Seed Production in tall fescue (*Festuca arundinacea* Schreb.)

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Abstract

A study of agronomic aspects of tall fescue (*Festuca arundinacea* Schreb.) seed production were investigated at Palmerston North, New Zealand (40° 23' south) from 1990 to 1992.

Sowing Grasslands Roa tall fescue monthly from October to April showed that spring and summer sowings (October to February) gave the highest first season seed yields. Seed yields were significantly ($P<0.05$) reduced when Roa tall fescue was sown in autumn (April) compared to sowing in spring (October). A further trial showed that the turf cultivar, Grasslands Garland, produced significantly ($P<0.05$) more seed from autumn sowings than the two pasture cultivars, Roa and Grasslands G48. Time of sowing in the autumn was found to be critical as a delay of only three weeks in autumn sowing (15 April compared to 25 March) reduced seed yields by between 500 and 1000 kg ha^{-1}. In all the time of sowing trials first year seed yields were highly dependent on the number of reproductive tillers produced.

Two field trials investigated undersowing tall fescue in the spring with a barley cover crop. Sowing rates of barley up to 75 kg ha^{-1} had no effect on first year seed yields of tall fescue compared to tall fescue sown alone. At barley sowing rates of 100, 150 and 200 kg ha^{-1}, seed yields and reproductive tiller numbers of tall fescue were reduced by 248 kg ha^{-1} and 145 m^{-2} respectively compared to tall fescue sown alone, but undersowing produced a net income of \$525 ha^{-1} more than tall fescue sown alone. Doubling the undersown tall fescue sowing rate from 7.5 to 15 kg ha^{-1} had no effect on tall fescue seed yields.

Immediate post-harvest management systems comparing burning, grazing and straw removal of tall fescue stubble following seed harvest produced similar seed yields. Autumn defoliation by grazing or cutting produced similar tall fescue seed yields compared to tall fescue plants which were undefoliated from the previous harvest. Applying atrazine (3 kg ai ha^{-1}) initially reduced vegetative tiller numbers but seed yields were not affected.

A study on vernalization requirements found that except for one plant tall fescue could not be vernalized as a germinating seed but was vernalized from any growth stage from main shoot and one leaf appearance onwards. In this study the maximum period of vernalization was 960 hours (40 days) and this was only sufficient to vernalize 64% of the plants. Only between 3 and 14% of plants which received less than 960 hours vernalization became fertile and 10% of plants which were not vernalized produced seed heads.

A field trial on the effects of fungicides on tall fescue seed yields, found that when

stem rust (*Puccina graminis*) invaded the seed crop before anthesis, propiconazole was effective in preventing a seed yield reduction of more than 1000 kg ha^{-1} compared to the yield from untreated plots. Green leaf area duration was increased and leaf senescence was reduced following propiconazole application. When stem rust was negligible in a second trial, neither propiconazole nor tebuconazole increased seed yields.

A study on the effects of frost on tall fescue showed that tall fescue seed heads are particularly sensitive to frost damage from ear emergence onwards. Two air frost levels (-2°C and -5°C) were applied to tall fescue reproductive tillers for six hours, (once only), at ear emergence, anthesis, or 4, 6 or 8 days after anthesis. A -5°C frost killed all seed heads. A -2°C frost at ear emergence and anthesis lowered seed yield per tiller, lowered seed weight and reduced germination compared to unfrosted plants. Plants frosted at -2°C after anthesis suffered no loss of germination or seed weight, but seed yield per tiller did decline. Two frost protectants, an ethylene oxide condensate (Teric) and cupric hydroxide (Kocide 101) failed to prevent frost damage but Kocide treated plants suffered a lesser seed yield reduction (39%) than untreated plants (53%) after a -2°C frost exposure.

Keywords: Tall fescue, *Festuca arundinacea*, burning, cover crops, establishment, frost, frost protectants, fungicides, grazing, post-harvest management, sowing rate, undersowing, vernalization.

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Michael Hare,
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Chapter 1

Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is a valuable grass of temperate grassland agriculture. In the US it occupies an estimated 12-14 million hectares in pure and mixed pasture swards and is considered there to be the predominant cool-season pasture grass species (Buckner, Powell and Frakes, 1979; Buckner, 1985). It has long been naturalised in Europe and Russia and has increased in importance in Canada, England, France, Chile, South Africa and Australia, particularly over the past twenty years with the release of improved cultivars (Asay, Frakes, and Buckner, 1979).

Tall fescue was introduced into New Zealand from Europe last century (Langer, 1977) and has become widespread along roadsides and in poorly drained waste areas. These naturalised plants are generally coarse and unpalatable to livestock and various forms of fescue poisoning (Bush, Boling and Yates 1979) can result after grazing, either due to the presence of endophyte (*Acremonium coenophialum*) or several alkaloids (Siegel, Latch and Johnson 1987). As a result, tall fescue has been regarded as a dangerous plant (Cunningham, 1948) to the point where early reports in New Zealand detailed eradication methods (Taylor, 1938; Saxby, 1949). Levy (1970) summarised tall fescue as being of some use on flooded or waterlogged soils, of little use on peat, useless on hill country, and a weed on moist fertile soils.

Overseas development of new cultivars which were endophyte free (Siegal *et al.*, 1987) and did not cause fescue poisoning, and the favourable evaluation of S170 tall fescue from the UK in New Zealand (Cullen, 1965; Allen and Cullen, 1975; Watkin, 1975; Sheath, Galletly and Greenwood, 1976), lead to increased local interest in tall fescue as a pasture plant. The release of Grasslands Roa in 1980 (Anderson, 1982) which was more productive and persistent in dry periods than ryegrass (Brock, 1982) and more tolerant to grass grub than ryegrass (East, Kain, and Douglas, 1980), strengthened demand for tall fescue as a drought-tolerant plant (Milne and Fraser, 1990).

Tall fescue grows best in warm temperate areas on fertile moist soils that are heavy to medium in texture and have considerable humus (Buckner, 1975). However, its massive root structure (5-7000 kg ha^{-1} of roots in the top 20 cm of soil) (Bums and Chamblee, 1979) contributes to its wide adaptation and growth on many different soil types. It can tolerate a wider pH range than ryegrass; thrives on thin droughty soils, but also forms dense sods and grows well on poorly drained soils (Buckner, 1985); and tolerates periodic flooding (Bums and Chamblee, 1979). The only soils where tall fescue has difficulty in surviving are coarse, deep, droughty sands and low fertility soils (Burns and Chamblee, 1979).

Recent droughts during the 1980s in New Zealand have further increased interest in tall fescue as a drought-tolerant plant. Seed production of Grasslands Roa in New Zealand in the 1980s often did not meet local demand and seed of American and UK cultivars has been imported or grown for seed here. There are now several overseas tall fescue pasture cultivars on the New Zealand market, eg Triumph, Cajun and S170.

The slow seedling establishment of Grasslands Roa tall fescue (Brock, 1973; Brock, Anderson and Lancashire, 1982) has been a major disadvantage in pasture establishment. AgResearch has therefore bred a new cultivar, G.48, which is reputed to have more vigorous seedling growth, greater tillering capacity and faster initial dry matter production than Grasslands Roa (S. Easton, pers. comm.). This cultivar has not yet been released.

The use of tall fescue as a frequently mown turfgrass is a recent development. Tall fescue's summer heat tolerance, its growth at low temperature, its good cover, and its persistence in spite of extreme neglect has made it a valuable turf grass in the US (Murray and Powell, 1979). Turf-type tall fescue cultivars have been selected for improved turf performance characteristics including narrower leaf width, greater leaf density, more prostrate growth habit, and a darker green colour than pasture types.

