tillers per plant for the same period. It was not until 224 d.a.s. when fescue plant size had increased to 4.3 tillers per plant and Argentine stem weevil had been eradicated that the change in in-row population required to effect a 25 % reduction in tiller number became similar for both species.

4.2.1.2.2 Leaf Number and Extended Height

4.2.1.2.2.1 Interactive Effect of Drill Method and Species

Table 4.2.1.3 describes the time and level of probability for main treatment effects and interactions between main treatments on leaf number and extended height for combined species, and for fescue and ryegrass from 178 to 244 d.a.s.. Rate and species effects on leaf number and extended height were consistent with those on tiller number. However, unlike tiller number, some significant drilling method effects and drilling method x species interactions were indicated.

Table 4.2.1.3 Time and Level of Probability for Main Treatment Effects and Interactions Between Main Treatments on Leaf Number and Extended Height for Combined Species and for Fescue and for Ryegrass from 178 to 244 d.a.s.

		LEAF NUMBER					**EXTENDED HEIGHT**				
		MAIN EFFECTS				INTER'N	MAIN EFFECTS				INTER'N
d.a.s. (Month)		Rate	Species	Drill	Position	†Drill x Species	Rate	Species	Drill	Position	Drill x Species
178 (Oct)	Combined Spp	⊙⊙⊙	⊙⊙⊙	⊙	(⊙)		⊙	(⊙)			⊙⊙
	Ryegrass	✧✧✧		✧	✧						
	Fescue	★					★		★★		
217 (Nov)	Combined Spp	⊙⊙⊙	⊙⊙⊙	⊙	⊙		⊙⊙⊙	⊙⊙⊙	⊙⊙⊙		⊙
	Ryegrass	✧✧✧		✧			✧✧				
	Fescue	★★			★		★		★★		
244 (Dec)	Combined Spp	⊙⊙	⊙⊙⊙		⊙	⊙		⊙⊙	⊙		⊙
	Ryegrass	★★									
	Fescue			★★★	(★)				★★		

Key
- ⊙ is the symbol indicating significant effect for combined species (**overall**)
- ✧ is the symbol indicating significant effect for **ryegrass**
- ★ is the symbol indicating significant effect for **fescue**
- † Only the Drill x Species interaction was significant

The drilling method effect on leaf number of ryegrass at 178 and 217 d.a.s. was such that it carried over into the combined species results so that a significant overall drill effect was indicated (Table A2.8, Appendix 2). Ryegrass plants in 75mm rows had more leaves than those in 150mm rows at 178 and 217 d.a.s. and more than those in cross drilled rows at 217 d.a.s. (Table 4.2.1.4). However, leaf number of fescue was not significantly affected by drilling method at those times.

Table 4.2.1.4 Effect of Drill Method on Leaf Number of Fescue and Ryegrass Plants

	DRILL METHOD	d.a.s. (month) 178 (Oct)	217 (Nov)	244 (Dec)
FESCUE	**75 mm**	2.6	4.3	4.9 a
	Cross drill	2.5	3.8	3.6 b
	150 mm	2.2	4.2	5.6 a
S.E.D. ±	75mm with 150mm	0.36	0.55	0.63
	Cross with 75 or 150	0.29	0.47	0.54
	Significance	n.s.	n.s.	* * *
RYEGRASS	**75 mm**	6.4 a	18.8 a	11.1
	Cross Drill	5.5 ab	13 b	11.1
	150 mm	4.7 b	13 b	9.6
S.E.D. ±	75mm with 150mm	0.68	2.17	1.99
	Cross with 75 or 150	0.58	1.86	1.70
	Significance	*	*	n.s.

At 244 d.a.s. there was a significant drill x species interaction on leaf number (Table 4.2.1.3). Ryegrass leaf number was not influenced by drill method but cross drilled fescue plants had less leaves than those in 75 or 150mm rows (Table 4.2.1.4).

There was a drilling method x species interaction at 178, 217 and 244 d.a.s. on extended height. Drilling method had a significant effect on the extended height of fescue but no effect on ryegrass at each measurement time although the effect was not consistent (Table 4.2.1.3). The extended height of fescue plants in 75mm rows was greater than those in 150mm and cross drilled rows at 178 d.a.s. (Table 4.2.1.5) which was consistent with the results for extended height at 145 d.a.s. (Table 4.1.4.6). At 217 and 244 d.a.s. extended heights of fescue plants in 75 and 150mm rows were not different. The extended height of cross drilled fescue plants was less than for other drilling methods at 217 d.a.s. and greater than other drilling methods at 244 d.a.s..

Table 4.2.1.5 Effect of Drill Method on Extended Height of Fescue and Ryegrass Plants

		EXTENDED HEIGHT (mm) d.a.s. (month)		
	DRILL METHOD	178 (Oct)	217 (Nov)	244 (Dec)
FESCUE	**75 mm**	156 a	293 a	158 a
	Cross drill	126 b	226 b	181 b
	150 mm	134 b	271 a	160 a
S.E.D. ±	75mm with 150mm	10.8	18.9	11.2
	Cross with 75 or 150	9.3	16.3	9.7
	Significance	*	*	**
RYEGRASS	**75 mm**	157	408	188
	Cross Drill	170	382	202
	150 mm	162	402	215
S.E.D. ±	75mm with 150mm	7.8	25	12.5
	Cross with 75 or 150	6.7	22	10.7
	Significance	n.s.	n.s.	n.s.

4.2.1.2.3 Plant Survival

Plant losses for the period 43 to 313 d.a.s. are categorised in Table 4.2.1.6. Overall losses were about 10 % of the original 576 tagged plants. 'Animal effects' (loss categories *1,2* and *3*) caused similar losses of plants from both fescue and ryegrass. Observations were made on plants in close proximity (within 20mm) to tagged plants. Where a close neighbouring plant (another sown grass, clover or weed) was observed in a previous recording interval and was found to dominate the position where a tagged plant had been, a loss of a tagged plant was recorded in category *5*. Table 4.2.1.6 shows that fescue was more prone to competition with neighbouring weeds and other fescue plants. Four of the thirty five dead fescue plants were killed by Argentine stem weevil. No ryegrass plant deaths were attributable to Argentine stem weevil damage, which reflected a lower level of infestation in the "high-endophyte" ryegrass sward (Table A2.6, Appendix 2). Fescue and ryegrass had the same level of plant mortality until 244 d.a.s. after which time a higher proportion of ryegrass plants survived than fescue plants (Table A2.12, Appendix 2).

Bellotti (1984) showed that increasingly skewed populations were more likely to suffer some plant mortality. Skewness for the distribution of a number of plant characteristics and indices were calculated for each measurement occasion of the late establishment period (178 to 313 d.a.s.) in the same manner as for the early establishment period as described in Section 4.1.3.1. The skewness of tiller number provided the most consistent results and so is presented here. The skewness for leaf number, extended height, T X L, Till X Hgt and Lf X Hgt indices are considered after plant survival and skewness of tiller number. The skewness of ryegrass was always greater than fescue and significantly different at 145, 178 and 313 d.a.s. (Table A2.13, Appendix 2).

Table 4.2.1.6 Number, Timing and Cause of Loss of Tagged Ryegrass and Fescue Plants.

Species	d.a.s.	Loss category[1] 1	2	3	4	5	6	Total
Fescue	145 (Sep)						1	1
	178 (Oct)						1	1
	217 (Nov)				3	2	1	6
	244 (Dec)	1		1	1	3	9	15
	275 (Jan)	1					4	5
	313 (Feb)	1		1		1	4	7
	Total	3		2	4	6	20	35
Ryegrass	145 (Sep)						1	1
	178 (Oct)		2				1	3
	217 (Nov)	2					2	4
	244 (Dec)			1			3	4
	275 (Jan)						2	2
	313 (Feb)			1			8	9
	Total	2	2	2			17	23
Both Species	Grand Total	5	2	4	4	6	37	58

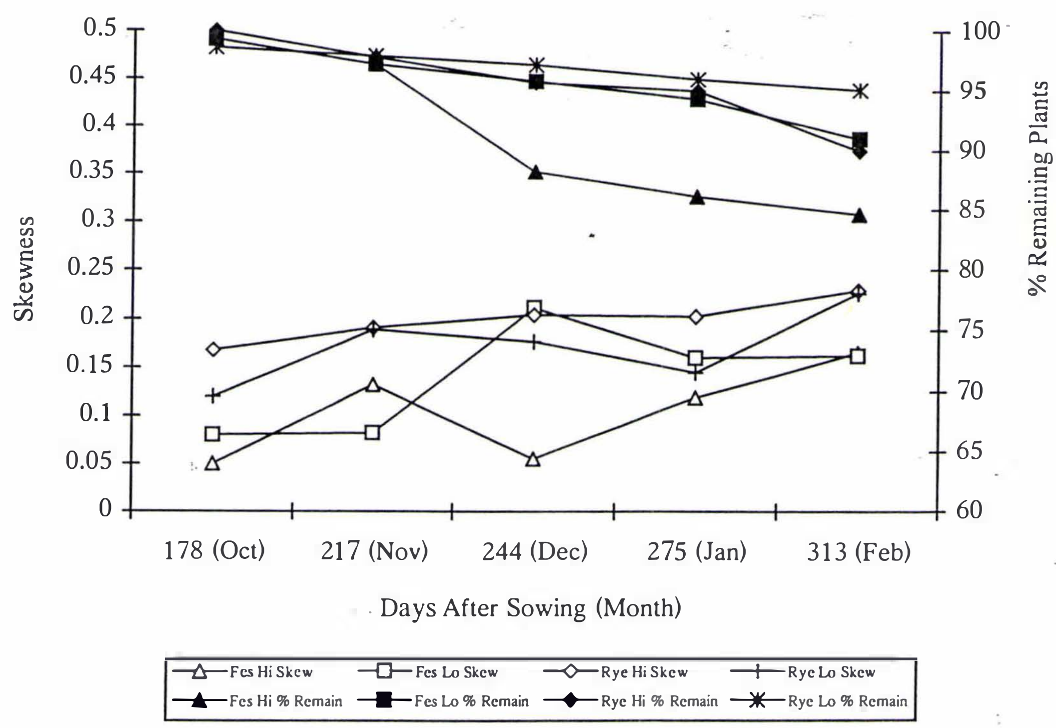
[1] *1* = dung damage by cattle excrement, *2* = pulled out by grazing cattle, *3* = trampling by hoof action of cattle, *4* = killed by Argentine stem weevil, *5* = visible competition from clover, weed grass or broadleaf, *6* = dead, no visible green herbage, no obvious animal damage and no visible competition from vegetation other than within species.

4.2.1.2.3.1 Effect of Seeding Rate on Fescue and Ryegrass

Figure 4.2.1.8 shows the effect of seeding rate on plant survival and skewness of the distribution of tiller number for fescue and ryegrass from 178 to 313 d.a.s.. The raw data for Figure 4.2.1.8 are located in Tables A2.16 and A2.17, respectively (Appendix 2).

Overall, plant survival was significantly better at low than high seeding rate after 217 d.a.s. (Table A2.14 Appendix 2). Overall, skewness was only significantly affected by seeding rate at 244 d.a.s. (Table A2.15, Appendix 2). Tiller number was significantly less positively skewed at high seeding rate than low seeding rate. This effect was confined to fescue as indicated by a significant interaction for skewness between species and seeding rate at 244 d.a.s. (Table A2.17, Appendix 2). At that time fescue had significantly fewer plants remaining at the high seeding rate than at the low seeding rate, whereas ryegrass plant survival was not affected by seeding rate (Table A2.16 Appendix 2). Fescue plants sown at the high rate were lost predominantly through competition with sown species and weeds (grass and broadleaf) (Table 4.2.1.6). Records showed that those plants which were lost had comparatively fewer tillers (1 to 2 tillers/plant) than the average tiller number which is consistent with the tendency for the distribution of tiller number to return to normality ie. distribution of tiller number of fescue became less positively skewed at 244 d.a.s. where it was sown at the high rate (Figure 4.2.1.8).

Figure 4.2.1.8 Effect of Seeding Rate on the Percentage of Remaining Plants and Skewness Coefficient for Fescue and Ryegrass .



4.2.1.2.3.2 Effect of Drilling Method on Plant Survival.

Table 4.2.1.7 describes the overall effect of drill method on plant survival. Plants sown in 75mm rows or cross drilled were not different with respect to the percentage of plants remaining in plots for the entire establishment period. However, there was a significantly higher percentage of plants remaining in 150 mm rows from 217 to 313 d.a.s. than either one or other or both of the 75mm and/or cross drilled treatments . This effect is not consistent with the overall effect of seeding rate which suggested that those plants sown at higher density (seeding rate) were less likely to survive than those sown at the low density.

Individual species analysis showed that fescue plants tended to survive equally well to 313 d.a.s. in cross drilled and 75mm rows but not as well as those in 150mm rows, although drill method had no significant effect on percentage plants remaining (Table A2.25a, Appendix 2). However, in ryegrass, the percentage of plants in 75mm and 150mm rows was not different, but significantly fewer plants remained in the cross drilled treatment than in 150mm row treatment at 313 d.a.s. (Table A2.25a, Appendix 2). Thus, although there were some significant effects on plant survival, there was no consistent effect across species, unlike the effect of seeding rate.

Drilling method had no significant effect on the skewness of tiller number from 178 to 313 d.a.s.. There were no significant interactions between drilling methods, species and/or seeding rates on plant survival or skewness of distribution.

Table 4.2.1.7 Effect of Drilling Method on the Percentage of Plants Remaining

d.a.s. (Month)		43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
75 mm		100	99.6	99.3	95.7 a	92.9 (a)	91.5 (a)	91.5 ab
Cross Drill		100	100	99.0	97.2 ab	92.7 (a)	91.2 (a)	86.3 a
150 mm		100	100	100	100 b	98.6 (b)	97.9 (b)	96.5 b
S.E.D. ± for Comparison	Cross with 7 or 150	0	0.32	0.84	1.47	2.7	3.2	3.9
	75 with 150	0	0.41	0.93	1.70	3.1	3.7	4.4
Significance			n.s	n.s.	*	(*)	(*)	*

There was no significant difference in the proportion of tagged plants which survived at the intersection of cross drilled rows compared with those located between the row intersections during the measurement period (Table A2.20, Appendix 2) which again is not consistent with the overall density (rate) effect on plant survival.

Skewness of tiller number tended to be more positive for plants at the intersection on each measurement occasion, but was only significantly different at 217 d.a.s. (Table 4.2.1.8). In general this result is consistent with the lower tiller number found for plants at the intersection compared with those at the between position of cross drilled rows.

Table 4.2.1.8 Effect of Position on the Skewness of Tiller Number

d.a.s (Month)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
Intersection	0.099	0.236	0.237	0.173	0.264
Between	0.043	0.103	0.133	0.118	0.169
S.E.D. ±	0.072	0.063	0.064	0.079	0.062
Significance	n.s.	*	n.s.	n.s.	n.s.

Although the skewness of tiller number was not always consistent with plant survival and tiller number it was more consistent than skewness of leaf number, extended height, Till X Leaf, Till X Hgt and Lf X Hgt. There were few significant differences for skewness of those parameters of plant size. The difference between species is one example (Tables A2.22, Appendix 2). The species x rate interaction on skewness of tiller number at 244 d.a.s. was not reflected by skewness of other plant parameters or plant size indices. Where there was a significant effect, it was consistent with the skewness of tiller number. Generally, skewness of tiller number was a better indicator of plant size distribution than skewness of plant size index except on one occasion. The position effect at 217 d.a.s. was significant at a higher level of probability (1%) for Leaf X Hgt index (Table A2.22, Appendix 2) than for tiller number (5%) (Table 4.2.1.8).

4.2.1.2.3.3 Effect of In-row Population

The regression for the percentage of plants remaining as a function of plants m^{-1} row was at no stage significantly different from zero throughout the establishment period (Table A2.23, Appendix 2) indicating that in-row population had no effect on plant survival. Correlations were on average very low indicating the in-row population explained less than 2% of the variation in plant survival.

Regression analysis of skewness as a function of plants m^{-1} row was also carried out. Table 4.2.1.9 describes the effect of in-row population on the frequency size distribution (skewness) of tiller number from 178 to 313 d.a.s..

Table 4.2.1.9 Effect of In-row Population on the Skewness of Tiller Number in Fescue and Ryegrass.

	d.a.s.	178	217	244	275	313
Fescue	Skewness	0.06	0.08	0.10	0.12	0.14
	slope of regression line	0.0003	0	-0.003	-0.002	-0.0004
	S.E.D. ±	0.001	0.0017	0.001	0.002	0.001
	Significance	n.s.	n.s.	*	n.s.	n.s.
	r^2	0.001	0	0.12	0.02	0.002
Ryegrass	Skewness	0.13	0.16	0.17	0.18	0.22
	Slope of regression line	-0.00003	0.001	-0.002	0.003	0.002
	S.E.D. ±	0.001	0.001	0.001	0.001	0.001
	Significance	n.s.	n.s.	n.s.	n.s.	(*)
	r^2	0	0.03	0.08	0.08	0.10

The distribution of fescue tiller number showed no association with in-row population except at 244 d.a.s. when skewness became less positive with increasing in-row population. This is consistent with the significantly less positive distribution of tiller number found at 244 d.a.s. for fescue sown at the high seeding rate compared with the low rate and the loss of fescue plants between 217 and 244 d.a.s. (Figure 4.2.1.8).

The relationship between the distribution of ryegrass tiller number and plants m^{-1} row was consistent at 217, 244, 275 and 313 d.a.s.. Skewness became more positive with increasing in-row population. The effect was more apparent at later measurement occasions and was significant at 313 d.a.s. but at a lower order of probability (10%) (Table 4.2.1.9).

4.2.1.3 Discussion

Tiller Number

Species

Tiller number for ryegrass plants was the same at the end of the 'late establishment' period in February (313 d.a.s.) as it was at the commencement of the first grazing in September (145 d.a.s.) but did vary slightly during that interval (Figure 4.2.1.1 and Table A2.1, Appendix 2). Fescue tiller number increased only slightly during that time (4.2 to 5.9 tillers per plant). Herbage mass of fescue and ryegrass prior to grazing at 150 d.a.s. was 1640 to 1759 kgDM ha^{-1}, respectively. Post grazing herbage mass was not specifically measured but herbage height after grazing was 40-70mm (visually assessed) and on that basis was estimated to be approximately 1000kgDM ha^{-1} (Holmes and Wilson, 1984; Thom et al., 1987a).

Grazing in October (181 d.a.s.) was similar in intensity and duration to that which occurred at 150 d.a.s. ie. post-graze herbage height 40-70mm, approximate herbage mass 1000kgDM ha^{-1}. High analysis fertiliser (60kgN, 40kgP, 40kgK and 32kgS ha^{-1}) was applied after grazing and 40mm water was applied by irrigation as soil moisture levels were approaching stress point (-100kPa, -40mm from field capacity, Figure A2.1, Appendix 2). Herbage mass had accumulated to a higher level prior to the next grazing in November (219 d.a.s.) than for the previous two occasions (3977 and 4581kgDM ha^{-1} for fescue and ryegrass, respectively, Table A2.27).

Tiller number of both fescue and ryegrass plants decreased between 145 and 178 d.a.s. (Figure 4.2.1.1). Ryegrass tiller number increased after 178 d.a.s. from 6.4 to 8.4 at 217 d.a.s. (Figure 4.2.1.1) while fescue tiller number remained unchanged for the corresponding period. This coincided with reproductive development in ryegrass (Figure 4.2.1.9). Of the 100 tagged plants sampled for each species for reproductive development at 217 d.a.s. 64% of ryegrass plants (16% of total tillers) had visible culm elongation in tillers and / or visible inflorescences (Table A2.24, Appendix 2) The trial area was "topped" to remove herbage above 80mm from the soil surface which included ryegrass seedheads and grass which had become rank, mainly in urine affected areas for both species. Prairie grass seedheads, mainly in the fescue sward, were also removed. A forage harvester was used for the topping operation so that cut herbage could be removed from the trial area to avoid the problem of decaying herbage smothering the live sward. The timing of reproductive development was similar to that observed for both 'Grasslands Nui' perennial ryegrass at Palmerston North (Korte et al., 1984) and 'Grasslands Ruanui' (Brougham, 1961; Browse et al., 1981). Anthesis for fescue occurred approximately one month earlier in spring than for ryegrass and the two close defoliation which occurred in

September and October minimised seedhead formation. Less than 1% of fescue tillers showed signs of reproductive development at 217 d.a.s..

Figure 4.2.1.9 *Trial Area Just Prior to the Grazing Which Occurred at 219 d.a.s. (November), Showing Seedhead Development in Ryegrass on the Right with Fescue on the Left*

Tiller appearance for fescue may have been similar to ryegrass from 178 to 219 d.a.s., but an infestation of Argentine stem weevil (*Listronotus bonariensis*) discovered in fescue at 217 d.a.s. is likely to have resulted in higher tiller death in fescue than ryegrass. Seventeen percent of fescue plants had one or more tillers which showed typical signs of larval damage, including dead emerging tillers, pin sized holes in the base of tillers and creamy white, legless grubs within grass tillers (Barker et al., 1984). On the other hand, ryegrass had only 3-4% infection (Table A2.6, Appendix 2), most likely due to the presence of the endophyte *Acremonium lolii* in the cultivar 'Supernui' (Dymock et al., 1989). The trial was sprayed with insecticide (2l/ha Vydate®, 240 g/litre oxamyl as active ingredient) in late November (230 d.a.s.) to control the pest. At subsequent tiller measurement occasions no noticeable Argentine stem weevil damage was apparent for either species except where some plants had been previously killed by the insect.

Plant losses for fescue and ryegrass were negligible (< 1%) to 217 d.a.s. (15 November, Table 4.2.1.6) therefore the product of tiller number per plant (the raw data rather than the back transformed data, Table A2.11, Appendix 2) and plant population provides an estimate of tiller density (tillers m^{-2}). For fescue this was 3093 and 3080 tillers m^{-2} for high and low seeding rate, respectively. Thus, density was slightly higher than that reported by Brock et al. (1982) for autumn sown 'Grasslands Roa' and 'Aberystwyth S170' tall fescue, using conventional cultivation in the Manawatu, (1020 and 1590 tillers m^{-2}, respectively, on 3 December) but similar to the 'Wild Type' tall fescue, established from seed collected in the Manawatu, which showed superior emergence under dry conditions in their field experiment. Tiller density in November was less than that reported for a 2½ year old tall fescue sward in the Manawatu (4880- 5170 tillers m^{-2}) (Brock, 1982) and a 1 year old sward at the Grassland Research Institute, Hurley, Nr.Madenhead, Berkshire, England during summer (4320 tillers m^{-2}, Sheehy and Peacock, 1977). Parallel tiller density figures for ryegrass were 7414 and 5815 tillers m^{-2}, which are similar to values reported by Thom et al. (1993) for the first spring after autumn establishment by direct drilling of 'Ellett' perennial ryegrass at Hamilton New Zealand (5000-6000 tillers m^{-2}) and similar to the equilibrium tiller density of 6000 tillers m^{-2} at a leaf area index of 3 reported by Kays and Harper (1974) and later by Simon and Lemaire (1987). Initial density for the latter reports ranged from 213 to 10000 plants m^{-2} for perennial and Italian ryegrass (*Lolium multiflorum*) and confirmed an earlier, similar, report (Holliday, 1953). Cessation of tillering was thought have been caused by severe competition for light in a closed canopy. The density of ryegrass was similar to that reported for intensively grazed dairy pasture, overdrilled with Nui ryegrass four years previously, during November in the Waikato (Hamilton) (approximately 6000 tillers m^{-2}, L'Huillier, 1987).

On the basis of those studies it would seem there was sufficient tiller density in the current trial at 217 d.a.s. (5800 to 7400 tillers m^{-2}) for a productive ryegrass sward but the density of fescue tillers was less than that of an established sward (3000m^{-2}). Ryegrass always had more tillers than fescue, although by 313 d.a.s. (February) tiller number of fescue sown at the low seeding rate was similar to the ryegrass sown at the high rate (6.3 and 7.7, respectively, Table A2.2, Appendix 2).

Grazing recommendations for perennial pasture, particularly ryegrass, established by direct drilling, have advocated that pasture should be kept short during the first winter / spring by grazing at a pasture height of 100-150mm, leaving a stubble of 40-60mm (Ritchie, 1986b). Thom et al. (1987a) suggested targets for pre and post grazing herbage mass in terms of kgDM ha^{-1} as well as herbage height for the same period. They recommended that grazing commence at a pre-grazing herbage mass of between 1500 to 1800kgDM ha^{-1}, and reduce herbage mass to 1000 to 1200kgDM ha^{-1} within a 24 hour period. In the current trial, this technique was used for the first two grazings where fescue and ryegrass were grazed at the same time eg. extended height in September (145 d.a.s.) was 131 and 178mm for fescue and ryegrass, respectively (Table 4.1.4.5). Corresponding figures were 138 and 163mm in October (178 d.a.s., Table 4.2.1.5). Evans (1973) suggested that this type of grazing management would encourage tillering in grasses, as well as minimise competition for light between grasses and clovers. The same grazing management may encourage grass species to fill the gaps between rows of drilled pasture plants (Ritchie, 1986b). Results from the current trial showed that tiller number of both ryegrass and fescue was in fact reduced with that type of grazing management but where herbage was allowed to accumulate to a higher level before grazing (4000kgDM ha^{-1}), tiller number of ryegrass increased. However, why this occurred in the current trial is unclear because of the confounding effect of fluctuating levels of moisture stress during the spring.

Conditions were dry during the interval between measurement times for tagged plants at 145 and 178 d.a.s. Soil water deficit reached -36mm, close to stress point, during the week prior to measurement of tagged plants on 7th October (178 d.a.s.) (Figure A2.1, Appendix 2). Only 11.3mm of rain had fallen during the month since the prior measurement at 145 d.a.s. when soil water deficit was -5mm. Rainfall for the month of September was 20% of the 30 year average (Figure A2.2, Appendix 2). Where moisture and nutrients are non-limiting, tillering occurs in response to changing temperatures (Hunt and Field, 1979) and light regimes (Mitchell 1953; Mitchell and Coles 1955). Usually tiller number increases after close defoliation, such as that which occurred at 150 d.a.s. in the current trial, because of the removal of leaf lamina and stem which allows light to penetrate to the base of the sward (Mitchell, 1953a; Langer, 1963; Jewiss, 1972). A 'tillering flush' has been observed in the Manawatu for 'Grasslands Nui' and Ruanui perennial ryegrass sward in early September as tillers appeared from buds "released" by grazing 10 days earlier (Hunt and Field, 1979). This pattern of tiller development is one mechanism leading to the commonly observed high tiller populations in frequently cut and continuously grazed swards, and low populations in infrequently cut high-yielding swards. Thus an increase in tiller number after grazing was expected from both fescue and ryegrass in the current trial after grazing in early September (150 d.a.s.).

Korte et al. (1984) demonstrated that during September in the Manawatu, tiller appearance of an 18 month old 'Grasslands Nui' perennial ryegrass in a mixed sward was greater than tiller death rate after a 'Hard' grazing by sheep (residual 700-1000kgDM ha^{-1}) resulting in a net increase (accumulation) in tiller density. Tiller number decreased in the current trial for the corresponding period (145 to 178 d.a.s.). Individual tillers were not identified so it is unclear whether new tillers appeared or not, or if tiller death rate simply increased. Low soil moisture has been shown to limit leaf appearance and extension, and tiller regeneration (Barker et al., 1985). Similar results have been reported for tall fescue (Horst and Nelson, 1979). From studies comparing tiller population dynamics of moisture stressed (soil water deficit, -180mm) and irrigated perennial ryegrass (cv Grasslands Nui) pasture, established by conventional cultivation the previous autumn, at a site within 1.5km of the current trial, Barker et al. (1985) reported that after 36 days without moisture (from 29 December to 3 February, a period of relatively higher evaporation as compared to September) tiller density was not significantly affected, indicating that tiller death and appearance were similar during that time. Tiller death and / or cessation of tiller production appears to have occurred comparatively sooner in the current trial. This may be related to plant spatial arrangement because tiller density was reduced as opposed to remaining static for a similar dry period (33 days) and soil moisture stress is unlikely to have been greater than that imposed by the 'rain out' shelter used by Barker et al. during summer. Perhaps plants in close proximity within a row are more likely to suffer the effects of drought than those with larger inter-plant distances which occur in a sward where seed has been broadcast.

Tiller number of ryegrass plants in the current trial recovered after rainfall and irrigation replenished soil moisture at 184 and 200 d.a.s. (29 October), and fertiliser was applied at 190 d.a.s.. Between 178 and 217 d.a.s., (October to November) there was a net increase of approximately 25 tillers m^{-2} day^{-1} after the grazing which occurred at 181 d.a.s. (630 plants m^{-2} x 1.5 tiller $plant^{-1}$ over 39 days, assuming no plant death), despite the onset of anthesis in ryegrass which may have limited tiller appearance as the number of tiller sites decreases during stem elongation and many younger weak tillers die (Garwood, 1969; Langer, 1963; Jewiss, 1972). Application of nutrients, especially nitrogen, would be expected to substantially increase tillering of perennial ryegrass plants in mixed grass-clover swards, especially after a dry spell (Ball and Field, 1982), as they suffer nitrogen stress at most times of the year which reduces tillering and growth (Harris et al., 1973). Korte et al. (1984) recorded net increases in tiller density of more than 6 times that recorded for the current trial from their Tuapaka trial where sheep grazing had reduced herbage mass from 3-4000kgDM ha^{-1} to between 1400 and 2500kgDM ha^{-1}. L'Huillier (1987) reported tiller appearance rates of 50-60 tillers $m^{-2}day^{-1}$ for perennial ryegrass based pastures grazed by dairy cattle during November at Hamilton, New Zealand, which has a comparable though slightly warmer climate than Palmerston North. Pre- and post-graze herbage mass was higher than that of the current trial (approximately 3000 and 1700 to 2100kgDM ha^{-1}, respectively). L'Huillier (loc cit) reported that the pattern of tiller death closely followed that of tiller appearance and overall tiller density decreased during spring (September-October-November). The grazing regime for the period September to November (145 to 217 d.a.s.) in the current trial would have been similar to grazing by sheep rather than by dairy cattle, therefore tiller accumulation might have been expected to have been similar to that described by Korte et al. (1984). Compensatory tillering might also be expected from a previously moisture stressed sward such as that in the current trial ie. a rate over and above that expected for unstressed swards of ryegrass (Barker et al., 1985) and tall fescue (Horst and Nelson, 1979). It appears that tiller accumulation was somewhat restricted in direct drilled pastures in comparison with pasture described by Korte et al. (1984) which was less than two years old and had been established by conventional cultivation.

The tiller numbers for ryegrass plants in the current trial were lower than those recorded by Thom et al., (1986a & d) for overdrilled 'Grasslands Nui' ryegrass into a dairy pasture containing paspalum at Ruakura Animal Research Station, Hamilton, New Zealand. Extrapolation from data presented in those papers for the first in their series of experiments (experiment 1, 1980-1981), show that for the first summer after overdrilling in autumn, tiller number of ryegrass peaked at an average of 18 tillers per plant in January whereas parallel data for the current trial was 8 tillers per plant (Figure 4.2.1.1). It should be noted that the data presented for tiller number in the present trial were back transformed $\log_{10}$ data which were actually 75% of the arithmetic mean because the distribution of tiller number was positively skewed. The difference may have related to the lower plant population recorded by Thom et al. (loc cit) (300 plants^{-2} by January vs 485 plants m^{-2} for the low seeding rate in the current trial, Table A1.5, Appendix 1) and shorter grazing intervals from sowing in April to January used by Thom et al. (loc cit) in comparison with the current trial (20 vs 30-40 days, respectively). However, in a subsequent experiment by Thom et al. (1986b), ryegrass seedlings with between 1 and 5 tillers, transplanted into live swards with low paspalum (*Paspalum dilatatum* Poir.) content in August, had around 7 tillers per plant by February and about half that number of tillers in swards with high paspalum content which is more in line with the results of the current trial. This seems a more likely plant size to expect, based on later work by Thom and his co-workers (Thom et al., 1993).

Reports for growth of individual ryegrass plants in a grazed sward established by direct drilling are basically limited to the work of Thom and his co-workers. A recent report by Thom et al. (1993) described the growth of 'Ellett' perennial ryegrass plants for a 5 year period after direct drilling in a cross-drilled pattern. Extrapolation from plant and tiller density data for the first January after autumn sowing shows that, for a similar type and rate of herbicide to that used prior to drilling in the current trial (2.16kg/ha glyphosate), tiller number per plant was almost identical at 7.8 tillers per plant (640 plants m^{-2} and 5000 tillers m^{-2}, Figures 1 & 2, Thom et al. 1993). Average tiller number per plant peaked at 11-12 tillers at about 2 years onwards, when population stabilised to around 300 to 270 plants m^{-2} and tiller density was 3500 tillers m^{-2}.

After 217 until 313 d.a.s. in the current trial, ryegrass tiller number remained fairly constant (8.4 to 7.9 tiller per plant). On the other hand, tiller number of fescue plants gradually increased from 3.8 to 5.9. The difference in tiller accumulation for that period may have been related to the residual herbage mass of fescue and ryegrass and the fact that Argentine stem weevil was controlled in the fescue sward at 200 d.a.s.. Increased tiller density for tall fescue swards sprayed with insecticide was reported by Prestidge et al. (1989) where levels of infestation were similar to that of the current trial (4 to 20% dead tillers). Ryegrass had a higher post-grazing herbage mass at 246, 278 and 315 d.a.s. (December, January and February, respectively) than fescue (range 2180 to 1275 and 3068 to 1875kgDM ha^{-1}, respectively, Table A2.32, Appendix 2) which would equate to a lax, infrequent grazing management for ryegrass and would not be conducive to increasing tiller number (Jewiss, 1972). Accumulation of herbage mass is a major cause of tiller death due mainly to adverse light relations (Ong et al., 1978). Tiller death rate rises sharply after 95% light interception is achieved, ie. once a 'closed canopy' is reached, irrespective of seasonal fluctuations (Hunt and Field, 1979) which is between 2000-4000kgDM ha^{-1} (leaf area index of 0.9-3.0, Korte et al., 1984). Death of vegetative tillers is caused by shading. L'Huillier (1987) reported that a higher death rate amongst perennial ryegrass tillers in dairy pastures was associated with greater pre- and post-grazing herbage mass (3340-2600kgDM ha^{-1} vs 3165-2105kgDM ha^{-1}, respectively) in spring and summer but tiller appearance rate was not affected by defoliation.

In the current trial, leaf number recorded at 178 d.a.s. (2.4 and 5.5 for fescue and ryegrass, respectively) was substantially less than values at 145 d.a.s. (7.6 and 15.6 leaves per plant, respectively, Table A2.9, Appendix 2). This equates to less than one fully expanded leaf per tiller present at 178 d.a.s.. Only fully expanded leaves were counted at 178 d.a.s.. Perennial ryegrass tillers typically produce new leaves every 8 to 20 days in spring at Palmerston North (Hunt and Field, 1979, Chapman et al., 1983) and leaf appearance rate is relatively insensitive to defoliation compared with tiller appearance rate (Anslow, 1966). Thirty three days had elapsed between measurements on tagged plants at 145 and 178 d.a.s., so each tiller should have had at least one new leaf. Obviously leaf production was severely limited for that period.

In the subsequent period (178 to 217 d.a.s., October to November), after rain had fallen and fertiliser had been applied, leaf number of ryegrass had increased along with tiller number to around 2 fully expanded leaves per tiller at 217 d.a.s. but fescue still had only one leaf per tiller present (Table A2.9, Appendix 1). This contrast in leaf production illustrates the debilitating effect of Argentine stem weevil, which feed on emerging leaves on tall fescue at that stage of growth. Damage to young tall fescue swards in New Zealand by Argentine stem weevil was reported from a survey of 13 sites in the Waikato (Prestidge et al., 1989). They suggested that reports of deterioration occurring in tall fescue swards over the first 2-4 years after sowing were related to the accumulation of tillers killed by stem weevil. Tall fescue is recommended as an alternative species to perennial ryegrass where Argentine stem weevil is a problem and a farmer may not wish to sow seed infected with the endophytic fungus *Acremonium lolii* (Pottinger et al., 1985). The endophyte confers resistance against Argentine stem weevil infestation (Barker et al, 1984; Prestidge et al., 1985a). However, one of the metabolites

Acremonium lolii produces, Lolitrem B, is a chemical toxin responsible for tremorgenic animal disorder, ryegrass staggers (Prestidge and Gallagher, 1985; Dymock et al., 1989). Tall fescue, which does not contain the endophyte, is not 'resistant' to but is said to be 'tolerant' of Argentine stem weevil attack because of its superior tiller production in comparison with ryegrass, in the face of larval attack during summer (Prestidge et al., 1985b). Grass seedlings of species not containing the endophyte are, however, susceptible to larval attack in the first year of establishment (Pottinger et al., 1985, Prestidge et al., 1989).

This was evidenced in the current trial by the lack of response in terms of leaf and tiller production during the period prior to the time when larval damage was noticed, a period during which leaf and tiller accumulation increased in perennial ryegrass which had considerably less larval damage. Larval damage is insidious and it is likely that undetected damage may well have occurred. The tall fescue cultivars sold in the United States of America, the country of origin of the AU Triumph tall fescue used in the current trial, have until recently been routinely sold containing the endophyte *Acremonium coenophialum* (Pedersen and Ball, 1990). The endophyte is known to improve germination rates and percentages in the laboratory (Pederson and Ball, 1990), and confer resistance to insects (Pottinger et al., 1985), disease and drought, resulting in better survival than uninfected lines. However the toxin it produces is unacceptable in New Zealand agriculture (Dr H.S. Easton, pers. com., 1993) because of associated animal health problems, namely fescue toxicosis of cattle which graze "wild" type fescue, heat stress or summer syndrome, (Idiopathic Bovine Hyperthermia) (Kearns, 1986) and the fescue foot syndrome (Anon, 1983, Fletcher et al., 1990).

Results from the current trial suggest that there is a trade off between acceptability to stock and plant persistence for tall fescue, similar to that described for perennial ryegrass (MacFarlane, 1990) for at least the establishment period. Other reports suggest that the longevity of tall fescue swards may face a similar threat to that of ryegrass which is uninfected by *Acremonium lolii* (Prestidge et al., 1989).

Seeding Rate

Tiller number per plant appeared to be somewhat static after an initial difference was achieved at 145 d.a.s. in the current trial eg. high vs low seeding rate (Figure 4.2.1.2). Brougham (1954a) recorded an increase in tiller number of broadcast autumn sown short-rotation ryegrass from 2.5 on the 8th August (136 d.a.s.) to 3.4 on the 20th October (198 d.a.s.) under grazing with sheep for a seeding rate of 53kgha^{-1}. In the current trial the average population of ryegrass and fescue was 63 plants m^{-1} row (Table 4.1.1.1), so on average, neighbouring plants were 16mm away. A seeding rate of 112kgha^{-1} in the context of Brougham's trial (short-rotation ryegrass, 70% field emergence) would be required to effect an average distance between plants of 16mm (if broadcast sown). Obviously it is not only the distance between plants in a row which controls growth, specifically tiller accumulation, because the average tiller number of ryegrass in the current trial was approximately 6-7 tillers in September-October (145-178 d.a.s.) (Figure 4.2.1.1) despite the fact that distance to nearest neighbouring plants was less than that for plants described from Brougham's trial sown at 53kgha^{-1}.

Estimated tiller density of fescue in the current trial was remarkably similar for high and low seeding rate treatments at 217 d.a.s. (3093 and 3080 tillers m^{-2}, respectively) but ryegrass tiller density at that time was slightly different (7414 and 5815 tillers m^{-2}, respectively). By 313 d.a.s. the difference in estimated tiller density (corrected for plant survival) for fescue had widened slightly to 4617 and 3653 tillers m^{-2} for high and low seeding rates, respectively and corresponding ryegrass tiller density remained steady at 7035 and 5901 tillers m^{-2}. Given the range in tiller number which may be expected for: (a) a ryegrass based dairy grazed pasture (3000-6000 tillers m^{-2}, L'Huillier, 1987), and (b) a 44 day growth period in summer for tall fescue of 3000-5100 tillers m^{-2}, (Sheehy and Peacock, 1977) and the inherent variation in tiller number (approximately $\pm$ 1 tiller per plant, Table A2.11, Appendix 2, or approximately 400-800 tillers m^{-2}), the calculated densities are unlikely to have been significantly different in terms of their influence on sward composition and herbage production.

Drilling Method

Drilling method had conflicting and variable effects on plant size (tiller and leaf number and extended height). The clearest contrast in in-row population was for 75 and 150mm row spacing comparisons (range 50 to 85 plants m^{-1} row). However, tiller number for fescue and ryegrass was not significantly different on any measurement occasion (Figure 4.2.1.4). Tiller number for fescue sown in 75mm and 150mm treatments was remarkably similar throughout the measurement period and yet 75mm row spacing had provided some advantage to sown species in terms of herbage mass (Table 4.1.5.2). Overall tiller number was inversely related to in-row population (Table 4.2.1.2). This relationship was consistent for both fescue and ryegrass from 178 to 313 d.a.s. but the difference was only significant at 178 and 217 d.a.s. and only for ryegrass. This was consistent with higher leaf number for ryegrass in 75mm rows compared with those in 150mm rows at those times (Table 4.2.1.5). The results for ryegrass infer that there may have been a size advantage to ryegrass plants from reducing row width, certainly in terms of leaf number and to a lesser extent tiller number at those times. Leaf number and tiller number for cross-drilled ryegrass plants were less than values for plants in 75mm rows at 217 d.a.s. (Table 4.2.1.4 and A2.4, Appendix 2, respectively) and were similar to values for plants in 150mm rows. As mentioned previously, the tiller number given by the average for plants at the two contrasting positions of the cross-drilled treatment was possibly less than the true average tiller number for the treatment. The inclusion of the plants at the intersection effectively reduced the average tiller number of plants in the cross drilling treatment to the extent that it was significantly less than plants in 75mm rows and that effect (which was significant for ryegrass only) was such that it was apparent in the overall results (Table A2.1, Appendix 2). Nonetheless, ryegrass plants at the 'between' position, the least populated of the two positions, had a similar number of tillers as those in 150mm rows (8.1 and 8.5 tillers per plant, respectively, Table A2.3, Appendix 2). So although narrower row spacing and the concomitant reduction in in-row plant population may have provided an advantage to ryegrass in 75mm rows in terms of plant size, the reduction in in-row population afforded by cross drilling did not.