In New Zealand, AgResearch released 'Grasslands Garland' tall fescue in 1989 (Rumball, Claydon and Forde, 1991) as a turf cultivar suitable for use in areas of moderate wear and moderate-low maintenance such as race courses and parks. It stays green and attractive in extremes of temperature and soil moisture.

Grasslands Roa has been the predominant tall fescue cultivar produced for seed in New Zealand. Seed production has increased from 5 tonnes in 1982 to 141.5 tonnes in 1991. Seed yields have never been high on farms in New Zealand, national average seed yields for Roa tall fescue being 188, 232 and 343 kg ha^{-1} in 1988, 1989 and 1990 respectively (J McKenzie, pers. comm.). In contrast, AgResearch produced 1040, 1450 and 773 kg ha^{-1} of seed in the same years. This situation is similar in the US where the average seed yield is approximately 335 kg ha^{-1} when fields are used for pasture and seed, but close to 1000 kg ha^{-1} in Oregon under specialist seed production (no livestock) (Youngberg and Wheaton, 1979).

In 1988/89 five tall fescue cultivars were grown for seed in New Zealand on 409 hectares, of which 359 hectares were planted in Roa. The following year, 1989/90, 12 cultivars were planted on 1818 hectares of which Roa occupied only 447 hectares. In 1990/91, 17 tall fescue cultivars were grown on 3134 hectares, of which Roa, the only pasture cultivar, was grown on 510 hectares. This increase in cultivars was brought about by the contracting of New Zealand growers by US companies to grow turf tall fescue cultivars for seed multiplication and re-export to the US.

Since 1988, increasing amounts of pasture tall fescue seed have been imported into New Zealand which have competed directly with Roa. The major competitor, the US cultivar Triumph, is increasingly popular due to its superior establishment vigour and cheaper price than Roa. The Triumph seed sold in New Zealand is grown in Australia. Roa now shares only 50% of the New Zealand pasture tall fescue market. The high seed yields of Triumph (over 1000 kg ha^{-1}) enable growers to receive a lower price per kg, whereas generally low Roa seed yields in New Zealand have kept grower prices high. Unless seed yields increase, enabling a lower price structure, the Roa tall fescue market share, which has fallen from 80% to 50% in two years, could continue to decrease. Seed crop management must be improved in order to increase seed yields.

The main objectives of this study were to investigate areas of tall fescue seed crop management which have not been studied in New Zealand before, in order that seed crop management may be improved and national seed yields and seed quality increased. Currently, only four main areas of tall fescue seed crop management have been researched in New Zealand, ie. nitrogen (Hare and Rolston, 1990), closing date (Brown, Rolston, Hare and Archie, 1988), herbicides (Rolston and Archie, 1990) and row spacing and seeding rate (Hickey, 1990).

In an attempt to add to, and complement, research in those areas the present study was designed to concentrate on time of sowing, undersowing with a cereal, post-harvest and autumn/winter defoliation management, vernalization and juvenility, fungicides and frost.

1. Time of sowing

Tall fescue is slow to establish and is usually spring-sown with the first seed crop being harvested 15 months later. Autumn-sown tall fescue crops usually produce little seed in the first summer and it therefore takes two seasons before autumn-sown crops reach maximum seed yields. However, the warm, temperate, moist autumn and winter in the North Island of New Zealand may allow tall fescue to establish more quickly from autumn-sowing and produce a seed crop in the same year of establishment. The objective of this trial was to determine the effects of time of sowing on seed yield in the year of establishment. A further autumn-sown trial looked at comparative seed production of three tall fescue cultivars, Grasslands Roa, G48 and Grasslands Garland.

2. Undersowing with a cereal

When tall fescue is spring planted no seed income is generated until 15 months after sowing. Planting tall fescue with an annual cereal could enable farmers to obtain income in the establishment year. No studies in New Zealand have examined tall fescue undersowing with cereals. The main objective of this trial was to investigate the influence of barley crops at different row spacings and seeding rates on the growth, development and seed production of undersown tall fescue.

3. Post-harvest and autumn/winter management

In North America and Europe post-harvest management of grass seed crops such as burning or cutting either take place immediately or within one-two months after harvest. Dry, cool, late summer - autumn periods result in slow autumn growth and the cold winters allow little winter growth resulting in the need for no other further defoliation until seed harvest. The warmer, temperate autumn/winter of the North Island of New Zealand allows tall fescue to grow vigorously from harvest through the autumn and into the winter. Further defoliations may be needed to remove this excess vegetation. The objective of this trial was to look at immediate post-harvest grazing or burning and the effects of subsequent autumn/winter grazing or cutting management on tall fescue tiller development and subsequent seed yields.

4. Vernalization and juvenility in tall fescue

It has been reported that tall fescue plants must pass through a juvenile phase and reach a certain vegetative maturity before they can be vernalized (Bean, 1970). What is not known is the botanical growth stage and duration of the juvenile phase and the length of vernalization required for various growth stages in tall fescue. The objectives of this study were to clearly define whether a juvenile phase exists in Roa tall fescue in terms of easily measurable botanical growth stages and to study the extent of vernalization following low temperature exposure of plants at various growth stages.

5. Fungicides

Fungicides applied pre- or at anthesis have been shown to increase seed yields in many temperate grasses but to date have not increased seed yields in tall fescue evaluated overseas. The objective of this trial was to see if, in New Zealand, fungicides could be used to increase seed yields in the absence of disease and, if diseases, e.g, stem rust and other pathogens were present, whether fungicides were more effective in preventing loss of seed yield.

6. Frost

New Zealand farmers suggest that late-season frosts during ear emergence, anthesis or seed development of some perennial grasses cause low seed weight, and empty or shrivelled seed, leading to low seed yields. Despite the lack of frost research data on grass seed crops, some farmers are spraying their seed crops with chemical 'frost protectants'.

Very little study has been done on frost effects on grass seed yields and no studies have apparently been done on tall fescue, yet it is known in the US and the UK that late spring frosts can reduce seed yields in tall fescue (Youngberg and Wheaton, 1979). The objective of this study was to examine the effects of frost at various stages of reproductive growth in tall fescue and to determine whether chemical 'frost protectants' could prevent or minimise frost damage.

Chapter 2

Literature Review

2.1 INTRODUCTION

The literature on herbage seed production is extensive, covering many of the areas of research in this thesis. However, relatively little information is available on tall fescue seed production. Although this will be referred to in this review it has also been necessary to draw on research on other species where appropriate. In particular the review will consider juvenility and vernalization in tall fescue, crop establishment including the undersowing of tall fescue seed crops with other crops, fungicidal effects on tall fescue seed yields, the effect of frost on tall fescue seed production and the post-harvest autumn/winter management of tall fescue seed crops.

2.2 JUVENILITY, VERNALIZATION AND INITIATION IN TALL FESCUE

2.2.1 Juvenility

Before flowering can occur some perennial grasses must pass through an initial vegetative phase during which they are insensitive to environmental conditions which may later promote flowering. In this juvenile stage plants increase in size and weight but make no progress towards flowering because they are not yet induced or 'competent to flower' (Calder, 1963). The juvenile phase may last for a few weeks as in cocksfoot (Calder, 1963), phalaris (Ketellaper, 1960) and tall fescue (Bean, 1970); or for several months as in some bamboos (Langer, 1972). In other perennial grasses, such as perennial ryegrass, no juvenile phase exists and plants can be induced by cold or short-day treatments given to the germinating seed or young seedling (Cooper and Calder, 1964).