Of the drill effects, 'position' had the most consistent effect on tiller number per plant. Plants at the intersection always had less tillers (and leaves) than those at the 'between' position in the cross-drilled treatment, and this difference appeared to become relatively larger as time progressed (Figure 4.2.1.3). Ryegrass plants at the 'between' position actually went against the trend of declining tiller number for ryegrass plants and increased from 8.1 at 217 d.a.s. to 9.1 at 313 d.a.s.. On the other hand, tiller number of those plants at the intersection of cross-drilled rows remained relatively static (6.7-7.1). The same trend occurred with fescue but to a greater extent (Table A2.3, Appendix 2). The plants at the intersection were not only in a more densely populated area but they were arranged differently in that they were surrounded by neighbouring plants, having a constriction in terms of space in at least two dimensions, whereas there was constriction in only one dimension for plants at the 'between' position. This was demonstrated by the fact that fescue plants at the intersection had fewer tillers than those in 150mm rows at 313 d.a.s. (Table A2.3, Appendix 2) although this was not the case for ryegrass plants.

The seeding rate x drilling method x species interaction at 313 d.a.s. showed a seeding rate effect on tiller number of cross-drilled plants of ryegrass (lower seed rate $\rightarrow$ more tillers) but no effect on those plants in 75 or 150mm row spacing and no drill and / or rate effect on fescue (Figure 4.2.1.6). The effect was consistent in that lower seeding rate increased tiller number and the effect had been indicated earlier at 275 d.a.s. although significant only at a lower level of probability at that stage (Fpr = 0.06, Table 4.2.1.2). Why this was only significant for the cross-drilled plants and only for ryegrass can not be explained.

The effect of drill method on tiller number of fescue plants was relatively consistent. Whereas extended height showed more variation in response to drilling method. Extended height of ryegrass was not influenced by drill method at any time. On the other hand, drill method appeared to influence extended height of fescue (Table 4.2.1.5). Fescue plants in 75mm rows at 178 d.a.s. had a greater extended height than those in 150mm or cross-drilled rows, which was consistent with the effects on extended height for fescue at 145 d.a.s. (Table 4.1.4.6). At 217 and 244 d.a.s. extended height of plants at 75mm and 150mm row spacing was similar, but cross-drilled plants alternated from less extended height at 217 d.a.s. to more at 244 d.a.s.. Interestingly, at 244 d.a.s. there was a greater extended height for cross-drilled fescue plants as compared with 75 and 150mm rows which coincided with a tendency for lower leaf number, so leaves were longer but there were less of them. The importance of drill effects on plant size will be discussed further in relation to herbage mass and composition in Section 4.2.2.3.

The position effect was the most consistent C-D effect on plant size (tiller and leaf number) for the tiller measurement period, but extended height was never different for contrasting positions (Table A2.5, Appendix 1, Table 4.2.1.3). Thus extended height was independent of density within a population of plants. This has been previously recorded and was termed 'co-operative' competitive interaction by Hozumi et al. (1955) and Yoda et al. (1957). Those authors indicated that equalisation of plant height in a population occurs through elongation responses induced by shading between neighbouring plants as they grow. The relative skewness of tiller, leaf and extended height were consistent with the above result. The frequency distributions for extended height tended to be less skewed than corresponding frequency distribution for tiller number and leaf number at each occasion when tagged plants were measured (Table A2.25, Appendix 2). A similar result was reported by Harris (1971) who showed that tiller length frequency distributions of simulated ryegrass populations were less skewed than the corresponding frequency distribution of plant weight and tiller number. The only deviation from that trend found in the current trial occurred at 26 d.a.s. when leaf number was more negatively skewed than extended height.

Plant Survival

Species

Plant persistence is the fundamental goal of the grazier establishing a new pasture and is reliant on the survival and maintenance of a productive population of sown species. Generally, major changes in plant population occur during the first year in the life of a pasture where they have been established by either conventional means (Charles, 1961; Kunelius et al., 1982) or by direct drilling (Thom et al., 1986a,b&c, 1993; Bellotti and Blair, 1989c). High survival rates were recorded in the current trial, where 88% of fescue plants and 92% of ryegrass plants which were tagged at 43 d.a.s., survived until 313 d.a.s. (Table A2.12, Appendix 2). This compares favourably with previous reports for direct drilled ryegrass where survival from sowing until 300 d.a.s. ranged from 18% to 70% (Kunelius et al., 1982; Bellotti and Blair, 1989c; Thom et al., 1993) and with ryegrass sown in spring by conventional means (25% to

50% Charles (1961) and Kunelius et al. (1982), respectively). The result is similar to that reported by Kruez (1969) where 10% of an initial stand density of 961 perennial ryegrass plants m^{-2} and 20% of meadow fescue (*Festuca pratensis* Huds) plants died in the first 18 months after establishment by conventional cultivation in the autumn in Germany.

Two basic factors are involved in the loss of emerged plants early in the life of a sward, irrespective of establishment method; (i) competition for moisture, nutrients and light amongst sown species (Charles, 1961; Bellotti and Blair, 1989c), and between sown species and spontaneously occurring grass and broadleaf weeds which germinate from the soil seed bank (Cullen and Meeklah, 1959; Hallgren, 1976a; Thom et al., 1986d, 1993), (ii) damage caused by stock grazing termed 'animal effects' by Thom et al. (1986a), also reported by Brock (1982) and Prestidge et al. (1989). A third factor, more prevalent in uncultivated seedbeds than cultivated seedbeds, is that of insect damage (Pottinger, 1979; Ritchie, 1986b; Barker, 1987; McCallum and Thomson, 1990). All three factors were identified as having caused plant mortality in the current trial (Table 4.2.1.6) but at a level that seems to have been minimal. 'Animal effects' were responsible for 26 and 14% of total ryegrass and fescue losses, respectively in the current trial which is similar to the results reported by Thom et al. (1986d). The other 74 to 86% of losses were most likely caused by a combination of insect damage and competitive stress in fescue and competitive stress in ryegrass.

In the current trial, obvious insect damage was found only in the fescue sward where 11% of plant deaths were directly attributable to Argentine stem weevil larvae feeding. Insect damage was therefore considered only a minor factor directly involved in overall plant deaths, but may have been a co-factor by weakening fescue plants and rendering them more susceptible to the competition they faced from neighbouring fescue plants or other species (loss categories 5 & 6, Table 4.2.1.6) (Prestidge et al., 1989). Animal effects accounted for 14% of fescue losses either from dung deposition or trampling. None were 'pulled' from the soil by grazing cattle. Only two ryegrass plants, less than 4% of total losses, were physically removed by the grazing cattle or pulled. Fescue has been reported to be more susceptible to 'pulling' than ryegrass because of its relatively slower developing root system and erect habit, and that major losses of plants can easily result (Brock, 1982; Brock et al., 1982). There is some latitude in the recommendations given for grazing fescue in the establishment year. Brock (1983) and Hume and Fraser (1985) suggested that tall fescue could not be grazed in a similar manner to ryegrass during establishment. They recommended lax defoliation (preferably cutting) to allow a strong root system to develop and that grazing should be delayed until the following winter unless young stock were used to give a light grazing in the first season. At that stage experience with tall fescue establishment was limited to cultivated seedbeds, and Brock's recommendations were based mainly on personal communication with B.R. Watkin who apparently observed 'pulling' with tall fescue at first grazing. Later reports confirmed fescue's susceptibility to 'pulling' (Prestidge et al., 1989), also from cultivated seedbeds, despite this, established swards were formed in summer. In an article relating field experience with new pasture cultivars in Canterbury, MacFarlane (1990) considered that tall fescue plants should not be grazed until well established, and then grazed laxly for 6-9 months after establishment. On the other hand, Thom et al., (1985) favoured long intervals (30 days) between intensive rather than lax grazing in conjunction with mowing to maintain a relatively intense defoliation over the establishment period. Results from the current trial concur with the latter recommendations. The retention of soil structure and density of the uncultivated seedbed in the current trial may have afforded a more secure medium for grass plant root anchorage than that provided by a cultivated seedbed as experienced by Brock (1983) which may in turn affect grazing management considerations.

There are few detailed accounts of seedling growth and survival of direct drilled tall fescue and no directly comparable results for establishing direct drilled fescue under grazing. Where plant survival of 'Grasslands Nui' perennial ryegrass established by either conventional means or direct drilling was directly compared under a sheep grazing regime, proportionately less seedlings survived in the cultivated than the direct drilled treatment after a spring sowing (Kunelius et al., 1982). However, those two treatments were not strictly comparable as they started out with almost a 3 fold difference in population and the surviving population of the latter treatment was less than the former at 140 days (approximately 80 and 190 plants m^{-2}). Surviving ryegrass seedlings in both treatments had approximately 10 tillers per plant and weighed around 1g at 140 d.a.s. which is higher than for the current trial (8 tillers and 0.255 gm at 145 and 135 d.a.s., respectively). This is not surprising considering the comparatively low population in the trial of Kunelius et al. (1982) (80-190 compared with 480-814) and comparatively higher temperatures and fertility resulting in higher growth rates from October to January. Seedling mortality was considered a function of competition amongst sown species and with weeds which emerged after cultivation or spraying, rather than pests and diseases, but no mention was made of animal effects on plant survival. Bellotti (1984) also compared survival of fescue and ryegrass established by either direct drilling or conventional cultivation but in the absence of grazing animals (the trial was mown to a height of 5cm when dry matter was greater than 2000 $kgha^{-1}$). By 350 d.a.s. survival of fescue plants which had emerged at 50 d.a.s. was similar (24-30% for cultivated and direct drilled treatments) but more ryegrass plants survived in the cultivated treatment (23 vs 33%, Table 1 of Bellotti and Blair, 1989c). No reasons were apparent as to why that may have occurred but the difference was probably not important considering the low overall survival rate.

Competitive stress was considered the dominant cause of plant loss in the current trial (Table 4.2.1.6). The pattern of variation in distribution of tiller number confirmed this to some extent. Specifically, the distribution of fescue tiller number per plant, sown at the high rate, became more symmetrical with the death of a number of individuals which had comparatively less tillers between 217 and 244 d.a.s. (Figure 4.2.1.8). This is consistent with the result reported by Bellotti (1984). He demonstrated that competitive stress experienced by seedling cohorts was the main cause of plant death as illustrated by trends in relative skewness (Figure 3 of Bellotti and Blair, 1989c). Plants were considerably smaller in Bellotti's trial as compared with the current trial (4.8 and 1.8 tillers for ryegrass and fescue, respectively at 250 d.a.s. cf 8.3 and 4.7 tillers at 244 d.a.s. in the current trial), populations were lower (eg. approximately 150-250 and 60-150 plants m^{-2} at 150 d.a.s.), and the climate was colder and drier. Nonetheless, relative skewness of the distribution of plant size index became more positive over time from a common figure at 50 d.a.s. for eight sowing methods ranging from aerial sowing to a cultivated seedbed. Treatments with the highest competitive stress from resident vegetation (overdrilling) in both fescue and ryegrass had the highest relative skewness, which peaked at about 100 d.a.s.. Frequency distribution changed from skewed to symmetrical distributions as the smaller, suppressed individuals died and larger, dominant individuals survived. Results from both Kunelius et al. (1982) and Bellotti and Blair (1989c) suggest that competition between plants is the major determinant of plant survival in both cultivated and direct drilled swards. However they did not indicate the relative impact of the grazing animal on developing fescue and ryegrass swards established by either method.

The major difference between the pattern of variation in skewness between the current trial and Bellotti's 1984 trial is the length of time over which the changes occurred. In Bellotti's trial skewness increased and decreased over a 200 day period but in the current trial increased symmetry of plant size distribution (tiller number) for a population in which plant death had occurred was only apparent briefly at 244 d.a.s. before the population returned to what was a permanent state of positive skewness for distribution of tiller number for the measurement period. This may be because in Bellotti's trial a much larger range in tiller number and plant mortality (up to 100%) occurred between treatments, and overall growth was slower as mentioned previously.

On the basis of the results from the current trial in comparison with results from Brock (1982), direct drilling of fescue would seem to have provided an advantage over cultivated seedbeds in terms of root anchorage, but no direct comparison was carried out. This suggestion is supported by results from Kunelius et al. (1982) where a higher proportion of ryegrass plants survived under direct drilling than under cultivation. However, that is not to say plant pulling is altogether avoided by direct drilling. Thom et al. (1986a,b&c) and Thom et al. (1993) made several detailed studies of the growth and survival of ryegrass plants introduced by either overdrilling, transplanting seedlings or direct drilling into dairy pastures containing paspalum at Hamilton in the Waikato. From a series of experiments from 1978 to 1990 they found that generally irrespective of establishment method, practically half of all introduced ryegrass plants disappeared in the first year. Thom et al (1986d) reported that 20% of total losses were directly attributable to damage caused by cow grazing. In one trial (Thom et al., 1986c) where animal related plant losses were high (51% of total losses), 11% of those losses were attributed to 'pulling' and plant pulling was generally considered a significant factor responsible for the loss of plants (Thom et al., 1986a,b&c).

In the current trial, of the 576 plants which were tagged at 43 d.a.s., only two were 'pulled'. On that basis plant pulling was not considered a significant problem. The relatively higher incidence of pulling reported by Thom and his co-workers may be related to soil type. The soils on which Thom and his co-workers ran their experiments ranged from well drained Bruntwood silt loams (Aquic Dystrandept) to imperfectly drained Te Kowhai silt loams (Aquic Andaquept), both of which are derived from alluvially deposited pumiceous sands. Flooding was less frequent than on the soil type used in the current trial. The topsoils (0-200mm) of the Bruntwood and Te Kowhai silt loams have been described as moderately weak (Singleton. 1981) whereas the Manawatu fine sandy loam is described as having moderately-developed blocky structure (Clothier, 1977). Thom et al. (1986d) stated that the mechanisms accounting for balance of plant losses (80%) were less easy to quantify but were related to competition for light, water and nutrients, climatic stresses and subtle animal damage to plant growth points, leaves and roots which is in line with the conclusions of Bellotti and Blair (1989c) and Kunelius et al. (1982).

A triple disc opener was used for most of Thom et al.'s experiments (Thom et al. 1986a,b&c,1993). That opener has been shown to create a seed groove which may restrict root development more than the groove made by the inverted T opener used in the current experiment (Baker and Mai, 1982). However, plant losses were similar where triple disc and inverted T openers were compared (Thom et al. 1986a), indicating that the generally different opener type between Thom et al.'s (loc cit) and the current trial was not responsible for the comparatively lower plant loss recorded for the current trial.

Susceptibility to 'pulling' has also been reported for established tall fescue plants in the Waikato, New Zealand (Prestidge et al., 1989). A higher incidence of Argentine stem weevil damage was found in fescue plants which were 'pulled' by dairy cows grazing over summer than 'unpulled' plants. However, 'pulled' plants were sampled for only 3 of the 13 sites surveyed by Prestidge et al. (loc cit), they did not mention whether or not 'pulling' was apparent at their other sites but the sites where 'pulled' plants were drawn from had less structured soils (peat) than that of the current trial. All the swards in their survey were established by cultivation in the autumn but the level of soil disturbance at sowing is unlikely to have affected soil density and presumably root anchorage by the following summer (Francis et al., 1987) when 'pulling' was noted.

Grazing interval is also an important factor in plant survival (Thom et al., 1986c&d). Thom et al. (loc cit) demonstrated that plant losses were always highest (30-40% of total) in the summer following their introduction by transplanting and overdrilling. A short grazing interval (14 day) over summer caused more plant mortality as compared with a long interval (28 day) and losses were further increased by the presence of summer growing paspalum competing with introduced ryegrass (Thom et al., 1986c). In a later trial, half of the 800 ryegrass plants established by direct drilling in autumn were lost in the first year after drilling (Thom et al., 1993), most (approximately 80% of total losses) were lost during the warm season (December to April). In fact all of the experiments of Thom et al. (1986a,b&c, 1993) suggested that it was a combination of dry, hot conditions (25-35 days with daily screen maximum temperatures over 25°C) and grazing pressure which led to the loss of plants with less than 10 tillers going into the summer, although in one trial, irrigation over summer did not improve survival of introduced plants because the resident species, namely paspalum, also responded to watering. The same factors featured in the current trial (ie summer conditions and grazing cows), but the magnitude of those factors was less in comparison with the experiments of Thom et al. (1986a,b&c, 1993). The most appropriate comparison to the current trial was provided by Thom et al.'s 1993 experiment. Grazing interval from November to February in the current trial was 32 days for both fescue and ryegrass which was longer in comparison with 15 to 35 days in spring / summer in their trial; pre and post-grazing herbage mass was greater for ryegrass (average 3557 and 2532kgDM ha^{-1} vs 1600-1700 and 2900-3000kgDM ha^{-1}, respectively) and temperatures were cooler (above 25°C on 7 days during November to February) but rainfall was similar (398mm). Ninety three percent of ryegrass plants survived until February in the current trial (Table A2.12, Appendix 2) whereas Thom et al. (loc cit) recorded approximately 70% survival to February of the first summer. This finding may have been related to the comparatively lax grazing regime for ryegrass during the first summer of the current trial .

Grazing of fescue was more intense than for ryegrass in the current trial because of preferential grazing of fescue. Post-grazing herbage mass was lower (average 1825 vs 2532kgDM ha^{-1} for fescue and ryegrass, respectively) from December to February (Table 2.32, Appendix 2).

However, this was not thought to be responsible for the higher loss of fescue plants because losses associated with animal effects were the same (2% of tagged plants) and no fescue plants were pulled. Fescue was grazed in preference to ryegrass because there was more (50% of total herbage mass) dead material in the ryegrass than in the fescue sward (35%) at 278 d.a.s. (January) (Table A2.29, Appendix 2). Also fescue had a higher white clover content (25% of live herbage) than ryegrass at 278 d.a.s. (10%) which would have improved palatability. The greater amount of dead material was a consequence of relatively poor grazing of ryegrass in December (post-grazing herbage mass 2655 and 2022kgDM ha^{-1} for ryegrass and fescue, respectively) and crown rust (*Puccinia coronata*) infection in the ryegrass whereas rust was not a noticeable problem in the fescue sward. Increased dead matter in 'Grasslands Ruanui' perennial ryegrass as compared with 'Grasslands Roa' tall fescue during summer as a result of rust-affected ryegrass has been previously noted by Brock (1982).

Estimates for plant density of a ryegrass based pasture range from 123-175 plants m^{-2} where simulated swards have been established (Harris, 1971; Harris and Sedcole, 1974) to 277 plants m^{-2} for optimal stand density at establishment at which plant mortality would be minimised (Kreuz 1969), to 400 plants m^{-2} for 'normal' pasture conditions (Hill and Shimamoto, 1973). Thom et al. (1993) showed that plant density of direct drilled perennial ryegrass declined from 800+ plants m^{-2} three months after drilling down to approximately 400 plants m^{-2} one year after drilling. So more plant mortality would be expected in the current trial especially for plants sown at the high rate where initial populations (May) of fescue and ryegrass were approximately 800 plants m^{-2}, and were down to approximately 700 plants m^{-2} at 313 d.a.s. (February).

Recording of tagged plants for tiller number was discontinued after 313 d.a.s. because in order to determine tiller number per plant considerable interference and modification of the immediate environment around the plants was occurring during the measurement procedure and it was thought that this might have 'released' the plant from immediate competition. This was especially so for plants at the intersection of cross-drilled rows where they were nestled in amongst other plants as opposed to being exposed on two sides as they were in rows for 'between', 75mm and 150mm row spacing plants. Soil divots 150mm long were dug from drill rows at 200 d.a.s. and taken back to the laboratory for separation into individual plants. This should have allowed a check on the validity of data for survival of tagged plants. However, it was found that by that stage plants in a row were not distinguishable from one and other and so this was impractical. As seeding rate and drilling method treatments had produced few significant effects on plant size, and herbage mass and composition, discontinuing individual plant measurements was not considered a major disadvantage at that stage. Observations made during sampling of post-graze herbage mass at grazings subsequent to 315 d.a.s. suggested that no noticeable plant 'pulling' occurred for the remainder of the trial.

Seeding Rate / Drilling Method

Aside from species, seeding rate provided the most consistent effect on plant survival. Higher plant losses were associated with higher seeding rate, suggesting that larger plants had a greater ability to survive stress (grazing and competitive) than did smaller plants in an establishing sward. This finding was consistent across species in the current trial and concurs with those of Hoen (1968), Harris et al. (1973) and Thom et al. (1986d). However, the density effect on plant survival was not wholly consistent across treatments as evidenced by the fact that there was no suggestion of higher mortality at the more densely populated intersection region of the cross drilled rows (Table A2.20, Appendix 2). This was despite the fact that skewness of tiller number was consistently more positive, and tiller number was lower, for plants which occurred at the intersection of cross-drilled rows than those between the intersection of cross-drilled rows (Table 4.2.1.8 and Figure 4.2.1.3, respectively). Also, higher plant losses were associated with 75mm row spacing and cross-drilled treatments which had lower in-row populations than 150mm rows (Table 4.2.1.7) and no relationship was found between in-row population and percentage plants remaining (Table A2.23, Appendix 2). Another factor which suggests that drill method did not influence plant survival was that drill method effects were inconsistent; (a) across species and (b) with the overall seeding rate effect which was consistent across species. The disparity between overall seeding rate effects and the effects of position and drill method indicate that as for the early determination of plant size (ie. to 145 d.a.s.), population on an area basis had more influence on plant survival than in-row population and plant spatial arrangement in the range of 75mm to 150mm row spacing and cross-drilling.

Skewness

Skewness of distribution of plant characteristics other than tiller number (eg. leaf number, extended height, Till X Lf, Till X Hgt and Lf X Hgt indices) were tested. However, in the populations under consideration, they did not provide a better indicator of stress than the skewness of the individual plant parameter. This finding is in contrast to those of Harris (1971) and Bellotti and Blair (1987) who demonstrated otherwise. The difference in the findings is most likely related to the random effects of grazing pressure within a sward caused by the grazing animal with the resultant variation in plant size that is not likely to be related to population density but more likely related to diet selection. The swards on which Harris (1971) and Bellotti and Blair (1987) reported were under a cutting regime where defoliation of individual plants was relatively homogeneous as compared with random defoliation by grazing animals in the current trial. Also plant populations were lower in the experiments of Harris

(1971) (initially 175 equidistant plants m^{-2}, in spring at Palmerston North) and Bellotti and Blair (1987) (60-250 plants m^{-2} at 150 d.a.s.). Plant spatial arrangement ranged from broadcast to drill rows in the experiment reported by Bellotti and Blair (1989c) and growth was generally slower than for the current trial. Changes in population structure were more likely to occur over a shorter time in the intensely competitive situation of plants confined to rows under good growing conditions in the current trial than in the experiment reported by Bellotti and Blair (1987).

The distribution of tiller number was more positively skewed in ryegrass than fescue (Table A2.13, Appendix 2), although this did not correspond with the higher plant mortality recorded for the fescue sward. This was not surprising considering that the structure of those pasture species was different with fescue being a more coarse plant and having fewer, larger tillers than ryegrass. For this reason Bellotti (1984) noted that skewness of ryegrass and fescue swards was not directly comparable.

On the basis of the fact that 'position' provided a contrast in skewness of tiller distribution for plants in the cross-drilled sward (Table 4.2.1.8) and the distribution of tiller number tended to become more positively skewed with increasing population in the ryegrass sward (Table 4.2.1.9), it would be reasonable to expect that seeding rate would also provide a contrast in skewness at least in the ryegrass sward. However, that was not the case. Populations of perennial grass plants operated independently of seeding rate in this regard as populations sown at both high and low seeding rate were similarly, positively skewed (Table A2.17, Appendix 2) except when significant plant death occurred between 217 and 244 d.a.s. in the fescue sward sown at the high rate (Table A2.16, Appendix 2).

4.2.2 Herbage Botanical Composition and Mass from 145 to 314 d.a.s.

4.2.2.1 Introduction

Grazing in October and November took place over six-day periods with the equivalent of 400, 17 month heifers ha^{-1} (183 and 221 d.a.s.) to achieve a close defoliation. The trial area was subsequently grazed with 250 milking cows (150 cows ha^{-1} equivalent) within a 24 hour period in December (246 d.a.s.) which was considered to be the beginning of the production phase in terms of herbage production. The trial area was continually monitored and treated as another paddock in the grazing rotation of the milking herd. Further grazings with the milking herd took place in January and February (278 and 315 d.a.s., respectively).

All plots were mechanically harvested at 182 d.a.s. to determine herbage accumulation for a 40 day period. Botanical composition and herbage mass of the sward was assessed at 219 (November) and 278 d.a.s. (January). Areas affected by urine deposition became obvious during winter and spring. These were also assessed for composition and mass of herbage at 150 and 182 d.a.s..

4.2.2.2 Results

4.2.2.2.1 Accumulation of Herbage Mass for a 40 day Period from August to October

Table 4.2.2.1 describes the effect of species, seeding rate and drilling method on herbage accumulation between 31 August (139 d.a.s.) and 11 October (182 d.a.s.). There were no significant main treatment effects on herbage accumulation. Herbage mass (total herbage above ground level) at the time of harvest for adjacent headland areas was approximately 1800 to 1850 kgDM ha^{-1} (Table A2.33, Appendix 2). Considering that drill methods and seeding rate had little or no impact on herbage accumulation, this would have been similar to the herbage mass on plot areas as the headland was sown in 150mm rows at an intermediate seeding rate to that sown on plots for each species.

There were no interactions between main treatment effects but individual analysis of species showed a drill effect for fescue (Table 4.2.2.2) which was consistent with fescue sown species yield at 150 d.a.s. (Table 4.1.5.3) but was significant only at a lower level of probability. Herbage accumulation was greater from 75mm rows than 150mm rows. Herbage accumulation from cross-drilled rows was intermediate between the other drill treatments but not different from either. Ryegrass once again showed no response to drilling method which also corresponds to the results from 150 d.a.s..

Table 4.2.2.1 Effect of Species, Seeding Rate and Drill Method on Accumulation of Herbage Mass for a 40 day Period in the First Spring After Sowing.

		Herbage Mass (kgDM ha^{-1})
SPECIES	**Fescue**	770
	Ryegrass	844
	S.E.D. ±	173
	Significance	n.s.
SEEDING RATE	**High**	810
	Low	804
	S.E.D. ±	51
	Significance	n.s.
DRILL METHOD	**75 mm row**	879
	Cross drill	798
	150 mm row	744
	S.E.D. ±	63
	Significance	n.s.

Table 4.2.2.2 Effect of Drilling Method on Accumulation of Herbage Mass of Fescue and Ryegrass for a 40 day Period in the First Spring After Sowing

		FESCUE	RYEGRASS
Drill Method	**75 mm**	905 a	852
	Cross Drill	744 ab	853
	150 mm	660 b	828
S.E.D. ±		100	77
Significance		(*) (Fpr =0.063)	n.s.

4.2.2.2.2 Overall Species, Seeding Rate and Drilling Method Effects at 219 d.a.s.

Table 4.2.2.3 describes the overall species, seeding rate and drilling method effects on the proportions and mass of sown species, clover and unsown species at 219 d.a.s.. The total mass of live herbage was not different for ryegrass and fescue at 219 d.a.s.. Clover and unsown species replaced the sown species component of the herbage mass in the fescue sward. As for 150 d.a.s., the increase in unsown component came from broadleaved weeds rather than grass weeds (Table A2.27, Appendix 2).

Table 4.2.2.3 Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 219 d.a.s. (21-11-90)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	37	22	37	1288	866	1273	3427
Ryegrass	71	11	18	2768	416	678	3862
S.E.D. ±	4.1	2.3	3.1	251	63	126	270
Significance	* * *	* *	* *	* *	* * *	* *	n.s.
SEEDING RATE							
High	55	21	24	2025	696	840	3560
Low	53	16	31	2032	586	1110	3729
S.E.D. ±	3.1	2.1	2.7	157	80	98	129
Significance	n.s.	*	*	n.s.	n.s.	* *	n.s.
DRILLING METHOD							
75 mm row	54	17	28	2093	613	1000	3707
Cross drill	54	18	28	2057	641	1001	3699
150 mm row	53	20	27	1935	669	924	3528
S.E.D. ±	3.8	2.6	3.3	192	98	120	158
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

The effect of seeding rate is described in the next section as there was a species x seeding rate interaction. Drilling method did not influence mass or composition of herbage of combined, or individual species at 219 d.a.s.. There were no species x drilling method or seeding rate x drilling method interactions at 219 d.a.s.. The effect of drilling method on herbage mass of sown species in the fescue and ryegrass swards is shown in appendices for completeness (Table A2.30, Appendix 2) because of the apparent response of ryegrass leaf number to drilling method at 217 d.a.s. (Table 4.2.1.3).

4.2.2.2.3 Interactive Effect of Seeding Rate and Species on the Proportion of Unsown Species

There was a species x seeding rate interaction in the proportion of unsown species at 219 d.a.s.. Table 4.2.2.4 describes the effect of seeding rate on the proportions and mass of sown species, clover and unsown species in fescue and ryegrass swards at 219 d.a.s.. Seeding rate did not influence the composition of herbage mass in the ryegrass sward but did have an influence in the fescue sward. The proportion of unsown species was higher where fescue was sown at the low rate. This coincided with a reduction in the proportion of clover although this effect was only significant at the lower order of probability (10%). Mass of sown species and clover was not significantly different but did tend to be depressed at the low seed rate which was consistent with the significant increase in the mass of unsown species (Table 4.2.2.4). The influence of seeding rate on fescue was such that it appeared to be an overall seeding rate effect (Table 4.2.2.3).

Table 4.2.2.4 Effect of Seeding Rate on Herbage Composition and Mass in Fescue and Ryegrass at 219 d.a.s. (21/11/90)

		Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
	Sowing Rate	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total Liv
FESCUE	**High**	40	28 a	31 a	1396	954	1064	3414
	Low	34	22 b	43 b	1181	778	1482	3441
S.E.D. ±		4.3	3.5	4.5	156	126	168	134
Significance		n.s.	(*)	*	n.s.	n.s.	*	n.s.
RYEGRASS	**High**	70	12 c	17 c	2653	437	617	3707
	Low	71	10 c	19 c	2884	395	739	4018
S.E.D. ±		4.4	2.5	3	272	97	99	221
Significance		n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Species X	S.E.D. ±	5.1	3.4	4.1	296	101	159	299
Rate Interaction	Significance	n.s.	(*)	(*)	n.s.	n.s.	n.s.	n.s.

4.2.2.2.4 Overall Species, Seeding Rate and Drilling Method Effects at 278 d.a.s.

Table 4.2.2.5 describes the overall species, seeding rate and drilling method effects on the proportions and mass of sown species, clover and unsown species at 278 d.a.s.. The proportion and mass of sown species was again higher for ryegrass than for fescue. Fescue had more clover and unsown species in the sward than ryegrass. Broadleaf weeds were still the dominant unsown species in the fescue sward, evidenced by the significant species effect for the 'Weed' category of unsown species (Table A2.29, Appendix 2) compared with no species effect on the other components of unsown species. Ryegrass had more dead material present in the herbage mass than fescue. Approximately 50% of the 3438kgDM ha^{-1} of ryegrass sward was dead material compared with 30% of the 3011kgDM ha^{-1} fescue sward (Table A2.29, Appendix 2).

Table 4.2.2.5 Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 278 d.a.s. (20-1-91)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	54	25	20	1060	473	406	1904
Ryegrass	80	10	9	1360	176	166	1702
S.E.D. ±	3.9	4.1	2.2	149	82	68	171
Significance	* * *	*	* *	(*)	*	*	n.s.
SEEDING RATE							
High	68	18	13	1210	337	261	1807
Low	66	18	16	1211	313	311	1835
S.E.D. ±	3.0	2.7	2.4	102	59	56	119
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DRILLING METHOD							
75 mm row	69	15	16	1313	306	333	1951
Cross drill	67	20	12	1213	339	233	1786
150 mm row	65	18	16	1105	330	291	1726
S.E.D. ±	3.7	3.3	2.9	125	72	68	146
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Seeding rate and drilling method had no significant effect on botanical composition or mass at 278 d.a.s.. There were no main treatment interactions. There was an indication of a continuation of the drilling method effect on the mass of sown species in the fescue sward at 278 d.a.s. (Table A2.31, Appendix 2). The mass of sown species from 75mm rows may have been greater than that of cross-drilled rows and 150mm rows but the effect was only significant at a low order of probability (Fpr = 0.104). No drilling method effects on sown species were apparent in the ryegrass sward.

4.2.2.2.5 Effects of Urine Deposition

Urine-affected Areas

Areas subject to urine deposition were very distinct as they were darker green and had far greater herbage mass than unaffected areas after the grazings which occurred at 55 and 150 d.a.s.. Nitrogen application was not included as a treatment in this trial. The urine affected areas may be seen as representative of an exceptionally large application of mineral nitrogen (c. 500kgN ha^{-1}; Saunders, 1984) and potassium (1000 kgK ha^{-1}; loc cit). Estimates of the amount of nitrogen applied range from 484kgN ha^{-1} for sheep to 970kgN ha^{-1} for cattle (Steele, 1982). Nitrogen and potassium application via urine deposition clearly had an impact on the establishing sward and may be indicative of the effect of such a fertility treatment, albeit an extraordinarily large treatment, and on that basis affected and unaffected areas were sampled.

Both affected and unaffected areas of the headland, which were sown in 150mm rows, at a median rate to that of the high and low seeding rate treatments of plot areas, were assessed in the same manner as herbage mass and botanical composition for trial areas (ie. quadrat cuts, three per block for both affected and unaffected areas). Headland areas of ryegrass were sampled at 150 d.a.s. and from fescue and ryegrass at 182 d.a.s..

The effect of urine deposition on herbage mass and composition for ryegrass at 150 d.a.s. is shown in Appendix 2 (Table A2.34 and A2.35) and for ryegrass and fescue at 182 d.a.s. in Table 4.2.2.6. Mass of sown species in affected areas was more than twice that of unaffected areas (Tables A2.34, 4.2.2.6). The mass of unsown species was also increased, due to an increase in grass weeds, mainly *Poa annua* in the ryegrass sward and broadleaf weeds in the fescue sward (Table A2.33, Appendix 2). The proportion of sown species increased in urine-affected areas in ryegrass at 182 d.a.s. with a concomitant reduction in the proportion of the clover component (Table 4.2.2.6).

Table 4.2.2.6 Effect of Urine Deposition on Herbage Mass and Composition of Fescue and Ryegrass at 182 d.a.s.

		Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
		% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
FESCUE	**Unaffected**	35	18	47	531	262	700	1493
	Affected	39	12	49	1276	395	1706	3377
	S.E.D. ±	5	6	7	83	120	271	206
	Significance	n.s.	n.s.	n.s.	***	n.s.	***	***
	Unaffected	64	9	26	1008	136	403	1548
RYEGRASS	**Affected**	74	4	22	2838	142	769	3749
	S.E.D. ±	4	2	4	433	61	103	379
	Significance	**	**	n.s.	***	n.s.	***	***

4.2.2.3 Discussion

The affect of urine deposition, being an unscheduled treatment is discussed first followed by the main treatment affects.

Urine-affected Areas

Nitrogen and potassium application via urine deposition did not reduce the proportion of unsown species in the ryegrass sward (Table 4.2.2.6). Grass weeds also responded to urine application in the ryegrass sward. Other workers have also reported increases in *Poa* spp in ryegrass / white clover based pastures treated with nitrogen (Ball and Field, 1982; Thom et al, 1986b). However, urine deposition increased the proportion of sown species (ryegrass) at the expense of the clover component which is consistent with the well documented evidence for depression of the clover component in the sward in pastures treated with nitrogen (Vallis, 1978; Ball and Field., 1982) and more specifically for urine infected areas (Saunders, 1984). Fescue also showed the same trend although differences were not significant.

The broadleaf weed component of the fescue sward showed a massive response to urine deposition. The mass of sown species showed a two fold increase from 530 to 1270kgDM ha^{-1}, but broadleaf weeds increased more than three fold from 287 to 1006kgDM ha^{-1} while the mass of weed grasses and clover showed no significant increase (Table A2.33, Appendix 2). This indicates that not only the grass weed component of an establishing pasture sward responds to applications of nitrogen and potassium. The effect is consistent with the interaction between drilling method and species on unsown species, principally the broadleaf component, at 150 d.a.s. (Section 4.1.5.2.3). The sown species of the fescue sward was depressed by broadleaf weeds in the cross-drilled treatment and indicates that the broadleaf weed component had a greater influence in the establishing fescue sward than in the ryegrass sward.

Thus urine, or nitrogen and potassium (N/P) application changed the grass / clover balance of the sward in favour of grass species, but did not affect the contribution from unsown species, indicating that although large amounts of broadcast fertiliser N and P may increase herbage mass it may not improve the relative contribution or survival of sown species. Further suppression of clover from already low levels in the ryegrass sward (< 10%) may result from application of N and P in the developing sward.

Species

Ryegrass

The competitive influence of ryegrass on pasture composition during establishment was clearly demonstrated in the current trial. Fescue clearly had a higher proportion of weeds and white clover which highlights the suppressive nature of ryegrass on companion and unsown species and the poor competitive ability of fescue during establishment. This finding supports those of Charles (1965), Anderson (1982), Anderson et al. (1982), Brock (1982, 1983), Lancashire and

Brock (1983) and Hill (1985).

The content of sown species in the ryegrass sward was consistently high (71-80% of live herbage) from June to February (55 to 278 d.a.s.) which is similar to that reported by Thom et al. (1993) for the establishment year of autumn direct drilled perennial ryegrass in the Waikato and for ryegrass established by conventional cultivation in the autumn Brougham (1954a,c) and in the spring (Kunelius et al., 1982) at Palmerston North. White clover content increased from 3-4% at 55-150 d.a.s. during winter / early spring to 10% of live herbage in November and February (219 and 278 d.a.s., Tables 4.2.2.3 and 5, respectively). This is lower than the clover content reported by Thom et al. (1993) where clover content was 6% of dry matter (DM) in October and increased to 17-21% of DM in December to February. Similar populations of white clover were established in the experiment of Thom et al. (1993) and in the current trial. More frequent and harder grazing in Thom et al.'s experiment most likely encouraged clover growth to a greater extent than the less frequent and laxer grazing in the current trial from November to February. Death of clover seedlings is caused by competition for light (Sears, 1953; Brougham, 1954b, 1959). More frequent grazing (eg. graze at 75 to 100mm rather than at 150 to 175mm) improves light penetration to clover seedlings in the base of the sward and encourages clover growth (Sears, 1950, 1953; Brougham, 1954b; Harris et al., 1973). The difference may also be related to the clover cultivar used in the respective trials. 'Grasslands Pitau' white clover, sown in the current trial has been shown to produce less herbage during summer than 'Grasslands Kopu', a larger leaved more upright growing clover (Van den Bosch et al., 1985; West and Steele, 1985), which was sown by Thom et al. (1993).

There was a higher content of unsown species in the current trial during the initial stages than reported by Thom et al. (1993). Up to 31% of live herbage (26% of DM) of the ryegrass sward of the current trial consisted of unsown species at 150 d.a.s., 18% (14% of DM) in November (219 d.a.s.) but only 4% of DM by February. Thom et al. (loc cit) stated that "*Poa* spp. prairie grass, other grass and weeds were always less than 10% of DM". The higher weed burden in the current trial may have been a result of a higher buried weed seed population because of more regular flooding of the trial area as evidenced by the higher than usual population of weeds found in the current trial (average of 625 total unsown species m^{-2} in fescue and ryegrass plots, Table 4.1.2.1).

Sown species made an increasing contribution to the fescue sward towards the later half of the establishment year (37 up to 54% of live herbage) with a concomitant reduction in unsown species from 51% to 20% of live herbage. Clover content increased from 9% in September (150 d.a.s., Table 4.1.5.2) to 22% in November (219 d.a.s., Table 4.2.2.3) and up to 25% in February (278 d.a.s., Table 4.2.2.5). Mass of clover in the fescue sward was always more than double that in ryegrass swards at 150, 219 and 278 d.a.s.. Mass of unsown species was also doubled with fescue and prairie grass showing a notable increase in mass in fescue at 219 d.a.s. (Table A2.28, Appendix 2). Anderson et al. (1982) also noted a large infestation of other grasses, chiefly prairie grass, in the establishment year in 'Grasslands Roa' tall fescue in

Palmerston North.

There are few accounts of herbage composition and mass during the establishment phase of direct drilled tall fescue. Some results for established swards are available so comparisons of the current trial with those studies are made in the next section describing the 'PRODUCTION PHASE'. For the purposes of this discussion it is worth noting that establishment in this trial compares favourably with others.

In the current trial a third of the unsown species were broadleaf weeds at 150, 219 and 278 d.a.s. (Tables A1.52, A2.27 and A2.29, respectively). The composition of the broadleaved weeds changed from predominantly catsear, dandelion, hawkesbeard, narrow leaved plantain and mouse eared chickweed with some shepherds purse and twincress in October to predominantly dandelion, hawkesbeard and narrow leaved plantain in the summer (278 d.a.s.) which is consistent with the pattern of succession of weed types in an establishing pasture predicted by Harris et al. (1977). Of the grass weeds about 30% was prairie grass with the balance mostly *Poa annua* in September and October (150 and 219 d.a.s.). In February there were equal amounts of broadleaf weeds, prairie grass and other grass weeds (mainly *Poa annua* with some soft brome (*Bromus hordeaceus* L.) in the ryegrass sward but broadleaf weeds were still the dominant category of unsown species in the fescue sward.

There was an interaction between relative mass of the three basic categories within the unsown species and sown species. In September and November the mass of weed grasses was similar for both fescue and ryegrass but the mass of broadleaf weeds was greater with fescue than ryegrass (Tables A1.52, Appendix 1 and A2.27, Appendix 2, respectively). This suggests that the emergence of grass weeds was somewhat independent of species but broadleaf weeds were better able to colonise the comparatively larger gaps in the fescue sward during establishment until at least late spring. This is possibly because of the more spreading growth habit of broadleaf weeds compared with weed grasses eg. *Poa annua* vs dandelion.

High seeding rate offered an advantage over low seeding rate in fescue with respect to the growth of unsown species and proportion of clover and sown species at 219 d.a.s. (Table 4.2.2.4). Although each category of unsown species contributed similarly to the increased mass of unsown species (Table A2.27, Appendix 2). The advantage given by higher seeding rate was somewhat transient as it was not apparent in the fescue sward when composition was assessed prior to 219 d.a.s. at 150 d.a.s., nor was it apparent subsequently at 278 d.a.s.. No such interaction was apparent for drilling method comparisons. Broadleaf weeds tended to do better with cross-drilling than 75 or 150mm row spacing (Table 4.1.5.2) or were no different (Tables 4.2.2.3 and 4.2.2.5) but, theoretically at least should have been greatest with 150mm row spacing because of decreased ground cover.

Mechanical harvesting of herbage which had accumulated over the 40 day period from late August to early October (139 to 182 d.a.s.) provided a direct measurement of herbage accumulation for a discrete period and avoided the problem of measuring herbage accumulation where trial plots were grazed over an extended period (6 days). The results of the mechanical harvest (Tables 4.2.2.1 and 2) were consistent with results for herbage mass recorded at 150 d.a.s. (Table 4.1.5.2). Accumulation of herbage mass was similar for fescue and ryegrass. Herbage accumulation rate for that 40 day period was 20kgDM ha^{-1} day^{-1}. This was 60% of the farm average for September of the previous eight years (G. Lynch pers. comm., 1991) and had presumably been influenced by the dry conditions which prevailed.

Seeding Rate

During establishment the high initial content of broadleaf and grass weeds and excellent white clover growth of the fescue sward was in marked contrast to the clean, uniform pasture of the faster establishing ryegrass. Two clearly different population structures were provided by these temperate herbage grasses from which to gauge the response of developing sown and unsown species to various seeding rates and drilling methods.

Increasing seeding rate from 12 to 23kgha^{-1} for ryegrass and 17 to 31kgha^{-1} for fescue did not increase the mass of herbage accumulated for a 40 day period from 139 to 182 d.a.s. (Late August to October, Table 4.2.2.1) or the mass of sown species at 219 d.a.s. (November) or 278 d.a.s. (January, Tables 4.2.2.3 and 4.2.2.5).

The mass of clover in the ryegrass and fescue swards in November and January was independent of seeding rate. Previous reports for ryegrass based-pasture established by conventional cultivation have demonstrated that lower ryegrass seeding rate reduced clover suppression and offered greater flexibility in timing of grazing during the first winter / spring after autumn sowing (Brougham, 1954b; Harris et al., 1973). Where ryegrass was sown in rows in the current trial, the suppressive effect on companion legumes of increasing seeding rate of the grass species was negated because of the greater control of plant spatial arrangement. There was never less than a 75mm gap on the soil surface in at least one horizontal direction for clover stolons to grow. Clover growth was independent of seeding rate to the extent that there was an indication that clover growth was actually enhanced at the high seeding rate with fescue at 219 d.a.s. (Table 4.2.2.4).

Drilling Method

For the purposes of discussion on the influence of drilling method on herbage mass and sward composition, 75mm row spacing and cross drilling will be compared with the industry standard of 150mm row spacing. Comparisons of 75mm row spacing and cross-drilled treatments are made to a lesser extent because, in practice, they would tend to be mutually exclusive as seed drills would only be capable of one or the other operation and not both.

As for the early establishment period, the extra pass of the seed drill required to establish the diamond pattern of plant arrangement in the cross-drilled treatment did not improve the mass of herbage accumulated over the 40 day from late August to early October, (Table 4.2.2.2), or the mass of sown species in November or January (Tables 4.2.2.4 and A2.31, Appendix 2, respectively) compared with standard 150mm row spacing, afforded by a single pass of the seed drill. This was the case for both the establishing fescue and ryegrass swards grazed by dairy cattle. Reducing row spacing from 150 to 75mm did not increase the mass of sown species in the ryegrass sward at any stage during late establishment. Narrower row spacing provided some growth advantage to fescue in the initial stages of late establishment (182 d.a.s. Table 4.2.2.2) and later at 278 d.a.s. (January, Table A2.31, Appendix 2), which was consistent with results for herbage mass recorded at 150 d.a.s. (Table 4.1.5.3) . However, the later results (182 and 278 d.a.s.) were significant only at the lower order of probability (10%) whereas the result recorded at 150 d.a.s. was significant at the 1% level, suggesting later benefits of reducing row spacing in fescue were less obvious but were nonetheless apparent.

Neither cross-drilling nor narrow row spacing influenced the mass of clover or unsown species in November or January in either fescue or ryegrass compared with 150mm row spacing. Cross-drilling was thought likely to reduce the opportunity for weeds to compete with introduced grass seedlings, especially during the establishment phase, where herbicides had left a bare paddock for pasture establishment (Thom and Ritchie, 1987). No trial results were available to validate their suggestion and considerable field experience questioned the long-term benefits of two-pass drilling (W.R. Ritchie, pers. comm., 1989). Results from the current trial indicate that a second pass of the drill is not justified in terms of herbage production of the sown species or suppression of weed species in the short-term development of the sward (year one). Interestingly the slower establishing fescue plants were not able to capitalise on the better coverage of the paddock afforded by the cross-drilling. In fact fescue herbage mass in that treatment was initially depressed from a relatively higher mass of unsown species at 150 d.a.s. (Table 4.1.5.3).

Where an advantage in herbage mass of sown species for a drill method was shown it was reflected in the measurement of extended height but not by measurements of tiller or leaf number, further suggesting that those plant characteristics were relatively independent of drill method, especially in fescue. Fescue tiller number had less association with in-row population than ryegrass, but the mass of sown species in fescue did respond to drill method. After 178 d.a.s., measurements for extended height were not consistent with the mass of sown species in the fescue sward (Table 4.2.1.5 as compared with A2.30, Appendix 2). At that stage total herbage mass (approximately 4000kgDM ha^{-1} at 219 d.a.s., Table A2.27, Appendix 2) was considerably higher than for previous measurement times (< 2000kgDM ha^{-1} at 150 and 182 d.a.s., Table A1.52 and A2.33, respectively) which may have reduced the importance of plant height relative to plant width (tillers, leaves) in relation to herbage mass.

Although the number of fully expanded leaves on ryegrass plants in 75mm rows was higher as compared with other drill treatments at 217 d.a.s. (Table 4.2.1.4) no significant drill effect on the mass of sown species was recorded (Table A2.30). Leaf number data did coincide with the trend for a higher mass of sown species for 75mm row spacing. The mass of sown species for the cross-drill treatments was very similar to 75mm row spacing (2916 and 2903kgDM ha^{-1}, respectively). However, it was not consistent with the lower leaf number recorded for the cross drill treatment (18.8 and 13 leaves/plant for the 75mm and cross drill treatments, respectively). As mentioned previously, tiller and leaf number of plants in the cross-drilled treatment were likely to have been underestimated. In this instance, the leaf number of plants at the intersection of drill rows was similar to plants at the 'between' position causing only a minor reduction in the average leaf number for the cross-drilled treatment (Table A2.26, Appendix 2). Thus measurements of fully expanded leaves did not necessarily reflect the mass of sown species as measured by quadrat cuts and botanical analysis at that stage (217 d.a.s.) or measurements of tiller number or extended height, all of which indicated no significant drill method effect for ryegrass at that time.

4.2.3 Summary

From September to November (145 to 219 d.a.s.) ryegrass tiller number were reduced where grazing occurred at 1800kgDM ha^{-1} on two consecutive occasions, but increased when herbage mass was allowed to reach approximately 4580kgDM ha^{-1} before grazing. On the face of it, this result would suggest that close, frequent defoliation does not necessarily improve tiller number per plant as has been found with broadcast sown pasture (Brougham, 1954a). Higher herbage mass may in fact be more compatible with encouraging tillering in establishing ryegrass swards sown by direct drilling. However, the unseasonable dry conditions which prevailed in September 1990 may have limited tiller initiation during that period, and the subsequent recharge of soil water and application of nitrogen may have been more influential in increasing tiller number in ryegrass than the fact that grazing was left until a higher herbage mass had accumulated in November. Comparison of tiller accumulation in the current trial with established swards suggests that tiller accumulation may have been lower where pasture was recently direct drilled. Tiller number per plant reached virtually a 'ceiling' level very quickly (145 d.a.s.) and showed only slight variation after that time. On the other hand, fescue tiller number did increase during the late establishment period. Tiller number did not recover in the same fashion as ryegrass after grazing in October because of damage to emerging tillers by Argentine stem weevil, but increased gradually after the insect was controlled in November. The susceptibility of tall fescue and the resistance of ryegrass infected with an endophyte (*Acremonium lolii*) to argentine stem weevil attack during the seedling stage was clearly demonstrated.

Over 90% of plants (93 and 88 % of ryegrass and fescue, respectively) which were identified 6 weeks after direct drilling in the autumn, survived until late in the following summer. When compared with ryegrass, fescue was not disadvantaged by the two close defoliations that occurred in the first spring. This suggests that tall fescue can be managed similarly to ryegrass once the above-ground portion of the plant has reached a weight of approximately 140 mg/plant or 600 kgDM ha^{-1}, during the establishment phase when established by direct drilling and grazed by dairy cattle. The reported susceptibility of fescue to 'pulling' by stock was also not repeated in the current trial presumably because of improved root anchorage provided by direct drilling.

High seeding rate provided a brief depression in growth of unsown species in November. However this was not sustained. Growth of sown species and clover was largely independent of seeding rate in the early and late establishment periods in fescue and ryegrass apart from an increase in the contribution of clover in November in fescue sown at the high seeding rate. The variations relating to seeding rate were transient and not important to sward development as a whole. There was a higher level of plant mortality and lower tiller number per plant associated with increasing seeding rate. From these results it would seem that under direct drilling, increasing the seed rate above that required to establish approximately 450 plants m^{-2} is not warranted in terms of reducing weed ingression or increasing herbage production from either ryegrass or fescue during the establishment phase, and that it may in fact have some negative effects in terms of reducing plant size and survival.

The relative insensitivity of ryegrass to seeding rate and drill method suggests that once a tiller density of over 4200 tillers m^{-2} (as at 145 d.a.s. at low seeding rate) is achieved in rows 150mm or less, plant size, sward composition and herbage mass are unaffected by plant spatial arrangement. Plants at 150mm row spacing were able to utilise resources (moisture, nutrients and light) equally as well as those in cross-drilled rows and rows spaced at 75mm , where in-row population was lower and the same number of plants m^{-2} were more evenly spaced over the soil surface to achieve better coverage. Better coverage increases light interception opportunities for sown species in the period following drilling or grazing when leaf area is not covering the entire soil surface. The lack of response to better coverage indicates that availability of nutrients was a greater limitation to growth than light. A higher nitrogen status throughout the trial may have allowed the treatments with better cover to capitalise on enhanced light interception opportunities. However, where 60kg nitrogen ha^{-1} was applied after grazing at 181 d.a.s. no advantage to cross-drilling or 75mm row spacing was apparent.

Broadleaf weeds rather than grass weeds colonised the gaps in the fescue sward during establishment . However, this shift in the type of pioneering weed species was not greatly influenced by drill method or seeding rate. Although the mass of broadleaf weeds was greater with cross drilling at 150 d.a.s. and lower seeding rate at 219 d.a.s. in the fescue sward, these effects were not sustained, unlike the species effect. Reducing row spacing was an advantage to the slower growing fescue sward, indicating that light utilisation was more important to fescue than ryegrass, most likely because of the lower tiller number (2838 vs 4850 tillers m^{-2} at 145 d.a.s.) and resultant higher unsown species content in the fescue sward. Light relations were more favourable for companion species in the fescue sward as evidenced by the higher content of clover and broadleaf weeds compared with the ryegrass sward. Increasing the length of drill row per unit area by cross-drilling at 150mm row centres was no advantage to fescue throughout the establishment phase, possibly because of the initial depression in the proportion of sown species and relatively high mass of unsown species in early spring (September, 150 d.a.s.). Post emergence application of a phenoxybutyric herbicide to control broadleaf weeds is recommended practice in establishing fescue swards (Anon, 1983). Had a herbicide been used in this trial all drill methods may have a had similar mass of sown species to that for the ryegrass sward at that stage, because competition for light would have been reduced.

Although nitrogen and or potassium deficiency was apparent, as evidenced by the large increase in herbage in urine affected areas, a broadcast application of these minerals did not reduce the proportion of unsown species in either the fescue or ryegrass swards but reduced clover content. This was due to the response of unsown species to nitrogen and or potassium, particularly the broadleaf weed component in the fescue sward.

The urine application had a larger effect on herbage botanical composition and mass of fescue and ryegrass swards than drill or seeding rate effects. This aspect of pasture development was considered worthy of further investigation (see Chapters five and six).

4.2.4 Further Investigations

Nitrogen and potassium application from urine deposition had a larger effect on herbage botanical composition and mass of fescue and ryegrass swards than drill or seeding rate effects. The possibility of an interaction between plant spatial arrangement and nutrient levels (particularly nitrogen) cannot be discounted. Sown species may benefit from better cover if nutrients were less limiting than light. It is possible that drill treatments which provide better cover may provide a benefit over those in which plants are more widely spaced, if nutrients are applied at establishment. However, it is also well understood that plants will respond to nitrogen irrespective of plant arrangement, as will the unsown component of the sward. In summing up a series of pasture establishment experiments, Brougham (1954d) suggested that a study of the effect of artificial nitrogen applied at various stages in the development of pastures under conventional cultivation would be of particular interest. It would be interesting to see if the same could be said for development of direct drilled pastures. There are few reports on work of this nature.

A second field trial to investigate this particular area of interest was therefore established in the autumn of 1991 and ran concurrently with the main trial.

4.3 Production Phase

4.3.1 Herbage Composition, Mass and Accumulation

4.3.1.1 Introduction

The trial was grazed with lactating dairy cows from December 1990 to January 1992 (246 to 625 d.a.s.). Herbage mass was measured before and after each grazing to give a continuous measurement of accumulation. As previously mentioned continuous measurement of herbage mass on the plots sown at 75mm row spacing ceased in late autumn (393 d.a.s.) because of restricted plot size. Only herbage composition was assessed for the 75mm row spacing in November. The final assessment of herbage composition and mass was made on 6 March 1992 for all treatments (684 d.a.s.).

Overall main treatment effects on herbage composition for the whole trial period are presented first, followed by effects on the mass of individual components for the production phase and lastly herbage mass accumulated for the production phase.

There were no interactions between the effects of main treatments on herbage composition during the production phase so presentation is confined to main effects of species and drill method.

4.3.1.2 Results

4.3.1.2.1 Herbage Composition and Mass

4.3.1.2.1.1 Effect of Species

Figures 4.3.1.1 and 4.3.1.2 describe the composition of live herbage on fescue and ryegrass plots, respectively. The Figures were drawn from data contained in Tables 4.1.5.1, 4.1.5.2, 4.2.2.3, 4.2.2.5 and Tables A3.1, A3.3, A3.5 A3.7 in Appendix 3. The proportion of sown species in the live herbage was greater for ryegrass than fescue, and clover contributed proportionately less to the ryegrass sward than to fescue. The grass / clover balance reached a similar level for both species by 684 d.a.s. (70% grass and 23% clover in the live herbage), (Table A3.7, Appendix 3). The proportion of unsown species was higher in fescue than ryegrass plots until 576 d.a.s., (Table A3.5, Appendix 3).

Figure 4.3.1.1 Composition of Live Fescue Herbage for the Trial Period

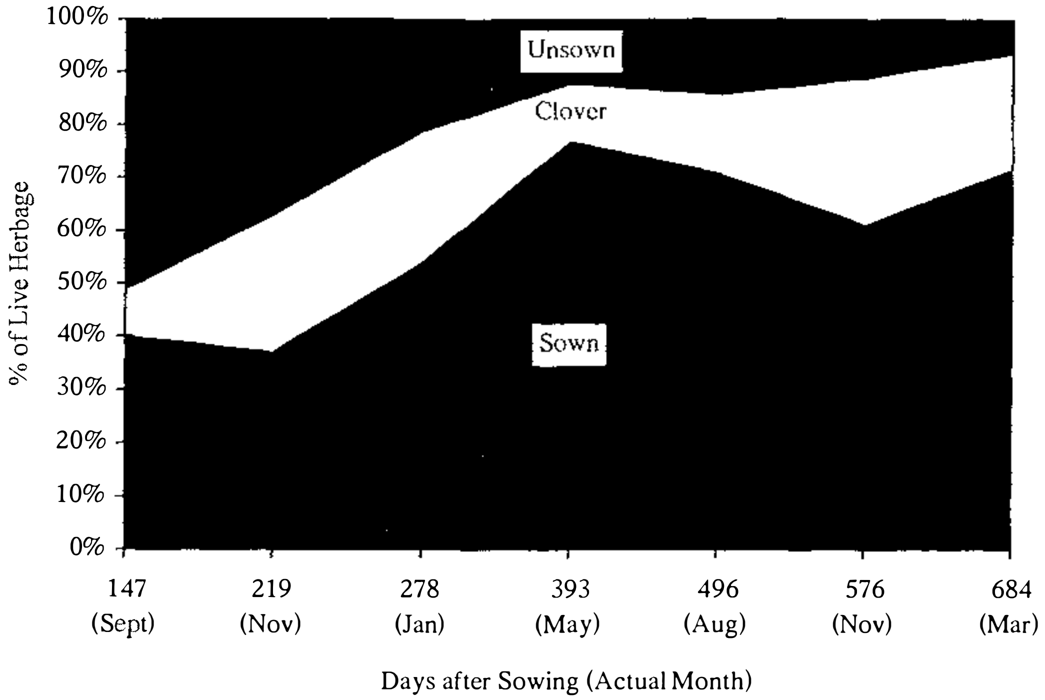


Figure 4.3.1.2 Composition of Live Ryegrass Herbage for the Trial Period

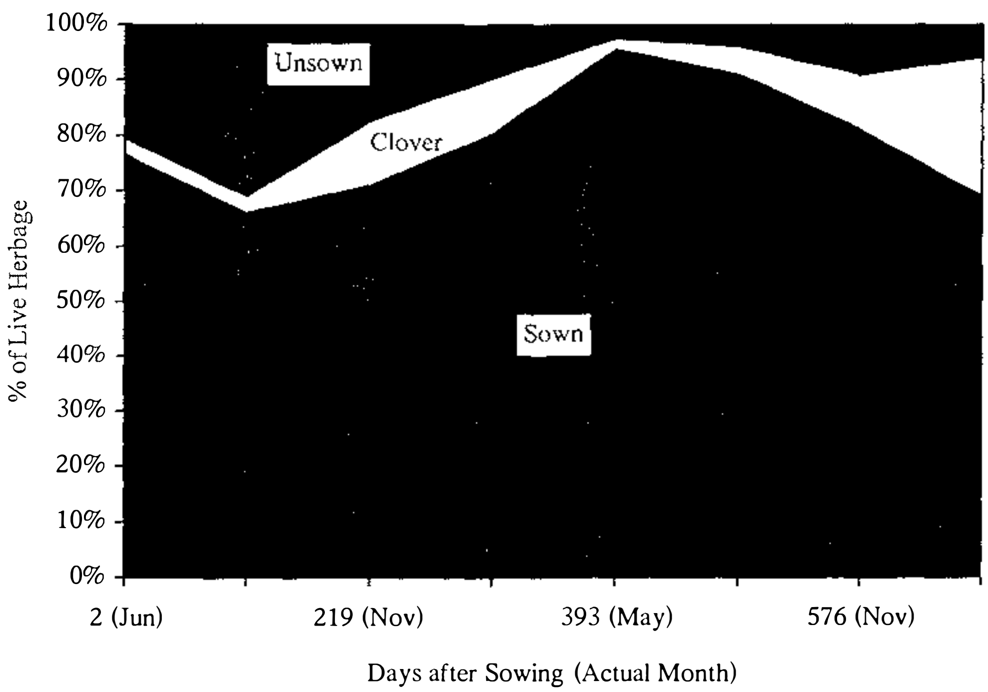


Table 4.3.1.1 lists the effect of species on the mass of sown species, clover, unsown species and total live herbage for the production phase. The mass of sown species was greater in the fescue than the ryegrass sward at 393 (Fpr=0.1) and at 684 d.a.s., the autumn of the first and second year after establishment. This coincided with a higher mass of dead material in the ryegrass sward on both occasions (Tables A3.2 and A3.8, Appendix 3). The mass of sown species was higher for ryegrass than fescue as was the mass of total live herbage at 576 d.a.s. (November), coinciding with the onset of anthesis for that species. Species had no effect on mass of sown species at 496 d.a.s. (August) but the mass of total live herbage in the fescue sward was greater than ryegrass at that time because of higher mass of clover and unsown species. Live herbage mass was higher for the fescue sward at 684 d.a.s..

Mass of clover was higher for fescue than ryegrass on each occasion until 684 d.a.s. when there was no longer a species effect. The mass of unsown species was similar for fescue and ryegrass at 576 d.a.s. and 684 d.a.s. (the second spring and autumn after sowing, respectively).

Table 4.3.1.1 Effect of Species on the Mass of Sown Species, Clover, Unsown Species and Total Live Herbage at 393, 496, 576 and 684 d.a.s.

Mass of ($kgDMha^{-1}$)	Days After Sowing (Date)	**393** (15 May 1991)	**496** (28 Aug 1991)	**576** (9 Nov 1991)	**684** (6 March 1992)
SOWN	**Fescue**	1806	1525	1530	1752
	Ryegrass	2000	1546	2491	1434
	S.E.D. ±	96	167	148	127
	Significance	(*)	n.s.	* * *	*
CLOVER	**Fescue**	241	312	722	526
	Ryegrass	33	70	314	520
	S.E.D. ±	42	76	135	115
	Significance	* *	*	*	n.s.
UNSOWN	**Fescue**	285	312	282	160
	Ryegrass	57	65	251	121
	S.E.D. ±	48	37	63	26
	Significance	* *	* * *	n.s.	n.s.
TOTAL LIVE	**Fescue**	2331	2150	2533	2443
	Ryegrass	2086	1681	3056	2075
	S.E.D. ±	124	70	85	83
	Significance	n.s.	* * *	* *	* *

4.3.1.2.1.2 Effect of Seeding Rate

Overall, seeding rate had no effect on herbage mass or composition so only limited results are presented here. Table 4.3.1.2 describes the effects of seeding rate on the mass of sown species for fescue and ryegrass for the production phase, and is typical of the seeding rate effect on all components of the sward. The mass of sown species was similar for both high and low seeding rates in fescue and ryegrass. The mass of clover, unsown species and total live herbage followed the same trend (Tables A3.1, A3.3, A3.5 and A3.7, Appendix 3). There were no interactions between species and seeding rate or between seeding rate and drill method.

Table 4.3.1.2 Effect of Seeding Rate on the Mass of Sown Species for Fescue and Ryegrass at 393, 496, 576 and 684 d.a.s. (kgDMha-1)

	Days After Sowing (Date)	**393** (15 May 1991)	**496** (28 Aug 1991)	**576** (9 Nov 1991)	**684** (6 March 1991)
FESCUE	**High**	1857	1576	1497	1756
	Low	1755	1475	1562	1757
	S.E.D. ±	174	124	118	121
	Significance	n.s.	n.s.	n.s.	n.s.
RYEGRASS	**High**	1921	1517	2607	1416
	Low	2080	1575	2375	1415
	S.E.D. ±	144	108	152	100
	Significance	n.s.	n.s.	n.s.	n.s.

4.3.1.2.1.3 Effect of Drilling Method

The proportion and mass of clover and unsown species was not influenced by drill method during the production phase (Tables A3.1, A3.3, A3.5 A3.7 in Appendix 3). However, the mass of sown species at 393 d.a.s. was affected by drill method. Table 4.3.1.3 shows the effect of drilling method on the mass of sown species and total live herbage.

The mass of sown species and total live herbage was significantly greater for the 75mm row spacing at 393 d.a.s. as compared to 150mm row spacing. The effect was only significant at 10% for sown species mass and 5% for total live herbage mass (Table 4.3.1.3). Cross-drilling was similar to 75mm row spacing for both sown species and total live herbage and not different from 150mm row spacing for total live herbage, but had a higher mass of sown species as compared to the 150mm treatment. A drill method x species interaction was indicated at 393 d.a.s. which showed that the above affect was only significant for fescue and not for ryegrass but was of sufficient magnitude that it was apparent in the overall results.

Table 4.3.1.3 Effect of Drilling Method on the Mass of Sown Species for Fescue and Ryegrass at 393, 496, 576 and 684 d.a.s. (kgDMha-1)

	Days After Sowing (Date)	**393** (15 May 1991)	**496** (28 Aug 1991)	**576** (9 Nov 1991)	**684** (6 March 1992)
	75 mm row	1980 (a)	N/A ‡	N/A	1612
SOWN	**Cross drill**	2011 (a)	1532	1997	1582
	150 mm row	1718 (b)	1539	2023	1592
	S.E.D. ±	138	82	96	96
	Significance	(*)	n.s.	n.s.	n.s.
	75 mm row	2326 a	N/A	N/A	2205
TOTAL LIVE	**Cross drill**	2266 ab	1902	2787	2302
	150 mm row	2039 b	1929	2803	2270
	S.E.D. ±	119	84	98	87
	Significance	*	n.s.	n.s.	n.s.

- ‡ Not available because of restricted plot size for 75mm row treatment

4.3.1.2.1.4 Interactive Effect of Species and Drilling Method

Table 4.3.1.4 describes the effect of drill method on the mass of sown species and total live herbage. Ryegrass was unaffected by drill method but the mass of sown species and total live herbage was higher for fescue sown at 75mm than 150mm row spacing. The mass of sown species in the cross-drilled rows was no different to that in 150mm and 75mm rows, but the mass of total live herbage on cross-drilled plots was less than that on plots sown at 75mm row spacing. The effects of drill method on mass of sown species for fescue and ryegrass at 496, 576 and 684 d.a.s. are listed in Table A3.9, Appendix 3.

Table 4.3.1.4 Effect of Drill Method on the Mass of Sown Species and Total Live Herbage for Fescue and Ryegrass at 393 d.a.s. (kgDMha-1)

	Days After Sowing	**Sown Species**	**Total Live Herbage**
	75mm row	2066 (a)	2668 a
FESCUE	**Cross Drill**	1826 (ab)	2279 b
	150mm row	1525 (b)	2047 b
	S.E.D. ±	214	134
	Significance	(*) Fpr=0.057	* *
	75mm row	1893	1984
RYEGRASS	**Cross Drill**	2196	2253
	150mm row	1911	2031
	S.E.D. ±	176	140
	Significance	n.s.	n.s.
Species X Drill	S.E.D. ±	187	185
Interaction	Significance	(*) Fpr=0.077	*

4.3.1.2.1.5 Volunteer Ryegrass Content of Fescue

Up to 8 % of the live herbage in the fescue plots was volunteer ryegrass between 278 and 484 d.a.s. (January to November). This subsequently declined to 3-4 %. Table 4.3.1.5 shows the proportion of volunteer ryegrass in the live herbage of the fescue sward. The proportion was not affected by seeding rate or drilling method.

Table 4.3.1.5 Proportion of Volunteer Ryegrass in the Live Herbage of the Fescue Sward from November 1990 to March 1992 (219 to 684 d.a.s.)

d.a.s. (Month)	219 (November)	278 (January)	393 (May)	484 (August)	576 (November)	684 (March)
% Volunteer Ryegrass	3	7	6	8	2	4

4.3.1.2.2 Accumulated Herbage Mass

4.3.1.2.2.1 Effect of Species, Seeding Rate and Drilling Method

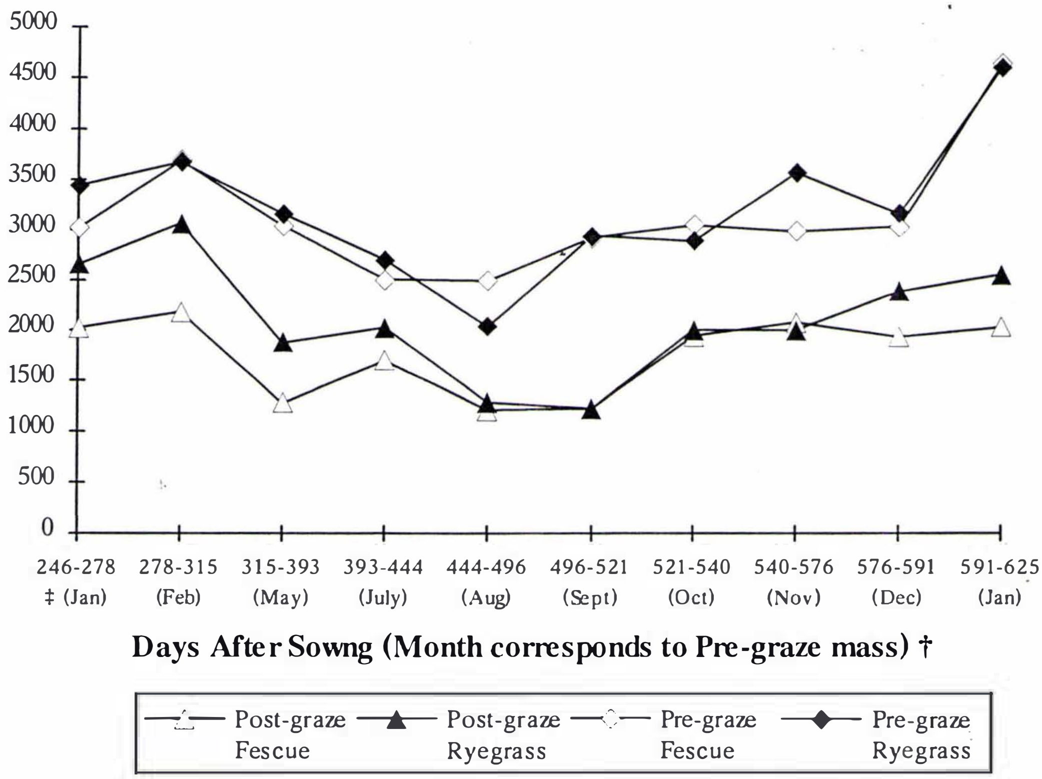
Table 4.3.1.6 describes the effect of species, seeding rate and drilling method on accumulated herbage mass for the first and second half of the production phase (periods one and two) and for the entire period. The end of the first period of the production phase corresponds with the time when monitoring of plots sown at 75mm row spacing was discontinued. Therefore drill method effects on accumulated herbage mass for the entire production phase are only available for cross-drill and 150mm row spacing comparisons. Accumulation of herbage was calculated as the sum of the differences between post-graze herbage mass at the previous grazing and pre-graze herbage mass at the current grazing. Figure 4.3.1.3 describes the pre- and post-grazing herbage mass of fescue and ryegrass for the entire production phase. The data from which Figure 4.3.1.3 was constructed are contained in Table A3.11, Appendix 3.

Table 4.3.1.6 Effect of Species, Seeding Rate and Drilling Method on Accumulated Herbage Mass (kgDMha^{-1}) During the Production Phase (246 to 625 d.a.s.)

	Period One	**Period Two**	**Entire Production Phase**
	December 1990 to May 1991	May 1991 to January 1992	December 1990 to January 1992
SPECIES			
Fescue	3980	9550	13530
Ryegrass	2700	8430	11130
S.E.D. ±	291	382	562
Significance	**	*	**
SEEDING RATE			
High	3220	9000	12220
Low	3470	8980	12440
S.E.D. ±	233	399	471
Significance	n.s.	n.s.	n.s.
DRILLING METHOD			
75 mm row	3618		
Cross drill	3310	8980	12289
150 mm row	3372	9000	12378
S.E.D. ±	286	399	471
Significance	n.s.	n.s.	n.s.

Higher accumulation of herbage mass was recorded for fescue as compared to ryegrass for each of the two periods and the entire production phase. The average pre-graze herbage mass of both species was similar at 3097 and 3137kgDMha^{-1}, for fescue and ryegrass, respectively (Table A3.10, Appendix 3). The post-graze herbage mass was not significantly different on average (1740 and 1915kgDMha^{-1}, for fescue and ryegrass, respectively) but was significantly lower for fescue after grazings at 246, 278, 315, 393, 576 and 591 d.a.s. (Table A3.11, Appendix 3) as compared with ryegrass. Ryegrass was never grazed to a lower herbage mass than fescue at any time during the production phase.

Figure 4.3.1.3 *Effect of Species an Pre- and Post-grazing Herbage Mass from 246 to 625 d.a.s.*



- ‡ First d.a.s. denotes to post-graze herbage mass at the previous grazing and second d.a.s. denotes pre-graze herbage mass at the current grazing (month)
- † Data for Figure 4.3.1.3 can be found in tabular form along with S.E.D.s of differences in Table A3.11, Appendix 3

The pre-graze herbage mass was greater for fescue at 496 d.a.s. (28 August, Table A3.11). That coincided with the initial stages of reproductive development in fescue, in which ear emergence was visually estimated to be 5-10% of tillers. In November (576 d.a.s.) a greater herbage mass was recorded for ryegrass which also coincided with anthesis for that species. Both species were topped at 576 d.a.s. (9 November) with a disc mower to 60-80mm above the soil surface to remove ungrazed seedheads after grazing.

Overall seeding rate and drilling method effects were not significant. However, there was a drill x species interaction for each of the two periods and the entire production phase.

4.3.1.2.2.2 Interactive Effect of Species and Drilling Method

Table 4.3.1.7 describes the effect of drill method on accumulated herbage mass for each of the two periods during the production phase and for the entire production phase. There were significant species x drill interactions for periods one and two and for the entire production phase. Drill method had a significant effect on the herbage mass accumulated on fescue but no effect on accumulated herbage mass for ryegrass.

In period one, fescue sown in 75mm rows accumulated more herbage mass than where it was cross-drilled or sown in 150mm rows (Table 4.3.1.7). In the remainder of the production phase (period two), fescue sown in 150mm rows had accumulated more herbage mass than where it was cross-drilled. This same effect on fescue was apparent for the entire production phase but was significant at a lower order of probability (Fpr=0.061).

Table 4.3.1.7 Effect of Drill Method on Herbage Mass Accumulated in Fescue and Ryegrass During the Production Phase (kgDMha-1)

		Period One	**Period Two**	**Entire Production Phase**
		December 1990 to May 1991	May 1991 to January 1992	December 1990 to January 1992
	75mm row	4910 a		
FESCUE	**Cross Drill**	3980 b	9020 a	12930 (a)
	150mm row	4080 b	10070 b	14110 (b)
	S.E.D. ±	362	484	578
	Significance	*	*	(*) Fpr= 0.061
	75mm row	2330		
RYEGRASS	**Cross Drill**	2730	8910	11640
	150mm row	2670	7930	10620
	S.E.D. ±	442	636	742
	Significance	n.s.	n.s.	n.s.
Species X Drill	S.E.D. ±	439	552	735
Interaction	Significance	*	*	*

In period one, a species x drill method interaction was also apparent for the average pre- and post-graze herbage mass. Table 4.3.1.8 describes the effect of drill method on the pre- and post-graze herbage mass of fescue and ryegrass for period one of the production phase. Fescue sown in 75mm rows had, on average, a greater pre-graze herbage mass than that sown by cross-drilling or at 150mm row spacing. Post-graze herbage mass was also higher for the 75mm row spacing treatment. Pre- and post-graze herbage mass of ryegrass was not affected by drill method on average during period one.

Table 4.3.1.8 Effect of Drill Method on Average Pre- and Post-graze Herbage Mass (kgDMha-1) for Period One of the Production Phase for Fescue and Ryegrass (246-393 d.a.s.)

	Drill Method	Pre-graze Herbage Mass	Post-graze Herbage Mass
	75mm	3706 a	2049 a
FESCUE	**Cross drill**	3084 b	1761 b
	150mm	3051 b	1700 b
	S.E.D. ±	151	120
	Significance	* * *	*
	75mm	3258	2289
RYEGRASS	**Cross drill**	3515	2475
	150mm	3382	2364
	S.E.D. ±	145	96
	Significance	n.s.	n.s.
Species X Drill	S.E.D. ±	238	151
Interaction	Significance	* * *	* *

Table 4.3.1.9 describes the effect of drill method on the pre- and post-graze herbage mass of fescue and ryegrass for the entire production period. The pre-graze herbage mass was similar for cross-drilled and 150mm row spacing treatments for both fescue and ryegrass. No species x drill method interaction was apparent for the entire production period (Table 4.3.1.9) but there was an interaction between species and drill method for post-graze herbage mass for period two (Table A3.12, Appendix 3). Post-graze herbage mass of fescue sown in 150mm rows was greater than for cross-drilled rows. The effect was the reverse in ryegrass but the difference in post-graze residual was significant at a lower level of probability (Fpr=0.095) as compared with fescue (Fpr=0.058). A lower post graze herbage mass for fescue sown in 150mm rows than that for the cross-drilled treatment was also indicated for the entire production period but at a lower order of probability (Fpr=0.1, Table 4.3.1.9).

Table 4.3.1.9 Effect of Drill Method on Average Pre- and Post-graze Herbage Mass (kgDMha-1) for the Entire Production Phase for Fescue and Ryegrass (246-625 d.a.s.)

	Drill Method	Pre-graze Herbage Mass	Post-graze Herbage Mass
FESCUE	**Cross drill**	3080	1780
	150mm	3100	1690
	S.E.D. ±	65	56
	Significance	n.s.	(*) Fpr=0.1
RYEGRASS	**Cross drill**	3250	2090
	150mm	3210	2150
	S.E.D. ±	80	72
	Significance	n.s.	n.s.
Species X Drill Interaction	S.E.D. ±	120	100
	Significance	n.s.	n.s.

4.3.1.3 Discussion

Species

Disparity between the competitive interaction of perennial ryegrass and the other sward components (white clover and unsown species) and tall fescue and other sward components was clearly demonstrated by the larger contribution of clover and unsown species to the fescue sward (Figures 4.3.1.1 and 4.3.1.2). This is consistent with the results of previous studies which have compared establishment and subsequent production based on either fescue or ryegrass under conventional cultivation (Charles, 1965; Anderson et al., 1982; Brock, 1982) or from oversowing (Moloney et al., 1993). A similar trend was shown under direct drilling by Bellotti and Blair (1989a) although in that study legume growth was good for both species because the clover-dominant vegetation present before drilling was only temporarily suppressed with herbicide. It has long been recognised that where ryegrass and fescue have been sown together, ryegrass is considered the aggressor species, and fescue the non-aggressor species (Frame and Hunt, 1964). In contrast to a previous study in the Manawatu (Brock, 1982) which was established by conventional cultivation in the autumn, the relative proportions of grass and legume components for ryegrass and fescue swards reached a common ratio by the second autumn after sowing (684 d.a.s., approximately 70, 23 and 7% of live herbage for sown, clover and unsown species, respectively, Table A3.7, Appendix 3). Average composition of Brock's 1982 trial for the third and fourth year of production in the fescue sward was 44, 7 and 49% for sown grass, clover and unsown species, respectively. Corresponding values for his ryegrass sward were 62, 13 and 25%.

The growth of unsown species reduced the proportion of sown species in the fescue sward in the current trial. Unsown species actively competed with fescue for resources rather than simply filling vacant space between rows during the establishment period. This was demonstrated by the interaction of drilling method and species at 150 d.a.s. (Table 4.1.5.3). The mass of unsown species was greater in fescue than ryegrass in period one of the production phase (393, 496 d.a.s., Table 4.3.1.1) which was consistent with the establishment phase. However, by 567 d.a.s., the second spring after sowing, the proportion and mass of unsown species was similar for both fescue and ryegrass swards (7%, 250-280 kgDM ha^{-1}, Table A3.5, Appendix 3 and Table 4.3.1.1, respectively). Data from Brock (1982) indicated that the proportion of unsown species in the fescue sward peaked at over 60% of the live herbage in the third and fourth spring, whereas unsown species featured to a lesser extent in the ryegrass sward (23% of live herbage). The proportion of unsown species was lower during the summer-autumn period in the fescue sward in Brock's trial (35%) reflecting the relatively better performance of fescue than the weed grasses of the unsown component (annual poa (*Poa annua*), browntop (*Agrostis tenuis*) and Yorkshire fog (*Holcus lanatus*)) during summer. As the proportion of unsown species in both the fescue and ryegrass swards in the current trial was less than 10% in both the spring and following autumn of the production phase, it would be reasonable to assume that sward composition had stabilised by the second spring after sowing. Failure to kill the previous turf, despite pre-cultivation herbicide and a 3 month fallow after ploughing, and allowing fescue pasture to become rank in the first spring after sowing which reduced plant density, were cited by Brock (loc cit) as the major cause of the high proportion of unsown species. 'Pulling' of fescue plants in summer was also thought to have contributed to a reduction in the density of sown species.

Direct comparison of the current trial with Brock (1982) suggests that direct drilling would be the preferred method for establishment of fescue for reasons of flexibility of grazing management and control of weed grasses, especially perennial types (browntop and Yorkshire fog). This is in direct contrast to McCallum and Thomson (1990) who stated that direct drilling of tall fescue "would not be a recommended method of establishment" on the basis of the poor establishment results they achieved with fescue in comparison with ryegrass. This contradiction in the literature highlights a danger when making comparisons of crop establishment by conventional cultivation and direct drilling. In the first instance (Brock (1982) vs current) a poor cultivation result (inadequate weed control) compares unfavourably with a good direct drilling result (good weed control). In the second instance (McCallum and Thomson, 1990) a poor direct drilling result (poor emergence) is compared with the assumption that conventional cultivation would have been better. Results from the current trial suggest otherwise. McCallum and Thomson's (loc cit) poor results may have been a function of pest damage or the drilling technology used rather than the innate slow growth of fescue during establishment. Where a direct comparison of cultivation and direct drilling of fescue and ryegrass has been made, ryegrass and fescue were established successfully under both systems (Bellotti and Blair, 1989a) although fescue did appear to perform better with cultivation, most likely because of the relatively larger difference in fescue population between the two systems with as compared with ryegrass (Bellotti and Blair, 1989c).