Little is known about juvenility in grasses or about the nature of those factors that control the length of this stage. Several possibilities have been suggested, including minimum leaf area, minimum leaf number, a certain number of mitotic cycles in the apical meristem, or the accumulation of carbohydrates within the plant (Calder, 1966; Bean, 1970). It is also not known whether juvenility is a property of each tiller or of the plant as a whole (Calder, 1966).

Calder (1966) stated that the concept of juvenility in herbaceous plants has been equated with minimum leaf number and the state of the 'ripeness to flower' condition. He stated that this presented difficulties because of the desire to relate physiological stages to morphologically recognisable stages. The morphological stages of juvenility are important to agronomists. By knowing what size, leaf and tiller number, or weight a plant or tiller should reach before it is capable of responding to inductive vemalizing conditions it may be possible to manipulate sowing dates and defoliation practices to allow tillers to complete their juvenile phase before the onset of winter vemalizing conditions. Work on tall fescue has still not clearly defined the juvenile phase in easily measurable morphological stages, although Bean (1970) has suggested that a juvenile phase does exist in tall fescue during which plants show a reduced response to inductive conditions.

2.2.2 Vernalization

Plants enter the inductive stage after the juvenile stage or, in its absence, immediately after germination. Many temperate grasses require low temperature induction, known as vemalization, before they can later respond to spring temperatures and photoperiods which stimulate inflorescence initiation (Cooper, 1960a; Evans, 1964).

The most effective vernalizing temperatures lie between 0 and 10°C (Evans, 1960; Calder, 1966; Langer, 1972), although the extent of response can vary with plant age, older plants requiring shorter duration of exposure (Evans, 1960; Bean, 1970). Each tiller must be vemalized independently, since there is no translocation of the vemalized state (Calder, 1966). Once the cold requirement has been satisfied the effects remain stable for a long time even if flower induction does not take place immediately (Langer, 1972). However, exposure to high temperatures may reverse the vernalized state if only partial vernalization has been achieved (Purvis and Gregory, 1952).

In some grasses, eg. cocksfoot (Calder, 1964), browntop (Cooper and Calder, 1964) and perennial ryegrass (Cooper and Calder, 1964), short days above 10°C can replace low-temperature vernalization as a requisite for subsequent flowering in long days (Cooper, 1960b).

The response of tall fescue to cold and short days can depend on place of origin (Bean, 1970). A tall fescue ecotype from Tunisia flowered after exposure to eight-hour photoperiods in which air temperatures were continuously above 8°C, but the S170 cultivar from England did not (Bean, 1970). When S170 was placed in short-day and low-temperature conditions it flowered profusely when put back into a heated glasshouse (Bean, 1970).

However, Bean (1970) also demonstrated there was a wide divergence in the induction requirements among genotypes in S170 which indicates the possibility of selecting for larger or smaller inductive requirements. It has also been observed that after a spring-sowing some panicle development and even seed formation occurs in the first summer (Templeton, Mott and Bula, 1961; Van Kearen and Canode, 1963). In New Zealand this can also be common in late-summer in spring-sown Roa tall fescue crops. This is probably due to the genotypic material used in the breeding of Roa which was based particularly on Mediterranean parent material (Anderson, 1982). Bean (1970) showed that ecotypes from Mediterranean environments produce a high percentage of inflorescences in late-summer after an early-spring sowing, but ecotypes from England and very cold regions do not flower.

In tall fescue, the larger the plants and tillers are before the onset of vernalization (Bean, 1970) and the longer their exposure to vernalization (Templeton *et al.*, 1961), the greater the number of large seed producing inflorescences.

2.2.3 Initiation

Once plants are fully induced they can initiate inflorescences when exposed to the appropriate photoperiod. Photoperiod is the main factor determining the timing of inflorescence initiation in vernalization requiring perennial species (Evans, 1964; Calder, 1966), long days being required for maximum flower initiation (Evans, 1964; Langer, 1972).

Ecotypes of different species may require a shorter exposure to long photoperiod before initiation depending on their place of origin. For example, cocksfoot ecotypes from the eastern Mediterranean initiate inflorescences and flower earlier than cocksfoot from England, in order to escape summer drought in their home environment (Calder, 1964; Calder, 1966). Conversely, Norwegian ecotypes require a long photoperiod for initiation in order that ear formation is not affected by late frosts (Calder, 1964; Calder, 1966). Similar photoperiod responses have been recorded in populations of phalaris (Cooper and McWilliam, 1966).

There is considerable evidence that the effect of day length can be modified by temperature (Cooper, 1952; Ryle and Langer, 1963). If the photoperiod is only marginally adequate then high night temperatures (above 18°C) can delay or inhibit flower initiation (Cooper, 1960a). The interaction between photoperiod and temperature on initiation in tall fescue has not been studied and more critical work is needed.

During inflorescence development in tall fescue it has been found that temperatures of 20-25°C compared with 15°C hasten the onset of anthesis, reduce the number of florets per spikelet, reduce the period of seed development and lower seed weight (Bean, 1971). These temperatures (20-25°C), while not high, still affected seed production of S170 tall fescue which originated in the cool-temperate United Kingdom. Similar results were found when temperature affected seed productivity of the British perennial ryegrass cultivar, S24 (Ryle, 1965). The effects of higher temperatures on cultivars of Mediterranean origin are not known, but it seems likely that their seed yield may not be reduced to the same extent as in cultivars of cool-temperate origin.

Other conditions may also influence the response to photoperiod. For example, low soil nitrogen levels have been found to delay flowering in cocksfoot (Calder and Cooper, 1961), while nitrogen applied at spikelet initiation increases the seed productivity of many temperate grasses (Hampton, 1987, 1988). Similarly, moisture stress at the time of initiation has been shown to markedly reduce spikelet numbers (Langer, 1972).

2.3 ESTABLISHMENT OF TALL FESCUE

2.3.1 Time of establishment

Tall fescue is slower establishing than ryegrass when grown from seed (Brock *et al.* 1982) and is usually spring-sown with the first seed crop being harvested 15 months later. Autumn-sown tall fescue crops produce less seed than spring/summer-sown crops in the first year of establishment (Van Keuren and Canode, 1963; Hare, Rolston, Archie and McKenzie, 1990), and it therefore takes two seasons before autumn-sown crops reach maximum seed yield. This is presumably because autumn-sown plants have not grown large enough or tillered adequately to be receptive to the autumn/early-winter vernalization required for maximum seed production (Templeton *et al.* 1963; Bean, 1970).

Differences between seed yields of spring- and autumn-sown crops are greatly influenced by environment. The moister autumn and warmer winter of the North Island compared with the cooler and drier South Island of New Zealand results in autumn-sown tall fescue in the North Island producing seed yields nearly equal to spring-sown crops in the South Island (Hare *et al.,* 1990). However, the difference in seed yields between spring- and autumn-sown tall fescue seed crops was nearly 700% in favour of spring sowing in Washington State, US (Van Keuren and Canode, 1963), where the autumn and winters are dry and cold. Wichman, Welty and Wiesner (1991) stated that to get good seed production of late-summer-sown tall fescue in the US, adequate autumn soil moisture was vital for successful germination and establishment. The introduction of new cultivars of tall fescue which may establish more quickly in the autumn than traditional tall fescue pasture cultivars may reduce this differential, particularly if they have been selected for improved seedling vigour and rapid early growth rate and tillering.

2.3.2 Method of sowing pure stands

Tall fescue grown for seed production can be established as a pure stand or under a cover crop. Cover crop establishment will be discussed in detail in section 2.4.