Main broadleaf weeds during the first summer were fleabane (*Erigeron sp*), catsear (*Hypochaeris radicata* L.) and narrow-leaved plantain (*Plantago lanceolata*) with some hawkesbeard (*Crepis capillaris* (L.) Wallr.) and large-flowered mallow (*Malva sylvestris* L.). Annual poa and prairie grass dominated the weed grass category with some summer grass, (*Digitaria sanguinalis* (L.) Scop. and knotroot bristlegrass (*Seteria gracilis* H.B.K) also present. Volunteer ryegrass was apparent in the fescue sward (Table 4.3.1.5). Later (period two) the main broadleaf weed was the prostrate perennial, narrow-leaved plantain and the main grass weeds were annual poa and prairie grass. The mass of broadleaf weeds continued to be higher in fescue than ryegrass until early in the second spring after sowing (496 d.a.s., Table 4.3.1.1). The pattern of succession of weed types was consistent with that predicted by Harris et al.,(1977). Broadleaf weeds (dicotyledonous annuals) were replaced by prostrate perennials and annual poa and the contribution of unsown species generally decreased with time under grazing. Had some perennial grass weeds been present such as paspalum, couch or browntop, the situation would have been different as these types of grass weeds may have been more competitive against sown temperate grasses (Harris et al., 1981; Brock, 1982; Thom et al., 1993).

Harris et al.,(1977) concluded that differences in weed suppression of temperate grasses and legumes were related to establishment rate, cool season growth rate and plant habit which determined the amount of ground cover and shading. In the current trial, slower establishment rate of fescue compared with ryegrass was the principle cause of the higher unsown species component in the fescue sward. Pest damage would also have reduced the competitive ability of fescue against unsown species during spring when growth of that component is generally greatest (Harris et al., 1977; Brock, 1982). White clover was able to compete with unsown species in the fescue sward because of its ability to proliferate by stolons, which would allow it to occupy bare spaces between drill rows and compete with unsown species. This was evidenced by the higher clover content in the fescue sward; if clover had not been able to compete with unsown species then clover presence may have been similar to that of the ryegrass sward.

Along with unsown species, the mass of clover was also greater in fescue in the current trial. The growth habit of clover is likely to have complemented grasses sown in drill rows because of its stoloniferous growth habit. Establishment of slower developing clover has been noted as a problem in conventional pasture establishment (Brougham, 1960; Cullen 1964). Encouragement of clover growth is desirable because it is a highly nutritious feed for livestock and contributes nitrogen for associated grass growth enabling high levels of animal production (Brougham et al., 1978). Generally careful grazing management during establishment of traditional ryegrass based pasture has been recommended to restrict competition for light between grasses and clovers and ensure survival of clover plants in order to obtain a well balanced sward (Brougham 1960; Hume and Fraser, 1985; Frame and Boyd, 1986). Brougham (1954b) showed that reducing the seeding rate of short rotation ryegrass allowed increased latitude in frequency of grazing without adverse effects on clover establishment, because competition for light between clover and sown grass was reduced. The range in grazing frequency required for satisfactory clover establishment may also be extended where clover is established in association with less vigorous grass species such as tall fescue.

Clover growth was poor in the ryegrass sward during the first 19 months of sward life (Figure 4.3.1.2). Clover contributed between 1 and 10% to the live herbage mass (1 and 8% of total DM) from 246 to 576 d.a.s. (between the first and second spring after sowing). This was generally lower than reported for trials established by conventional cultivation in the autumn, which were subsequently grazed by sheep at lower pre- and post-grazing herbage masses than those in the current trial (Brougham, 1954a; Harris et al., 1973). In those trials clover content averaged 22 and 17% of total DM, respectively for the first 12 months after sowing. Numerous trials have shown that in temperate environments, close and frequent grazing encourages growth of white clover while its establishment is often poor where grazings are infrequent

(Sears, 1953, Brougham, 1954b, Harris et al., 1973).

Another trial which compared establishment and production of ryegrass and fescue showed that clover growth may not necessarily be better with fescue than with ryegrass. Data from Brock (1982) showed that the average clover content of a fescue sward in the initial production years was 7% of total DM, whereas the corresponding value for perennial ryegrass was 13%. Both swards were established by conventional cultivation. Poor clover growth in fescue was thought to be related to the close grazing (grazed down to 2-3cm), particularly over summer, and competition from the browntop-dominant volunteer base species present in the fescue sward. Hunt (1956) also found that white clover was not compatible with tall fescue.

As mentioned previously clover content in the current trial was less than that reported for direct drilled ryegrass in the Waikato by Thom et al., (1993) where clover accounted for 24% of total DM present one year after sowing, despite that fact that only 15 of the original 114 Kopu white clover plants m^{-2} survived to that stage. This is in marked contrast to 1% clover content recorded for the current trial in the autumn following sowing (Table A3.1, Appendix 3). This may be due to several factors. White clover present before drilling in the current trial would have been suppressed to a greater extent than in the trial of Thom et al., (1993) because of the inclusion of a herbicide active against clovers (Granstar®) in the current trial. The herbicide glyphosate used by Thom et al., (loc cit) is not particularly active against clover (O'Connor, 1990). Thus unlike the current trial, the clover content in Thom et al.'s trial was not solely reliant on growth of establishing clover plants from either sown or buried seed, but would have been augmented by resident clover growth. The larger clover presence recorded by Thom et al., (loc cit) in early December supports this argument (17 vs 9% of total DM). In the current trial, resident clover, present before spraying, was not totally killed but visual observations suggested that there was little contribution from any resident clover that did survive. There was a high content of dead material (50% in January, Table A2.29, Appendix 2) and high post-graze herbage mass from December to February in the ryegrass sward in the current trial (1875-3068kgDM ha^{-1}, Table A3.11, Appendix 3) as compared to that of the trial reported by Thom et al., (loc cit) (1600-1700kgDM ha^{-1}). That would also have mitigated against clover growth during summer in the current trial because it would have restricted light penetration to the base of the sward.

Competition for light is the main determining factor of the contribution of white clover to a grass/legume based sward (Brougham et al., 1978). Clover content in fescue was also reduced during the first summer in the current trial, but not to the low levels of the ryegrass sward. Clover content in fescue, which was 25% of live herbage (22% of total DM) in late November (Table 4.2.2.3), was reduced to 8% of live herbage in May (393 d.a.s.). The content of dead material was lower for the fescue sward in February (35%) and post-herbage mass was also lower during summer 1275-2180kgDM ha^{-1} as compared to ryegrass. Grazing of fescue in the current trial was sufficiently intense to avoid clumps developing. Topping in spring would also have reduced this tendency (Thom et al., 1985)

It was not until the second autumn after sowing (684 d.a.s.) that clover growth was similar for both fescue and ryegrass at around 23% of live herbage (17% of total DM) (Table A3.7, Appendix 3) and the ryegrass sward was considered to represent a well balanced grass/clover sward. At that stage the levels of dead material were lower than had been experienced the previous summer (19 and 30% for fescue and ryegrass, respectively, Table A3.8). The increase in clover in the ryegrass may have come from surviving sown seedlings or from regrowth of clover which was present before the trial area was sown. New clover seedlings may also have established from buried clover seed (Hyde and Suckling 1953). In the ryegrass in the current trial, clover accounted for as little as 2% of DM during summer (Tables 4.2.2.5 and A2.29, Appendix 2). Where clover was as low as 4% of DM in an establishing sward as a result of inter-species competition for light, intra-species competition for nitrogen followed, effectively reducing grass growth (Brougham, 1954a). This allowed clover to grow, and in cases where soil fertility was low may lead to a clover-dominant sward (Brougham et al., 1978). Eventually an equilibrium grass/clover balance is reached. This pattern of clover development usually takes place over a shorter period of time (within the first year) than was the case for the current trial, possibly because of the high herbage mass present in the first summer in ryegrass.

There was contrast in the competitive interaction of sown species and clover as compared to sown species and unsown species for fescue and ryegrass. Sown species had no influence on the unsown component of pasture at 576 d.a.s. (mass of unsown species 282 and 251kgDMha^{-1} for fescue and ryegrass, respectively, Table A3.5, Appendix 3) but the mass of clover with fescue was more than double that with ryegrass. It seems that the ryegrass had a suppressive effect on clover and unsown species but with fescue, after the establishment phase, the relationship between sown species and clover was mutually beneficial or complementary and this combination had a suppressive effect on unsown species. However, this portrayal of the contrasting competitive interactions for communities of different relative competitive abilities may be simplistic as temperature and defoliation are also important determinants of the botanical composition of pasture (Harris et al., 1981). For example, the small difference between the optima for the growth of temperate grasses and legumes (approximately 3-6°C, Mitchell, 1956) contributes to the beneficial association of temperate grasses and legumes in temperate environments (Brougham et al., 1978). In the Manawatu, a more severe grazing during November-December within a rotation increases the production of white clover in an established pasture during its active summer growth period (Sheath et al., 1987). The effect species, drilling method or seeding rate may have on sward development can not be considered in isolation of defoliation management.

The content of weed grasses (mainly annual poa and prairie grass), though usually slightly higher in the fescue sward, was never significantly different between species as opposed to the broadleaf weed component of the swards which was higher in fescue than ryegrass during establishment (Tables A1.52, A2.27, A2.29, A3.2, A3.4, A3.6 and A3.8). The broadleaf weed component in fescue was eventually reduced to levels similar to that in ryegrass by the second spring after sowing. This suggests that the application of post-emergence herbicide should be delayed as it appears that the early establishing annual broadleaf weeds are not a serious problem for fescue in established under cattle grazing, as in the current trial. Delaying herbicide application until after several grazings have taken place to obtain control of the later establishing prostrate perennial weeds such as narrow-leaved plantain, may be better for sward longevity, as fescue may then be in a better position to compete with weed grasses. Given that the vigour of fescue was reduced by Argentine stem weevil, a post-emergence herbicide used after the first grazing in the current trial may have swung the balance of species in favour of weed grasses.

More herbage accumulated in the fescue sward than the ryegrass sward. This was related to the fact that fescue was generally grazed to a lower post-graze herbage mass but recovered to a similar pre-graze herbage mass (Figure 4.3.1.3). The extra growth of fescue was most likely related to the higher mass of white clover which would have resulted in improved nitrogen status as compared with the ryegrass sward. Work with legumes in hill country (Ledgard et al., 1987) found that for sloping sites the amount of N fixed from the atmosphere was estimated to be 4% of the mass of legume (kgDM ha^{-1}). There was little variability for all sites which ranged from gentle to steep slopes. In the current trial, clover averaged 20% and 10% of live herbage (15 and 7% of total DM) of fescue and ryegrass, respectively, during the production phase. This equates to 2078 and 788kgDM clover ha^{-1} during the production phase for fescue and ryegrass, respectively which, using the above conversion factor, translates to 83 and 31 kgNha^{-1}. These values are low compared with the average value reported for developed lowland pastures (184kgN ha^{-1}, Keeny and Gregg, 1982). Nonetheless more nitrogen would have been available to fescue than to ryegrass swards. The increase in herbage mass accumulation in fescue as compared to ryegrass may also have been a function of post-graze herbage mass during the first summer (> 2000kgDM ha^{-1}, Thom et al., 1985). However, increased herbage accumulation for fescue was also recorded in period two (Table 4.3.1.6) when post-graze herbage mass was similar and generally less than 2000kgDM ha^{-1} for both species (Figure 4.3.1.3).

The fact that fescue was usually grazed to a lower or similar mass than ryegrass (Figure 4.3.1.3) indicates that fescue may have been more acceptable to lactating cows than ryegrass, although differences in acceptability reported by Anderson et al., (1982) may have been masked by the buffering effect of the clover and volunteer grasses present in the fescue and the higher dead matter content of the ryegrass sward (Brock, 1982). Where the mass of dead matter was similar for both species (444-576 d.a.s., Table A3.4 and A3.6, Appendix 3), post-graze mass was similar (Table A3.11, Appendix 3) indicating that the fescue sward was no less acceptable than the ryegrass sward.

Some volunteer ryegrass became established in the fescue sward (Table 4.3.1.5). Tall fescue suffers severely from competition when grown in association with faster growing species such as ryegrass and it is not recommended to sow these species together (Anon, 1983; Lancashire, 1990). Feeding out hay which contains other grass seeds is also not recommended as this may lead to stand deterioration through competition from other grasses (G. Milne pers. comm. 1990). However, it appears that volunteer ryegrass content did not increase in the current trial once it was established and in fact may have been reduced. Volunteer ryegrass formed 8% of live herbage in August (496 d.a.s.) but only 4% the following March (684 d.a.s.). This is not a major reduction, but there was no suggestion that ryegrass increased in the fescue sward. If volunteer ryegrass was an annual or short rotation or was an older perennial type (eg. Ruanui) which were not infected with endophyte, then its relative reduction in contribution may have been due to Argentine stem weevil damage during summer (Pottinger et al., 1985). The type of volunteer ryegrass was not determined (ie. whether it was annual or perennial) so only minor importance is placed on this result. The importance of defoliation interval to the outcome of competition between tall fescue and perennial ryegrass was demonstrated by Bell (1985). In a simulated 50/50 sward of the two species, fescue was more competitive under longer defoliation interval and less competitive under a shorter interval (range 21 to 63 days). Results from the current trial indicate that there may some scope to alter the balance of the these two species in the sward.

Seeding Rate

Seeding rate did not affect composition or herbage mass of fescue or ryegrass swards during the production phase. The absence of seeding rate effects in the second year after sowing on composition and/or herbage mass of a pasture sward is not unusual. There are numerous reports for this occurring where temperate grass species have been established by conventional cultivation.

Composition and mass of perennial and/or short-rotation ryegrass swards have repeatedly been shown to be independent of seeding rates which ranged from 7 to 68kg ha^{-1}, certainly in the second year after sowing (Holliday, 1953; Cullen, 1964; Keane, 1980; Frame and Boyd, 1986) and frequently within the seeding year (Sears, 1953; Brougham, 1954a,b&d; Cullen, 1958; Harris et al., 1973; Cross, 1959; Culleton et al., 1986). The situation may be different for Italian ryegrass. Culleton and Murphy (1987) recorded an increase in herbage accumulation for Italian ryegrass (*Lolium multiflorum*) in the first and second year from pasture sown at 22kg ha^{-1} as compared with 11kg ha^{-1}. Tiller density was very low in their trial (1300 to 2000 tillers m^{-2}) and nitrogen application was very high (450kgN ha^{-1}), but the finding serves to illustrate the diversity in results achievable.

Herbage mass of fescue swards sown at rates ranging from 6-56kgha^{-1} have shown no response to seeding rate in the second year after sowing (Frame and Hunt, 1964; Pedersen and Ball, 1990). However, an increase in herbage production was attributed by Keane (1980) to increasing seeding rate of fescue from 16-22kgha^{-1} to 45kgha^{-1} in the second year after establishment, although this result was related to only one harvest during the two year study and was inconsistent with the first year after establishment in which seeding rate did not have an effect. Sward composition, as distinct from herbage accumulation, may reflect differences in seeding rate. Frame and Hunt (1964) showed that increasing seeding rate of the fescue from 11.3 to 22kgha^{-1} increased the contribution of fescue to total herbage in the second year after the establishment year but had no such effect in subsequent years. Higher seeding rates, recommended to provide sufficient initial competition with volunteer grasses and broadleaf weeds to permit the establishment of a sward composed mainly of the sown species (Cullen and Meeklah, 1959), were thought to have been a more important consideration for slow establishing species such as tall fescue (Camlin and Gilliand (1985) cited by Culleton and Murphy, 1987). It is apparent from the literature that seeding rate may have more influence in fescue swards than ryegrass swards in the second year after establishment. No evidence of interaction between species and seeding rate was found in the current trial.

Drilling Method

A drill method effect was evident in the fescue sward but not in the ryegrass sward during period one of the production phase. This was consistent with results from the establishment phase. In comparison to 150mm row spacing, narrow row spacing was advantageous to the mass of sown species present in the fescue sward at 393 d.a.s. (Table 4.3.1.4), though cross-drilling was not. Higher herbage mass accumulated with narrow row spacing in the fescue sward during period one than with wider row spacing or cross-drilling. This was related to higher average pre-graze herbage mass (Table 4.3.1.8) and was consistent with the higher mass of sown species at 393 d.a.s.. The species X drill method interaction for sown species and total live herbage at 393 d.a.s. (Table 4.3.1.4), herbage mass accumulated during period one (Table 4.3.1.7) and higher average pre-graze herbage mass during period one (Table 4.3.1.8) clearly showed that reducing row spacing was worthwhile in the fescue sward but gave no advantage in ryegrass as compared to sowing in 150mm rows. Cross-drilling fescue and ryegrass did not improve herbage mass relative to the standard 150mm row spacing.

Cross-drilling is an intermediate treatment in terms of reducing row spacing and improving ground cover. In fact the mass of sown species for cross-drilling was intermediate between those for 75 and 150mm row spacing in fescue at 393 d.a.s. (Table 4.3.1.4), although this was not the case for herbage accumulation over period one where 75mm row spacing was clearly better than cross-drilling and 150mm rows which were themselves very similar (3980 and 4080kgDM ha^{-1}, respectively, Table 4.3.1.7). Any advantage cross-drilling may have provided over 150mm row spacing was not sufficient to bring about an increase in herbage mass.

Measurements of the 75mm treatment were scaled down after 393 d.a.s.. Those measurements which were taken show that the composition of herbage mass in fescue and ryegrass was not influenced by drilling method at 576 d.a.s.. Composition and mass was also found to be independent of drill method at 684 d.a.s. (Table A3.9, Appendix 3). This suggests that the advantage provided by narrow row spacing to fescue did not persist throughout the trial.

Herbage accumulation from different drill methods was again not consistent between fescue and ryegrass during the second period or over the entire production phase (Table 4.3.1.7). Standard 150mm row spacing appeared to have accumulated more herbage than where an extra pass of the drill had been made in the fescue sward. Although the converse appeared to have occurred in the ryegrass sward, herbage accumulation was similar for cross-drilling and 150mm row spacing. When these results were combined in the overall analysis, the drill effects effectively cancelled each other out (Table 4.3.1.6). The herbage mass present before grazing was on average unaffected by drill method for both species for the entire production phase (Table 4.3.1.9) but there was an indication that fescue in 150mm rows was grazed to lower levels than where it was cross-drilled whereas the converse was true for ryegrass. This effect was strongest in period two (Table A3.12, Appendix 3). The results suggest a palatability contrast for drill treatment, dependent on species. Higher levels of clover and / or less dead material might improve herbage acceptability and result in lower post-graze herbage mass. However, results for drill effect on herbage composition do not support this (Tables A3.14 and A3.15, Appendix 3). The fact that pre-graze herbage mass was similar for drill treatments (Tables 4.3.1.8, A3.12, Appendix 3, and 4.3.1.9) and that the mass of sown species for fescue and ryegrass at 496, 576 and 684 (Table A3.9) was also unaffected by drilling method, suggests that cross-drilling and 150mm row spacing produced similar amounts of herbage. Comparative results of cross-drilling vs 150mm row spacing are distinct from the increase in pre-graze herbage mass recorded in conjunction with higher herbage accumulation for fescue in 75mm rows.

With the exception of 75mm row spacing in fescue, sward composition and herbage accumulation were independent of drill method. Well balanced, relatively weed free pasture swards were achieved regardless of drilling method.

4.3.1.4 Summary

The proportion of unsown species was higher in the fescue sward than the ryegrass sward until early in the second spring after sowing, when both fescue and ryegrass had similar contents of unsown species. This was achieved despite high weed populations initially and without using post-emergence herbicide. Increasing seeding rate had no influence on the composition of fescue or ryegrass swards (ie. ratio of sown species:clover:unsown species) during the production phase. Clover content was always higher in the fescue sward until two years after sowing when both swards had similar clover content. The degree to which clover plants grew successfully in autumn sowing of simple mixtures of temperate grasses and legumes was a function of the vigour of the sown grass species.

In the current trial pre-graze herbage mass for both ryegrass and fescue over the first summer-autumn (December to May) was 3000 to 3700 kgDMha^{-1}, 2000 to 3000kgDM ha^{-1} over winter-early spring (May to October) and 3000 to 4600 in late spring-summer (October to January). Post-graze herbage mass for fescue ranged from 1200 to 2200kgDM ha^{-1} (average 1740) for the production period. Post-graze herbage mass for ryegrass was higher than fescue during the first summer-autumn (1900 to 3000kgDM ha^{-1}) but was subsequently similar to fescue (1200 to 2500kgDM ha^{-1}). This appeared to be suitable to maintain production and feed quality in fescue. Post-graze herbage mass of ryegrass was above the 2000kgDM ha^{-1} level in summer. This was described as a critical level, above which intake and subsequent regrowth may be affected (Thom et al., 1985). This led to a decline in the quality of pasture offered at subsequent grazings (increased proportion of dead material) and a significant reduction in clover content as compared with fescue. Higher clover content in the fescue sward improved its nitrogen status and so more herbage accumulated in the fescue than the ryegrass sward. Herbage of the fescue sward was no less acceptable than herbage of the ryegrass sward.

It seems that reducing row spacing was of benefit to herbage accumulation in fescue but did not provide an advantage for ryegrass. Despite the increased ground cover and reduced in-row population achieved by cross-drilling as compared with 150mm row spacing, no obvious benefits in terms of weed suppression or improved contribution of sown species were sustained for either fescue or ryegrass under rotational grazing with dairy cattle.

5. Row Spacing, Seeding Rate and Nitrogen Interactions in Tall Fescue Swards Established by Direct Drilling

5.1 Introduction to Experimental Procedure

Farmers have a range of management options when considering pasture establishment by direct drilling including species, seeding rates and drilling method, as shown in the main trial. Another is fertiliser application. Results from the main trial showed that cross-drilling provided no advantage, in terms of herbage composition and mass, over the more common 150mm row spacing. Nonetheless, nutrient levels may influence plant response to spatial arrangement (Donald, 1963). It was felt that the possibility of an interaction between plant spatial arrangement and nutrient levels (particularly nitrogen) could not be discounted. Sown species may benefit from a more equidistant distribution of seed if nutrients were less limiting than light. It is possible sown species may be favoured in drill treatments which provide a more equidistant distribution compared with those in which plants are more widely spaced, if nutrients are applied at establishment. However, it is also well understood that plants will respond to nitrogen irrespective of plant arrangement, as will the unsown component of the sward. In summing up a series of pasture establishment experiments, Brougham (1954d) suggested that a study of the effect of artificial nitrogen, applied at various stages in the development of pastures under conventional cultivation, would be of particular interest. It was considered interesting to see if the same could be said for development of direct drilled pastures. There have been few reports on work of this nature. For example, was it possible to maximise the light-harvesting potential of cross-drilled plants by providing nitrogen? Or would the money saved by not cross-drilling ($50-60 per hectare, Fleming and Burtt, 1993) better spent on nitrogen fertiliser?

A second field trial was therefore established in the autumn of 1991 and ran concurrently with the main trial. This investigated the interactions between the application of nitrogen at sowing, drill methods and seeding rate, specifically herbage composition and accumulation . Fescue had shown some response to drill method and seeding rate treatments in the main trial (eg. drill method x species interaction at 150 d.a.s., Section 4.1.5.3) whereas the herbage composition and mass of the establishing ryegrass sward was relatively independent of plant spatial arrangement and population. Therefore fescue was the only species used for the nitrogen trial.

5.2 Methods and Materials

5.2.1 Description of Trial Site

Location

The second field experiment described in this chapter and Chapter six occupied the whole of paddock 86 (1 ha) at No. 4 Dairy Farm, Massey University. Palmerston North, New Zealand, situated 2.5km south of the main University Campus (latitude 40° 23' S, longitude 175° 37' E). Altitude was similar to the main field trial at approximately 40m above sea level. State Highway 57 was approximately 150m to the South-West. Weather data for the trial period was acquired from the same meteorological station used for the main trial which was located approximately 3km north of the nitrogen trial site and operated by the New Zealand Pastoral Agriculture Research Institute Ltd (AgResearch).

Soil Type

The soil type was Ohakea silt loam (Cowie, 1978). It is classified as an Aeric Fragiaqualf (gleyed yellow-grey earth), the youngest example in the area (Cowie, loc cit). It occurs on the lowest terrace (Ohakea terrace) on the river flats of the Manawatu River. The trial area was adjacent to one of its tributaries. Natural drainage was reported to be poor, and gley features, such as subsurface grey or brownish grey horizons with mottles and concretions, were prominent. The profile of the area on which the nitrogen trial was established had a dark greyish weakly structured brown silt loam topsoil to a depth of 200mm, overlying 180mm of greyish brown heavy silt loam with some yellowish brown mottles and few concretions. This graded through to pale grey compact subsoil with many distinct yellowish-brown mottles and clay accumulation. A very compact and hard parent material apparently occurred 600 to 900mm below the surface of the soils of the terraces of the Manawatu River. This is commonly called the fragipan. This slows the downward drainage of rainwater through the soil. The soils may dry out for several months of the summer but in winter a perched water table was likely to be present. Artificial drainage (tile drainage) was installed in the area in the year prior to establishing the trial and mole drainage had been carried out since then. The soil type was much heavier than that used for the main trial. A further site on Manawatu fine sandy loam was not available at that time.

The resident species consisted of a ryegrass / white clover based pasture with some Yorkshire fog (*Holcus lanatus* L.), cocksfoot (*Dactylis glomerata* L.) and *Poa* spp also present and the main broadleaf weed was giant buttercup (*Ranunculatus acris* L.). The pasture had become 'open' due to pugging damage on the area received during several winters prior to the installation of drainage.

The trial area had previously received annual autumn maintenance dressings of 30, 30 and 15 kg/ha of phosphorus, potassium and sulphur, respectively as 15% Potassic Longlife Super. Soil tests taken over the trial area just prior to sowing indicated a good phosphate fertility (Olsen P 25). The soil had very low exchangeable potassium levels with medium exchangeable magnesium (Cornforth and Sinclair, 1984). The average pH in the upper 75mm of soil was 6.0. Land use was mainly dairying, with limited cropping.

Site Preparation

The paddock required for the trial was sprayed on 4 April 1991 with 6l/ha Roundup® (2.16kgha^{-1} glyphosate as active ingredient) on actively growing, existing vegetation which had been allowed to 'recover' after grazing. A relatively high rate of Roundup® was used to ensure a good kill of existing vegetation. Less importance was placed on clover establishment in this trial as compared to the main trial, so a herbicide which was particularly active against clover was not added. The paddock was grazed and harrowed prior to sowing as for the main trial (Section 3.2).

5.2.2 Experimental Design and Treatments

Initially, three drilling methods, two seeding rates and ± nitrogen treatments were planned for this trial. However, due to a combination of damp conditions and a slightly sloping site, it was not possible to direct drill in 75mm rows because the openers of the second pass were constantly slipped into the grooves made by the first pass of the drill. So the combination of two drilling methods, two seeding rates and ± nitrogen treatments were factorially combined in a trial layout with four replicates in a randomised complete block design. As for the main trial, comparisons were available of seeds sown at both a constant rate per unit area and constant rate per unit row length. Plots which were to have been sown at 75mm row spacing were treated as headland area from then on. Sowing was delayed until 3 May, 1991 because of wet weather. Rainfall during April 1991 was twice the 30 year average (Figure A2.2, Appendix 2).

Plots were 7m x 7m with a 6 m buffer between each plot in the trial (Figure 5.2.1). Each block covered 0.23 ha. Four replications were used such that the whole paddock was covered to ease later grazing management. The end result was;

2 seeding rates x 2 drilling methods x ± nitrogen x 4 replications = 32 plots.

Treatment Descriptions

<u>Nitrogen</u>

Two nitrogen treatments were applied at sowing:

A number of recommendations have centred on applying nitrogen fertiliser as a broadcast application 2-4 weeks after grass seedlings have emerged (O'Connor and Feyter, 1987). This has been to avoid the possibility of germination injury where ammonia-producing (acidic) fertilisers are drilled with the seed ie. nitrogenous fertiliser applied "down the spout" (Mason, 1971, 1985; Menzies, 1982a; Baker and Afzal 1986). However, targeted application of nitrogen has been recommended to maximise uptake by the introduced grass seedlings either by placing the fertiliser near the seed or timing the application (or release) to coincide with seedling emergence (Pollock, 1989). The former option was chosen because banding fertiliser with seed may make less nitrogen available to unsown species which colonise inter-row spaces and previous work by Baker and Afzal (1981) had shown marked responses by maize to nitrogenous fertiliser placed close to the seed at the time of direct drilling compared with broadcast application.

Lime (Calcium) Ammonium Nitrate (CAN), a granulated fertiliser (27:0:0:0:), was applied with the seed. This was not injurious to seed as this formulation of nitrate fertiliser has a neutral reaction in the soil and nitrogen is rapidly available for uptake by plants (Menzies, 1982b). A rate of 110kg CAN ha^{-1} (30kgN ha^{-1}) was chosen as the cost of this was \$60 ha^{-1}, equivalent to one pass of a direct drill.

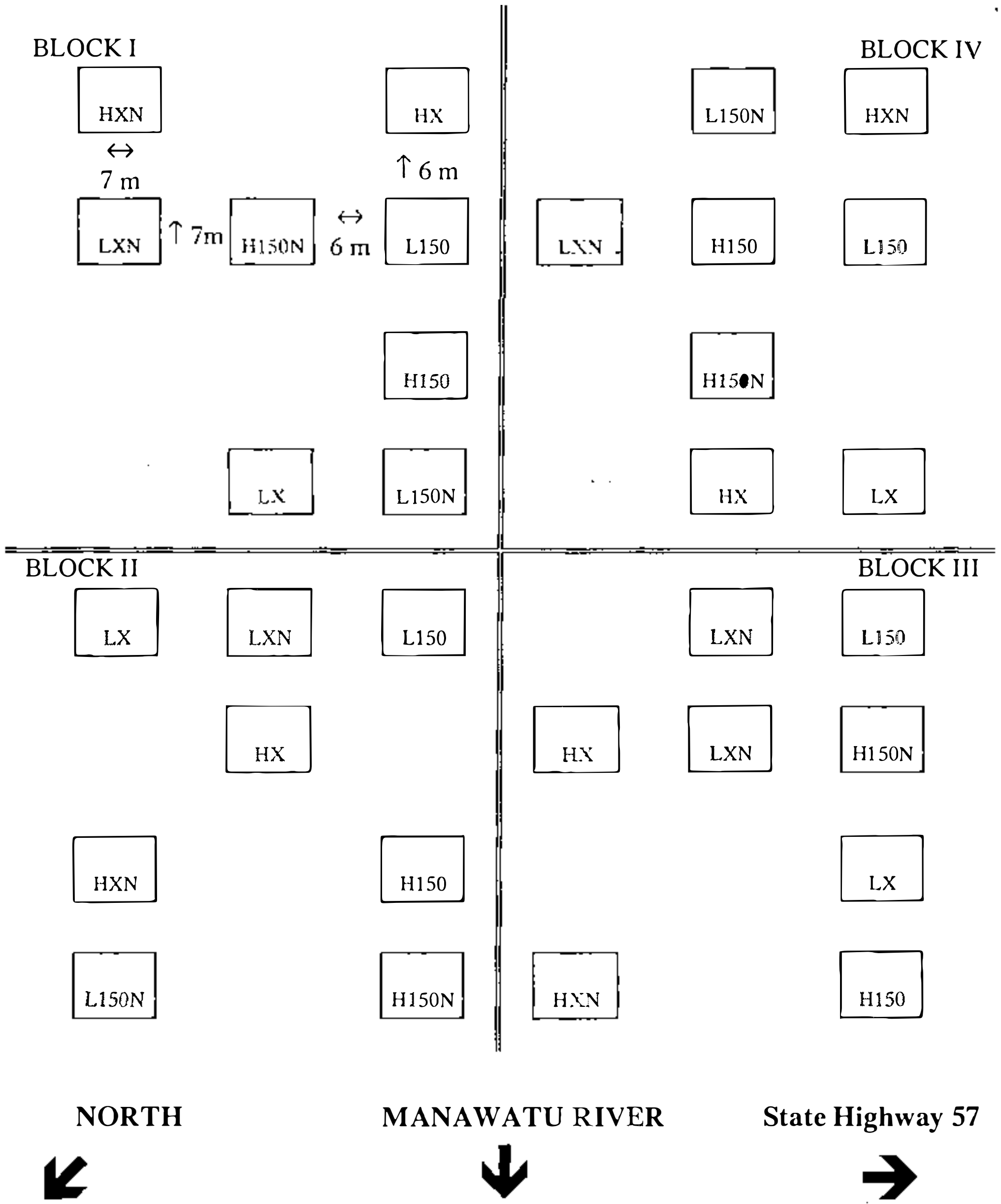
Drilling Method

The two drilling methods were:

Single pass drilling at 150mm row spacing; two pass drilling at 150mm row spacing in a diamond pattern, with the second pass of the drill crossing the first at 30°, which is the treatment referred to as cross-drilling. Narrow row spacing (75mm) was not possible in the nitrogen trial as described above. Sowing direction for the 150mm row spacing treatment and for the first pass of the cross-drill treatment was approximately east-west.

The same seed drill used in the main trial was used for the nitrogen trial (Aitchison seedmatic 1100 series with "Baker boot" inverted T openers) and in the same manner as for the main trial ie. a "run in" of at least 1 metre.

Figure 5.2.1 *Layout of Trial plots (not to scale) with Main Plots Differentiated by Double Lines*



Note * N = nitrogen application at drilling

* 150 = 150mm row spacing X = Cross-drilling
* L = Low seed rate, H = High seed rate
* Empty spaces show where the 75mm row spacing treatments were to have been sown

Seeding Rate

Two seeding rates were used based on target populations of:

500 plants m^{-2} for low seeding rate and 1000 plants m^{-2} for high seeding rate as for the main

trial.

As for the main trial, this trial was sown with "AU Triumph" tall fescue. Table 5.2.1 describes the desired and actual seed rates used in the trial along with the average number of viable seeds sown for each treatment. Desired seed rates were calculated on the basis of seed weight of 2.43 mg seed^{-1} of "AU Triumph' and expected field emergence of 75% (85% expected field emergence minus 10% to accommodate mid to late autumn sowing time) and 66% germination percentage for tall fescue seed (tested at Seed Technology Centre, Massey University). Seed was treated with fungicide (120g of 80% captan 100kg^{-1} of seed).

Table 5.2.1 Target Seeding Rate and Seeding Rate Achieved for Fescue

		DESIRED		*ACTUAL*		
SEEDING RATE	**Drill Method**	kg ha^{-1} of viable seed	Viable Seeds m^{-2}	kg ha^{-1} of viable seed	Viable Seeds m^{-2}	Viable Seeds m^{-1} row
High	Cross Drill	32	1320	35	1450	108
	150 mm rows	32	1320	30.5	1260	188
Low	Cross Drill	16	660	20	810	61
	150 mm rows	16	660	16.5	670	100

Grass seed output from the drill was required to be altered 4 times during sowing so drill calibration was carried out the day before drilling and the required output positions were marked on the seed adjustment quadrant to minimise delays in the field. A check of grass seed output was made just prior to drilling by collecting the seed from four openers which was later weighed to determine actual seeding rate. As in the main trial, a discrepancy between desired and actual seeding rate was recorded during the drilling of the nitrogen trial (Table 5.2.1).

White clover (*Trifolium repens*) cv 'Grasslands Kopu' and Phorate® granular insecticide (200 g/kg phorate) were sown at a constant rate of 3kg ha^{-1} and 5kg ha^{-1}, respectively, in the same manner as for the main trial (Section 3.3) (ie. "down the spout"). No spillage of clover seed form seed tubes was noticed during drilling. Germination of clover had been previously found to be unaffected by contact with Phorate® during drilling (Table A1.9, Appendix 1). Plots were harrowed after drilling and 10kg ha^{-1} granular Blitzem® molluscicide (27g/kg metaldehyde) was broadcast onto drilled areas within 24 hours of drilling to control slugs. Headlands were sown with the same species as the plots at a median seed rate. Figure 5.2.2 shows the trial paddock at 126 d.a.s. (12 September, 1991).

Figure 5.2.2 *Trial Paddock at 126 d.a.s. (12/9/91)*

5.2.3 Fertiliser Policy and Weed Control

Maintenance levels of non-nitrogenous fertiliser were applied as normal farm practice in April. This was 350kg ha^{-1} 0.9.8.7 (31, 28, 24kg ha^{-1} of phosphorus (P), potassium (K) and sulphur (S), respectively) as 15% Potassic Longlife Super. No lime was applied during the experimental period, as the pH was relatively stable at 5.8-6.0. All soil tests were carried out by the Fertiliser and Lime Research Centre at Massey University.

In order to observe weed growth that may have occurred in response to the various treatments, no post emergence herbicide was used so that sown species were in competition with spontaneously appearing weeds.

Irrigation facilities were not available.

5.2.4 Grazing Management

All defoliations were carried out by yearling dairy heifers. As this trial was concerned with the establishment phase, only four grazings took place at approximately 30 day intervals. As with the main trial, two-wire temporary electric fences were used to confine cattle to one block.

Table 5.2.2 shows the schedule for grazing and topping in terms of d.a.s. and calender date.

Table 5.2.2 Schedule for Grazing and Topping

d.a.s.	Date	Grazing	Topping	Sward Measurement
		Heifers	Disc Mower	Herbage Composition and Mass
154	7 October 1991	√	√	√
182	5 November 1991	√		
213	6 December 1991	√		√
249	12 January 1992	√		√

Grazing usually took place over three to four days with approximately 100 x yearling heifers (300-350 kgs liveweight, 400 heifers/ha equivalent). Cattle were removed from an area when a target stubble height of 40-70mm was reached, usually within 24 hours. The sequence in which blocks were grazed was the same throughout the study period. The first grazing in early October was not grazed to an acceptable stubble height so topping was carried out with a disc mower to a height of 80mm. This cut fescue seedheads but was above most of the fescue stubble.

5.2.5 Sampling Procedure

5.2.5.1 Emergence of Sown Grass Seed

Emergence of sown seed was assessed at 45 d.a.s.. The numbers of emerged seedlings per 0.4m row for 150mm row spacing treatment and for the three positions within the cross-drilled treatment using the template described in Figure 3.6.2. were counted at six positions. The position of the rod used for measuring 0.4m row and the template was determined by random number tables as described in Section 3.6.1.

5.2.5.2 Clover and Weed Emergence

The number of clover plants, broadleaf and grass weeds were counted at 51 d.a.s. in the same manner used for the main trial ie. 3 quadrats, 0.2 x 0.35m, (0.07 m^2) per plot positioned using random number tables.

5.2.5.3 Individual Seedling Weight

Seedlings from three 0.6m row lengths per plot were collected at 53, 67, 87 and 121 d.a.s.. The numbers of plants per 0.6m row were counted at 53, 67 and 87 d.a.s. and then plants from 0.6m row were cut off at ground level with a scalpel. At 121 d.a.s. tiller numbers as opposed to plant numbers, were recorded because individual plants were difficult to distinguish. The template used for determination of population in the cross-drilled plots was used for collecting seedlings from the three positions described in Figure 3.6.1. Thus the total weight of seedlings collected per unit row length was comparable for both 150mm and cross-drilled treatments (0.6m each). The location of samples was determined by random number tables. Seedling weight (shoot dry weight) was determined by weighing after drying in a forced air oven at 84° for 24 hours.

5.2.5.4 Herbage Mass

Herbage mass was determined in a manner similar to that used for the main trial (Section 3.6.7) at 154, 182, 213 and 249 d.a.s. (Table 5.2.2). Estimates of herbage mass per plot were derived from weighted means of quadrat measurements made on 'High', 'Low' and Medium' areas and placed to avoid dung and/or urine soiled areas or previously cut areas (3 quadrats for each plot). Long narrow quadrats (0.165 x 0.910m, 0.15 $m^{2)}$ placed perpendicular to drill rows were used as for the production phase of the main trial.

5.2.5.5 Botanical Composition

Botanical dissections of pre-graze herbage samples were carried at 154, 182, and 249 d.a.s. (Table 5.2.2). Samples were processed in a similar manner to that used in the main trial (Section 3.6.8).

5.2.6 Statistical Analysis

Generally the data were analysed as a factorial set with nitrogen, drilling method and seeding rate combinations allocated to main plots. Where 'Position' of plants was included in the analysis of seedling weight, data were analysed as a split plot. The Genstat® 5 statistical analysis software package (Lawes Agricultural Trust, Rothamsted Experimental Station) available on the Sun network at Massey University was used for analyses in conjunction with a basic program developed by Mr G.C. Arnold, Statistics Department, Massey University. The data from seedling weight showed a non-normal distribution. Log10 transformation was used to reduce this problem. Backtransformed values are presented unless stated otherwise, with S.E.D.s converted to percentage values.

When the F test for a particular source of variance as indicated by the analysis of variance was significant at or below the 5% level of probability, treatment means were separated by calculating least significant differences (Little and Hills, 1978) as for the main trail. Mean relative growth rates were calculated in the same manner as for the main trial (Section 3.6.3).

5.3 Results and Discussion

5.3.1 Introduction

The objectives of this study were to investigate the interactions between the application of nitrogen at sowing and drill methods and seeding rate. Interactions between drilling methods and nitrogen were expected to provide the most useful data of the study. For example, nitrogen application may improve the competitive ability of plants in cross-drilled rows against the increase in unsown species which were found to feature more than where 150mm row spacing was used in the main trial. This may improve the position of sown species in the developing sward.

As for the main trial, the nitrogen trial is described in three time periods although they are shorter in duration. Sections 5.3.2.1 and 5.3.2.2 describe emergence of sown and unsown species and population from sowing until 87 d.a.s.. Section 5.3.2.3 describes plant growth from 53 to 121 d.a.s.. Herbage production and botanical composition were assessed from 154 until 249 d.a.s. and are presented in Section 5.3.2.4.

The main or overall effects provided by nitrogen, seeding rate and drilling method are presented prior to discussing the interactions, since the main effects were reasonably consistent. This order of presentation is used for each set of measurements. The reduced size of the nitrogen trial in comparison to the main trial meant that all overall effects could be tabulated. All significant differences between main treatments and interactions between main treatments are reported at the 0.05 level of probability or less, unless otherwise stated.