For tall fescue seed production in pure stands drilling is preferred to broadcasting because of the more uniform stand which results from placing the seed at a relatively constant depth (1-2 cm) and covering the seed by chain harrowing or rolling, aids germination and emergence (Youngberg and Wheaton, 1979). Moreover, the solid stands which result from broadcasting decline in seed productivity at a much faster rate as they age than drilled row stands (Spencer, 1950; Green and Evans, 1957; Bean, 1978).

Row spacings of between 30 and 60 cm are most commonly used with success on high fertility soils in moist regions (Bean, 1978; Youngberg and Wheaton, 1979; Hickey, 1990). Despite the fact that at the first harvest, 30 cm row-spaced crops may produce more seed than 60 cm row-spaced crops, there may then be no difference in seed yields between the two spacings at later harvests (Hickey, 1990). In dry regions and on less fertile soils, wider row spacings (70-100 cm) are recommended (Youngberg and Wheaton, 1979).

The use of wide rows (60 to 70 cm) has also been recommended to avoid the development of 'sod-bound' stands (Spencer, 1950; Youngberg and Wheaton, 1979). The term sod-bound is associated with the thickening of the stand as a result of the plants spreading vegetatively by tillers. Seed yields from older stands can decline due to this sod-bound condition because there is competition for space and few reproductive tillers are produced, despite excellent forage growth (Youngberg and Wheaton, 1979). Stands planted in wide rows and at low seeding rates do not become sod-bound provided correct post-harvest management is used to prevent (or delay) this condition (Section 2.7).

It is generally recognised that lower seeding rates can be used to establish seed production crops than to establish pastures. Hickey (1990) found that with tall fescue in

New Zealand in the establishment year, a 5.0 kg ha^{-1} sowing rate gave equal seed yields to a 10.0 kg ha^{-1} sowing rate and significantly more seed than a 2.5 kg ha^{-1} sowing rate. In the second and third year of this trial, however, the lowest rate (2.5 kg ha^{-1}) produced superior seed yields to the two higher rates (Hickey, 1990). A 'normal' pasture sowing rate of tall fescue in New Zealand could be 15-18 kg ha^{-1} in a pasture mixture (MacFarlane, 1990), and 25-30 kg ha^{-1} in a sward with clover (Hume and Fraser, 1985). By comparison, the recommended tall fescue seed crop sowing rates and row spacings in New Zealand are 3-5 kg ha^{-1} in 30 cm spaced rows (Hare, Rolston and Brown, 1986). In the US 9-11 kg ha^{-1} of seed are sown in 30 to 35 cm spaced rows and 3.4 to 5.6 kg ha^{-1} of seed when wider rows (76-107 cm) are used (Youngberg and Wheaton, 1979). In US pasture mixtures the rates are lower than those used in New Zealand, 15-20 kg ha^{-1} for pure swards, and between 2.2 and 17.7 kg ha^{-1} for mixed swards (Taylor, Wedin and Templeton, 1979). In the UK 5-7 kg ha^{-1} of seed sown in 60 cm rows gives the best establishment for tall fescue seed crops (Bean, 1978).

2.4 UNDERSOWING GRASS SEED CROPS WITH COVER CROPS

2.4.1 Purpose of undersowing

The establishment of grass seed crops under cereals or other crops has been in use in many countries for a long time. Its main purpose is to compensate for either low first-year seed yields from pure stands of autumn-sown crops or to provide a cash-crop income when spring-sown grasses do not produce any seed in the first summer (Bean, 1978). The crop sown with the grass seed is variously called a 'cover crop', 'nurse-crop' or 'companion crop' (Santhirasegaram and Black, 1965). The first two terms are used in the UK and the last term mainly in the US. In New Zealand the term cover crop is most commonly used and the grass is referred to as being 'undersown'. The undersown term is a little loose as the grass is usually sown on the same day but not at the same time as the cover crop and not after cover crop establishment. The cover crop is normally sown at 5-6 cm depth and the grass at 1-2 cm depth. The cover crop, especially if it is a cereal, emerges before the grass and then rapidly grows up and covers the emerging young grass.

2.4.2 Problems of undersowing grass seed crops

Undersowing can provide a number of problems for the undersown grass, particularly as a result of intense competition for nutrients, soil moisture and light. Cereals in particular, have larger seeds, higher growth rates, taller stems and bigger root systems than most grass species, and the undersown grass can suffer severe growth retardation and, in some cases, may even fail to establish (Santhirasegaram and Black, 1965; Bean, 1978).

Cover crops intercept light and shade the grass, thereby influencing the growth and development of the undersown species. Cereals (wheat, barley and oats), reduce the photosynthetic photon flux density (PPFD) incident on undersown red and tall fescue plants by as much as 90% at peak cereal leaf area (Chastain and Grabe, 1988a, 1989). Under these conditions, fescue seedling growth is seriously impaired, particularly in terms of tiller population and dry matter production. Tillers also become more elongated than tillers grown without cover cereals. Meijer (1987) found that meadow and red fescues stop tillering when a wheat cover crop intercepts more than about 85% of light. Similarly, growth rates of cocksfoot, perennial ryegrass and meadow fescue are also reduced when light is reduced by <80 to 100% of full sunlight (Blackman and Black, 1959). Ryle (1967) reported that shading inhibits tiller production and reduces the rate of leaf primordia formation on shoot apices of meadow fescue and perennial ryegrass. Shading also reduces plant weight, water soluble carbohydrates, and tiller numbers of cocksfoot (Auda, Blaser and Brown, 1966). Langer's (1972) work has also shown that, in perennial ryegrass, tiller numbers per plant decline continuously as natural light is reduced from 100 to 5%.

It is not only shading from cover crops that affects the undersown grass species.

Soil water content is reduced in spring cereal crops which, together with shade, reduce undersown tall fescue tiller populations and dry matter (Chastain and Grabe, 1989). Norris (1982) observed that tall fescue growth rate and tiller numbers are reduced when soil moisture deficits exceed 100mm, although in another trial, soil moisture content was not decreased by establishing a cover cereal crop with red fescue (Chastain and Grabe, 1988a).Soil temperatures can also be lower by up to 1.8^{0}C under cereal cover crops and unsown grass than under grass planted alone (Chastain and Grabe, 1989).

The management of undersown cover crops has tended to concentrate on reducing cover crop competition. This management includes consideration of sowing date, type of cover crop, seeding rates of cover crop and undersown grass, row spacing and row direction and cover crop harvest residue management.

2.4.3 Methods adopted to reduce competition

Sowing date. Nearly all successful sowings of undersown grasses and cover crops have been made when both have been planted separately but preferably on the same day. When grass seed crops have been spring-sown into a cover crop sown in the previous autumn, the competition has been so severe that the undersown grass in many cases has failed to establish (Meijer, 1987). No work has been published on autumn-sown grass seed crops overdrilled with a spring-sown cover crop.

Autumn/winter establishment of undersown grasses appears to be more successful than spring establishment. Seed yields of timothy and cocksfoot, for example, are not affected when grown under winter wheat, winter barley or spring oats, although smooth brome seed yields have been decreased under winter wheat in one trial, but not in other trials (Pardee and Lowe, 1963). Red fescue seed yields are also not affected by cover crops of winter wheat or winter barley (Chastain and Grabe, 1988b), despite impaired growth and tiller numbers at cereal harvest compared to red fescue sown alone (Chastain and Grabe, 1988a). However, in Kentucky bluegrass (*Poa pratensis*) seed yields in

Sweden and Denmark have been depressed when undersown along with winter wheat (Cedell, 1975; Nordestgaard, 1979).

Spring-sown cover crops of wheat, oats and barley have reduced first year seed yields of cocksfoot, timothy, meadow fescue and tall fescue but not bent grass (*Agrostis tenuis*) or perennial ryegrass (Roberts, 1964; Bean, 1978; Mikhailichenko and Svetlichnyi, 1987; Chastain and Grabe, 1989). However, in the latter species inconsistent results have been obtained in the UK, with seed yields being reduced by undersowing with spring barley in only one year out of three (Hebblethwaite and Peirson, 1983).

Type of cover crop. Crops with the least amount of leaf, small stature and stiff straw that do not lodge are most suitable for cover cropping since they cast the least amount of shade. Chastain and Grabe (1989) found that seed yields of tall fescue were depressed more under oats than wheat or barley in one trial, but the reverse was true in another trial. Nordestgaard (1984) found that undersown grasses produce better seed yields under early-maturing barley than under late-maturing barley. The early removal of barley means that grasses can recover and establish greater tiller populations before the autumn than grasses under late-maturing barley. Chastain and Grabe (1988b) found that red fescue planted with barley produced a greater first-year seed yield than when planted with wheat, because barley plants allowed more light transmission, used less soil water and matured earlier.

Seed rate of cover crop. Most recommendations on cover cropping for pasture establishment suggest sowing the cover crop at rates lower than normal (Santhirasegaram and Black, 1965). However, there are few reported seed production trials where a lower sowing rate has been used without altering row spacing. Nordestgaard (1984) found that grasses, such as cocksfoot, red fescue and meadow fescue, produced more seed in the first year when established under barley sown at 90 kg ha^{-1} than at 120 kg ha^{-1} of seed. The row spacing of the barley, 12 or 24 cm, was apparently unimportant.

Seed rate of undersown grasses. There have been no reported studies on increasing the seeding rate of undersown grasses under cover crops, whether they are established for pasture or as seed crops. This is surprising considering that one of the major drawbacks to undersowing is the risk of total establishment failure of undersown grass. Seed crops are usually sown at half the seeding rate used to establish pastures (Hickey, 1990). The effects of using a pasture sowing rate to establish the undersown seed crop in order to reduce the risk of establishment failure needs to be investigated. If the cover crop sowing rates are not lowered would cover crop grain yield be compromised in order to give better estabiishment to the undersown grasses? Undersown grass establishment at various seeding rates also needs to be studied.

Row spacing and direction. Wider row spacing of the cover crop has been used to lessen the competition between undersown grasses and cover crops. Nordestgaard (1984), for example, found that Kentucky bluegrass seed yield was increased if the cover crop row spacing was increased from 12 to 24 cm. Meijer (1987) also reported that red fescue and Kentucky bluegrass seed yields were greater when winter wheat crops were sown at a 37.5 or 50 cm row spacing rather than 12.5 or 25 cm. However, at wider spacings, Meijer (1987) believed the resultant low grain yield would be unacceptable to growers. Chastain and Grabe (1988a) found that increasing row spacings of wheat and barley from 15-30-45-60 cm apart improved red fescue establishment, although increased row spacing did not improve red fescue seed yields at the first harvest.

Competition can also be reduced if the grass and cover crop are sown at right angles to each other. In a review on pasture undersowing (Santhirasegaram and Black, 1965) it was concluded that pastures sown in the above manner established better as the spatial arrangement allows more light penetration and better utilisation of soil moisture and nutrients by the grass. In more recent trial work on undersowing grass seed crops Chastain and Grabe (1988a,b and 1989), and Nordestgaard (1984) also sowed the cover crop and grass at right angles to one another.

Another possibility is to sow the grass and the cover crop in alternate rows (Hare *et al.* 1990) or miss out some cereal rows to achieve partial cover. Certainly, cocksfoot seed yields were improved when a sparse oat cover crop was used rather than a full cover crop (Roberts, 1964). Whether the financial returns from such a system is 'acceptable' is debatable.

Sowing depth. Although no trial work has compared various depths of sowing with cover crop establishment, most small-seeded grasses establish better when seed is sown at a depth of 1.0-1.5 cm rather than depths of 2 cm or more (Cullen, 1966; White, 1977). Cereals, however, establish better when sown at a 5-6 cm depth. Thus, if the cover crop is sown first at the greater depth, the grass seed can then be shallow drilled over the top at right angles, provided this is done immediately.

Cover crop harvest residue management. If cover crop harvest residue remains on undersown grass too long after cereal harvest, grass recovery will be severely impaired. Meijer and Vreeke (1988a) found that seed yields of Kentucky bluegrass and red fescue were significantly improved if the wheat stubble was cut close to ground level (2-5 cm) rather than left as a high stubble. Close cutting of the stubble immediately after harvest rather than cutting 4-6 weeks later, also increased seed yields, particularly if the grass was sparse after harvest (Meijer and Vreeke, 1988a).

Grass recovery and regrowth is needed before the autumn in order for tillers to receive full winter vernalization (Robson, 1968). Chastain and Grabe (1989) concluded that nitrogen fertiliser and irrigation greatly facilitated regrowth of tall fescue after a cereal harvest and maximised autumn tiller numbers. Similarly, Meijer and Vreeke (1988a) found that nitrogen applied in early-autumn was beneficial for weak undersown grass, but where undersown grass was vigorous after the cereal harvest, then late-autumn nitrogen was more beneficial. Nordestgaard (1976) also found that late-autumn rather than early-autumn nitrogen gave better seed yields in undersown red fescue seed crops. However, these various nitrogen responses may have been a result of dry early-autumn weather rather than timing (Meijer and Vreeke, 1988a).

Growth of volunteer cereal plants from fallen seed must be controlled following the cereal harvest, otherwise further cereal/grass competition can occur in the autumn and winter. Annual grasses and broadleaf weeds must also be controlled. Most papers do not mention herbicide use. However, Hebblethwaite and Peirson (1983) successfully used ethofumesate and TCA to control *Poa annua, P trivialis* and volunteer barley in undersown perennial ryegrass. Broadleaf weeds were controlled with dicamba, MCPA and mecoprop. Similarly, in undersown red fescue, Chastain and Grabe (1988) used simazine to control annual grasses, sethoxydin for volunteer cereals and MCPA and dicamba for broadleaf weed control. In their subsequent tall fescue trials, Chastain and Grabe (1989) used the same herbicides except for sethoxydin, which was replaced by ethofumesate for volunteer cereal control.

After cover crop harvest it is essential the undersown grasses are given the maximum opportunity to recover. If soil moisture and nitrogen are not limiting and volunteer cover crop and weed competition are controlled, then once the shading effect is removed, the undersown grasses should resume tillering at the same rate as grasses that have not been shaded (Langer, 1972).

2.5 USE OF FUNGICIDES ON GRASS SEED CROPS

2.5.1 Causes of seed yield increases by fungicide

The use of fungicides, such as propiconazole, on grass seed crops has increased over the last ten years, as growers have become more aware of the seed yield losses that disease, such as stem rust (*Puccinia graminis*) can cause. Fungicide application has been found to increase seed yields in perennial ryegrass (Hampton and Hebblethwaite, 1984; Hampton, 1986; Horeman, 1989; Welty, 1989b, 1990), cocksfoot (Rolston, Hampton, Hare and Falloon, 1989; Welty, 1989a) and prairie grass (Rolston *et al.*, 1989) but not in tall fescue (Welty, 1989b).