5.3.2 Results

5.3.2.1 Tall Fescue Seedling, Clover and Unsown Species Emergence and Population

5.3.2.1.1 Overall Nitrogen, Seeding Rate and Drill Method Effects

Seedling emergence is quoted as a nominal figure as for Section 4.1.1. The population of grass seedlings was recorded on four occasions between 45 and 87 d.a.s.. Table 5.3.2.1 describes main treatment effects on both in-row (plants m^{-1} row) and area (plants m^{-2}) seedling population. The population of seedlings peaked at 53 d.a.s. so nominal percentage seedling emergence as a percent of viable seeds sown was based on those values (as at 26 June, 1991).

Overall, 54% of viable fescue seeds had emerged by 53 d.a.s.. Neither nitrogen, seeding rate nor drilling method influenced percentage seedling emergence. Not surprisingly plots sown at the high seeding rate had a higher population of seedlings than those sown at the low seeding rate although the difference declined with time due to a loss of plants on plots sown at the high seeding rate. The seedling population of cross-drilled areas was approximately 10% higher than that on areas sown at 150mm row spacing, and the difference was significant at each measurement time from 45 to 87 d.a.s. (Table 5.3.2.1). It appears that the emergence of cross-drilled treatments had peaked by 45 d.a.s. but emergence may have continued in 150mm rows until 53 d.a.s.. However, subsequent population counts (67 and 87 d.a.s.) showed a similar magnitude in variation and trend between successive counts although at a lower population levels. There were no significant interactions between nitrogen, seeding rate or drilling method treatments.

Table 5.3.2.1 Effects of Nitrogen, Seeding Rate and Drilling Method on Population of Seedlings at 45, 53, 67 and 87 d.a.s. and on Percentage Emergence at 53 d.a.s.

NITROGEN	Population at 45 d.a.s. †	Population at 53 d.a.s.	Nominal Seedling Emergence (%) at 53 d.a.s.	Population at 67 d.a.s.	Population at 87 d.a.s.
With	562 (50)	623 (56)	56	482 (43)	496 (45)
Without	602 (53)	595 (54)	52	469 (41)	533 (48)
S.E.D. ±	30 (3.0)	27 (1.7)	3.2	38 (2.0)	44 (2.4)
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
SEEDING RATE					
High	783 (69)	801 (72)	56	578 (52)	602 (55)
Low	380 (34)	417 (38)	52	372 (32)	427 (38)
S.E.D. ±	30 (3.0)	27 (1.7)	3.2	38 (2.0)	44 (2.4)
Significance	* * *	* * *	n.s.	* * *	* * *
DRILL METHOD					
Cross Drill	634 (48)	641 (48)	55	516 (38)	545 (41)
150 mm rows	424 (64)	514 (77)	53	354 (53)	423 (63)
S.E.D. ±	34 (3.5)	31 (1.9)	3.5	44 (3.4)	50 (2.8)
Significance	* * *	* * *	n.s.	* * *	*

† plants m^{-2}; plants m^{-1} row in parenthesis

5.3.2.1.2 Effect of Position in the Cross Drill Treatment on Population and Seedling Emergence

Table 5.3.2.2 describes the effect of position on population of seedling grass plants at 45, 53, 67 and 87 d.a.s. and nominal percentage seedling emergence at 53 d.a.s.. As for the main trial, the number of seeds sown in the each of the three row sections of the cross-drilled plots was potentially the same, allowing accurate comparisons of emergence percentages for seeds sown at different in-row densities. Significantly higher emergence was evident from the angle[1] portion of the cross drill rows than at the intersection of the rows. In-row population was significantly higher in the angle portion than at the intersection at 45, 53 and 87 d.a.s. whereas the in-row population of the straight portion was intermediate between the other two portions.

Table 5.3.2.2 Effect of Position (Within the Cross Drill Treatment) on Population of Seedlings at 45, 53, 67 and 87 d.a.s. and on Percentage Emergence at 53 d.a.s.

POSITION	Population at 45 d.a.s. †	Population at 53 d.a.s.	Nominal Seedling Emergence (%)	Population at 67 d.a.s.	Population at 87 d.a.s.
Intersection	585 (44)	561 (42) a	48 a	487 (36)	453 (34) a
Straight	610 (46)	636 (48) ab	53 ab	526 (39)	511 (38) ab
Angle	708 (53)	725 (54) b	61 b	533 (40)	671 (50) b
S.E.D. ±	45 (3.7)	47 (2.3)	4.4	54 (2.6)	60 (2.9)
Significance	*	*	*	n.s.	**

- † plants m^{-2}; plants m^{-1} row in parenthesis

The objective of establishing comparative swards sown at both a constant seed rate per unit row length, and a constant seed rate per unit area was not as closely met in the nitrogen trial as in the main trial. The in-row population of cross-drilled rows sown at the high rate was higher than the in-row population of 150 mm rows sown at the low rate at 45, 53 and 67 d.a.s. but was similar at 87 d.a.s.. Population on a area basis was always different within seeding rates for the two drill methods (Table A4.6, Appendix 4).

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[1]The three portions of the cross-drilled rows are described in Figure 3.6.1

5.3.2.2 Seedling White Clover, Broadleaf Weed and Grass Weed Populations

5.3.2.2.1 Overall Nitrogen, Seeding rate and Drill Method Effects

The populations of seedling white clover, broadleaf weeds and grass weeds were recorded 49 d.a.s.. Germination of clover seed was 91 % as tested by the Seed Technology Centre, Massey University. Thousand seed weight of white clover was 1.24g so 340 viable seeds m^{-2} were distributed in all treatments. New clover seedlings were distinguishable because regrowth of resident clover arose from stolons and did not have cotyledons or simple leaves, only "true" trifoliate leaves (Langer 1982). Only new clover seedlings on or close to the drill row were counted. Giant buttercup, annual mouse eared chickweed and annual *Poa* were the most abundant weed types so were given individual categories. Although toad rush was an obvious weed later at the first grazing (Table 5.3.2.11), it was not noticeable at the time when the weed population was determined.

Table 5.3.2.3 shows the overall effect of seeding rate and drilling method on the seedling population of clover, giant buttercup, annual mouse eared chickweed, annual poa, other broadleaf weeds and "Total Unsown", which did not include clover seedlings. Dock (*Rumex obtusifolius* L.), cocksfoot and volunteer ryegrass were included in the category "other broadleaf weeds" as there was only a small number of those species. Nitrogen had no effect on emergence of white clover or any unsown species so details are located in Table A4.1. Appendix 1.

Table 5.3.2.3 Effect of Seeding Rate and Drill Method on Population of White Clover and Unsown Species Seedlings at 49 d.a.s. (22/6/91)

		UNSOWN SPECIES (plants m^{-2})				
SEEDING RATE	**WHITE CLOVER** (plants m^{-2})	Buttercup	Mouse eared chickweed	Other Broadleaf Weeds	Annual Poa	Total Unsown
High	165	20	31	37	200	288
Low	191	18	33	41	273	365
S.E.D. ±	17	4.6	6.3	7.7	31	31
Significance	n.s.	n.s.	n.s.	n.s.	*	*
DRILL METHOD						
Cross Drill	183	24	40	41	247	352
150mm	173	14	23	36	227	300
S.E.D. ±	17	4.6	6.3	7.7	31	31
Significance	n.s.	*	*	n.s.	n.s.	(*)

Emergence of clover seedlings was unaffected by seeding rate or drilling method. On average 178 white clover plants m^{-2} became established (52% nominal emergence of viable seed).

A higher number of buttercup and mouse eared chickweed established under cross-drilling than 150mm row spacing but the total unsown species was only marginally increased by cross-drilling (significant at 10% probability). However, the total unsown species was significantly higher where plots were sown at the low seeding rate as compared with the high seeding rate. This was mainly due to the higher number of annual poa seedlings present in the low seeding rate treatment.

There were no significant interactions between main treatments.

5.3.2.3 Treatment Effects on Fescue Shoot Weight and Tiller Number and Weight

5.3.2.3.1 Overall Nitrogen, Seeding rate and Drill Method Effects on Shoot Weight

The shoot weight of seedlings was derived from records of the number and weight of seedlings (above ground weight) per 0.6m row catalogued at 53, 67 and 87 d.a.s.. Table 5.3.2.4 compares the effects of nitrogen, seeding rates and drilling methods on shoot weight at 53, 67, and 87 d.a.s..

Seeding rate had no effect on shoot weight until 87 d.a.s. at which point plants sown at the high seeding rate were significantly lighter than those sown at the low rate. Drilling method did not influence shoot weight in the first 87 d.a.s.. Nitrogen had little effect on shoot weight, although there was an indication that applying some nitrogerr increased shoot weight at 67 d.a.s., but this was not sustained (Table 5.3.2.4).

The shoot weight of seedlings collected from the three positions within the cross-drilled treatment were not significantly different at 53, 67 or 87 d.a.s. (Table A4.2, Appendix 4). Once again no significant interactions were found between main treatments.

Table 5.3.2.4 Effect of Nitrogen, Seeding Rate and Drill Method on Shoot Weight at 53, 67 and 87 Days After Sowing (mg/plant)

	Days After Sowing		
NITROGEN	53	67	87
With	6.83	13.4	30
Without	6.41	11.4	29
S.E.D. ±	0.347	1.2	2.0
Significance	n.s.	(*) Fpr = 0.1	n.s.
SEEDING RATE			
High	6.39	12.0	27
Low	6.86	12.7	31
S.E.D. ±	0.347	1.2	2.0
Significance	n.s.	n.s.	* *
DRILLING METHOD			
Cross drill	6.67	12.2	29
150 mm row	6.45	12.8	31
S.E.D. ±	2.4	1.4	2.4
Significance	n.s.	n.s.	n.s.

5.3.2.3.2 Overall Effect of Nitrogen, Seeding Rate and Drill Method on Mean Relative Seedling Growth Rate

Table 5.3.2.5 compares the effect of nitrogen, seeding rate and drill method on mean relative seedling growth rate ($\log_{10}$ transformed data). Relative growth rate (RGR) from 0 to 53 d.a.s. was calculated from the shoot weight minus seed weight divided by 53 days. RGR for subsequent periods (53 to 67 d.a.s. and 67 to 87 d.a.s.) were calculated from shoot weight and time data according to the equation described in Section 3.6.3. There were no significant main or interactive effects on relative growth rate up to 87 d.a.s.. There was no significant interaction between main treatments.

Table 5.3.2.5 Effect of Nitrogen, Drill Method and Seeding Rate on the Mean Relative Growth Rate of Fescue and Ryegrass up to 87 Days After Sowing ([mg mg^{-1}]day^{-1})

	Days After Sowing		
NITROGEN	0 - 53	53 - 67	67 - 87
With	8.4 †	21	17
Without	7.9	18	20
S.E.D. ±	0.42	3.4	2.5
Significance	n.s.	n.s.	n.s.
SEEDING RATE			
High	7.9	19	17
Low	8.5	19	20
S.E.D. ±	0.42	3.4	2.5
Significance	n.s.	n.s.	n.s.
DRILL METHOD			
Cross drill	8.3	19	19
150 mm row	8.0	21	19
S.E.D. ±	0.48	3.9	2.9
Significance	n.s.	n.s.	n.s.

- † all values transformed data ($\log_{10}$) multiplied by 10^3

5.3.2.3.4 Overall Nitrogen, Seeding Rate and Drill Method Effects on Tiller Number and Weight

At 121 d.a.s. it was difficult to distinguish between individual plants so the number of tillers per 0.6m row was recorded. Thus comparisons of tiller weight are made at 121 d.a.s. rather than shoot (plant) weight. Table 5.3.2.6 describes the effect of nitrogen, seeding rate and drill method on tiller number m row^{-1} and m^{-2}, tiller weight and weight of tillers m^{-2} at 121 d.a.s.. Nitrogen had no influence on tiller weight or number. Increasing the seeding rate increased the weight of tillers per m^{-2} by 20% through an increase in tiller number rather than an increase in individual tiller weight, and the difference was significant. The weight of tillers m^{-2} was significantly higher on cross-drilled plots than on plots sown in 150mm rows by 10%. This was also a result of higher number of tillers m^{-2}.

Table 5.3.2.6 Effect of Nitrogen, Seeding Rate and Drill Method on Tiller Number m row^{-1} and m^{-2}, Tiller Weight and Weight of Tillers m^{-2} at 121 Days After Sowing

NITROGEN	Tiller Number tillers m^{-2} (tillers m^{-1} row)	Tiller Weight (mg $tiller^{-1}$)	Weight of Tillers (g m^{-2})
With	2114 (193)	26.6	56.2
Without	2233 (198)	24.8	55.4
S.E.D. ±	133 (13)	1.40	4.71
Significance	n.s. (n.s.)	n.s.	n.s.
SEEDING RATE			
High	2404 (220)	25.5	61.3
Low	1944 (173)	25.9	50.3
S.E.D. ±	133 (13)	1.40	4.71
Significance	** (**)	n.s.	*
DRILLING METHOD			
Cross drill	2298 (171)	26.1	59.9
150 mm row	1801 (270)	24.6	44.3
S.E.D. ±	153 (15)	1.63	5.44
Significance	** (***)	n.s.	**

5.3.2.3.5 Effect of Plant Position on Tiller Weight and Number

Table 5.3.2.7 describes the effect of plant position on tiller number m row^{-1} and m^2, tiller weight and weight of tillers m^2 at 121 d.a.s.. There were significantly less tillers at the 'intersections' of drill rows than there were at the 'straight' and 'between' positions although the difference was only significant at the lower order of probability (Fpr = 0.054). Despite similar individual tiller weights for all positions, the weight of tillers m^{-2} was not different.

Table 5.3.2.7 Effect of Position on Tiller Number m row^{-1} and m^{-2}, Tiller Weight and Weight of Tillers m^{-2} in the Cross-drilled Treatment at 121 Days After Sowing

POSITION	Tiller Number tillers m^{-2} [tillers m^{-1} row]	Tiller Weight (mg tiller^{-1})	Weight of Tillers (g m^{-2})
Intersection	2025 a [152] a	26.4	53.5
Straight	2449 b [184] b	25.6	62.7
Between	2421 b [181] b	26.4	63.9
S.E.D. ±	188 [18]	2.01	6.16
Significance	(*) [(*)]	n.s.	n.s.
	Fpr = 0.054		

5.3.2.3.6 Interactive Effect of Seeding Rate and Drill Method on Tiller Weight and Number

Table 5.3.2.8 describes the interactive effect of seeding rate and drill method on tiller number m row^{-1} and m^{-2}, tiller weight at 121 d.a.s. and weight of tillers m^{-2} at 121 d.a.s.. There was an interaction between seeding rate and drilling method on tiller weight and tillers m^{-1} row. Tiller number and weight was influenced by seeding rate when sown in 150mm rows but no significant effect was recorded in the cross-drilled plots. Higher seeding rate increased tiller number and reduced tiller weight of seedlings in 150mm rows.

Table 5.3.2.8 Interactive Effect of Seeding Rate and Drill Method on Tiller Number m row^{-1} and m^{-2}, Tiller Weight and Weight of Tillers m^{-2} at 121 Days After Sowing

DRILL METHOD	SEEDING RATE	Tiller Number tillers m^{-2} [tillers m^{-1} row]	Tiller Weight (mg tiller^{-1})	Weight of Tillers (g m^{-2})
Cross Drill	**High**	2499 [186] a	26.6 a	66.5
	Low	2067 [156] a	25.5 a	53.5
150mm rows	**High**	2119 [316] b	22.3 b	48.0
	Low	1483 [221] a	27.0 a	40.0
S.E.D. ±	150 with 150 §	266 [26.0]	2.99	9.42
for	150 with Cross	217 [21.1]	2.34	7.69
comparing	Cross with Cross	153 [15.0]	1.638	5.44
	Significance	n.s. [*]	(*) Fpr = 0.066	n.s.

§ Note that comparisons involving cross drilled treatments have lower S.E.D. because means are drawn from a larger sample number (three samples for each treatment, from separate positions).

5.3.2.3.7 Effect of In-row Population on Seedling and Tiller Weight

Linear regression analyses of the average shoot weights of 10 plants at 53, 67 and 87 d.a.s. as a function of the population (average plot population, plants m^{-1} row) were carried out. Analysis the average weight of 10 tillers at 121 d.a.s. as a function of in-row population as at 87 d.a.s. was also carried out. Data were pooled from all nitrogen, drilling method and seeding rate combinations. In-row population (plants m^{-1} row) rather than population on an area basis (plants m^{-2}) was used for the above analysis as that was previously found to have the most consistent relationship with shoot weight (Section 4.1.4.2.1.4).

Table 5.3.2.9 describes the effect of in-row population on tiller weight at 121 d.a.s.. In-row population had no influence on shoot weight 53, 67 and 87 d.a.s. (Table A4.11, Appendix 4). However, tiller weight at 121 d.a.s. decreased significantly as population increased in the range 20 to 120 plants m^{-1} row.

Table 5.3.2.9 Effect on In-row Population on Tiller Weight at 121 d.a.s.

	Weight of 10 Tillers (g)
d.a.s.	121
mean	0.266
slope of regression line	-0.0072
S.E.D. ±	-0.001
significance	* * *
r^2	0.29

5.3.2.4 Treatment Effects on Herbage Composition and Mass

5.3.2.4.1 Overall Nitrogen, Seeding Rate and Drill Method Effects at 154 d.a.s.

Table 5.3.2.10 describes the overall effect of nitrogen, seeding rate and drill method on herbage composition and mass. Variation of nitrogen and drill method did not influence herbage composition or mass. Increasing the seeding rate significantly increased the mass of sown species at 154 d.a.s.. The mass of clover and unsown species was not influenced by seeding rate.

Table 5.3.2.10 Effect of Nitrogen, Drill Method and Seeding Rate on the Herbage Composition and Mass at 154 d.a.s. (7-10-91)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
NITROGEN	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
With	43	17	40	1564	602	1475	3641
Without	49	15	36	1699	561	1305	3564
S.E.D. ±	3.5	2.5	3.5	128	90	166	188
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEEDING RATE							
High	48	14	37	1766	539	1411	3716
Low	43	17	39	1496	624	1369	3488
S.E.D. ±	3.5	2.5	3.5	128	90	166	188
Significance	n.s.	n.s.	n.s	*	n.s.	n.s.	n.s.
DRILL METHOD							
Cross drill	44	16	39	1607	618	1433	3659
150 mm row	47	15	38	1655	544	1347	3546
S.E.D. ±	3.5	2.5	3.5	128	90	160	188
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

† The category "Unsown" includes giant buttercup, toad rush (*Juncus bufonius* L.), docks, annual mouse eared chickweed, cocksfoot, annual poa, Yorkshire fog, volunteer ryegrass, annual Poa and other broadleaf weeds

5.3.2.4.2 Effect of Drill Method on Unsown Species at 154 d.a.s.

Table 5.3.2.11 describes the effect of drill method on the mass of each of the components in the unsown category. The mass and composition of the unsown species was on the whole unaffected by main treatments (Table 5.3.2.10). However, the mass of giant buttercup and toad rush in the "unsown" category was higher in the cross drilled plots compared with plots sown in 150mm rows. The effect of nitrogen and seeding rate on the mass of each of the components in the category "unsown" and main treatment effects on the total herbage mass and the mass of dead material are shown in Table A4.3, Appendix 4.

Table 5.3.2.11 Effect of Drill Method on the Mass of Giant Buttercup, Toad Rush, Other Broadleaf Weed Species and Other Unsown Grass Species at 154 d.a.s. (7-10-91)

	Yield (kgDM ha^{-1})			
	Buttercup	Rush	Weed	Other †
Cross drill	179	156	271	819
150 mm row	89	74	217	957
S.E.D. ±	49	46	71	170
Significance	(*) FPr = 0.08	(*)	n.s.	n.s.

- † The category "Other" represents other grasses and consists mainly of annual poa with some Yorkshire fog, cocksfoot, and volunteer ryegrass.

5.3.2.4.3 Overall Nitrogen, Seeding Rate and Drill Method Effects at 213 d.a.s.

Table 5.3.2.12 describes the overall effect of seeding rate and drill method on herbage composition and mass at 213 d.a.s.. Increasing seeding rate increased the proportion of sown species and decreased the proportion of unsown species in the sward. The mass of sown species and total mass of live herbage increased significantly with seeding rate, the mass of unsown species and clover was not influenced by seeding rate. There was a higher proportion and mass of unsown species in cross-drilled plots compared with those sown in 150mm rows. Significantly higher masses of other grasses and giant buttercup were responsible for that increase in unsown species (Table A4.4, Appendix 4). Nitrogen had no influence herbage mass or composition at 213 d.a.s. (Table A4.12, Appendix 4). There was no interaction between main treatments.

Main treatment effects on the mass of each of the components in the category "unsown" and on the total herbage mass and the mass of dead material are shown in Table A4.4, Appendix 4. Significant effects shown in Table A4.4 were consistent with main treatment effects. A larger mass of broadleaf weeds was present at low seeding rate compared with high seeding rate.

Table 5.3.2.12 Effect of Nitrogen, Drill Method and Seeding Rate on the Herbage Composition and Mass at 213 d.a.s. (6-12-91)

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SEEDING RATE	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
High	55.7	17.2	27.1	1572	482	774	2828
Low	43.7	21.5	34.9	1105	522	893	2520
S.E.D. ±	3.2	3.4	2.9	96	79	100	104
Significance	* * *	n.s.	*	* * *	n.s.	n.s.	* *
DRILL METHOD							
Cross drill	47.7	17.4	34.9	1327	461	961	2750
150 mm row	51.2	21.3	27.0	1350	542	706	2598
S.E.D. ±	3.2	3.4	2.9	96	79	100	104
Significance	n.s.	n.s.	*	n.s.	n.s.	*	n.s.

5.3.2.4.4 Overall Nitrogen, Seeding Rate and Drill Method Effects at 249 d.a.s.

There were no significant main treatment effects on herbage mass or composition at the last grazing of the trial at 249 d.a.s. (Table A4.13, Appendix 4). Table A4.5, Appendix 4, shows main treatment effects on each of the components of "unsown", on the mass of dead material and on the total mass of herbage at 249 d.a.s..

5.4 Discussion

Introduction

Results from the nitrogen trial support those from the main trial, in that drilling method and seeding rate had minimal effects on sward development, and confirm that the practice of cross-drilling had no agronomic benefit.

The following discussion is divided into several sections, the first outlines the effect of nitrogen and subsequent sections describe successive phases of pasture development during the trial.

Nitrogen

The lack of response of fescue to nitrogen application (30kgN ha^{-1}) was the most notable feature of the results from the trial. Nitrogen application had no effect on seedling growth, (Tables 5.3.2.4, 5.3.2.5, 5.3.2.6) botanical composition or herbage mass (Tables 5.3.2.10, to 5.3.2.12, and A4.13, Appendix 4).

This lack of response to nitrogen application was likely to have been related to the cool and moist conditions which prevailed during May to July 1991, during the early establishment phase. Rainfall for the month prior to drilling (April) was more than twice the 30 year average rainfall (162 cf. 68mm, Figure 2.2, Appendix 2) and had delayed drilling (Section 5.3). Water holding capacity in the rooting zone of the soil at the trial site was estimated to be 60mm based on the work of Scotter et al. (1979) for similar soil close to where the nitrogen trial was located (Tokomaru silt loam), so the soil would have been close to saturation at drilling. A further 138mm of rain fell during the time of early establishment (May, to August, Figure A4.1, Appendix 4) and because evapotranspiration for the period was low (estimated maximum of 44mm, Figure A4.1, Appendix 4) a considerable amount of water would have drained through the soil profile. For example, 38mm of rain fell on the 25th day after sowing.

Soil nitrogen is generally low where vegetation has been blanket sprayed prior to direct drilling, as nitrogen is immobilised by soil microrganisms (Ludecke, 1979; Keeney and Gregg, 1982). Although available soil nitrogen is immobilised or 'locked up' by this process, 30kg N ha^{-1} should have been sufficient to achieve a N response as this amount is similar to a standard N fertiliser recommendation for fescue establishment by direct drilling (Mr S. Moloney, pers comm., 1993).

Nitrate is very subject to leaching (Lynch, 1982) and the potential for leaching losses has been demonstrated by the discovery of high levels of nitrate in the ground waters from grazed pasture on this soil (Ball, 1979). Nitrate was available for leaching from the Calcium Ammonium Nitrate (CAN) at the time of drilling and, although the soil was very damp, some biological oxidation of ammonium to nitrate would be likely to have occurred at the soil surface (0-30mm) as soil temperatures were adequate for nitrification (Stevens, 1988). Thus, fertiliser nitrogen may have been lost through direct leaching as nitrate before it was taken up by establishing seedlings.

Another explanation is that soil nitrogen was adequate for emergence and subsequent growth. Ball and Field (1982) noted that a nitrogen response would not be expected in a newly establishing pasture unless soil nitrogen status was low. Some nitrogen would have been available from decaying clover nodules and root tissues (Steele, 1982). Drilling took place four weeks after spraying, so mineralisation subsequent to initial immobilisation may also have been occurring shortly after sowing (Ludeke, 1979). Declining temperatures and light levels in late autumn / early winter limit the potential for nitrogen responses by pasture plants reducing the demand for nitrogen. However, a growth response from an established pasture has been recorded from a May application of N in the Manawatu (Ball and Field, 1982).

As there was no residual response to nitrogen application later in the trial, indicating that the applied nitrogen was lost to the developing sward, it would seem that the lack of response to nitrogen was a function of both the poor growth conditions and the loss of fertiliser nitrogen via direct leaching losses as nitrate.

Nitrogen fertiliser can be phytotoxic when placed in close proximity to germinating seeds. Such toxicity may be due to local high concentrations of ammonia, or to nitrite formed during nitrification (Menzies, 1982b, Mason, 1985). Seedling emergence was not affected by nitrogen fertiliser (Table 5.3.2.1) suggesting that the addition of 30kg N ha^{-1} as CAN with the seed in the groove did not cause seed damage or reduce seedling vigour. The damp conditions which prevailed during the emergence period helped to reduced the risk of any deleterious effect the fertiliser may have had on the germinating seed (Mason, 1971; Baker and Afzal, 1986).

Early Establishment - Emergence

The overall emergence of tall fescue seed was lower in the nitrogen trial compared with the main trial (54 cf 71%, respectively). Temperature has a large impact on the rate of germination of tall fescue (Hill et al., 1985; Charlton et al., 1986; Charles et al., 1991). Average air temperatures were similar for the two trials during the first 42 days after sowing (15.2—7.2 and 14.4—6.7 °C, maximum—minimum, main and nitrogen trials, respectively) and 10 cm soil temperatures were also similar (Table A4.7, Appendix 4). However, average grass minimum temperatures were considerably lower for the nitrogen trial at 3.0 °C compared with 5.7 °C for the main trial. Hamilton-Manns (1994) in a similar trial sown at a range of dates throughout autumn in the Manawatu showed a strong decline in fescue emergence as soil and ambient temperatures declined. No sampling was carried out to determine the fate of unemerged fescue seeds in the current trial. Seed was treated with a fungicide, as cool, damp soil conditions leading to slower emergence rate, predispose tall fescue to fungal attack (Campbell and Swain, 1973).

Visual examination by the author and Messrs W. R. Ritchie and C. D. Kernohan during drilling of the trial found that the seeding depth achieved was similar for the main and the nitrogen trials. The similarity between clover seed emergence reported for the two trials would support that observation (46 and 52% of viable seed for main and nitrogen trials, respectively, Tables 4.1.2.1 and 5.3.2.3). The findings of Charles et al., (1991b) which showed that the emergence of white clover was found to be relatively unaffected by low temperature (3-6°C) compared with tall fescue at a seeding depth of 0-15mm but similarly affected by seeding depth would support this assumption. This suggests that an increase in seed depth was not responsible for the comparatively lower emergence of fescue recorded for the current trial. Soil moisture was obviously adequate so the reduced seedling emergence was attributed to the relatively lower temperatures recorded.

Seedling emergence was lower at the intersection than the angle portion of cross-drilled rows (Table 5.3.2.2). A similar effect was recorded for the main trial and was thought to be related to increased seed density at the intersection. However, unlike the main trail, seedling emergence from the straight portion of the cross-drilled rows was similar to that from the intersection of cross-drilled rows in the current trial. Seeds in the angle portion of the cross-drilled rows, which showed the highest percentage emergence, were least likely to be affected by physical disturbance caused by the drill opener passing through the groove made by the first pass of the drill. Considering that fescue was less affected by in-row seed density than ryegrass in the main trial and that there was no seeding rate effect on nominal emergence in the nitrogen trial (Table 5.3.2.1), it is more likely that in the nitrogen trial, physical disturbance (ie. variation in seeding depth) was responsible for the variation in emergence within the cross-drilled treatment.

Higher populations of seedlings were established in the cross-drilled treatment compared with 150mm row spacing (Table 5.3.2.1). This occurred at both high and low seeding rates (Table A4.6, Appendix 4). Analysis of variance indicated an interactive effect of seeding rate and drill method on seedling population, but not on emergence. This apparent contradiction was a function of the actual seeding rate achieved with the drill (Table 5.3.1) rather than seed emergence. The population in 150mm rows sown at the high seeding rate was within 100 plants m^{-2} of the cross-drilled treatment sown at the low rate (Table A4.6, Appendix 4) but overall, populations in low and high seeding rate treatments were significantly different (Table

5.3.2.1).

A higher population of unsown species was present at 49 d.a.s. for the low seeding rate as compared with high seeding rate and for the cross-drilling as compared with 150mm row spacing treatments (Table 5.3.2.3). It was annual poa rather than broadleaf weeds which capitalised on the reduced competition from sown species during early establishment. This provides further evidence that grass weeds may be more of a problem in pasture established by direct drilling than where cultivation has taken place (see Section 4.1.2.3). Unlike the main trial, the increased disturbance of the soil surface from the second pass of the drill in the nitrogen trial did in fact increase the population of broadleaf weeds (buttercup and mouse eared chickweed) which established in the cross-drilled plots (Table 5.3.2.3). The establishment of unsown species was not influenced by seeding rate or drill effects in the main trial. This suggests that where the vigour of fescue was reduced by cool damp conditions, unsown species were able to take advantage of cultural differences offered by variation in seeding rate and soil disturbance, and fescue seedlings were more susceptible to competition than where growth conditions were better.

Treatment effects on the establishment of unsown species may also have reflected the longer delay between spraying and drilling which occurred in the nitrogen trial as compared with the main trial (31 vs 24 days, respectively). Delayed sowing would have improved the relative competitive position of the unsown grass weed species (annual poa) on or close to the soil surface, as they may have had a four week growth advantage over sown species by virtue of the fact that they were present at the time of spraying. Broadleaf species would not have been similarly advantaged as soil disturbance is more of a factor in releasing them from their dormancy mechanisms than is the case for grass weeds (Froud-Williams, 1988). Despite the seeding rate and drill effects on unsown species, the increased population of unsown species was not evidenced by increased mass of unsown species for the respective treatments in the herbage at the first harvest at 154 d.a.s. (Table 5.3.2.10).

Some variation in population of sown species occurred between successive population determination dates. Population increased slightly from 45 to 53 d.a.s. (582 to 609 plants m^{-2}, respectively, Table 5.3.2.1), indicating emergence was not complete at 45 d.a.s. and attesting to the slow emergence of fescue under the cool weather conditions. After 53 d.a.s, population was found to be 475 and 514 plants m^{-2} at 67 and 87 d.a.s., respectively. This equates to approximately a 20% reduction in overall population. Seedling mortality was highest for the plots sown at the high seeding rate (26% vs 4% reduction, based on the average population at 67 and 87 d.a.s, Table 5.3.2.1). Calculations after Robinson and Whalley (1988) indicated that plant mortality was not the result of density related stress according to the $-\frac{3}{2}$ thinning rule

(Table A4.10, Appendix 4). Plant mortality may have been a function of the slow emergence. Late emerging seedlings may have been in a weak position to compete with those which had emerged beforehand. This appears to have been augmented where seedling density was higher.

Seedling Growth

The growth rate of fescue seedlings from sowing to 87 d.a.s. for the current trial was approximately half that recorded for fescue in the main trial. The shoot weight of plants in the current trial at 87 d.a.s. was 30 mg plant^{-1} compared with 69 mg plant^{-1} at 85 d.a.s. for the main trial. The mean relative seedling growth rate was 15.4 mg mg^{-1} day^{-1} up to 87 d.a.s. (Table 5.3.2.5), substantially less than the corresponding figure of 29.2 for the main trial (Table 4.1.4.3). This was related to the relatively lower temperatures during that period in the nitrogen trial (Table A4.8, Appendix 4). Shoot weight at 53 d.a.s. in the current trial was approximately one quarter of that reported by Brock et al. (1982) for fescue seedlings 37 days after sowing in a glasshouse during a Manawatu winter. This contrast illustrates the large impact of temperature on the growth of fescue during establishment and agrees with previous reports for fescue establishment (Hill et al., 1985; Charles et al., 1991a, 1991b).

Seedling growth was monitored closely until 121 d.a.s.. Seedling density in the range tested had relatively minor influence on seedling growth (350 to 620 plants m^{-2}, Table A4.6, Appendix 4). At 87 d.a.s., shoot weight was 13% lower for plants sown at the high seeding rate than for those sown at the low rate (Table 5.3.2.4). The seeding rate ('C-D') effect was evident earlier (87 vs 135 d.a.s.) and when fescue plants were considerably lighter (29 vs 150mg/shoot) in the nitrogen trial as compared with the main trial (Table 5.3.2.4 vs Table 4.1.4.2, respectively) where a similar contrast in seedling population existed (2-300 plants m^{-2} difference in population between high and low seeding rate). The early detection of a seeding rate effect in the current trial was not thought to be related to the accuracy of the different measuring techniques used for ascertaining shoot weight in the two trials as the coefficient of variation was similar for the two sets of data.

This raises the question as to which factor, light or nutrients (moisture was abundant) was limiting the growth of plants at the higher density. Competition for nutrients was thought to be the major limiting factor in the main trial rather than light because both tiller weight and tiller number per plant were lower for plants sown at higher density (Section 4.1.4.3). Tiller weights of plants sown at high seeding rate were similar to plants in the low seeding rate treatment at 121 d.a.s. in the current trial (Table 5.3.2.6.). This suggests that the increased shoot weight at 87 d.a.s. was a function of tiller number per plant rather than individual tiller weight. This would implicate light as being the major factor for which plants were competing, given that Mitchell (1954) showed that tiller number per plant was reduced with shading but that average tiller weight remained relatively constant. Shoots would have consisted of either one or two tillers at that stage (average tiller weight 25mg, Table 5.3.2.6). No firm conclusion as to the causal factor involved with the 'C-D' effect can be drawn from the data collected in this field trial. It is important to note, however, that where growth conditions were poor due to low temperature, competition between seedlings occurred at densities commonly sown in establishing pastures.

Fewer tillers were found at the intersection as compared with the 'between' sections (angle and straight) of cross-drilled rows but weight was the same for tillers from all sections (Table 5.3.2.7). Again the results from Mitchell, (loc cit) would suggest competition for light between adjacent plants at the intersection. Greater competition between plants at the intersection as compared with other sections of cross-drilled rows was also found in the main trial.

The interactive effect of drilling method and seeding rate on tiller weight at 121 d.a.s. reflected the influence of seedling density on inter-plant competition. A 20% increase in in-row tiller density between high and low seeding rates had no influence on tiller weight within the cross-drilled treatment (156 to 186 tillers m^{-1} row, Table 5.3.2.8). In comparison, a larger (43%) increase in tiller density per unit row length reduced tiller weight of plants in 150mm rows by 17% (221 to 316 tillers m^{-1} row, 27.0 to 22.3 mg $tiller^{-1}$, Table 5.3.2.8). That effect was only significant at the lower order of probability (10%) but was consistent with the effect of in-row seedling population at 121 d.a.s. which showed a decrease in tiller weight as population increased in the range 20 to 120 plants m^{-1} row (Table 5.3.2.9). Assuming no further plant mortality occurred after 87 d.a.s., an approximation of tillers per plant can be made by dividing tillers per m^{-1} row at 121 d.a.s. by plants m^{-1} row at 87 d.a.s.. On this basis plants sown at the high and low seeding rate in 150mm rows would have had 3.9 and 4.9 tillers per plant, respectively. So it appears tiller weight and tillers per plant were influenced by seedling density suggesting competition for nutrients was occurring between plants sown at the high rate in 150mm rows. The comparatively lower difference in seedling / tiller number m^{-1} row would be less inclined to induce a density related effect on seedling growth. Thus at 121 d.a.s. a 20% increase in in-row tiller density reduced tiller numbers.

The fact that no seeding rate effect was evident on tiller weights recorded for the cross-drilled treatment suggests that intra-row competition was not occurring within that drilling treatment. This is consistent with the lower overall seedling density relative to plants sown in 150mm rows (171 vs 270 tillers m^{-1} row, Table 5.3.2.6). Seedlings sown in cross-drilled rows may have had an advantage at this stage over seedlings sown in 150mm rows in the nitrogen trial. However, tiller weights were similar for the two drilling treatments.

Botanical Composition and Herbage Mass

Although the first grazing of the current trial took place at a similar time relative to sowing as the main trial (150 cf. 154 d.a.s), more than twice the herbage mass was present in the current trial, even although early seedling growth was faster in the main trial (Total live 3600 vs 1389kg DM ha-1, Tables 5.3.2.10 vs 4.1.5.2, respectively). The corresponding herbage mass of fescue in the current trial was almost three times that for the main trail (1631 kg DM ha^{-1} (average herbage mass) vs 570 kg DM ha^{-1}, Tables 5.3.2.10 and 4.1.5.2, respectively).

The proportion of unsown species was lower in the nitrogen trial as compared to the main trial (38 cf 51%). The difference was due to an increase in the proportion of clover from 9 to 16% and an increase in fescue from 40 to 45% in the nitrogen trial. Herbage mass of clover in the nitrogen trial was 5 times higher than for the main trial (580 cf 111kg DM ha^{-1}) which was more than the proportional increase in sown species (3 times herbage mass in main trial). The larger proportional increase in clover herbage mass was likely to have been related to the higher level of phosphate for the site where the nitrogen trial was sown (Olsen P 15 vs 25) as higher levels of plant available phosphate in the soil improves clover growth (Langer, 1982).

The high pre-grazing herbage mass made it difficult to achieve the target post-grazing height of 50-70mm, so the plots were topped to a height of 60mm with a disc mower after grazing to eliminate clumps, as recommended by Thom, Thomson and Clayton (1985). The cut herbage arising from mowing was left on the trial area as it was thought not to be sufficient in quantity to affect sward regrowth.

Growth of fescue plants was initially slower in the nitrogen trial as compared with the main trial as indicated by relatively higher shoot weight at 135 d.a.s. in the main trial, (143 mg/plant) Figure A4.4, Appendix 4) as compared with shoot weight in the nitrogen trial at 121 d.a.s. (108 mg/plant, as calculated from population at 87 d.a.s. and total weight of tillers m row^{-1} at 121 d.a.s.) and assuming no plant death (Tables 5.3.2.1 and 5.3.2.6, respectively). Individual tiller weight was also lower in the nitrogen trial at 25mg/tiller at 121 d.a.s in the nitrogen trial (Table 5.3.2.6) as compared with approximately 38mg at 135 d.a.s, (Table 4.1.3.6). After 121 d.a.s. in the nitrogen trial growth of fescue increased rapidly before the first harvest at 154 d.a.s.. The relatively higher growth rate during the month prior to the first harvest in the nitrogen trial was due to higher phosphate fertility described above and the warmer conditions which prevailed during that time. The month preceding the first harvest of the nitrogen trial coincided with September rather than August as for the main trial. Meteorological records show that August 1990 had less sunshine hours (1029 vs 1260) and lower average temperature (10.1 vs 11.6 °C) than September 1991.

The nil response to nitrogen shown by seedling growth during early establishment was also reflected by sward mass and composition.

The proportion of unsown species in the fescue sward was reduced from 38 to 22% of total live herbage as the sward developed (Tables 5.3.2.10 and A4.13, Appendix 4). Giant buttercup is a noted problem broadleaf weed in dairy pastures (Bourdot and Hurrell, 1990) and remained the dominant broadleaf species during the trial, whereas toad rush, after being obvious initially, virtually disappeared after the first grazing (Tables A4.3 to 5, Appendix 4). The proportion of grass weeds (category 'Other') was reduced from 25% of total live herbage at the first grazing to 14% at the third grazing (Tables A4.3 and A4.5, Appendix 4). The improvement in the relative position of fescue in the sward is consistent with the main trial. It shows that, despite poor seedling growth from late sowing, the position of fescue in the sward was improved where fertility was high and herbage mass at grazing was 3000 to 3700 kg DM ha^{-1}. This grazing strategy appears to have controlled the ingress of grass weeds in the developing fescue sward. This strategy is similar to that advocated by Charlton and Thom (1984) for establishing fescue pasture.

Drilling method did not influence the overall herbage mass or composition at 154 d.a.s.. The proportion and mass of fescue, clover and unsown species was similar for areas which were cross-drilled, compared with those sown in 150mm rows (Table 5.3.2.10). Although the total mass of unsown species was not affected by drilling method, the mass of giant buttercup and toad rush was higher in cross-drilled areas than in areas sown at 150mm spacing (Table 5.3.2.11). This was consistent with the higher seedling population of giant buttercup and higher overall population of unsown species which established in the cross-drilled treatment after drilling compared with the 150 row spacing treatment (Table 5.3.2.3), and is likely to be related to the increased soil surface disturbance of the cross-drilled treatment. The higher population of unsown species at establishment was evidenced by a 35% increase in the proportion and mass of sown species in the cross-drilled treatment at 213 d.a.s. (Table 5.3.2.12). However, this increase in unsown species did not affect the growth of fescue at that time. In fact drilling method had no influence on the herbage production from sown species at any stage of the trial (Table 5.3.2.10, 5.3.2.12 and A4.13, Appendix 4), showing that the fescue sown in 150mm rows performed equally as well as cross-drilled fescue in terms of weed suppression, and dry matter production. It appears there may in fact be disadvantages from cross-drilling fescue in terms of increased emergence and growth of unsown species as compared to single pass drilling. These results are consistent with the main trial.