Even when disease incidence has been extremely low or even absent, fungicide application has still been shown to increase seed yields in perennial ryegrass (Hampton and Hebblethwaite, 1984; 1985; Hampton, Clemence and McCloy, 1985), cocksfoot (Rolston *et al.*, 1989) and prairie grass (Rolston *et al.*, 1989).

Many heavy-yielding grass seed crops lodge soon after ear emergence or at or about anthesis. Lodging creates a microclimate which can promote fungal growth (Griffiths, 1969) and encourages stem and leaf diseases such as *Drechslera* sp., *Erysiphe graminis, Puccinia coronata and P. graminis.* If such pathogens are present, they may destroy fertile tillers, reduce photosynthetic capability, disrupt assimilate supply, cause complete leaf decay, destroy seed and seed heads, and lower seed weight.

It is perhaps surprising that where there has been little or no disease outbreak, fungicides have still increased seed yields. These yield responses have apparently been due to increased green leaf area duration during anthesis and seed development, brought about by fungicides delaying the senescence of photosynthetic tissue (Hampton and Hebblethwaite, 1984; Rolston *et al.*, 1989).

The period between anthesis and seed harvesting in grasses is particularly influenced by early application of fungicide as a direct response through increased numbers of seeds per spikelet and seed weight (Hampton and Hebblethwaite, 1984, 1985). Other seed yield components generally have not been affected, although most researchers have not reported the number of spikelets per tiller or seeds per spikelet after anthesis and at seed harvest. Hampton and Hebblethwaite (1984, 1985) and Hampton (1986) are the only reports in which seed component data just before or at harvest have been presented. Such data at harvest are of extreme importance since they enable clear explanation of the positive, promotive effects of fungicides in reducing the high levels of seed abortion of developing seeds which occurs in the absence of fungicide (Hampton and Hebblethwaite, 1984).

In perennial ryegrass, seed abortion can occur because of an assimilate shortage resulting from elongating stem competition (Clemence and Hebblethwaite, 1984), competition from vegetative tillers (Hampton and Hebblewaite, 1985), and loss of photosynthetic leaf tissue (Hampton and Hebblethwaite, 1984). If photosynthetic tissue is being lost during seed development and seed fill, insufficient assimilate is available to meet the nutritional demands of the developing seed heads. The role of fungicides in delaying leaf senescence is not clear, although Hampton and Hebblethwaite (1984) suggest that fungicides may also affect microflora which have an active role in senescence. Also, some fungicides, such as carbendazim, retard the breakdown of chlorophyll (Staskawicz, Kaw-Saichney, Slaybauch, Adams and Galston, 1978).

2.5.2 Timing of fungicide application

Hampton and Hebblethwaite (1984) applied fungicide (triadimefon plus carbendazim plus captafol) five to six times at monthly intervals from spring tillering until seed harvest, to a perennial ryegrass seed crop. They recorded a significant increase in seed yield. In further work, Hampton (1986) showed significant seed yield responses from the above fungicides applied either once (at ear emergence) or twice (at ear emergence and just before anthesis) in perennial ryegrass. Triadimefon alone, also significantly increased seed yields when applied at the same times to perennial ryegrass (Hampton, 1986).

Rolston *et al.* (1989) obtained significant seed yield increases in prairie grass with propiconazole applied once (after ear emergence), twice (after ear emergence and immediately after peak anthesis), but not when applied only once after anthesis. They also obtained increased seed yield in cocksfoot when propiconazole or mancozeb were applied once at early anthesis.

In cocksfoot, Welty (1989a) found that one or more applications of chlorothalonil at the 'boot' or heading stage (ear emergence) resulted in significantly higher seed yields compared with untreated plants. Welty (1990) also found significant increases in one cultivar of perennial ryegrass but not in another, when propiconazole was applied twice during ear emergence. Horeman (1989) found that applying fenpropimorp or propiconazole three times (early ear emergence, before and after anthesis) was more effective in increasing seed yields than fewer applications.

However, generally, fungicide applications at ear emergence, before the onset of disease, appear to be most effective in controlling disease and preventing seed yield losses. Fungicides applied after anthesis are generally least effective.

2.5.3 Types of fungicides and rates

The most widely used and effective fungicide in recent work has been propiconazole (Horeman, 1989; Rolston *et al.*, 1989; Welty, 1989a,b,c, 1990). This is the only fungicide registered for use in ryegrass seed crops in New Zealand, a rate of 125 g ai ha^{-1} being recommended to control stem and leaf rusts (O'Connor, 1989). In Oregon, however, propiconazole, chlorothalonil and triadimefon are all registered for use in controlling foliar diseases of grasses grown for seed (Welty, 1989b). The new triazoles (tebuconazole, cyproconazole and hexaconazole) have been reported to be more efficient than propiconazole, because of greater persistency (Clinkspoor, 1991).

Propiconazole at 125 g ai ha^{-1} and triadimefon at 125 g ai ha^{-1} have both increased seed yields in prairie grass by 250 kg ha^{-1} in New Zealand when they were applied twice (after ear emergence and immediately after peak anthesis) (Rolston *et al.*, 1989). Triadimefon applied at ear emergence at 125 g ai ha^{-1} has also increased seed yields in perennial ryegrass by 170 kg ha^{-1} compared with untreated plots (Hampton, 1986).

In tall fescue (Welty, 1989b) found that up to five applications of triadimefon at 700 g ai ha^{-1} did not significantly increase seed yields above the untreated controls, even when applications were begun at ear emergence.

2.6 FROST EFFECTS ON SEED PRODUCTION

2.6.1 Frost damage in grasses and cereals

One of the climatic factors that appears to limit seed production of tall fescue is late-spring frost at the time the inflorescence emerges from the tiller (Youngberg and Wheaton, 1979). Farmers in New Zealand are also suggesting that late-season frosts during ear emergence, anthesis or seed development can cause low seed yields in some ryegrass and tall fescue crops (A Lill, and D Ritchie, pers. comm.). These seed yield reductions have been associated with low seed weight, empty florets, shrivelled seed and reduced germination. There may be other seed yield components affected which farmers have not measured. The implication of frost damage has lead some farmers to spray grass seed crops with horticultural crop frost protectants, despite a lack of research data on frost effects on grass seed crops and whether these chemicals are effective.

Frost effects on seed production of grasses has never been studied in New Zealand and indeed very little work has been done elsewhere. Cocksfoot is a grass species known to be particularly susceptible to late-season frosts (Ede, 1968). Nikolaevskaya (1973) subjected flowering plants of cocksfoot to one frost at -3 or -6°C for 3.5 to 5 hours. The heavier frost destroyed pollen viability and stigmas and as a result no seed was formed. The lighter frost reduced pollen viability by 72%, delayed seed development and reduced seed germination by 30%. In subsequent work, Niemelainen (1989) treated cocksfoot plants during early reproductive tiller development to -3, -6 and -10°C for 17, 14 and 11 hours respectively. Panicle production at -10°C failed completely and at the other temperatures panicle numbers were reduced compared with no frost. Frost at ear emergence was more damaging than frost at early reproductive tiller development (Niemelainen, 1989).

Many detailed studies have been made on frost damage to cereals and ice formation in cereal plant tissue after frost. An excellent review on frost injury in wheat has been published by Single (1985). The cereal plant is particularly sensitive to frost from ear emergence to grain development (Suneson, 1941; Langer and Olugbemi, 1970; Single and Marcellos, 1974). Pollen grains are killed (Suneson, 1941), grain numbers per spikelet are reduced by floret sterility (Langer and Olugbemi, 1970; Single and Marcellos, 1974) and, in some cases, complete tiller death occurs (Banath and Single, 1976).