Seeding rate had a major influence on herbage composition and mass. The mass of sown species at the high seeding rate was 18 and 42% higher at 154 d.a.s. and 213 d.a.s., respectively, compared with plots sown at the lower rate (Tables 5.3.2.10 and 5.3.2.12, respectively). At 213 d.a.s. the proportion of sown species was higher and the proportion of unsown species was lower with high seeding rate as compared with the low seeding rate, indicating that higher seeding rate had suppressed the growth of unsown species. This reflected the higher tiller density (1944 vs 2404 tillers m^{-2}) and mass of sown species at 121 d.a.s. (613 vs 503 kg DM ha^{-1}, Table 5.3.2.6) of plots sown at the high seeding rate as compared with those sown at the low rate.

Herbage mass and composition of the fescue sward were unaffected by seeding rate in the main trial despite the 100% increase in seedling population from low to high seeding rate (489 vs 814 plants m^{-2} at 42 d.a.s., Table A1.5, Appendix 1). In comparison there was a 41% increase (427 vs 602, plants m^{-2} for low and high seeding rate, respectively at 87 d.a.s.) in the nitrogen trial. In terms of herbage mass of sown species, the lower number of fescue plants establishing at low seed rate in the main trial was compensated for by heavier and more tillers per plant, as compared with plants sown at the high rate (Tables 4.1.3.7 and A2.2, Appendix 2, respectively). Although some evidence of a similar compensatory effect was shown by plants sown in 150 mm rows at 121 d.a.s. in the nitrogen trial, the effect was not sufficient to accommodate the lower plant and tiller density. Average tiller population was similar for the two trials (average 2800 tillers m^{-2} at 145 d.a.s. as calculated from population at 42 d.a.s. (Table 4.1.1.1) and plant tiller number at 145 d.a.s (Table A2.10, Appendix 2) assuming no plant death, and 2200 tillers m^{-2} at 121 d.a.s. (Table 5.3.2.6) for main and nitrogen trials, respectively). Comparison of the two trials would suggest that, where growth of fescue seedlings was limited in the early stages of sward development (up to 121 d.a.s.) because of late sowing, and where yield potential was higher, increasing seeding rate from 18 to 33 kg ha^{-1} improved the success of fescue. The advantage of higher seeding rate at the first harvest reinforced the relative position of the sown species in the sward at the second harvest (213 d.a.s., Table 5.3.2.12). By the third grazing at 249 d.a.s. the mass of herbage produced was similar for both seeding rates (Table A4.13, Appendix 4) but still tended to be higher for the high seeding rate treatment.

5.5 Summary

Application of 30kg N ha^{-1} as Calcium Ammonium Nitrate with the seed in late autumn did not improve the growth of tall fescue where soil conditions were cool and damp. Percentage emergence of tall fescue was lower (54% of viable seed) for a cool, damp May in the Manawatu as compared to an earlier sowing (April) of the previous year where emergence was 75% of viable seed and conditions were drier. The addition of CAN did not affect seed emergence. Had there been a growth response to the addition of N at sowing it would be interesting to know if any evidence of seed damage would also result.

Seeding rate did not influence percentage seedling emergence. A higher population of unsown (broadleaf) species established in the cross-drilled plots. This was thought to be a function of increased soil disturbance where two passes of the drill had been made and the 4 week delay between spraying and drilling. This led to a higher mass of broadleaf weeds in cross-drilled areas as compared with areas sown at 150mm row spacing.

Twenty percent of seedlings died between peak emergence at 53 d.a.s. and 87 d.a.s.. Mortality was higher amongst seedlings sown at the high seeding rate than for those sown at the low rate indicating inter-plant competition was a factor in causing seedling mortality.

Increasing seeding rate reduced tiller weight of plants sown in 150mm rows at 121 d.a.s. but seeding rate did not influence tiller weight in the cross-drilled treatment. This suggests the overall inter-plant competition was greater where plants were sown in 150mm rows and the size of fescue seedlings may have been improved by sowing with two passes of the drill. However, this was not evident in later botanical composition and herbage mass results.

Increasing the seeding rate from 18 to 33 kg ha^{-1} resulted in higher plant and tiller populations four months from sowing. This led to an increase in the proportion and production of sown species in the sward where sowing was delayed until early May in a cool, damp Manawatu autumn. Some increase in tiller size and number of plants sown at the low rate was found but this was not sufficient to compensate for reduced plant numbers.

Although variation in seedling / tiller population on an area basis influenced herbage mass and composition, drilling method did not. There was no interaction between drilling method and seeding rate in terms of herbage mass or composition, indicating that cross-drilling gave no advantage to establishing fescue seedlings as compared to drilling in 150mm rows, irrespective of emerged population in the range 417 to 804 plants m^{-2}.

6. CONCLUSION

Establishment is the first stage of pasture management and perhaps the most critical to the life of the pasture. This study focused specifically on the influence of sowing method, seeding rate and species, and to a limited extent nutrient status on the effectiveness of establishment. The underlying strategy was to explore the relative importance of plants per unit area (plants m^{-2}) and plants per unit row length (plants m row^{-1}) to the development of pasture sown by direct drilling, in a temperate environment, within the boundaries of commercial practices and to assess possible interactions with perennial pasture species.

6.1 The major conclusions from this project are:

6.1.1 Drilling Pattern

No agronomic justification was found for the practice of using two passes of a direct drill, the second at a 30° angle to the first ('cross drilling'), to sow perennial ryegrass or tall fescue in a pasture which is to be rotationally grazed by dairy cattle. There are in fact good reasons to avoid this practice, specifically the increased cost (up to \$80 ha^{-1}, Fleming and Burtt, 1993) and the increased mass of unsown species present in cross drilled areas as compared with areas sown with a single pass of the drill (150 mm rows) (the mass of sown species was unaffected) during the pasture development phase up to 12 months from sowing.

6.1.2 Row Spacing

Reducing row spacing improved the establishment performance of tall fescue, but did not affect that of perennial ryegrass. However, any advantage gained for fescue from reduced row spacing declined with time and, by the second spring after sowing, no difference was apparent between 150 and 75mm row spacing treatments.

6.1.3 Drill Design

Drills capable of direct drilling at reduced row spacing are likely to have extra costs associated with them. This study showed that any extra costs are not justified for sowing traditional perennial ryegrass-based pastures. However, this does not preclude the option of 'narrow' row spacing in designing future direct drills specifically intended for sowing alternative pasture species. Evaluations of establishment programmes using drought tolerant pasture species (Hume and Lyons, 1993; Milne et al., 1993; Smith et al., 1993) have highlighted such a requirement. It would appear that these drills should have emphasis primarily on seed depth control but also on row spacing. An effective compromise may be 100-125 mm row spacing.

6.1.4 Clover Emergence

Seedling emergence was lower for clover than for grass species in both trials. As with cultivated seedbeds, seed depth and competition from other species appeared to be important determinants of clover establishment. Most establishment studies focus on the grass component and white clover is often neglected. This may be because the seed is cheap, only sown in small amounts, there is usually a considerable pool of ungerminated clover seed in the soil and clover regenerates after spraying. However, it should be considered more closely in establishment studies as graziers may wish make use of new clover cultivars such as those described by West and Steele (1985).

6.1.5 Seeding Rates

a) Aggressive species such as perennial ryegrass are unlikely to benefit from increases in seeding rates above that required to establish about 500 plants m^2 (11 kg ha^{-1}). The same could be said for less aggressive grasses such as tall fescue which also showed no agronomic benefit from increasing seeding rate when sown midway through a mild autumn (Trial 1). However, where sowing was delayed until late autumn of the following year (Trial 2) in which cool and moist conditions prevailed, establishing 800 plants had a considerable advantage over 400 plants m^2 in terms of reduced unsown species and improvement in herbage mass of sown species in December. Increasing seeding rate accommodated the slower, and reduced percentage emergence of tall fescue under adverse conditions.

   These population targets can be used to assess whether or not establishment by direct drilling has been successful, and provides information on which to base decisions on the suitability of remedial actions such as spraying for broadleaf weeds or overdrilling to increase plant number during the early stage of development.

b) As for similar studies under cultivation, in this study any effects of seeding rate from direct drilled pasture were not apparent one year after sowing.

c) These results can be used to assist the planning of seeding rates for these and other pasture species. Apart from the fact that there is a significant cost saving from using targeted seeding rates (in the case of early sown tall fescue approximately \$78 ha^{-1} (13 kg @ \$6 /kg), higher seeding rates had other disadvantages including decreased emergence percentage, smaller plants and lower survival.

6.1.6 Tiller Population

An addition to initial seedling population, tiller population in spring following autumn sowing may also provide a useful gauge of establishment success. By combining tillers per plant with plant population data in Trial 1, tiller populations in the spring following autumn establishment for tall fescue were estimated at 4000-5000 tillers m^{-2} in early September. Direct measurements showed a tiller population of only 1900-2400 tillers m^{-2} at a corresponding time in Trial 2 where seeding rate was found to influence pasture composition. Relative to the variation in the number of plants which established in late autumn-early winter (400-800 plants m^{-2}), pasture composition was more sensitive to subtle variations in tiller population at that later stage when tiller population was at or below 2400 tillers m^{-2}. Seeding rate effects for late sowing of perennial ryegrass were not tested but, if adjustments are necessary as a function of timing, there are unlikely to be as critical as for tall fescue.

6.1.7 Nitrogen Application

Improvements in the growth of sown species were not automatically associated with nitrogen application to tall fescue at sowing. It would seem that timing of application and growth rate of sown species are important factors which influence the response of establishing pasture to nitrogen application. However, no firm linkage was established between these factors in this limited investigation of the affects of nitrogen application on establishing pasture.

6.1.8 Species Performance

The divergence in establishment manner of perennial ryegrass and tall fescue was not unexpected and confirms earlier work (Brock, 1973; Brock et al., 1982; Hill, 1985; Bellotti and Blair, 1989a,b&c). This contrast in establishment performance provided the necessary latitude in pasture species to reflect differences in response to variations in cultural techniques which are likely to occur in practice on the farm.

This study has shown that sensitivity to establishment practices is a function of species and the interaction between species and variations in 'management' both macro-environment (weather, timing and soil type) and micro-environment (seed depth, row spacing, seeding rate, establishment method).

6.2 Future Work

Recommendations for grazing alternative, slower establishing pasture species are conflicting (Charlton and Thom, 1984; Turner, 1992). Hard, frequent initial grazing did not appear to be inappropriate for establishing tall fescue in this study. It is suggested that some effort be directed toward comparing the effects of timing and intensity of grazing on establishing alternative pasture species, and possible interactions with establishment method (direct drilling vs cultivation) and soil type (peat vs loam vs sand vs clay).

Although cross drilling proved to be of no value where establishing pastures were rotationally grazed with cattle, the results may be different under other stock types and grazing management such as set stocked pastures close grazed by sheep .

The effect of opener type on soil disturbance may also alter the nature of the competitive environment into which establishing species may emerge and the reliability of emergence performance which could potentially influence the pasture response to drilling pattern.

Considerable savings are possible from using reduced seeding rate and single-pass drilling (typically \$100 to 150 ha^{-1}). This capital may be directed towards applying nitrogen to establishing pastures. However, future studies are required on the effect of timing of fertiliser nitrogen application relative to sowing date and season, placement of N fertiliser (banded vs broadcast), the form of nitrogen (readily available vs slow release) and the relationship with grazing management to evaluate cost effectiveness of the operation.

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Appendices

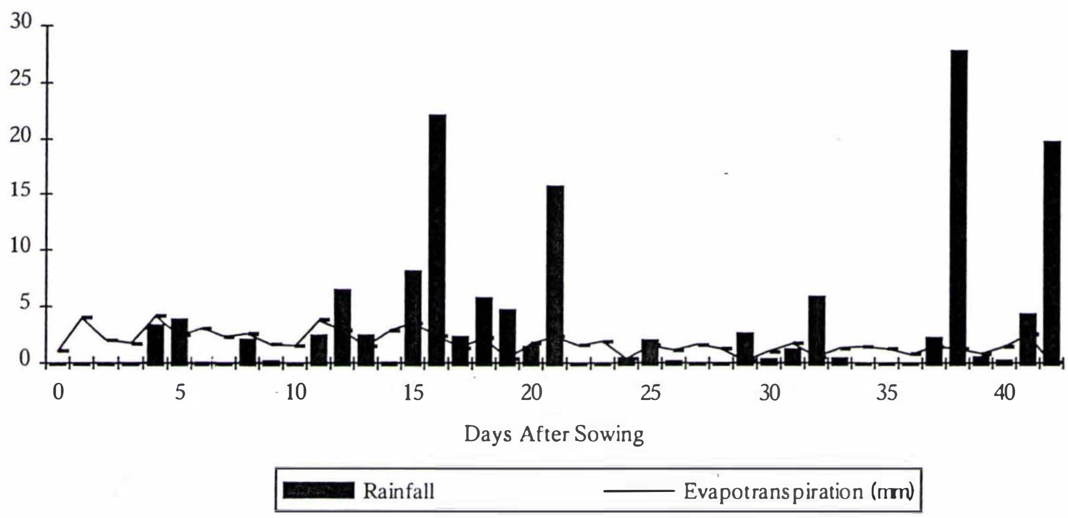
Appendix One

Table A1.1 *Soil Moisture Content, Trial One, Paddock 18, No 1 Dairy Farm, Massey University, 12 April, 1990*

	Gravimetric water content (w) = mass water/mass dry soil	Volumetric water content (θ) = vol water/total soil vol (ϱ_{soil} = 1200 kg/m^3)
1	0.26	0.312
2	0.23	0.27
3	0.26	0.312
average	0.25	0.3

Conversion from gravimetric to volumetric, water content: θ = w. soil bulk density/water bulk density OR $\theta = w.\ \varrho_{soil}/\varrho_{water}$

Figure A1.1 *Rainfall and Evapotranspiration from Sowing to Population Determination (12/4/90 - 23/4/90)*



Pan Evaporation values were corrected to transpirational water use using a figure of 0.7 based on the Priestly and Taylor formula (D.R Scotter, pers. comm., 1990)

Figure A1.2 *Cumulative Weekly Water Balance From Sowing to 145 d.a.s. (12/4/90 - 4/9/90)*

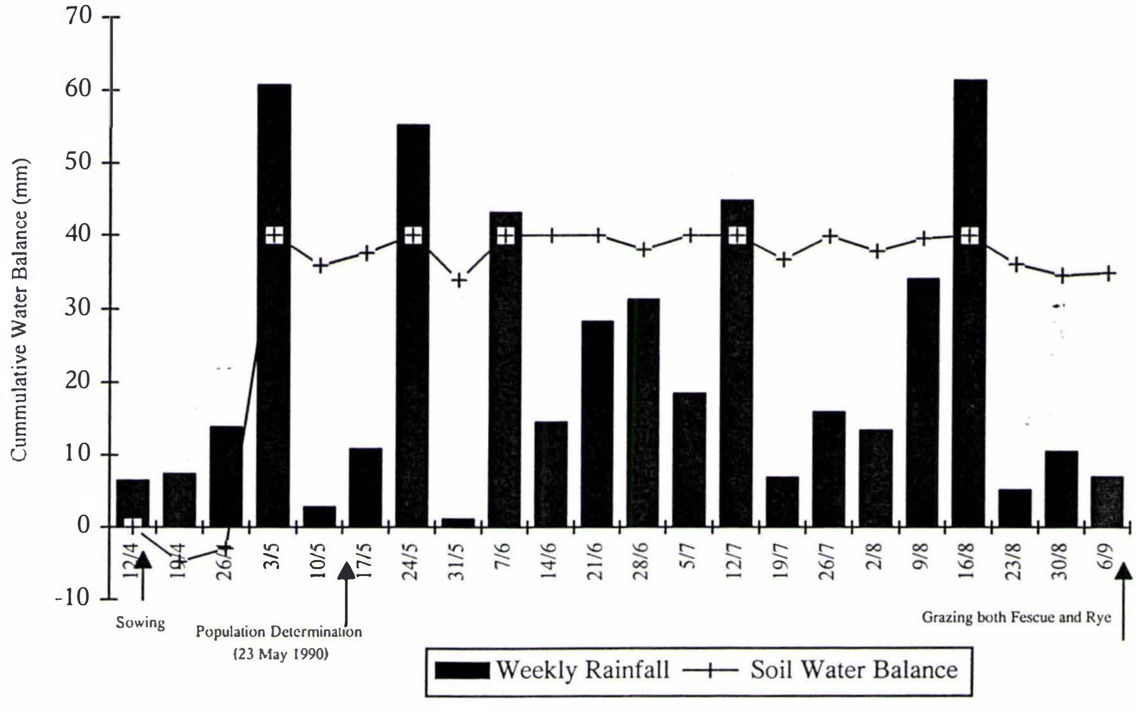


Figure A1.3 *Average Weekly Temperatures from Sowing to 145 d.a.s. (12/4/90 - 4/9/90)*

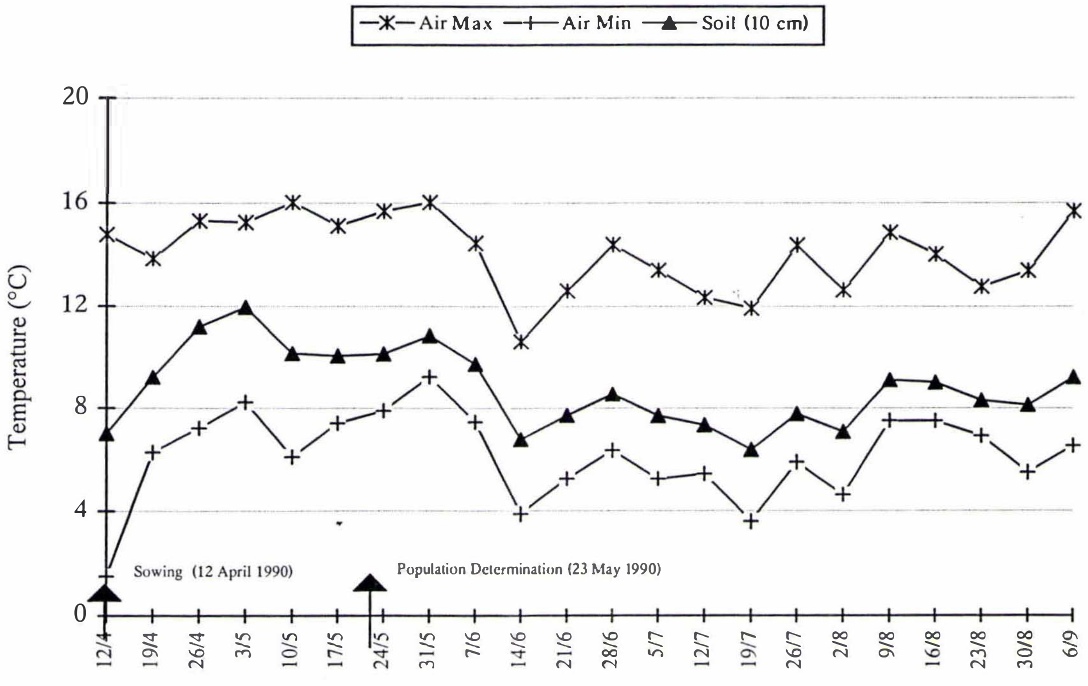


Table A1.2 *Conversion Factors for Calculating Population*

Treatment	Description	Plants m^{-1}row Formula	Plants m^{-2} Formula
75 mm rows	75 mm rows	pl/ 0.4 m row x 2.5§	pl/ 0.4 m row x 33.334
Cross Drill	2 x 150 rows	pl/ 0.2 m row x 5	pl/ 0.2 m row x 66.667
150 mm rows	150 mm rows	pl/ 0.4 m row x 2.5	pl/ 0.4 m row x 16.667

- § pl = plant

Table A1.3 *Conversion Factors for Calculating Nominal Emergence Percentage*

Treatment	Seeding Rate (kg/ha)	T. S. W. (grams)	Formula Seeds sown m^{-2}†	Formula % Emergence
Fescue High seed rate 75 mm rows	31.6	2.5	31.6 x 1000/2.5	pl m/seedsm^{-2}
Fescue High seed rate Cross drill	31.6	2.5	31.6 x 1000/2.5	pl m/seedsm^{-2}
Fescue High seed rate 150 mm rows	28.9	2.5	28.9 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Fescue Low seed rate 75 mm rows	18.5	2.5	18.5 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Fescue Low seed rate Cross drill	18.5	2.5	18.5 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Fescue Low seed rate 150 mm rows	14.8	2.5	14.8 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass High seed rate 75 mm rows	21.2	2.23	21.2 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass High seed rate Cross drill	21.2	2.23	21.2 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass High seed rate 150 mm rows	23.6	2.23	23.6 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass Low seed rate 75 mm rows	11.8	2.23	11.8 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass Low seed rate Cross drill	11.8	2.23	11.8 x 1000/2.5	pl m^{-2}/seedsm^{-2}
Ryegrass Low seed rate 150 mm rows	11.5	2.23	11.5 x 1000/2.5	pl m^{-2}/seedsm^{-2}

- ‡ T.S.W. = Thousand Seed Weight
- † Seeds sown m^{-2} = kg/ha x 1000/T.S.W.

Table A1.4 *Percentage Emergence and Population for Species, Seeding rate and Drilling Method at 21 Days After Sowing*

SPECIES	Population (plants m^{-2})	Percent of population at 42 d.a.s. (%)
Fescue	440	67
Ryegrass	449	71
S.E.D. ±	40	3
Significance ‡	n.s.	n.s.
SEEDING RATE		
High	551a	69
Low	339 b	69
S.E.D. ±	45	7
Significance	***	n.s.
DRILLING METHOD		
75 mm rows	529a	80a
150 mm rows	336b	59b
S.E.D. ±	43	7
Significance	***	**

Table A1.5 *Effects of Seeding rate and Drilling Method on Percentage Emergence and Population of Perennial Ryegrass and Tall Fescue (42 d.a.s.)*

	FESCUE			RYEGRASS		
	Nominal Seedling Emergence (% of viable seeds)	Population (plants m^{-2})	In-row Population (plants m^{-1} row)	Nominal Seedling Emergence (% of viable seeds)	Population (plants m^{-2})	In-row Population (plants m^{-1} row)
SEEDING RATE						
High	68	814a	79a	78a	778a	76a
Low	73	489b	47b	91b	485a	47b
S.E.D. ±	3	28	3	3.5	25	2.5
Significance	n.s.	* * *	* * *	* * *	* * *	* * *
DRILLING METHOD						
75 mm rows	69	672a	50a	87a	647a	48a
Cross Drill	72	706a	53a	89a	676a	51a
150 mm rows	69	577b	86b	77b	571b	85b
S.E.D. ±	3.7	34	3.7	4.3	31	3
	n.s.	* * *	* *	*	* *	* * *

Table A1.6 *Effects of Drill Method and Sowing Rate on Nominal Percentage Emergence and Population*

	COMBINED SPECIES			FESCUE			RYEGRASS		
	% of viable seeds	plants m^{-2}	plants m^{-1} row	% of viable seeds	plants m^{-2}	plants m^{-1} row	% of viable seeds	plants m^{-2}	plants m^{-1} row
High 75mm	72	792	59	67	820	61	78	764	57
High Cross	80	873	65	74	902	67	87	844	63
High 150mm	58	721	108	64	719	108	71	725	109
Low 75mm	84	526	39	73	523	39	97	531	40
Low Cross	81	508	38	71	509	38	93	507	38
Low 150mm	79	425	64	76	435	65	83	416	62
S.E.D. ±	4	33	1.3	5.4	48	2.07	6	44	1.7
Significance	n.s.	(*)	* * *	n.s.	n.s.	*	n.s.	n.s.	* * *

- Nominal Seedling Emergence (% of viable seeds)
- Population (plants m^{-2})
- In-row Population (plants m^{-1} row)

Table A1.7 *Effect of Position on Relative Seedling Number at 21 D.A.S. in Cross drilled Tall Fescue and Perennial Ryegrass.*

	Combined Species	Fescue	Ryegrass
Intersection	100†	100	100
Straight	116	112	119
Angle	117	117	116
S.E.D. ±	4.5	6.7	5.4
Significance	**	(*)	**

- † Seedlings m^{-1} row, expressed as a proportion of the seedlings at the intersection (Intersection = 100)

Table A1.8 *Effect of Position in the Cross Drill Treatment on Population and Emergence Percentage in Fescue and Ryegrass.*

	FESCUE			RYEGRASS		
SEEDING RATE	Emergence %	Plants m^{-2}	Plants m^{-1} row	Emergence %	Plants m^{-2}	Plants m^{-1} row
High	74	906	68	87	801	61
Low	71	511	38	93	491	36
S.E.D. ±	4.3	40	3.0	5.0	42	3.1
Significance	n s	***	***	n s	***	***
POSITION						
Intersection	65	660	49	77	581	43
Straight	76	739	55	90	702	53
Angle	73	726	54	87	669	50
S.E.D. ±	5.2	50	3.7	6	51	3.8
Significance	(*)	n.s.	n.s.	(*)	(*) Fpr = 6.8	(*) Fpr = 6.8

Table A1.9 *Effect of Insecticide on White Clover Germination*

	3 Days Contact with Phorate		16 Days Contact with Phorate	
	Control	Phorate	Control	Phorate
% Clover Germination §	90	89	89	89
S.E.D. ±	2.1	1.5	2.5	2.4

- § germination test carried out at Seed Technology Centre, Massey University

Table A1.10 *Treatment effects on Transmission of Photosynthetically active Radiation (PAR) to 30mm Above Soil at Midday on a Cloudless Sunny Day*

	Days After Sowing (Date)	
	35 (17 May 1990)	65 (17 June 1990)
Light Above the Sward	0.705 (100%)	0.626 (100%)
SPECIES		
Fescue	87 §	74
Ryegrass	80	54
S.E.D. ±	3	3.6
Significance	*	***
SEEDING RATE		
High	80	61
Low	87	67
S.E.D. ±	3	*
Significance	*	4
DRILL METHOD		
75 mm rows	79	56
Cross drill	88	69
150 mm rows	84	68
S.E.D. ±	4.5	5.9
Significance	n.s.	*

§ - % of above sward PAR as measured by a LI-COR quantum light sensor

Table A1.11 *Effect of Drill Method on Population of White Clover and Unsown Species Seedlings*

DRILLING METHOD	WHITE CLOVER (plants m^{-2})	UNSOWN SPECIES (plants m^{-2}) Broadleaf Weeds	Prairie	Other Grasses	Total Unsown
75mm row	177	434	102	116	651
Cross Drill	174	450	72	102	624
150mm row	153	390	78	140	608
S.E.D. ±	16	34	18	17.5	43
Significance	n.s.	n.s	n.s	n.s	n.s

Table A1.12 *Effect of Species, Sowing Rate and Drill Method on the Number of Leaves per Plant at 26, 43 and 145 d.a.s.*

D.A.S. (Month	26 (May)	43 (May)	145 (Sep)
Fescue	1.96	3.9	7.6
Ryegrass	2.92	7.1	15.6
S.E.D. ±	0.115	0.39	0.6
Significance	* *	* * *	* * *
High	2.46	5.3	10.2
Low	2.42	5.7	12.7
S.E.D. ±	0.138	0.16	0.47
Significance	n.s.	*	* * *
75 mm row	2.48	5.6	11.8
Cross drill	2.55	5.6	11.1
150 mm row	2.28	5.3	10.8
S.E.D. ±	0.168	0.23	0.67
Significance	n s	n s	n s

Table A1.13 *Effect of Position on Leaf Number and Skewness of Leaf Number*

d.a.s. (Month)	43 (May)		145 (Sep)	
POSITION	Leaf Number	Skew Leaf	Leaf Number	Skew Leaf
Intersection	5.556	0.169 a	9.9 a	0.012
Between	5.563	0.033 b	12.4 c	0.095
75mm	5.625	0.090 ab	11.8 cb	0.037
150mm	5.347	0.0997 ab	10.8 ab	0.101
S.E.D. ±	0.2279	0.059	0.67	0.061
Significance	n s	(*) Fpr= 0.078	* * *	n.s.

Table A1.14 *Effect of Position on Plant Size Index for Ryegrass and Fescue.*

	d.a.s. (Month)	**43**		**145**	
	Size Index	Till X Lf	Lf X Hgt	Till X Lf	Lf X Hgt
FESCUE	**Intersection**	6.95	281	26 a	804
	Between	6.85	277	39 b	951
	75mm	6.53	273	35 ab	1142
	150mm	6.00	244	33 ab	933
S.E.D. ±		0.716	23	6.4	137
Significance		n.s.	n.s.	(*) Fpr = 0.056	n.s.
RYEGRASS	**Intersection**	18.57	630	96 a	2359 a
	Between	19.16	629	140 b	3005 b
	75mm	19.31	634	131 bc	2684 ab
	150mm	17.27	619	105 ac	2428 a
S.E.D. ±		2.15	46	16.4	257
Significance		n.s.	n.s.	* *	*

Table A1.15 *Effect of In-row Population on the Number of Leaves per plant at 43 and 145 d.a.s.*

	FESCUE		RYEGRASS	
d.a.s. (Month	43 (May)	145 (Sep)	43 (May)	145 (Sep)
Leaf Number	3.9	7.6	7.1	15.6
Slope	-0.005	-0.02	-0.012	-0.07
S.E.D. ±	0.003	0.01	0.008	0.02
Significance	(*)	n.s.	n.s.	*
r^2	0.07	0.06	0.06	0.25

Table A1.16 *Effect of In-row Population on the Tiller Weight at 43 and 145 d.a.s.*

	FESCUE		RYEGRASS	
d.a.s. (Month	43 (May)	145 (Sep)	43 (May)	145 (Sep)
mean	0.0819	0.386	0.118	0.361
slope of regression line	0.0002	-0.00131	0.00002	-0.0009
S.E.D. ±	0.0002	0.001	0.0002	0.0009
significance	n.s.	n.s.	n.s.	n.s.
r^2	0.07	0.06	0.0003	0.05

Table A1.17 *Regression coefficients of Shoot Weight Against Leaf Number, Tiller Number and Extended Height at 43 and 145 d.a.s.*

	Fescue						Ryegrass					
d.a.s.	43			145			43			145		
Characteristic	Tillers	Leaves	Height	Tillers	Leaves	Height	Tillers	Leaves	Height	Tillers	Leaves	Height
mean	1.6	3.9	66	4.4	7.3	137	2.6	7.1	88	7.7	15.6	173
slope of regression line	1.05	0.97	33	0.5	1.08	3.2	-0.71	-1.34	-17	1.1	1.77	5.3
S.E.D. ±	1.16	2.6	37	0.41	0.72	15	0.89	3.3	17	0.19	0.38	5.4
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	n.s	***	***	n.s
r^2	0.04	0.006	0.04	0.07	0.09	0.002	0.03	0.007	0.04	0.60	0.50	0.04

Table A1.18 *Treatment Effects on Coefficient of Variation*

d.a.s.	26		43			145		
Characteristic	Leaf Number	Height	Tiller Number	Leaf Number	Height	Tiller Number	Leaf Number	Height
Species (Spp)		*		* * *		* * *	* * *	
Seeding Rate								
Drill Method		*						
Position	N/A‡	N/A	*					
Rate X Drill								
Species X Rate								
Drill X Species					*			
Rate X Position	N/A	N/A						
Rate X Drill X Spp								
Drill X Posi X Spp	N/A	N/A						

Table A1.19 *The Coefficient of Variation‡ of Tiller Number, Leaf Number and Plant Height for Fescue and Ryegrass at 26, 43 and 145 d.a.s.*

d.a.s. (Month)	26 (May)		43 (May)			145 (September)		
Characteristic	Leaf	Height	Tiller	Leaves	Height	Tiller	Leaves	Height
Fescue	0.39	0.483	0.201	0.404	4.25	0.97	1.55	13.1
Rye	0.93	0.307	0.284	0.682	3.44	2.14	4.13	17.4
S.E.D. ±	0.69	0.055	0.042	0.042	0.498	0.197	0.375	3.29
Significance	n.s.	*	n.s.	* * *	n.s.	* * *	* * *	n.s.

‡ - Coefficient of Variation = standard deviation / mean

Table A1.20 *Effect of Drill Method and Plant Position on the Coefficient of Variation of Tiller and Leaf Number and Plant Height for Ryegrass and Fescue at 43 d.a.s.*

	Drill Method				Plant Position			
	Characteristic	Tiller	Leaf	Height		Tiller	Leaf	Height
FESCUE	**75mm**	0.177a	0.308 a	4.13 ab	**Intersection**	0.209 ab	0.400	3.58
	Cross Drill	0.181a	0.378 a	3.26 a	**Between**	0.153 a	0.356	2.94
	150mm	0.267 b	0.552 b	6.37 b	**75mm**	0.177 a	0.308	4.13
	S.E.D. ±	0.0343	0.128	1.352	**150mm**	0.267 b	0.552	6.37
	Significance	*	(*)	* *	S.E.D. ±	0.0396	0.1044	1.104
					Significance	*	n.s	n.s
RYEGRASS	**75mm**	0.222	0.644	3.37	**Intersection**	0.389a	0.707	3.66
	Cross Drill	0.296	0.632	3.69	**Between**	0.202 b	0.557	3.71
	150mm	0.323	0.818	3.03	**75mm**	0.222 a	0.644	3.37
	S.E.D. ±	0.076	0.171	0.883	**150mm**	0.323 a	0.818	3.03
	Significance	n.s.	n.s.	n.s.	S.E.D. ±	0.087	0.1973	0.883
					Significance	*	n.s.	n.s.
Interaction Species	S.E.D. ±	0.064	0.119	0.89	Species S.E.D. ±	0.0682	0.157	1.056
X Drill	Significance	n.s.	n.s.	*	X Posi Significance	n.s.	n.s.	n.s.

Table A1.21 *Effect of Seeding Rate and Drill Method on Relative Growth Rate of Fescue and Ryegrass ([mg mg^{-1}]day^{-1})*

	FESCUE				RYEGRASS			
	Growth Period (d.a.s.)				Growth Period (d.a.s.)			
SEEDING RATE	0 - 26	26 - 49	49 - 85	85 - 135	0 - 26	26 - 49	49 - 85	85 - 135
High	-1.88 †	29.8	18.0	5.33	8.01	35.5	16.2	4.26
Low	-2.49	28.0	20.9	6.81	6.10	38.7	17.6	5.79
S.E.D. ±	0.729	2.03	1.52	0.905	0.89	1.88	1.27	1.060
Significance	n.s.	n.s.	(*)	n.s.	*	n.s.	n.s.	n.s.
DRILL METHOD								
75 mm row	-0.41	26.0	21.3	5.85	8.28	33.2 a	17.9	5.37
Cross drill	-2.26	29.7	19.0	5.80	6.80	39.9 b	16.8	4.80
150 mm row	-3.88	31.1	18.0	6.56	6.08	38.2 b	16.0	4.90
S.E.D. ±	0.893	2.48	1.86	1.11	1.089	2.30	1.56	1.836
Significance	**	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.

- † all values transformed data ($\log_{10}$) multiplied by 10^3

Table A1.22 *Effect on In-row Population on Shoot Weight of Ryegrass in 150mm rows*

	135 d.a.s.
Mean Shoot Weight	240mg
Slope	-2.20
S.E.D. ±	0.1
level of significance for slope of regression line	***
r^2	0.54

Table A1.23 *Effect of Seeding Rate on Leaf Number, Tiller Number and Leaves/Tiller of Fescue and Ryegrass at 26, 43 and 145 d.a.s.*

		Leaf Number			Tiller Number		Leaves/Tiller	
d.a.s. (Month)	*Sowing Rate*	26 (May)	43 (May)	145 (Sep)	43 (May)	145 (Sep)	43 (May)	145 (Sep)
FESCUE	**High**	1.92	3.83	6.44	1.576	3.89	2.42	1.64
	Low	1.99	4.20	8.20	1.646	4.83	2.56	1.69
S.E.D. ±		0.12	0.14	0.51	0.0702	0.303		
Significance		n.s	*	***	n.s.	**		
RYEGRASS	**High**	2.99	6.83	13.14	2.514	6.6	2.72	1.98
	Low	2.84	7.24	17.12	2.653	8.77	2.76	1.95
S.E.D. ±		0.30	0.29	0.439	0.112	0.439		
Significance		ns	n.s.	***	n.s.	***		
Spp x Rate Interaction Significance		n.s.	n.s.	* LSD 0.05=1.23	n.s.	* LSD 0.05=0.79		

Table A1.24 *Effect of Plants m^{-2} on the Leaf Number at 43 and 145 d.a.s.*

	FESCUE		RYEGRASS	
d.a.s. (Month	43 (May)	145 (Sep)	43 (May)	145 (Sep)
Mean Number of Leaves per Plant	3.9	7.6	7.1	15.6
Slope	-0.0001	-0.002	-0.001	-0.008
S.E.D. ±	0.0004	0.001	0.001	0.003
Significance	n.s.	n.s.	n.s.	*
r^2	0.003	0.04	0.04	0.14

Table A1.25 *Effect of Position on the Number of Leaves of Ryegrass and Fescue Plants*

	RYEGRASS		FESCUE	
d.a.s. (month	43 (May)	145 (Sep)	43 (May)	145 (Sep)
Intersection	6.93	13.42 a	4.18	6.36 a
Between	7.03	16.66 b	4.01	8.08 b
75mm	7.29	16.19 b	3.96	7.47 ab
150mm	6.87	14.25 ab	3.82	7.36 ab
S.E.D. ±	0.41	1.24	0.20	0.73
Significance	n s	* *	n s	*

Table A1.26 *Effect of Seeding Rate on Extended Height of Fescue and Ryegrass at 26 Days After Sowing*

	FESCUE	RYEGRASS
High	62.1	66.9
Low	58.9	64.1
S.E.D. ±	0.13	0.19
Significance	*	n.s.

Table A1.27 *Effect of Drill Method on Extended Height (mm)*

d.a.s. (Month)	26 (May)	43 (May)	145 (Sep)
75 mm	64	77	159
Cross	62	78	153
150 mm	63	76	151
S.E.D. ±	1.4	2.1	7
Significance	n s	n s	n s

Table A1.28 Effect of Position on Extended Height (mm)

POSITION	d.a.s. (Month) 43 (May)	145 (Sep)
Intersection	78	150
Between	78	155
75mm	77	159
150mm	76	151
S.E.D. ±	2.0	7
Significance	n s	n.s.

Table A1.29 Effect of Drill Method on the Tiller Number of Ryegrass and Fescue Plants

d.a.s. (Month) *SPECIES*	*Drill Method*	43 (May)		145 (September)	
		Leaves	Tillers	Leaves	Tillers
	75 mm	3.96	1.611	7.5	4.39
FESCUE	Cross	4.14	1.639	7.2	4.29
	150 mm	3.82	1.556	7.4	4.47
S.E.D. ±		0.245	0.0992	0.63	0.428
Significance		n.s.	n.s.	n.s.	n.s.
	75 mm	7.29	2.611	16.2	8.11
RYEGRASS	Cross	6.98	2.625	15.0	7.62
	150 mm	6.87	2.472	14.2	7.38
S.E.D. ±		0.35	0.1584	1.12	0.621
Significance		n.s.	n.s.	n.s.	n.s.

Table A1.30 Effect Plants m^{-2} on Tiller Number of Fescue and Ryegrass.

	Fescue		**Ryegrass**	
d.a.s.	43	145	43	145
Tillers/plant	1.60	4.54	2.60	7.96
slope of regression line	-0.0001	-0.0006	-0.0003	-0.004
S.E.D. ±	0.00021	0.0009	0.0004	0.002
significance	n.s.	n.s.	n.s.	*
r^2	0.008	0.01	0.02	0.14

Table A1.31 *Treatment Effects on Leaf and Tiller Number and Extended Height*

d.a.s.	26		43			145		
Characteristic	leaf #	height	tiller #	leaf #	height	tiller #	leaf #	height
Species	* * *	*	* * *	* * *	* * *	* * *	* * *	*
Seeding Rate		*		*		* * *	* * *	*
Drill Method								
Position						* * *	* * *	* *
Rate X Drill				(*)				
Species X Rate						* *	*	
Drill X Species								* †
Rate X Positoin								
Rate X Drill X Species								
Drill X Position X Species								

- † shaded area denotes a significant interaction which was not apparent from the analysis of variance of plant size indices

Table A1.32 *Treatment Effects on Plant Size Indices*

d.a.s.	26	43			145		
Plant Size Index	Lf X Hgt	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H
Species	* * *	* * *	* * *	* * *	* * *	* * *	* * *
Seeding Rate		(*)			* * *	* * *	* * *
Drill Method							
Position	N/A†				* *	* *	* *
Rate X Drill			(*)				
Species X Rate					* * *	*	* * *
Drill X Species							
Rate X Position	N/A						
Rate X Drill X Species							
Position X Species	N/A				(*) (0.079) ‡	(*) (0.093)	* (0.036)

- ‡ "F" probability for significance
- † N/A = indicates non-assessment at 26 d.a.s., leaf and height data was not available.

Table A1.33 *Effect of Drill Method and Species on Skewness Coefficient of Tiller and Leaf Number and Length of Extended Height at 26, 43 and 145 d.a.s.*

d.a.s. (Month)	26 (May)		43 (May)			145 (September)		
Characteristic	Leaf	Height	Tiller	Leaves	Height	Tiller	Leaves	Height
Fescue	-0.315	-0.03	0.067	0.127	-0.052	0.034	0.006	0.018
Rye	-0.274	-0.064	0.006	0.068	-0.037	0.157	0.116	0.086
S.E.D. ±	0.1329	0.053	0.064	0.028	0.076	0.019	0.037	0.044
Significance.	n.s.	n.s.	n.s.	n.s.	n.s.	* * *	*	n.s.
High	-0.277	-0.050	0.062	0.127	-0.076	0.034	0.006	0.036
Low	-0.312	-0.045	0.011	0.068	-0.013	0.157	0.116	0.068
S.E.D. ±	0.0982	0.0427	0.080	0.052	0.051	0.048	0.043	0.042
Significance.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm	-0.319	-0.065	-0.019	0.090	-0.005	0.094	0.037	0.053
Cross Drill	-0.287	-0.021	0.057	0.101	-0.061	0.080	0.054	0.046
150 mm	-0.278	-0.055	0.050	0.097	-0.051	0.126	0.101	0.064
S.E.D. ±	0.120	0.0522	0.098	0.064	0.062	0.058	0.053	0.051
Significance.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A1.34 *Effect of In-row Population on Skewness Leaf and Tiller Number and Extended Height for both Fescue and Ryegrass.*

	Fescue						**Ryegrass**					
d.a.s.	43			145			43			145		
Characteristic	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height
mean	0.033	0.08	-0.05	0.063	0.04	0.009	-0.028	0.058	-0.046	0.16	0.11	0.1
slope	0.004	0.0035	-0.0006	-0.0006	-0.0007	-0.002	0.00006	-0.001	-0.001	0.001	0.002	0.003
S.E.D. ±	0.002	0.001	0.001	0.002	0.001	0.001	0.002	0.001	0.0017	0.001	0.001	0.001
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
r^2	0.06	0.08	0.005	0.003	0.007	0.05	0.05	0.02	0.016	0.04	0.05	0.09

Table A1.35 *Effect of Plants m^{-2} on Skewness Leaf and Tiller Number and Extended Height for both Fescue and Ryegrass.*

	Fescue						**Ryegrass**					
d.a.s.	43			145			43			145		
Characteristic	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height	Skew Tillers	Skew Leaves	Skew Height
mean	0.026	0.085	-0.051	0.06	0.04	0.009	-0.08	0.058	-0.046	0.16	0.11	0.1
slope	0.0001	0.0003	0.0002	-0.00009	-0.0002	0	0.00003	-0.0002	-0.0003	0.0003	0.0003	0
S.E.D. ±	0.0003	0.0003	0.00002	0.0002	0.0001	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	n.s	n.s	n.s	n.s
r^2	0.003	0.05	0	0.005	0.023	0	0.0002	0.03	0.06	0.07	0.08	0

Table A1.36 *Effect of Seeding Rate and Drilling Method on the Skewness Coefficient of Plant Size Indices*

d.a.s. (Month)	26 (May)	43 (May)			145 (September)		
Characteristic	Lf X Hgt	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H
High	-0.001	0.050	0.105	0.196	0.107	0.106	0.226
Low	-0.041	0.048	0.066	0.125	0.111	0.103	0.225
S.E.D. ±	0.052	0.048	0.042	0.048	0.037	0.039	0.038
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75mm	-0.040	0.043	0.106	0.164	0.066	0.095	0.205 a
Cross Drill	-0.008	0.054	0.089	0.164	0.105	0.101	0.198 a
150mm	-0.014	0.047	0.059	0.150	0.159	0.176	0.302 b
S.E.D. ±	0.064	0.059	0.073	0.083	0.046	0.048	0.047
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	(*) Fpr=0.078

Table A1.37 *Effect of Plants m^{-2} on Skewness of Plant Size Indices for both Fescue and Ryegrass.*

	Fescue						**Ryegrass**					
d.a.s.	43			145			43			145		
Size Index	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H
mean	0.11	0.09	0.17	0.16	0.06	0.19	0.12	0.06	0.12	0.24	0.14	0.26
slope of regression line	0.0002	0.0002	0.0001	-0.0005	-0.0005	-0.0002	0.00008	-0.0001	0.0001	0.0003	0.0003	0.0003
S.E.D. ±	0.0003	0.0002	0.0002	0.001	0.001	0.001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	(*)	n.s.	*
r^2	0.02	0.023	0.007	0.003	0.039	0.0006	0.004	0.01	0.016	0.09	0.07	0.11

Table A1.38 *Treatment Effects on Skewness Coefficient of Leaf Number and Tiller Number and Extended Height*

d.a.s.	**26**		**43**			**145**		
	Leaf Number	Height	Tiller Number	Leaf Number	Height	Tiller Number	Leaf Number	Height
Species						***	*	
Seeding Rate								
Drill Method								
Position	N/A‡	N/A		*				
Rate X Drill								
Species X Rate				*		*	*	
Drill X Species								
Rate X Position	N/A	N/A						
Rate X Drill X Spp								
Drill X Posi X Spp	N/A	N/A						

‡ - N/A indicates non assessment, at 26 d.a.s. leaf data was not available from tagged plants

Table A1.39 *The Effects of Seeding Rate, Drill Method and Plant Position on Coefficient of Variation of Tiller Number, Leaf Number and Extended Height at 26, 43 and 145 d.a.s.*

d.a.s. (Month)	26 (May)		43 (May)			145 (September)		
Characteristic	Leaf	Height	Tiller	Leaves	Height	Tiller	Leaves	Height
High	0.46	0.354	0.221	0.525	3.6	1.42	2.63	13.5
Low	0.86	0.437	0.264	0.560	4.1	1.68	3.04	16.9
S.E.D. ±	0.681	0.046	0.034	0.09	0.528	0.437	0.836	6.7
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm	0.76	0.314 a	0.199	0.476	3.75	1.48	2.61	17.3
Cross Drill	1.14	0.398 ab	0.238	0.505	3.47	1.47	2.77	14.7
150 mm	0.08	0.474 b	0.295	0.685	4.7	1.78	3.21	14.1
S.E.D. ±	0.834	0.056	0.059	0.1335	0.646	0.267	0.512	4.1
Significance	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Intersection	N/A	N/A	0.299 a	0.553	3.62	1.32	2.6	15.3
Between	N/A	N/A	0.178 b	0.457	3.33	1.62	2.95	14.2
75mm	0.76	0.314	0.199 b	0.476	3.75	1.48	2.61	17.3
150mm	0.08	0.474	0.295 a	0.685	4.7	1.78	2.77	14.7
S.E.D. ±	0.834	0.056	0.0482	0.1109	0.746	0.309	0.591	4.74
Significance	n.s.	*	*	n.s.	n.s.	n.s.	n.s.	n.s.

Table A1.40 *Effect Plants m^{-2} on Coefficient of Variation of Tiller Number and Leaf Number and Plant Height for Fescue and Ryegrass.*

	Fescue						Ryegrass					
d.a.s.	43			145			43			145		
Characteristic	Tiller	Leaf	Height	Tiller	Leaf	Height	Tiller	Leaf	Height	Tiller	Leaf	Height
mean	0.19	0.39	4.31	1.04	1.7	13.2	0.24	0.67	3.37	2.2	4.15	17.1
slope	-0.0001	0.0001	-0001	-0.0003	-0.0009	0.009	0.00004	0	0.0003	0.01	0.016	-0.12
S.E.D. ±	0.00007	0.0002	0.002	0.0007	0.001	0.0008	0.0001	0.0004	0.002	0.009	0.016	0.146
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
r^2	0.05	0.01	0.07	0.005	0.02	0.003	0.026	0.0005	0.0006	0.035	0.03	0.02

Table A1.41 *Effect Plants m^{-2} on Plant Size Indices for both Fescue and Ryegrass.*

	Fescue						Ryegrass					
d.a.s.	43			145			43			145		
Characteristic	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H	Till X Lf	Lf X Hgt	T X L X H
mean	6.4	264	435	37	1029	5022	18	627	1655	131	2825	24018
slope of	0.0002	0.006	0.06	-0.02	-0.13	-1.48	-0.006	-0.08	-0.043	-0.13	-1.97	-29
S.E.D. ±	0.001	0.049	0.13	0.01	0.36	2.3	0.005	0.13	0.54	0.06	0.96	13
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	*	*
r^2	0	0	0.007	0.05	0.004	0.01	0.03	0.02	0.02	0.13	0.1	0.12

Table A1.42 *Effect Plants m^{-2} on Shoot Weight for Fescue and Ryegrass.*

	Fescue				Ryegrass			
d.a.s.	26	49	85	135	26	49	85	135
mean	0.0311	0.148	0.74	1.5	0.05	0.36	1.46	2.7
slope of regression line	0.000005	0.0003	-0.0007	-0.0008	0.00001	-0.00001	-0.0002	-0.001
S.E.D. ±	0.000004	0.00003	0.0001	0.0004	0.00001	0.00009	0.0003	0.001
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
r^2	0.05	0.02	0.06	0.1	0.07	0.0005	0.014	0.04

Table A1.43 *Effect In-row Population on Shoot Weight for Fescue and Ryegrass.*

	Fescue				Ryegrass			
d.a.s.	26	49	85	135	26	49	85	135
mean	0.0311	0.148	0.74	1.5	0.05	0.36	1.46	2.7
slope of regression line	-0.00003	0.0003	-0.002	-0.007	0.000004	-0.0005	-0.002	-0.016
S.E.D. ±	0.00003	0.0003	0.001	0.003	0.00006	0.0006	0.002	0.008
significance	n.s.	n.s.	*	*	n.s.	n.s.	n.s.	n.s.
r^2	0.025	0.03	0.11	0.11	0.0001	0.02	0.03	0.11

Table A1.44 *Effect of Seeding Rate and Drilling Method on Fescue and Ryegrass Tiller Weight at 49 and 135 d.a.s.*

d.a.s. (Month)	FESCUE		RYEGRASS	
Characteristic	49	135	49	135
High	8.38	35.6	10.87	31.5
Low	8.01	41.6	12.89	40.7
S.E.D. ±	1.14	5.5	1.43	4.01
Significance	n.s.	n.s.	n.s.	*
75 mm	7.89	41.5	10.87	36.5
150 mm	8.50	35.7	12.88	35.7
S.E.D. ±	1.08	5.2		
Significance	n.s.	n.s.	n.s.	n.s.

Table A1.45 *Effect of Drill Method on Tiller and Leaf Number at 145 d.a.s. and Shoot and Tiller Weight at 135 d.a.s. for Fescue and Ryegrass at High and Low Seeding Rate*

	SEEDING RATE	*DRILL METHOD*	Plants m^{-1} row	Plants m^{-2}	SHOOT DW (mg/plant)	TILLER DW (mg/tiller)	LEAF NUMBER	TILLER NUMBER
Fescue	HIGH	75mm (H75)	61 a	820 a	132 a	36.8 a	4.03 ab	6.69 a
		Cross (HX)	67 b	902 a	130 a	N/A §	3.69 a	6.29 a
		150mm (H150)	108 c	719 b	128 a	34.5 a	4.14 ab	6.50 a
	LOW	75mm (L75)	39 d	523 c	204 b	46.1 a	4.75 ab	8.25 b
		Cross (LX)	38 d	509 c	160 ab	N/A	4.89 b	8.15 b
		150mm (L150)	65 a	435 c	151 a	37.0 a	4.79 b	8.23 b
	S.E.D. ±	Comparison	SED 2	SED 48	SED 23	SED 4.7		
		Cross with Cross					0.42	0.728
		Cross with 75 or 150					0.52	0.892
		75 with 150					0.60	1.03
Ryegrass	HIGH	75mm (H75)	57 a	764 ab	205 ab	32.4 a	6.92 ac	14.22 a
		Cross (HX)	63 b	844 a	285 ab	N/A	6.42 a	12.75 a
		150mm (H150)	109 c	725 b	182 a	30.6 a	6.67 ac	12.83 a
	LOW	75mm (L75)	40 d	531 c	375 b	40.6 a	9.31 b	18.15 b
		Cross (LX)	38 d	502 cd	295 b	N/A	8.83 b	17.33 b
		150mm (L150)	62 b	416 d	306 b	40.8 a	8.09 cb	15.66 ab
	S.E.D. ±	Comparison	SED 1.7	SED 44	SED 56	SED 5.5		
		Cross with Cross					0.621	1.12
		Cross with 75 or 150					0.760	1.38
		75 with 150					0.621	1.59

- Unlike letters in a column denote significant differences
- § N/A indicates not assessed (plant weight and was not recorded for plants at the intersection of cross drilled rows)

Table A1.46 *Weight/Density Relationships for 135 d.a.s. Calculated for Ryegrass and Fescue from Seeding Rate Comparisons.*

	Population (plants m^{-2})	Shoot Weight (mg/plant)	$\frac{\log W1 - \log W2}{\log D1 - \log D2}$ §
FESCUE	489	171	<1
	814	130	
RYEGRASS	485	326	<1
	778	224	

- § where W = shoot DW and D = population

Table A1.47 *Effect of Plants m^{-1} row on Tiller Weight for Fescue and Ryegrass at 43 at 145 d.a.s.*

	Fescue		Ryegrass	
d.a.s.	43	145	43	145
mean	0.0819	0.386	0.118	0.361
slope of regression line	0.00001	-0.0002	-0.00006	-0.0001
S.E.D. ±	0.00003	0.0002	0.00004	0.0001
significance	n.s.	n.s.	n.s.	n.s.
r^2	0.007	0.04	0.07	0.04

Table A1.48 *Effect In-row Population on Plant Size Indices for both Fescue and Ryegrass.*

	Fescue				Ryegrass			
d.a.s.	43		145		43		145	
Size Index	Till X Lf	Lf X Hgt	Till X Lf	Lf X Hgt	Till X Lf	Lf X Hgt	Till X Lf	Lf X Hgt
mean	6.4	264	37	1029	18	627	131	2825
slope	-0.015	-0.61	-0.11	-2.7	-0.066	-0.68	-1.12	-16.5
S.E.D. ±	0.012	0.37	0.11	2.7	0.037	0.91	0.38	6.5
significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	*
r^2	0.05	0.07	0.03	0.03	0.08	0.02	0.2	0.15

Table A1.49 *Levels of Significance for Seeding Rate Effect on Plant Size and Correlation Coefficients for Regression of In-row Population on Plant Size for Ryegrass and Fescue*

		Leaf Number		Tiller Number	Extended Height	Shoot weight		Tiller weight
	d.a.s	43	145	145	145	85	135	135
Significance for seeding rate	FESCUE	0.012	0.004	0.004	0.094	n.s.	0.005	n.s.
	RYEGRASS	n.s.	<0.001	<0.001	0.083	0.027	0.004	0.034
Size increase as a % of high seed rate	FESCUE	10 %	30 %	24 %	10 %	13 %	32 %	18 %
	RYEGRASS	27 %	30 %	32 %	8 %	15 %	45 %	29 %
r^2 (plant size on plants m^{-1} row)								
FESCUE		0.07	0.06	0.03	0.003	0.11	0.11	0.06
Significance		(*)	n.s.	n.s.	n.s.	*	*	n.s.
RYEGRASS		0.06	0.25	0.17	0.02	0.03	0.11	0.05
Significance		n.s.	*	**	n.s.	n.s.	*	n.s.

Table A1.50 *Effect of Drill Method and Seeding Rate Combinations on the Shoot Weight and Mass of Fescue and Ryegrass*

		Fescue		Ryegrass	
		Shoot weight mg/plant (135 d.a.s.)	Sown Mass kgDM ha^{-1} (150 d.a.s.)	Shoot weight mg/plant (135 d.a.s.)	Sown Mass kgDM ha^{-1} (150 d.a.s.)
HIGH	75 mm row	126	688	198	908
	Cross drill	125	509	278	954
	150 mm row	124	589	180	1059
LOW	75 mm row	192	768	321	972
	Cross drill	155	415	286	962
	150 mm row	150	451	300	918
S.E.D. ±		23	118	48	117
Significance for interaction		n.s.	n.s.	n.s.	n.s.

Table A1.51 *Effect of Drill Method and Seeding Rate on the Herbage Composition and Mass of Ryegrass at 54 d.a.s.*

	Proportion of live Herbage			Mass (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
High	4	4	10	11	14	32	122	466
Low	5	5	14	14	13	40	120	405
S.E.D. ±	1.4	1.1	2.6	4	4	8	17	29
Significance	n.s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
75 mm row	5	4	14	13	12.5	43	129	451
Cross drill	4	5	10	11	15	31	120	434
150 mm row	5	5	11	14	15	34	114	421
S.E.D. ±	1.7	1.4	3.2	5	4.5	10	21	31
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A1.52 *Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 150 d.a.s. (9-9-90)*

	Proportion of live Herbage			Mass (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
Fescue	25	18	8	336	261	111.5	250	1640
Ryegrass	11	15	6	144	227	87.7	292	1759
S.E.D. ±	2.5	1.3	1.7	30	31	30	31	126
Significance	**	*	n.s.	***	n.s.	n.s.	n.s.	n.s.
High	18	17	6	249	252	86	291	1741
Low	18	16	8	232	236	113	251	1657
S.E.D. ±	2.3	1.7	1.1	32	29	16	25	61
Significance	n.s.	n.s.	n.s.	n.s.	n.s	ns	n.s.	n.s.
75 mm row	16	15	7	203 a	227	102	267	1434
Cross drill	21	17	8	295 b	264	115	270	1471
150 mm row	17	18	6	222 ab	241	81	277	1380
S.E.D. ±	2.9	2.1	1.4	39	35	20	31	75
Significance	n.s.	n.s.	n.s	*	n.s.	n.s.	n.s.	n.s.

Table A1.53 *Effect of Drill Method on the Composition and Mass of Fescue and Ryegrass at 150 d.a.s.*

		Proportion of Live Herbage			Mass (kgDM ha^{-1})		
		% Weed	% Other	% Prairie	Weed	Other	Prairie
	75 mm row	21	16	9	277	257	134
FESCUE	Cross drill	30	19	9	420	274	132
	150 mm row	25	20	5	312	251	69
S.E.D. ±		4.5	3.1	1.9	62	54	31
Significance		n.s.	n.s.	n.s.	(*)	n.s.	(*)
	75 mm row	11	13	5	129	196	69
RYEGRASS	Cross Drill	13	16	636	171	254	100
	150 mm row	9	15	666	133	231	94
S.E.D. ±		3.6	2.7	1.7	46	46	25
Significance		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Species X Drill	S.E.D. ±	4.1	2.8	2.4	54	50	38
Interaction	Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A1.54 *Effect of Drill Method on the Composition and Mass at Two Seeding Rates (Fescue and Ryegrass combined)*

		Proportion of Live Herbage		Mass (kgDM ha^{-1})		
		% Sown	% Unsown	Sown	Unsown	Total live
HIGH	75mm rows	56	38 a	798	518 a	1386
	Cross drill	46	48 b	732	760 b	1585
	150 mm row	58	36 a	824	482 a	1379
LOW	75mm rows	59	36 a	870	545 a	1481
	Cross drill	49	44 ab	688	590 a	1357
	150 mm row	49	44 ab	685	608 a	1382
S.E.D. ±		4	3.7	83	64	93
Significance for Interaction		(*) Fpr =0.053	(*) Fpr =0.054	n.s.	**	*

Table A1.55 *Effect of Drill Method on the Broadleaf and Grass Weed Component at Two Seeding Rates (Fescue and Ryegrass Combined)*

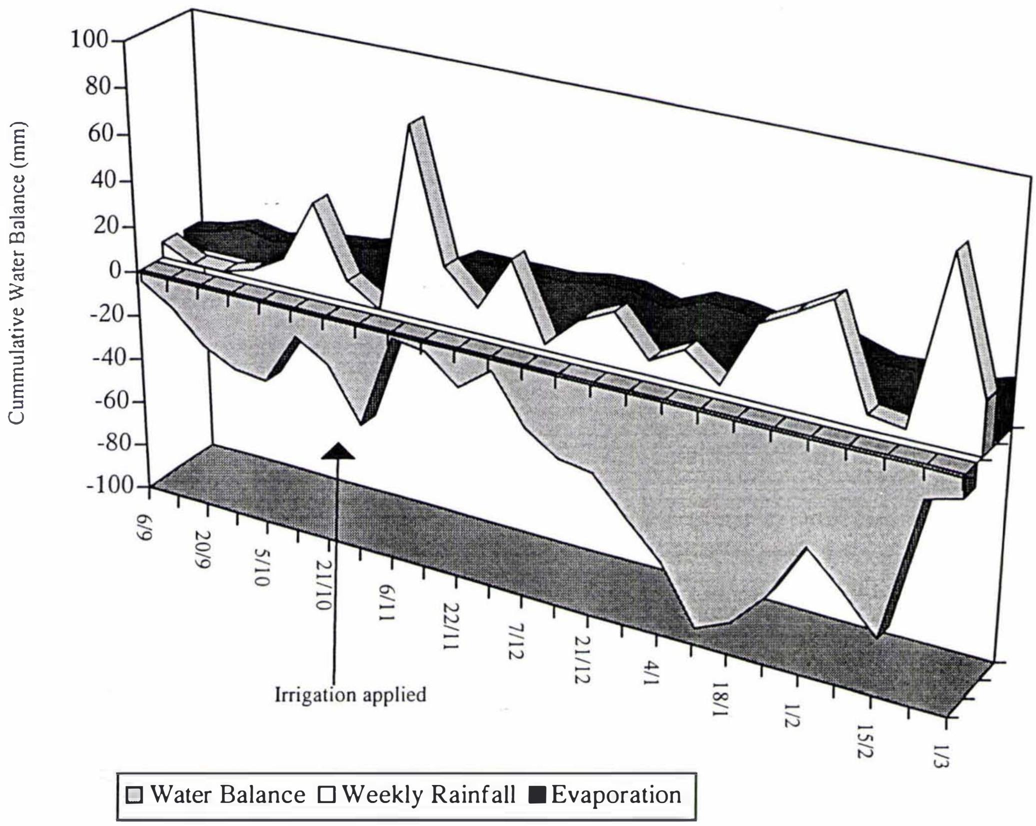
		Proportion of Live Herbage			Mass (kgDM ha^{-1})		
		% Weed	% Other	% Prairie	Weed	Other	Prairie
HIGH	75mm rows	19	14	5	250 ab	204	65
	Cross drill	21	20	8	321 a	315	123
	150 mm row	14	18	5	176 bc	236	70
LOW	75mm rows	12	16	9	157 b	249	138
	Cross drill	22	15	7	270 ac	213	107
	150 mm row	21	17	6	269 ac	246	92
S.E.D. ±		4	3	2	55	50	28
Significance for Interaction		*	n.s.	n.s.	(*) Fpr =0.053	n.s.	n.s.

Table A1.56 *Effect of Seeding Rate on the Composition and Mass of Fescue and Ryegrass at 150 d.a.s.*

		Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})		
		% Sown	% Clover	% Unsown	Sown	Clover	Unsown
FESCUE	**High**	42	7.6	50	595	101	699
	Low	38	9.4	52	545	122	718
S.E.D. ±		2.9	2.1	2.9	68	28	57
Significance		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
RYEGRASS	**High**	65	3.7	31	974	56	475
	Low	66	2.7	31	951	34	444
S.E.D. ±		3.6	0.08	3.1	67	12	47
Significance		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

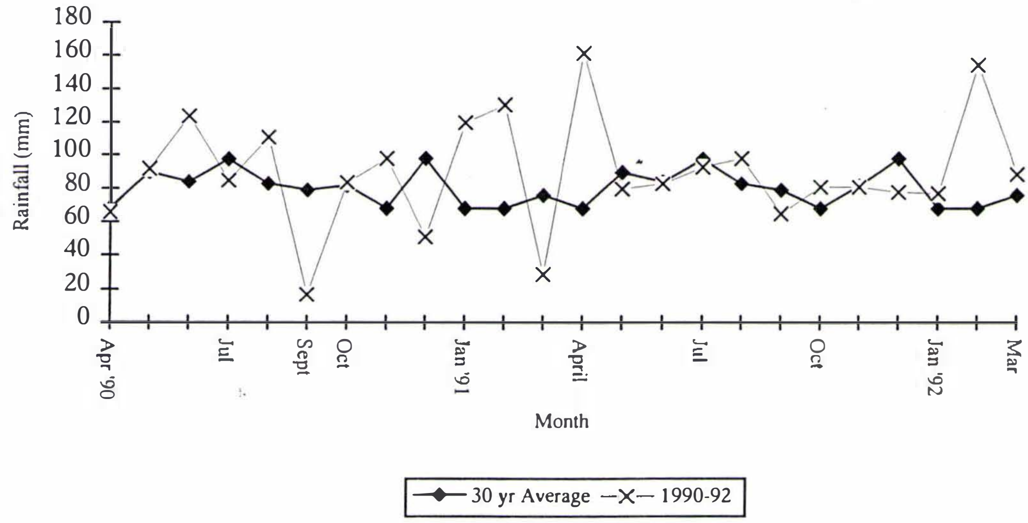
Appendix Two

Figure A2.1 *Cumulative Weekly Water Balance for 'LATE ESTABLISHMENT' (145 to 315 d.a.s., 4/9/90 - 21/2/91)*



- Weather data was acquired from a meteorological station located approximately 500m from the trial site operated by the New Zealand Pastoral Agriculture Research Institute Ltd (AgResearch)

Figure A2.2 *Monthly Rainfall for the Trial Period (12/4/90 - 6/3/92) and 30 Year Averages of Monthly Rainfall*



- 30 Year averages from records kept at a meteorological station located approximately 500m from the trial site operated by the New Zealand Pastoral Agriculture Research Institute Ltd (AgResearch) (Yvonne Gray pers. comm., 1993)

Figure A2.3 *Monthly Mean Temperature for the Trial Period (12/4/90 - 6/3/92) and 30 Year Averages of Mean Temperature*

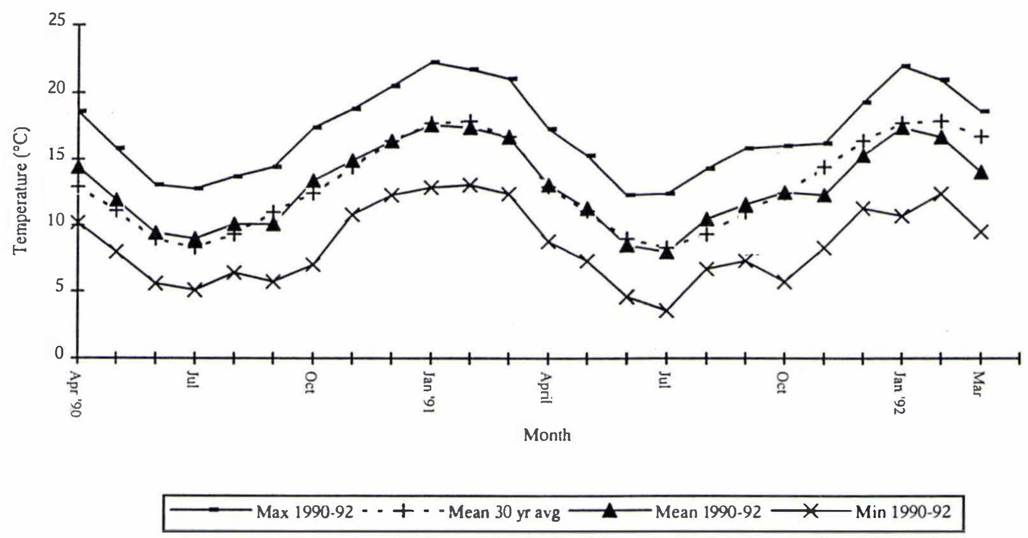


Table A2.1 *Effect of Species, Seeding Rate and Drilling Method on the Tiller Number from 0 to 313 d.a.s. (back transformed data)*

d.a.s. (Month)		43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
SPECIES								
Fescue		1.61	4.2	3.6	3.8	4.3	4.7	5.9
Rye		2.58	7.4	6.4	8.4	8.3	8.0	7.9
S.E.D. ±		0.101	0.29	0.29	0.30	0.44	0.18	0.20
Significance		***	***	***	***	***	***	***
SEEDING RATE								
High		2.04	4.9	4.2	4.8	5.2	5.4	6.3
Low		2.15	6.3	5.5	6.7	6.9	7.0	7.5
S.E.D. ±		0.066	0.27	0.27	0.36	0.45	0.51	0.57
Significance		n.s.	***	***	***	***	***	**
DRILLING METHODS								
75 mm		2.11	5.7	5.2	6.7 a	6.7	6.8	7.5
Cross		2.13	5.5	4.7	5.1 bc	5.6	5.9	6.76
150 mm		2.01	5.6	4.6	6.0 ac	6.0	6.0	6.48
S.E.D. ± (150 vs 75mm)		0.093	0.37	0.39	0.52	0.64	0.73	0.83
Significance when Comparing	75 with 150 mm	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Cross with either 75 or 150	n.s.	n.s.	n.s.	* (S.E.D. ± = 0.45)	n.s.	n.s.	n.s.

Table A2.2 *Effect of Species and Sowing Rate on Tiller Number for the period 43 to 313 d.a.s. (back transformed data)*

d.a.s. (Month)	*Sowing Rate*	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**High**	1.576	3.8	3.2	3.3	3.7	4.2	5.6
	Low	1.646	4.7	4.1	4.5	4.9	5.3	6.3
S.E.D. ±		0.0702	0.303	0.33	0.35	0.45	0.57	0.60
Significance		n.s.	* *	* * *	* * *	* *	*	n.s.
RYEGRASS	**High**	2.514	6.5	5.5	7.1	7.3	6.9	7.0
	Low	2.653	8.6	7.3	9.9	9.6	8.9	9.0
S.E.D. ±		0.112	0.439	0.47	0.11	0.93	.95	1.1
Significance		n.s.	* * *	* * *	* * *	*	*	(*)

Table A2.3 *Effect of Drill Method on the Number of Tillers for Ryegrass and Fescue Plants*

d.a.s. (Month) *SPECIES*	*Drill Method*	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**75 mm**	1.61	4.2 ab	3.7	4.1 a	4.6	5.1 a	6.1 a
	Intersection	1.62	3.7 b	3.4	3.1 b	3.5	3.6 b	4.5 b
	Between	1.65	4.7 a	3.8	4.1 a	4.3	5.4 a	7.2 a
	150 mm	1.57	4.3 ab	3.6	4.2 a	4.6	4.9 ab	6.4 a
S.E.D. ±		0.099	0.50	0.47	0.50	0.65	0.83	0.87
Significance		n.s.	*	n.s.	*	n.s.	*	* * *
RYEGRASS	**75 mm**	2.61	7.8	7.2	10.8 a	9.7	9.2 (a)	9.3
	Intersection	2.59	6.7	5.5	6.7 b	7.3	6.9 (b)	7.1
	Between	2.65	8.2	7.0	8.1 ab	8.5	8.9 (ab)	9.1
	150 mm	2.47	7.2	5.9	8.5 ab	7.7	7.2 (ab)	6.6
S.E.D. ±		0.158	0.56	0.67	1.13	1.35	1.37	1.59
Significance		n s	n s	n s	*	n s	(*) LSD 0.1 = 2.3	n.s.

Table A2.4 *Effect of Drill Method on Tiller Number of Fescue and Ryegrass Plants*

		FESCUE	RYEGRASS
		217 (Nov)	217 (Nov)
DRILL METHOD	**75 mm**	4.1	10.8
	Cross drill	3.6	7.4
	150 mm	4.2	8.5
S.E.D. ±	75mm with 150mm	0.50	1.13
	Cross with 75 or 150	0.43	0.97
	Significance	n.s.	*

Table A2.5 *Effect of Position on the Tiller Number of Plants (Combined Species)*

d.a.s.	43	145	178	217	244	275	313
(Month)	(May)	(Sep)	(Oct)	(Nov)	(Dec)	(Jan)	(Feb)
75mm	2.11	5.7 a	5.2 a	6.7 a	6.7 a	6.8 a	7.5 a
150mm	2.01	5.6 ac	4.6 ab	6.0 a	6.0 ab	6.0 ab	6.5 ab
Intersection	2.11	4.9 bc	4.3 b	4.6 b	5.0 b	5.0 b	5.7 b
Between	2.15	6.2 a	5.2 a	5.7 a	6.2 a	6.9 a	8.0 a
S.E.D. ±	0.093	0.37	0.39	0.52	0.64	0.73	0.83
Significance	n.s.	***	*	*	*	**	***

Table A2.6 *Argentine Stem Weevil infestation of Perennial Grass Tillers at 217 d.a.s.*

Species	Number of tagged plants sampled	Number of plants with one or more tillers showing visible signs of larval damage
Fescue	144	25
Ryegrass	144	5

Table A2.7 *Effect of Drill Method on Tiller Number at 275 and 313 d.a.s. for Fescue and Ryegrass at High and Low Seeding Rate*

	SEEDING RATE	*DRILL METHOD*	275 (Jan)	313 (Feb)
		75mm (H75)	4.5	6.1
	HIGH	**Cross Drill** (HX)	4.0	5.5
FESCUE		**150mm** (H150)	4.21	5.3
		75mm (L75)	5.7	6.1
	LOW	**Cross Drill** (LX)	4.8	5.9
		150mm (L150)	5.7	7.7
		Cross with Cross	0.83	0.87
S.E.D. ±	Comparison	Cross with 75 or 150	1.03	1.08
		75 with 150	1.21	1.29
	Significance		n.s.	n.s.
		75mm (H75)	8.5	9.1 ac
	HIGH	**Cross Drill**(HX)	5.9	6.0 a
RYEGRASS		**150mm** (H150)	7.6	7.4 ac
		75mm (L75)	9.9	9.6 ac
	LOW	**Cross Drill** (LX)	10.4	10.7 bc
		150mm (L150)	7.0	5.9 a
		Cross with Cross	1.37	1.59
S.E.D. ±	Comparison	Cross with 75 or 150	1.71	1.99
		75 with 150	2.01	2.34
	Significance		n.s.	*

Table A2.8 *Effect of Drilling Method on Leaf Number from 178 to 244 d.a.s.*

	d.a.s.	178	217	244
	(Month)	(Oct)	(Nov)	(Dec)
75mm		4.1 a	9.0 a	7.44
Cross Drill		3.7 ab	7.0 b	6.34
150mm		3.2 b	7.3 b	7.30
	75mm with 150mm	0.35	0.76	0.79
S.E.D. ±	Cross with 75 or 150	0.30	0.65	0.68
	Significance	*	*	n.s.

Table A2.9 *Effect of Species on the Leaf Number from 0 to 244 d.a.s.*

d.a.s. (Month) / SPECIES	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)
Fescue	3.9	7.6	2.4	4.0	4.3
Rye	7.1	15.6	5.5	14	10
S.E.D. ±	0.39	0.6	0.22	0.51	0.61
Significance	* * *	* * *	* * *	* * *	* * *

Table A2.10 *Effect of Species, Seeding Rate, Drilling Method and Position on the Tiller Number from 0 to 313 d.a.s. (raw data)*

d.a.s. (Month)		43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
SPECIES								
Fescue		1.61	4.36	4.25	4.46	5.41	6.04	7.49
Rye		2.58	7.68	7.43	10.24	10.61	10.76	11.44
S.E.D. ±		0.101	0.296	0.355	0.468	0.59	0.274	0.290
Significance		* * *	* * *	* * *	* * *	* * *	* * *	* * *
SEEDING RATE								
High		2.045	5.25	5.04	6.36	7.01	7.36	8.41
Low		2.149	6.80	6.64	8.34	9.01	9.44	10.52
S.E.D. ±		0.0658	0.267	0.296	0.439	0.584	0.595	0.752
Significance		n.s.	* * *	* * *	* * *	* * *	* * *	* *
DRILLING METHODS								
75 mm		2.111	6.25	6.37	8.73	8.69	8.58	9.63
Cross		2.132	5.96	5.66	6.87	7.85	8.59	9.64
150 mm		2.014	5.92	5.73	7.7	7.63	7.83	8.93
S.E.D. ± (150 vs 75mm)		0.0930	0.377	0.418	0.621	0.826	0.858	1.063
Significance when Comparing	75 with 150 mm	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Cross with either 75 or 150	n.s.	n.s.	n.s.	* * (S.E.D. ± = 0.68)	n.s.	n.s.	n.s.

Table A2.11 *Effect of Species and Sowing Rate on Tiller Number for the period 43 to 313 d.a.s. (raw data)*

d.a.s. (Month)	Sowing Rate	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**High**	1.576	3.89	3.7	3.80	4.51	5.19	6.76
	Low	1.646	4.83	4.79	5.12	6.32	6.88	8.21
S.E.D. ±		0.0702	0.303	0.312	0.389	0.612	0.662	0.722
Significance		n.s.	* *	* * *	* * *	* *	*	*
RYEGRASS	**High**	2.514	6.6	6.38	8.92	9.51	9.53	10.05
	Low	2.653	8.77	8.48	11.57	11.71	11.99	12.83
S.E.D. ±		0.112	0.439	0.507	0.794	1.004	1.028	1.331
Significance		n.s.	* * *	* * *	* * *	*	*	*

Table A2.12 *Effect of Species on the Percentage of Plants Remaining*

d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
Fescue	100	99.6	99.3	97.2	92	90	87.8
Rye	100	99.3	99.3	97.8	96.5	95.8	92.6
S.E.D. ±	0	0.8 %	0.9%	1.1 %	1.5 %	2.4 %	2.2 %
Significance	n.s.	n.s.	n.s.	n.s.	*	(*)	(*)

Table A2.13 *Effect of Species the Skewness of Tiller Number*

d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
Fescue	0.07	0.03	0.06	0.11	0.13	0.14	0.16
Rye	0.01	0.16	0.14	0.19	0.19	0.17	0.22
S.E.D. ±	0.064	0.019	0.018	0.047	0.056	0.037	0.022
Significance	n.s.	* * *	* *	n.s.	n.s	n.s.	*

Table A2.14 *Effect of Sowing Rate the Percentage of Plants Remaining*

d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
High	100	99.8	99.6	97.5	91.9	90.6	87.3
Low	100	99	98.9	97.6	96.5	95.4	93.1
S.E.D. ±	0	0.6 %	0.7 %	1.2 %	2.2 %	2.6 %	3.1 %
Significance	n.s.	n.s.	n.s.	n.s.	*	(*)	(*)

Table A2.15 *Effect of Sowing Rate on the Skewness of Tiller Number*

d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
High	0.062	0.034	0.109	0.162	0.105	0.161	0.197
Low	0.011	0.157	0.098	0.136	0.223	0.153	0.194
Significance	0.0804	0.0474	0.054	0.0449	0.0443	0.0559	0.0663
S.E.D. ±	n.s.	n.s.	n.s.	n.s.	* *	n.s.	n.s.

Table A2.16 *Effect of Seeding Rate on the Percentage of Plants Remaining for Fescue and Ryegrass*

d.a.s. (Month)	*Sowing Rate*	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**High**	100	99.7	99.3	97.2	88.2	86.1	84.6
	Low	100	100	99.3	97.2	95.8	94.3	91.0
S.E.D. ±		0	0.51	0.91	1.80	4.00	4.75	5.45
Significance		0	n.s.	n.s.	n.s.	(*)	(*)	n.s.
RYEGRASS	**High**	100	100	100	97.8	95.7	95	90
	Low	100	99.7	98.6	97.2	97.2	96	95
S.E.D. ±		0	0.45	0.99	1.6	1.79	2.10	3.25
Significance		0	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.17 Effect of Seeding Rate on the Skewness Coefficient for Fescue and Ryegrass

d.a.s. (Month)	Sowing Rate	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**High**	0.05	0.13	0.05	0.12	0.165
	Low	0.08	0.08	0.21	0.16	0.162
S.E.D. ±		0.076	0.069	0.064	0.086	0.066
Significance		n.s.	n.s.	*	n.s.	n.s.
RYEGRASS	**High**	0.17	0.19	0.20	0.20	0.23
	Low	0.12	0.19	0.18	0.15	0.23
S.E.D. ±		0.069	0.057	0.059	0.073	0.057
Significance		n.s.	n.s.	n.s.	n.s.	n.s.
Species X Rate Interaction	S.E.D. ±	0.054	0.065	0.072	0.067	0.044
	Significance	n.s.	n.s.	*	n.s.	n.s.

Table A2.19 Effect of Drilling Method on the Skewness of Tiller Number

d.a.s. (Month)		178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
75 mm		0.151	0.141	0.102	0.217	0.157
Cross Drill		0.071	0.169	0.200	0.146	0.205
150 mm		0.121	0.115	0.156	0.119	0.214
S.E.D. ± for Comparison	Cross with 75 or 150	0.062	0.055	0.054	0.068	0.053
	75 with 150	0.072	0.063	0.063	0.079	0.062
Significance		n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.20 Effect of Position on the Percentage of Plants Remaining

d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
Intersection	100	100	98.6	97.9	93.1	90.1	86
Between	100	100	99.3	96.5	92.4	92.4	86.7
S.E.D. ±	0	0	0.95	1.67	3.1	3.67	4.46
Significance	0	0	n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.21 *Effect of Position on the Skewness of Tiller Number*

d.a.s. (Month)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
Intersection	0.099	0.236	0.237	0.173	0.264
Between	0.043	0.103	0.133	0.118	0.169
S.E.D. ±	0.072	0.063	0.064	0.079	0.062
Significance	n.s.	*	n.s.	n.s.	n.s.