Single and Marcellos (1974) found that provided no crystallisation of water occurred in plant tissues, no injury was suffered in wheat as a result of quick supercooling or by so called 'temperature shock' through sudden chilling. However, once crystallisation occurred, freezing progressed from cell to cell via the protoplasts, and plant tissue death resulted.

Single (1985) stated that ice fronts do not spread universally across the surface of wheat ears nor do they enter the plant tissues with ease. Lindow (1983) maintained that plant surface-inhabiting bacteria, for example, *Pseudomonas syringae*, are capable of initiating freezing in water at between -1 and -2°C,temperatures which are quite 'light' in frost terms. Single (1985), however, believed that the role of these bacteria in affecting the extent of freezing in wheat, and whether they can be manipulated to advantage in wheat, is unclear.

Single (1985) also stated that wheat ears that survived a -4°C frost succumbed to a later frost of -3°C to -3.5°C. The second frost followed rain, confirming other observations that moisture plays a most important part in promoting injury.

During anthesis and early seed formation in wheat, most severe injury occurred from freezing between -2° and -2.5°C (Single, 1985). Later, towards seed maturity, a -3°C frost lowered seed weight but did not damage germination. The frost tolerance of wheat grains therefore increased as they developed from anthesis to seed maturity.

2.6.2 Overcoming frost damage

Ede (1968) recommends planting cocksfoot seed fields away from frost pockets. In wheat, frost resistant cultivars have been bred and planting strategies planned to enable wheat to avoid frost during its reproductive development. In horticulture, several methods have been used, all with the same goal of maintaining the temperature of a frost-sensitive plant part above the temperature at which ice can form. These include mixing the cold layer of air nearest the ground with warmer air above by stationary wind machines or helicopters, heating the air around the plants with heaters or frost pots; watering the soil with sprinklers or furrow irrigation. Water can also be applied to plant parts during freezing temperatures. Ice forms, but is limited to the exterior of the plant and the latent heat of fusion, released when it freezes to form ice, maintains the ice-water mixture on leaves at 0°C (Lindow, 1983b). Ice held at 0°C on the surface of the plant will not penetrate and damage the plant.

These methods of frost control create problems of application in grass seed crops. Firstly, frost can sometimes strike in so-called frost-free areas and so frost-free pockets are not always safe sites. Secondly, sprinkler irrigation is often not available and, if available, large volumes of water are needed to provide continuous wetting of the grass seed heads. Thirdly, wind machines and heating methods are expensive and are impractical in large broad-field activities.

Recently, bactericides and biodegradable detergents have been used to obtain frost protection (Lindow, 1983a,b; Wilson and Jones, 1983a,b). Significant frost control has been achieved with experimental applications of bactericides on several different crops, including maize, beans, potatoes, squash, tomatoes, pear, almond, citrus and avocado (Lindow, 1983b). These bactericides include copper-containing fungicides such as Kocide (cupric hydroxide) and such antibiotics as streptomycin and oxytetracycline. They significantly reduce the populations of epiphytic ice-nucleation active bacteria (*Pseudomonas syringae, Erwinia herbicola, P fluorescens),* which Lindow (1983a,b) has shown cause ice to form on and in plants. The bactericides are mainly effective in light frosts, -2° to -3°C, but have the practical disadvantage that, to be effective, they must be applied 2-5 days prior to anticipated frost conditions. They give protection from frost for 10 to 14 days.

Biodegradable detergents work differently. When sprayed on to plants they alter the physical properties of solutions during the freezing process (Wilson and Jones, 1983a).

These chemicals, when absorbed, increase cell solution osmotic concentration and therefore decrease intracellular osmotic potential. This lowers the plants' freezing point and Increases flower and fruit frost hardiness (Burke, Gusta, Quamme, Weiser and Li, 1976). By using Teric 12A 23B, a biodegradable detergent, on blackcurrant bushes at flowering, Wilson and Jones (1983b) doubled fruit set compared with unsprayed frosted controls. Teric provided protection by lowering the freezing point to near -6°C in these trials. Furthermore, one single spray of Teric applied at flower emergence provided protection for at least six weeks (Wilson and Jones, 1983a).

Some farmers in Canterbury are using Teric and Kocide on wheat, ryegrass and brassica seed crops (A Lill, pers. comm.) in an attempt to obtain frost protection. However, no research has been published to suggest Teric or bactericides in fact do provide protection of these seed crops from frost damage.

2.7 POST-HARVEST MANAGEMENT

2.7.1 Purpose of post-harvest management

In perennial grass seed crops, particularly those harvested for several successive years, field management after harvest is extremely important to ensure their continued seed productivity. In perennial grasses, particularly those that require vemalization, reproductive tillers for the next season's harvest are produced in the autumn and early winter, and accumulated straw, debris or stubble from the previous harvest can seriously impair new tiller development, thereby lowering seed yields (Youngberg and Wheaton, 1979).

Shading can also seriously reduce new tiller development. Ryle (1961) showed that if tillers of timothy were shaded to less than 50% full sunlight they either failed to initiate or their fertility was reduced by half. In further studies, Ryle (1966) also found that few cocksfoot tillers produced ears in less than 50% natural light, wnile shading has also been shown to reduce tiller production and tiller weight in other experiments on cocksfoot (Auda, Blaser and Brown, 1966). Rye (1967) similarly reported that shading inhibited tiller production in meadow fescue and perennial ryegrass. Langer (1972) showed that perennial ryegrass tiller numbers per plant decline continuously as natural light is reduced from 100 to 5%, but once shade is removed they resume tillering at the same rate as plants which have not been shaded. Also, if sunlight penetrates to the plant base after harvest more tillers emerge before the autumn (Ensign, Hickey and Bernardo, 1983).

Removal of harvest straw and stubble also helps to control diseases and insects which can seriously reduce seed yield in grasses such as ryegrass, Kentucky bluegrass and red fescue (Chilcote, Youngberg, Stanwood and Kim, 1980; Youngberg, 1980). Some methods of post-harvest management, such as burning, also control weeds and prevent thatch build-up (Chilcote *et al.,* 1980).

2.7.2 Post-harvest management practices

Burning: Burning of grass seed crop residue after harvest began in 1948 in the U.S. (Hardison, 1948) for control of the fungus *Gloeotinia temulenta* which causes blind seed disease in perennial ryegrass. Burning has become a common practice in many grass seed crops to dispose of residue, control diseases and weeds and to enhance seed yields (Youngberg, 1980). Burning also exposes a greater soil area for improved effectiveness of autumn applied herbicides (Youngberg, 1980).

A more open canopy after post-harvest burning allows more vigorous tillering in perennial grasses, better flower induction and higher panicle production in the spring (Chilcote *et al.,* 1980). In the US burning stubble and straw as soon as possible after harvest has increased tall fescue seed yields by more than 20% compared with only baling and removing the straw (Youngberg, 1980). In perennial ryegrass, continued post-harvest burning has also been found to be the only treatment capable of maintaining high seed yields in successive crops (Young, Youngberg and Chilcote, 1984a).

Autumn tillering in burned plots of red fescue began earlier and at a greater rate than tillering in unburned plots (Chilcote *et al.,* 1980). The tillers on burnt plots were exposed to a longer period of short-day/low-temperature induction resulting in more reproductive tillers forming in the spring than tillers on unburnt plots. Furthermore, tillers on burnt plots received more light during the winter because of reduced canopy cover and thus were more receptive to vernalization. Subsequently, they initiated spikelets and florets earlier which lead to a longer period of differentiation. This longer differentiation period generally results in a larger number of florets per spikelet, more spikelets per tiller and more seeds per tiller, although this response has not been consistent in all trials where burning has been conducted (Chilcote *et al.,* 1980; Young *et al.,*1984a).