Table A2.22 *Time and Level of Probability for Main Treatment Effects and Interactions Between Main Treatments on Skewness of Tiller Number, Leaf Number and Extended Height, and Till X Leaf, Till X Hgt and Hgt X Leaf Indices.*

		Species	Rate	Drill	Position	Interaction
178 (Oct)	Tiller	* *				
	Leaf					
	Ext Hgt					
	T x L					
	T x H	*				
	H x L					
217 (Nov)	Tiller				*	
	Leaf					
	Ext Hgt					
	T x L	(*)				
	T x H					
	H x L				* *	
244 (Dec)	Tiller		* *			* (Rate x Species)
	Leaf					
	Ext Hgt			*		
	T x L		(*)			
	T x H					
	H x L					
275 (Jan)	Tiller					
313 (Feb)	Tiller	*				

Table A2.23 *Effect In-row Population on the Percentage of Plants Remaining for Fescue and Ryegrass.*

	d.a.s.	43	145	178	217	224	275	313
Fescue	% Remaining	100	99.6	99.3	97.2	92	90	87.8
	slope of regression line	0	0.0024	0.0048	0.039	0.019	0.019	-0.036
	Significance	0	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	r^2	0	0.0001	0.002	0.02	0.0001	0.001	0.002
Ryegrass	% Remaining	100	99.3	99.3	97.8	96.5	95.8	92.6
	Slope of regression line	0	0.008	0.013	0.049	0.047	0.043	-0.0006
	Significance	0	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	r^2	0	0.0001	0.002	0.01	0.02	0.02	0.06

Table A2.24 *Proportion of Reproductive Tillers at 217 d.a.s.*

Species	Number of tagged plants sampled	Number of plants with visible culm elongation in tillers and / or visible inflorescences	% reproductive tillers
Fescue	100	13	< 1%
Ryegrass	100	64	16%

Table A2.25 *Skewness of Frequency Distributions of Tiller and Leaf Number and Extended Height for Fescue and Ryegrass*

Species	Characteristic	26 (May)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)
FESCUE	Tiller	N/A	0.006	0.034	0.06	0.11	0.13
	Leaf	-0.315	0.085	0.04	0.14	0.04	0.16
	Extended Height	-0.03	-0.052	0.018	0.06	0.002	-0.017
RYEGRASS	Tiller	N/A	0.067	0.157	0.14	0.19	0.19
	Leaf	-0.274	0.058	0.11	0.17	0.16	0.21
	Extended Height	-0.064	-0.037	0.086	0.1	-0.092	-0.051

Table A2.25a *Effect of Drilling Method on the Percentage of Fescue and Ryegrass Plants Remaining*

	d.a.s. (Month)	43 (May)	145 (Sep)	178 (Oct)	217 (Nov)	244 (Dec)	275 (Jan)	313 (Feb)
FESCUE	**75 mm**	100	99.6	98.6	94.4	88.9	86.1	86.1
	Cross Drill	100	100	99.3	97.2	91.0	89.4	84.6
	150 mm	100	100	100	100	97.2	95.8	95.8
S.E.D. ± for Comparison	Cross with 75 or 150	0	0.32	1.11	2.21	4.9	6.72	6.68
	75 with 150	0	0.41	1.28	2.55	5.68	5.82	7.71
Significance			n.s	n.s.	n.s.	n.s.	n.s.	n.s.
RYEGRASS	**75 mm**	100	99.6	100	96.9	96.9 ab	96.9 ab	96.9 b
	Cross Drill	100	100	98.6	97.2	94.4 a	93.1 a	88.1 a
	150 mm	100	100	100	100	100 b	100 b	97.2 b
S.E.D. ± for Comparison	Cross with 75 or 150	0	0.32	1.22	1.97	2.19	2.56	3.98
	75 with 150	0	0.41	1.41	2.28	2.53	2.96	4.59
Significance			n.s	n.s.	n.s.	*	*	*

Table A2.26 *Effect of Position on Leaf Number of Fescue and Ryegrass at 217 d.a.s.*

	FESCUE	***RYEGRASS***
Intersection	3.2	11.9
Between	4.4	14.1
S.E.D. ±	0.55	2.17
Significance	*	n.s.

Table A2.27 *Effect of Species, Seeding Rate and Drill Method on the Botanical Composition and Yield at 219 d.a.s. (21-11-90)*

	Proportion of live Herbage			Yield (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
Fescue	15	12	8	517	414	255	550	3977
Ryegrass	6	8	4	214	301	163	719	4581
S.E.D. ±	2.3	2.0	1.7	64	92	69	57	300
Significance	*	(*)	(*)	* *	n.s.	n.s.	*	(*)
High	10	9	4.3	326	323	153	642	4202
Low	11	11	7.5	405	392	264	627	4356
S.E.D. ±	2.1	1.3	1.24	76	45	43	55	123
Significance	n.s.	n.s.	*	n.s.	n.s.	*	n.s.	n.s.
75 mm row	10	10	6.4	349	386	219	654	4360
Cross drill	13	9	5.5	445	326	211	653	4352
150 mm row	9	10	5.8	303	360	196	596	4125
S.E.D. ±	2.6	1.6	1.52	93	56	53	67	151
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.28 *Effect of Seeding Rate on the Composition and Yield of Fescue and Ryegrass at 219 d.a.s. (21-11-90)*

		Proportion of Live Herbage			Yield (kgDM ha^{-1})		
		% Weed	% Other	% Prairie	Weed	Other	Prairie
FESCUE	**High**	13	10	5.4	455	358	174
	Low	17	14	10	579	469	336
S.E.D. ±		3.3	2.2	2.1	120	79	64
Significance		n.s.	n.s.	*	n.s.	n.s.	*
RYEGRASS	**High**	6	7	3.3	197	287	132
	Low	6	8	5.0	231	315	193
S.E.D. ±		2.7	1.2	1.3	93	44	56
Significance		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Species X Drill	S.E.D. ±	3.2	2.4	2.1	99	103	81
Interaction	Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.29 *Effect of Species, Seeding Rate and Drill Method on the Botanical Composition and Yield at 278 d.a.s. (20-1-91)*

	Proportion of live Herbage			Yield (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
Fescue	6	3.1	3.2	111	84	59	1071	3011
Ryegrass	4	3.8	2.4	64	54	47	1736	3438
S.E.D. ±	1.0	0.9	1.3	31	22	31	105	252
Significance	*	n.s.	n.s.	(*)	n.s.	n.s.	* * *	n.s.
High	4.6	3.1	2.7	82	63	54	1432	3239
Low	5.2	3.8	2.8	93	75	52	1375	3210
S.E.D. ±	1.3	1.2	0.98	25	26	21	78	163
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm row	3.9	4.3	3.6	72	91	70	1476	3428
Cross drill	5.5	2.2	3.1	100	42	55	1358	3134
150 mm row	5.1	3.9	1.7	91	74	33	1377	3102
S.E.D. ±	1.5	1.5	1.1	31	32	26	96	199
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A2.30 *Effect of Drilling Method on Mass of Sown Species in Fescue and Ryegrass Swards at 219 d.a.s. (kgDM ha^{-1})*

		FESCUE	RYEGRASS
Drill Method	**75 mm**	1271	2916
	Cross Drill	1210	2903
	150 mm	1384	2489
S.E.D. ±		191	333
Significance		n.s.	n.s.

Table A2.31 *Effect of Drilling Method on Sown Species Yield in Fescue and Ryegrass Swards at 278 d.a.s.*

		FESCUE	RYEGRASS
Drill Method	**75 mm**	1314	1311
	Cross Drill	981	1446
	150 mm	885	1324
S.E.D. ±		202	148
Significance		(*) (Fpr =0.104)	n.s.

Table A2.32 *Effect of Species on Pre- and Post-grazing Herbage Mass form 246-315 d.a.s. (kgDM ha^{-1})*

	d.a.s. (Month)	Residual Herbage	d.a.s. (Month)	PreGraze Herbage		Net Accuml'n	Utilised
Fescue	246	2022	278	3013		991	833
Ryegrass	(Dec)	2655	(Jan)	3437		782	369
S.E.D. ±		155		253		265	
Significance		* * *					
Fescue	278	2180	315	3691		1511	2416
Ryegrass	(Jan)	3068	(Feb)	3677		611	1802
S.E.D. ±		186		163		213	
Significance		* * *				* * * *	
Fescue	315	1275	393	3042		1766	1347
Ryegrass	(Feb)	1875	(May)	3162		1286	1133
S.E.D. ±		109		204		228	
Significance		* * *				* *	

Table A2.33 *Effect of Urine on Herbage Mass of Unsown Species for Ryegrass and Fescue at 182 d.a.s. (Quadrats Taken from Headland Adjacent to Plots)*

	FESCUE Herbage Mass (kgDM ha^{-1})					RYEGRASS Herbage Mass (kgDM ha^{-1})				
	Weed	Other	Prairie	Dead	Total	Weed	Other	Prairie	Dead	Total
Unaffected	287	258	155	320	1813	108	163	132	297	1844
Affected	1006	421	279	289	3666	164	472	133	453	4202
S.E.D. ±	172	104	163	83	237	58	88	85	79	438
Significance	***	n.s.	n.s.	n.s.	***	n.s.	***	n.s.	n.s.	***

Table A2.34 *Effect of Urine Deposition on Herbage Mass and Composition of Ryegrass at 147 d.a.s.*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Unaffected	0.66	0.05	0.29	1164	94	532	1791
Affected	0.77	0.05	0.18	3428	211	819	4457
S.E.D. ±	0.07	0.04	0.05	225	151	193	213
Significance	n.s.	n.s.	*	***	n.s.	n.s.	***

Table A2.35 *Effect of Urine on Herbage Mass of Unsown Species for Ryegrass at 147 d.a.s.*

	Herbage Mass (kgDM ha^{-1})				
	Weed	Other	Prairie	Dead	Total
Unaffected	147	326	59	243	2034
Affected	105	441	272	628	5085
S.E.D. ±	69	108	141	65	262
Significance	n.s.	n.s.	n.s.	***	***

Appendix Three

Table A3.1 *Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 393 d.a.s. (15/5/91)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	59%	8%	12%	1806	241	285	2331
Ryegrass	66%	1%	3%	2000	33	57	2086
S.E.D. ±	2.2	1.9	1.8	96	42	48	124
Significance	***	**	**	(*)	**	**	n.s.
SEEDING RATE							
High	87%	7%	7%	1889	139	160	2188
Low	86%	6%	8%	1917	134	181	2233
S.E.D. ±	2.7	2.0	1.9	113	41	57	97
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DRILLING METHOD							
75 mm row	86%	6%	8%	1980 (a)	136	210	2326 a
Cross drill	89%	6%	6%	2011 (a)	120	135	2266 ab
150 mm row	84%	8%	8%	1718 (b)	154	167	2039 b
S.E.D. ±	3.4	2.5	2.4	138	50	46	119
Significance	n.s.	n.s.	n.s.	(*)	n.s.	n.s.	*

Table A3.2 *Effect of Species, Seeding Rate and Drill Method on the Composition and Mass of Unsown Species, Dead Material and Total Herbage at 393 d.a.s.*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
Fescue	2%	1%	2%	46	26	63	743	3074
Ryegrass	1%	1%	1%	27	16	13	950	3040
S.E.D. ±	0.5	0.5	0.8	7.6	12.4	22.2	83.2	188
Significance	n.s.	n.s.	n.s.	*	n.s	(*)	*	n.s.
High	1%	1%	1%	30	29	21	829	3016
Low	2%	1%	2%	43	14	55	864	3097
S.E.D. ±	0.9	0.4	0.9	13.9	9.9	22.4	76	14
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s
75 mm row	1%	1%	2%	16	22	68	807	3133
Cross drill	2%	1%	1%	40	23	30	905	3171
150 mm row	3%	1%	1%	54	19	16	827	2866
S.E.D. ±	0.7	0.5	1.0	17	12	27	62	169
Significance	*	n.s.	n.s.	(*)	n.s.	n.s.	n.s.	n.s.

Table A3.3 *Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 496 d.a.s. (28/8/91)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	71%	15%	14%	1525	312	312	2150
Ryegrass	91%	5%	4%	1546	70	65	1681
S.E.D. ±	5.5	4.4	1.6	167	76	37	70
Significance	*	(*)	***	n.s.	*	***	***
SEEDING RATE							
High	83%	9%	7%	1546	188	160	1894
Low	79%	10%	11%	1525	194	218	1937
S.E.D. ±	3.1	1.8	2.7	82	34	62	84
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DRILLING METHOD							
Cross drill	82%	9%	9%	1532	184	186	1902
150 mm row	81%	10%	9%	1539	198	191	1929
S.E.D. ±	3.1	1.8	2.7	82	34	62	84
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A3.4 *Effect of Species, Seeding Rate and Drill Method on the Composition and Mass of Unsown Species, Dead Material and Total Herbage at 496 d.a.s.*

	Proportion of Live Herbage		Herbage Mass (kgDM ha^{-1})			
	% Weed	% Other	Weed	Other	Dead	Total
Fescue	2%	4%	51.6	81	349	2498
Ryegrass	2%	2%	24.3	41	356	2038
S.E.D. ±	0.8	1.0	14	27	46	107
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	* *
High	2%	3%	30.5	74	323	2216
Low	2%	3%	45.5	48	383	2319
S.E.D. ±	0.7	1.1	14	26	34	96
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Cross drill	2%	3%	35	59	379	2281
150 mm row	2%	3%	41	63	326	2255
S.E.D. ±	0.7	1.1	15	26	34	96
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A3.5 *Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 576 d.a.s. (9/11/91)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	61%	28%	11%	1530	722	282	2533
Ryegrass	81%	10%	9%	2491	314	251	3056
S.E.D. ±	4.5	2.5	2.2	148	135	63	85
Significance	* *	* *	n.s.	* * *	*	n.s.	* *
SEEDING RATE							
High	72%	19%	9%	2052	506	232	2789
Low	70%	19%	11%	1968	530	302	2800
S.E.D. ±	2.9	2.3	1.4	96	73	35	98
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	(*)	n.s.
DRILLING METHOD							
75mm row	75%	16%	9%	N/A ‡	N/A	N/A	N/A
Cross drill	73%	16%	11%	1997	517	273	2787
150 mm row	74%	16%	10%	2023	519	260	2803
S.E.D. ±	2.4%	2.7	1.7	96	74	35	98
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

- ‡ Composition determined by cutting strips of herbage to ground level from 75mm treatment

Table A3.6 *Effect of Species, Seeding Rate and Drill Method on the Composition and Mass of Unsown Species, Dead Material and Total Herbage at 576 d.a.s.*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})				
	% Weed	% Other	% Prairie	Weed	Other	Prairie	Dead	Total
Fescue	3%	3%	1%	111	83	23	554	3088
Ryegrass	4%	3%	2%	101	102	48	625	3680
S.E.D. ±	1.1	1.5	1.0	28	38	22	50	79
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	* * *
High	4%	3%	1%	104	76	26	605	3394
Low	3%	3%	1%	108	109	45	574	3374
S.E.D. ±	1.1	0.9	0.5	29	24	16	45	115
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm row	4%	2%	1%	N/A	N/A	N/A	N/A	N/A
Cross drill	3%	3%	2%	96	95	48.5	670	3457
150 mm row	4%	3%	1%	116	90	22.3	509	3312
S.E.D. ±	1.0	0.8	0.6	29	24	16	45	115
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	* * *	n.s.

Table A3.7 *Effect of Species, Seeding Rate and Drill Method on the Herbage Composition and Mass at 684 d.a.s. (6/3/92)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
SPECIES	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
Fescue	72%	22%	7%	1752	526	160	2443
Ryegrass	69%	25%	6%	1434	520	121	2075
S.E.D. ±	5.8	5.4	1.1	127	115	26	83
Significance	n.s.	n.s.	n.s.	*	n.s.	n.s.	* *
SEEDING RATE							
High	72%	23%	6%	1586	506	133	2226
Low	70%	24%	6%	1600	539	149	2292
S.E.D. ±	2.6	2.4	1.1	78	55	25	71
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DRILLING METHOD							
75mm row	73%	21%	5%	1612	474	119	2205
Cross drill	69%	24%	8%	1582	541	178	2302
150 mm row	70%	25%	6%	1592	554	125	2270
S.E.D. ±	3.2	2.9	1.3	96	67	31	87
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A3.8 *Effect of Species, Seeding Rate and Drill Method on the Composition and Mass of Unsown Species, Dead Material and Total Herbage at 684 d.a.s.*

	Proportion of Live Herbage		Herbage Mass (kgDM ha-1)			
	% Weed	% Other	Weed	Other	Dead	Total
Fescue	1.0%	1.6%	12	41	581	3020
Ryegrass	1.0%	4.5%	28	93	935	3010
S.E.D. ±	0.3	0.9	6.6	20	120	128
Significance	n.s.	(*)	(*)	(*)	*	n.s.
High	1.0%	3.0%	23	71	811	3036
Low	1.0%	3.0%	17	63	707	2993
S.E.D. ±	0.36	0.79	8.0	17	74	100
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75 mm row	1.0%	3.0%	15	67	837	3042
Cross drill	1.0%	3.0%	27	72	687	2989
150 mm row	1.0%	3.0%	18	62	752	3022
S.E.D. ±	0.44	0.97	9.9	21	91	123
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A3.9 *Effect of Drill Method on the Mass of Sown Species at 484, 576 and 684 d.a.s. and Percent Sown Species at 576 d.a.s. for Fescue and Ryegrass (kgDMha^{-1})*

	Days After Sowing	**496** (28 August 1991)	**576** (9 Nov 1991)		**684** (6 March 1991)
			Mass Sown	% Sown	
	75mm row	N/A	N/A	67	1824
FESCUE	**Cross Drill**	1479	1512	66	1711
	150mm row	1572	1548	66	1734
	S.E.D. ±	124	113	5	148
	Significance	n.s.	n.s.	n.s.	n.s.
	75mm row	N/A	N/A	84	1399
RYEGRASS	**Cross Drill**	1585	2482	81	1453
	150mm row	1507	2499	82	1449
	S.E.D. ±	108	152	3	123
	Significance	n.s.	n.s.	n.s.	n.s.

Table A3.10 *Effect of Species on the Average Pre- and Post-graze Herbage Mass for the Entire Production Phase (246 to 625 d.a.s.)*

Species	Average Post-graze Herbage Mass ($kgDMha^{-1}$)	Average Pre-graze Herbage Mass ($kgDMha^{-1}$)
Fescue	1740	3097
Ryegrass	1915	3137
S.E.D. ±	111	90
Significance	n.s.	n.s.

Table A3.11 Effect of Species on Pre- and Post-graze Herbage Mass

d.a.s. (Month of Pre-graze Mass)	Species	Post-graze Herbage Mass	Pre-graze Herbage Mass
246-278 (January)	**Fescue**	2022	3013
	Ryegrass	2655	3437
	S.E.D. ±	130	252
	Significance	**	n.s.
278-315 (February)	**Fescue**	2180	3691
	Ryegrass	3068	3677
	S.E.D. ±	216	200
	Significance	**	n.s.
315-393 (May)	**Fescue**	1275	3042
	Ryegrass	1875	3162
	S.E.D. ±	102	189
	Significance	**	n.s.
393-444 (July)	**Fescue**	1695	2511
	Ryegrass	2028	2704
	S.E.D. ±	102	65
	Significance	*	*
444-496 (August)	**Fescue**	1211	2500
	Ryegrass	1286	2037
	S.E.D. ±	153	107
	Significance	n.s.	**
496-521 (September)	**Fescue**	1226	2931
	Ryegrass	1224	2951
	S.E.D. ±	111	146
	Significance	n.s.	n.s.
521-540 (October)	**Fescue**	1946	3053
	Ryegrass	2006	2893
	S.E.D. ±	126	144
	Significance	n.s.	n.s.
540-576 (November)	**Fescue**	2084	2995
	Ryegrass	2008	3580
	S.E.D. ±	114	83
	Significance	n.s.	***
576-591 (December)	**Fescue**	1937	3044
	Ryegrass	2397	3173
	S.E.D. ±	179	153
	Significance	*	n.s.
591-625 (January)	**Fescue**	2037	4655
	Ryegrass	2566	4615
	S.E.D. ±	105	198
	Significance	**	n.s.

Table A3.12 *Effect of Drill Method on Average Pre- and Post-graze Herbage Mass ($kgDMha^{-1}$) for the Period Two of the Production Phase for Fescue and Ryegrass (246-625 d.a.s.)*

	Drill Method	Pre-graze Herbage Mass	Post-graze Herbage Mass
FESCUE	**Cross drill**	3078	1800
	150mm	3120	1682
	S.E.D. ±	81	58
	Significance	n.s.	*
RYEGRASS	**Cross drill**	3142	1831
	150mm	3131	2000
	S.E.D. ±	92	95
	Significance	n.s.	(*)
Species X Drill	S.E.D. ±	137	121
Interaction	Significance	n.s.	*

Table A3.13 Effect of Drill Method on Pre- and Post-graze Herbage Mass (kgDMha^{-1})

d.a.s. (Month of Pre-graze Mass)	Drill Method	FESCUE Post-graze Herbage Mass	FESCUE Pre-graze Herbage Mass	RYEGRASS Post-graze Herbage Mass	RYEGRASS Pre-graze Herbage Mass
246-278 (January)	**75mm**	2227	3487	2649	3369
	Cross drill	2073	2780	2600	3507
	150mm	1787	2773	2718	3438
	S.E.D. ±	180	328	198	229
	Significance	(*)	(*)	n.s.	n.s.
278-315 (February)	**75mm**	2473	4164	2991	3613
	Cross drill	2093	3493	3244	3678
	150mm	2060	3604	2969	3744
	S.E.D. ±	184	229	188	174
	Significance	(*)	*	n.s.	n.s.
315-393 (May)	**75mm**	1513	3471	1807	2791
	Cross drill	1296	2978	1973	3364
	150mm	1258	2771	1784	2962
	S.E.D. ±	143	225	126	254
	Significance	n.s.	*	n.s.	(*)
393-444 (July)	**Cross drill**	1698	2411	2080	2767
	150mm	1691	2611	1980	2644
	S.E.D. ±	124	145	165	213
	Significance	n.s.	n.s.	n.s.	n.s.
444-496 (August)	**Cross drill**	1213	2522	1184	2040
	150mm	1209	2478	1389	2036
	S.E.D. ±	111	138	166	135
	Significance	n.s.	n.s.	n.s.	n.s.
496-521 (September)	**Cross drill**	1287	2860	1189	2858
	150mm	1169	3000	1260	3047
	S.E.D. ±	64	128	67	191
	Significance	(*)	n.s.	n.s.	n.s.
521-540 (October)	**Cross drill**	2087	3202	1898	2727
	150mm	1807	2904	2116	3058
	S.E.D. ±	108	180	124	182
	Significance	*	n.s.	(*)	(*)
540-576 (November)	**Cross drill**	2153	3076	1947	3638
	150mm	2016	2916	2073	3524
	S.E.D. ±	147	135	173	190
	Significance	n.s.	n.s.	n.s.	n.s.
576-591 (December)	**Cross drill**	2004	3031	2342	3107
	150mm	1871	3056	2453	3236
	S.E.D. ±	108	150	164	162
	Significance	n.s.	n.s.	n.s.	n.s.
591-625 (January)	**Cross drill**	2060	4431	2424	4853
	150mm	2016	4880	2709	4380
	S.E.D. ±	137	208	206	273
	Significance	n.s.	n.s.	n.s.	n.s.

Table A3.14 *Effect of Drill Method on the Proportion of Clover in the Live Herbage at 393, 484, 576 and 684 d.a.s. for Fescue and Ryegrass*

	Days After Sowing	**393** (15 May 1990)	**496** (28 August 1991)	**576** (9 Nov 1991)	**684** (6 March 1991)
FESCUE	**Cross Drill**	10	16	23	22
	150mm row	13	14	21	23
	S.E.D. ±	4.8	2.9	4.7	4.0
	Significance	n.s.	n.s.	n.s.	n.s.
RYEGRASS	**Cross Drill**	1	2.7	9.7	25
	150mm row	2	6.4	10.5	26
	S.E.D. ±	1	2.1	2.6	4.3
	Significance	n.s.	(*)	n.s.	n.s.

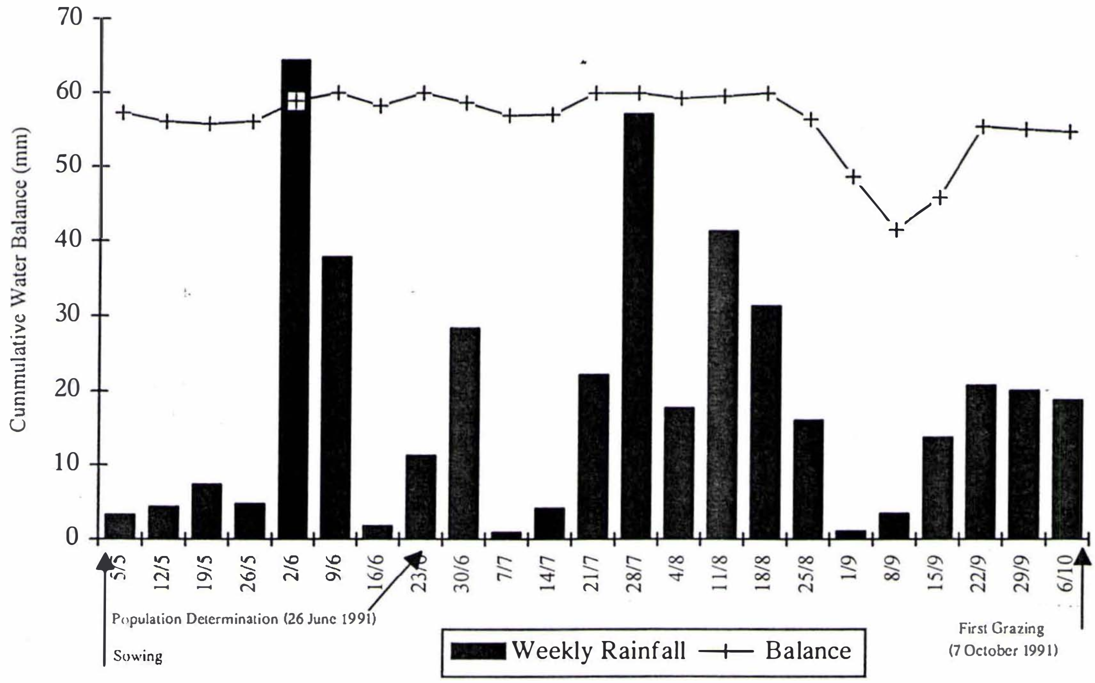
Table A3.15 *Effect of Drill Method on the Proportion and Mass of Dead Material at 393, 484, 576 and 684 d.a.s. for Fescue and Ryegrass*

	Days After Sowing	**393** (15 May 1991)		**496** (28 August 1991)		**576** (9 Nov 1991)		**684** (6 March 1991)	
		% Dead‡	Mass †	% Dead	Mass	% Dead	Mass	% Dead	Mass
FESCUE	**Cross Drill**	23	699	15	395	21	653	17	495
	150mm row	26	725	12	303	18	456	18	557
	S.E.D. ±	2.2	98	1.4	44	2.6	60	3.0	111
	Significance	n.s.	n.s.	*	(*)	n.s.	**	n.s.	n.s.
RYEGRASS	**Cross Drill**	33	111	17	364	18	688	28	880
	150mm row	31	930	16	349	15	562	2830	948
	S.E.D. ±	2.2	115	2.1	52	1.9	68	3.6	144
	Significance	n.s.	n.s.	n.s.	n.s.	n.s.	(*)	n.s.	n.s.

- ‡ Dead material as a percentage of total dry matter
- † Mass in Kilograms dry matter per hectare ($kgDMha^{-1}$)

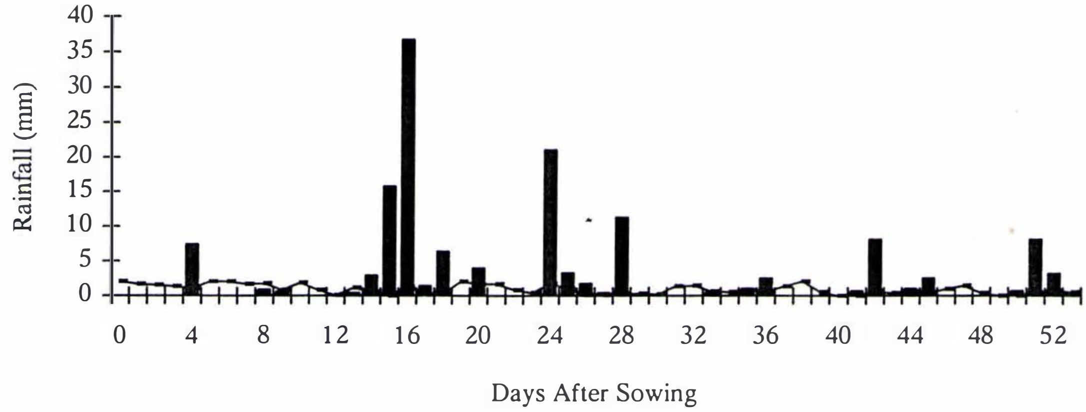
Appendix Four

Figure A4.1 *Cumulative Weekly Water Balance from Sowing to First Grazing at 154 d.a.s. (3/5/91 - 7/10/91)*



- Note Weather data for the trial period was acquired from the same meteorological station used for the main trial which was located approximately 3km north of the nitrogen trial site operated by the New Zealand Pastoral Agriculture Research Institute Ltd (AgResearch).

Figure A4.2 *Rainfall and Evapotranspiration from Sowing to Maximal Emergence at 53 d.a.s. (3/4/91 - 26/6/91)*



Pan Evaporation values were corrected to transpirational water use using a figure of 0.7 based on the Priestly and Taylor formula (D.R Scotter, pers. comm., 1990)

Figure A4.3 *Average Weekly Temperatures from Sowing to First Grazing at 154 d.a.s. (3/5/91 - 7/10/91).*

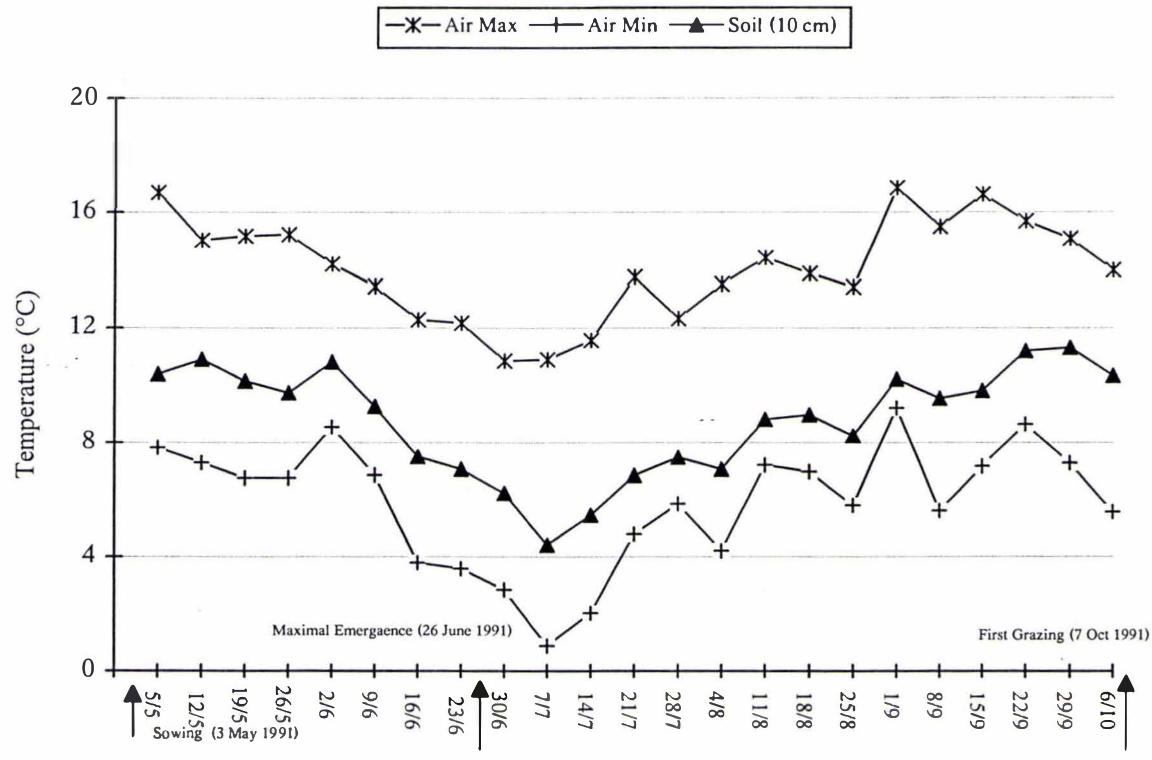


Figure A4.4 *Shoot Weight vs Days After Sowing for Main and Nitrogen Trials*

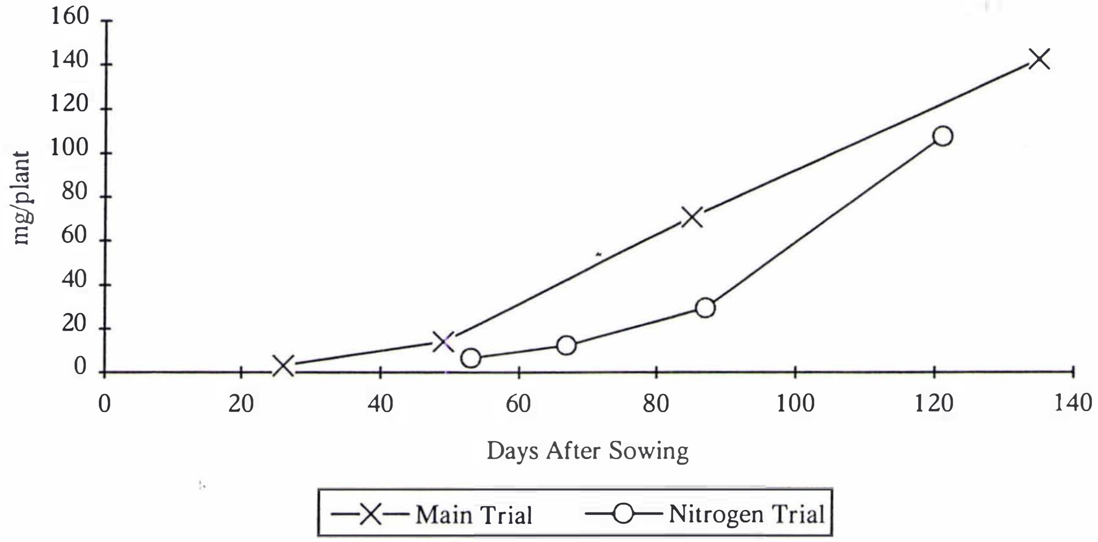


Table A4.1 *Effect of Nitrogen on Population of White Clover and Unsown Species Seedlings at 49 d.a.s. (22/6/91)*

			UNSOWN SPECIES (plants m^{-2})					
		WHITE CLOVER (plants m^{-2})	Buttercup	Mouse eared chickweed	Other Broadleaf Weeds	Annual Poa	Total Unsown
NITROGEN	**With**	173	21	31	40	229	323
	Without	183	17	33	38	244	330
	S.E.D. ±	17	4.6	6.3	7.7	31	31
	Significance	n.s.	n.s.	n.s.	n.s.	*	*

Table A4.2 *Effect of Position on Shoot Weight of Seedlings sown by Cross drilling up to 87 Days After Sowing (mg/plant)*

	Days After Sowing		
POSITION	53	67	87
Intersection	6.99	11.6	27
Straight	6.28	11.8	32
Between	6.77	13.2	27
S.E.D. ±	0.44	1.43	2.7
Significance	n.s.	n.s.	n.s.

Table A4.3 *Effect of Nitrogen, Drill Method and Seeding Rate on Mass of Giant Buttercup, Toad Rush, Broadleaf Weed, Other Grasses, Dead Material and Total Herbage at 154 d.a.s. (7-10-91)*

	Herbage Mass (kgDM ha^{-1})					
NITROGEN	Buttercup	Rush	Weed	Other †	Dead	Total
With	121	170	258	915	154	3885
Without	147	59	230	861	153	3717
S.E.D. ±	49	46	71	170	21	174
Significance	n.s.	*	n.s.	n.s.	n.s.	n.s.
SEEDING RATE						
High	149	57	223	964	168	3967
Low	119	178	265	812	149	3635
S.E.D. ±	49	46	71	170	21	174
Significance	n.s.	*	n.s.	n.s.	n.s.	(*) FPr =0.07
DRILL METHOD						
Cross drill	179	156	271	819	161	3910
150 mm row	89	74	217	957	146	3692
S.E.D. ±	49	46	71	170	21	174
Significance	(*) FPr = 0.08	(*) FPr = 0.1	n.s.	n.s.	n.s.	n.s.

- † The category "Other" represents other grasses and consists mainly of annual poa with some Yorkshire fog, cocksfoot, and volunteer ryegrass.

Table A4.4 *Effect of Nitrogen, Drill Method and Seeding Rate on Mass of Giant Buttercup, Toad Rush, Broadleaf Weed, Other Grasses, Dead Material and Total Herbage at 213 d.a.s. (6-12-91)*

	Herbage Mass (kgDM ha^{-1})					
NITROGEN	Buttercup	Rush	Weed	Other	Dead	Total
With	151	16	115	510	373	3090
Without	105	11	70	569	332	2962
S.E.D. ±	34	8.5	46	82	44	129
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEEDING RATE						
High	180	9	45	502	366	3194
Low	106	17	140	578	338	2858
S.E.D. ±	34	8.5	46	82	44	129
Significance	n.s.	n.s.	*	n.s.	n.s.	*
DRILL METHOD						
Cross drill	180	10	95	638	366	3115
150 mm row	76	17	90	442	338	2937
S.E.D. ±	34	8.5	46	82	44	129
Significance	n.s.	n.s.	n.s.	*	n.s.	n.s.

Table A4.5 *Effect of Nitrogen, Drill Method and Seeding Rate on Mass of Giant Buttercup, Toad Rush, Broadleaf Weed, Other Grasses, Dead Material and Total Herbage at 249 d.a.s. (12-1-92)*

	Herbage Mass (kgDM ha^{-1})				
NITROGEN	Buttercup	Weed	Other	Dead	Total
With	110	116	439	368	3831
Without	149	173	472	336	3661
S.E.D. ±	36	42	76	57	233
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
SEEDING RATE					
High	149	149	435	390	3710
Low	110	140	476	315	3781
S.E.D. ±	36	42	76	57	233
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
DRILL METHOD					
Cross drill	124	174	430	397	3659
150 mm row	135	115	481	307	3832
S.E.D. ±	36	42	76	57	233
Significance	n.s.	n.s.	n.s.	n.s.	n.s.

Table A4.6 *Interactive Effects of Seeding Rate and Drilling Method on Population of Seedlings at 45, 53, 67 and 87 d.a.s. and on Percentage Emergence at 53 d.a.s.*

SEEDING RATE	DRILL METHOD	Population at 45 d.a.s. †	Population at 53 d.a.s.	Nominal Seedling Emergence at 53 d.a.s.	Population at 67 d.a.s.	Population at 87 d.a.s.
CROSS DRILL	**High**	856 [64]	842 [63]	58	617 [45]	621 [46]
	Low	413 [31]	440 [32]	54	415 [31]	469 [35]
150mm ROWS	**High**	565 [84]	679 [101]	54	464 [69]	543 [81]
	Low	284 [43]	350 [52]	52	244 [36]	304 [45]
S.E.D. ±	150 with 150	60 [5.9]	54 [3.4]	4.8	76 [4.1]	87 [4.8]
	150 with Cross	49 [4.8]	44 [2.7]	4.4	62 [3.4]	71 [3.9]
	Cross with Cross	35 [3.4]	31 [1.9]	3.8	44 [2.4]	50 [2.8]
Significance for Interaction		* [n.s.]	n.s. [* *] ‡	n.s.	n.s. [*]	* * [*]

- † plants m^{-2}, plants m^{-1} row in square parenthesis
- ‡ asterisk in square parenthesis refers to level of significance for interaction and indicated where F probability is 5% or less ie. asterisk in parenthesis does not indicate significance at 10% level in this case.

Table A4.7 *Average Weekly Temperatures form Sowing to Population Determination for the Main and Nitrogen Trials (°C)*

	Main Trial						Nitrogen Trial							
Days After Sowing	7	14	21	28	35	42	7	14	21	28	35	42	49	56
Week Ending	19/4	26/4	3/5	10/5	17/5	23/5	10/5	17/5	24/5	31/5	7/6	14/6	21/6	28/6
Air Maximum	13.9	15.3	15.3	16.0	15.1	15.7	15.3	15.4	15.3	14.3	14.2	12.0	12.4	10.9
Air Minimum	6.3	7.2	8.2	6.1	7.4	7.9	6.8	7.3	7.4	7.0	7.8	4.2	4.2	3.2
Ambient	10.1	11.3	11.7	11.1	11.3	11.8	11.1	11.4	11.4	10.7	11.0	8.1	8.3	4.1
Grass Minimum	8.0	6.9	9.0	2.7	4.1	3.6	3.0	3.2	3.3	3.3	4.7	0.6	-0.3	3.5
Soil (10 cm)	9.2	11.2	12.0	10.2	10.1	10.1	10.7	10.6	10.0	10.1	10.2	7.5	7.6	7.2

Table A4.8 *Average Temperatures from Sowing to 87 d.a.s. for the Main and Nitrogen Trials (°C)*

	Main Trial	Nitrogen Trial
Days After Sowing	85	87
Week Ending	28/6	28/7
Air Maximum	14.4	12.9
Air Minimum	6.7	4.6
Soil (10 cm)	10.2	8.2

Table A4.9 *Coefficient of Variation for Shoot Weight Data form Sowing to 87 d.a.s. for the Main and Nitrogen Trials (%)*

Days After Sowing	26	49	85	135
Main Trial	4	10	8	9
Days After Sowing	53	67	87	
Nitrogen Trial	5	9	6	

Table A4.10 *Weight/Density Relationships for 87 d.a.s.*

	Population (plants m^{-2})	Shoot Weight (mg/plant)	$\frac{\log W1 - \log W2}{\log D1 - \log D2}$ §
FESCUE	427	31	<1
	602	27	

§ where W = shoot DW and D = population

Table A4.11 *Effect on In-row Population on Shoot Weight at 53, 67 and 87 d.a.s..*

	Weight of 10 Shoots (g)		
d.a.s.	53	67	87
mean	0.062	0.124	0.295
slope of regression line	-0.00003	0.00009	-0.001
S.E.D. ±	0.00008	0.0004	0.0007
significance	n.s.	n.s.	n.s.
r^2	0.0035	0.0012	0.04

Table A4.12 *Effect of Nitrogen on the Herbage Composition and Mass at 213 d.a.s. (6-12-91)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
NITROGEN	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
With	50.5	18.9	30.6	1374	497	847	2717
Without	48.9	19.8	31.3	1303	507	820	2630
S.E.D. ±	3.2	3.4	2.9	96	79	100	104
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table A4.13 *Effect of Nitrogen, Drill Method and Seeding Rate on the Herbage Composition and Mass at 249 d.a.s. (12-1-92)*

	Proportion of Live Herbage			Herbage Mass (kgDM ha^{-1})			
NITROGEN	% Sown	% Clover	% Unsown	Sown	Clover	Unsown	Total live
With	52	27	21	1791	932	740	3463
Without	47	28	24	1664	1009	862	3535
S.E.D. ±	3.5	3.3	2.6	121	114	107	110
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEEDING RATE							
High	52	25	23	1823	898	801	3521
Low	47	30	22	1632	1043	802	3477
S.E.D. ±	3.5	3.3	2.6	121	114	107	110
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DRILL METHOD							
Cross drill	50	27	22	1743	949	781	3473
150 mm row	49	28	23	1711	992	821	3525
S.E.D. ±	3.5	3.3	2.6	121	114	107	110
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.