Burning must be completed as soon as possible after harvest and before autumn regrowth commences. Late burning has resulted in seed yields being reduced by 11.7 to 34.9% compared with midsummer burning (Youngberg, 1980). Similarly, autumn burning of red fescue stands in New Zealand has been shown to lower seed yields by 14% in one cultivar and 66% in another (Hare and Archie, 1990).

Cutting: In the absence of burning, close cutting the crop stubble to approximately 250 mm can give seed yields nearly equal to those obtained following burning (Chilcote *et al.,* 1980; Young *et al.,* 1984a; Coats, Young and Gowe, 1990). However, cutting has resulted in increased weed seed content in grass seed crops compared with burning (Young *et al.,* 1984b).

Grazing: There has been very little work on the effectiveness of immediate post-harvest grazing compared with burning or cutting on tall fescue seed yields. Although, Hare and Archie (1990) found that immediate post-harvest grazing was just as effective as burning or cutting in red fescue seed crops, Coats *et al.,* (1990) found that ungrazed areas outyielded grazed areas when cut stubble of Kentucky bluegrass was grazed by sheep after seed harvest. The latter authors did not state length of grazing intensity or frequency of grazings. They did, however, comment that farmers usually found grazing to be better than not grazing.

Cultivation: Edes (1968) stated that after a tall fescue seed harvest, severe harrowing or gapping could effectively reduce the density of the stand. With age, seed crops can become overpopulated with tillers and an excessive tiller population can lead to a drop in seed yield as inter-tiller competition reduces seed yield per tiller. Bean (1978) also considered that tall fescue appears to benefit from gapping in second and subsequent harvest years.

Some perennial grass crops that have been drilled in rows less than 60 cm apart have benefited more from gapping than crops planted in wider rows. Cocksfoot seed yields, for example, have been increased by 33% when 30 cm of grass was removed every 30 cm of drill row in crops originally drilled in rows 30 or 60 cm apart (Lambert, 1963). However, when cocksfoot was grown in 91 cm rows, removing 30 cm of grass from the row reduced seed yield by 29% (Canode, 1972).

Gapping does not benefit all species. Large 'clump-like' grasses like tall fescue and cocksfoot appear to derive some benefit from it in their second and subsequent harvest years. Timothy and meadow fescue seed yields, however, have been reduced by gapping (Lambert, 1964). Kentucky bluegrass seed yields have been increased when stands were gapped at low nitrogen rates, but decreased when gapped at high nitrogen rates (Evans and Canode, 1971).

Gapping is usually done by rotary cultivators. However, herbicide spraying can also be used. Some tall fescue seed crops in New Zealand have been sown in 15 cm rows and once established, have been handsprayed with glyphosate at right angles (spray 10 cm, leave 15 cm) (Hare *et al.,* 1990), with no effect on seed yield.

2.7.3 Autumn-winter defoliation

In nearly all recent studies on post-harvest management there has been no subsequent defoliation following the burning or cutting after harvest. These studies have been mainly in Oregon where, because of the dry summer and then cold winter, there is very little growth from harvest until the next spring. Perennial grass plants enter a dormant period of 35-40 days after harvest as a result of the dry summer, before the onset of autumn tillering. However, once winter starts, growth of the grass almost stops (Youngberg, 1980). Therefore, any autumn-winter defoliation could remove the potentially productive seed producing autumn-formed tillers.

This situation is not the same in the warm temperate climate of New Zealand and to a lesser extent, parts of the UK, Australia and other States of the US, where tall fescue continues growth throughout the year. In New Zealand tall fescue has been shown to be capable of producing over 10,000 kg DM ha^{-1} in the first five months after harvest (Hare, unpub. data). This large bulk of vegetation must be removed to allow light into the plant base and so encourage tillering. This strongly suggests there must be a combination of post-harvest and autumn-winter management to ensure maximum seed production.

Brown, Rolston, Hare and Archie (1988) found that grazing tall fescue seed stands to a stubble height of 3-4 cm until August did not decrease seed yields compared with earlier final grazing dates. Later grazings, however, decreased seed yields by lowering numbers of reproductive head numbers. However, the earlier grazing heights used in this study may have been too low since the highest seed yields obtained were never over 1,000 kg ha^{-1} (hand-harvested), whereas in more recent crops in the same locality, hand harvested yields have often reached over 2,000 kg ha^{-1} under much more lenient post-harvest grazing or cutting management (Hare *et al.,* 1990).

Careful and controlled management of grazing is necessary. Marked reductions in seed yield of tall fescue has been reported in the UK, Australia and the US following late-closing of crops (Green and Evans, 1957; Roberts, 1961; Williams and Boyce, 1978; Watson and Watson, 1982). In Missouri cattle grazing and seed production co-exist but seed yields are almost one-third lower than yields in Oregon where most seed production occurs in the absence of livestock (Youngberg, 1980). Repeated autumn-winter grazings of tall fescue at monthly intervals has been shown to lower seed yields, but one autumn grazing or one autumn plus one mid-winter grazing do not decrease seed yields in the U.K. (Green and Evans, 1957). In these studies autumn-grazed tall fescue seed crops outyielded seed crops which were ungrazed from seed harvest to seed harvest by 270 kg ha^{-1}.

Chapter 3

Time of establishment of tall fescue

3.1. INTRODUCTION

Tall fescue is usually spring-sown, with the first seed crop being harvested 15 months later. In the US autumn-sown tall fescue crops usually produce little seed in the first summer (Youngberg and Wheaton, 1979) and take two seasons before reaching maximum seed yields. This is because a combination of slow establishment (Brock *et al.*, 1982) and cold autumn and winter climate limits tall fescue tiller production resulting in low reproductive tiller numbers in the first summer (Wichman, Welty and Wiesner, 1991).

However, the warm, moist, temperate autumn and winter (Appendix 1.1) in the North Island of New Zealand may allow tall fescue to establish more quickly from autumn sowings and subsequently produce a seed crop in the year of establishment. If this was possible, growers could harvest a summer cereal or legume crop (eg. peas) and sow tall fescue immediately afterwards, without suffering the loss of income in the first summer which occurs with a spring sowing. Also, if autumn-sown crops established and developed well they may produce similar seed yields to spring-sown crops.

A time of sowing field trial was therefore established with the main objective to determine whether autumn-sown tall fescue cv. Grasslands Roa could produce a seed crop in the year of establishment, and if so, whether seed yields were comparable to those obtained from spring-sown crops.

Two new tall fescue cultivars have been bred by AgResearch, i.e. G48, a pasture cultivar, selected for more vigour and quicker establishment and bred to replace Grasslands Roa (S. Easton, pers. comm.), and Grasslands Garland a turf cultivar, which tillers profusely (Rumball *et al.*, 1991) and also appears to establish quicker than Roa. Both of these new cultivars may be better suited to rapid autumn establishment than Roa.

To investigate this situation, a second autumn establishment field trial was conducted to compare the seed production performance of these three cultivars.

3.2. MATERIALS AND METHODS

3.2.1 Time of sowing field trial

This trial was conducted at the AgResearch Grasslands farm 'Aorangi', Manawatu, North Island (latitude 40° 23' south), on a weakly leached, slowly accumulating, poorly drained, recent gley soil, from quartzo-feldspathic silty alluvium (Kairanga silt loam). Rainfall and soil temperatures (10 cm depth) were recorded at a meteorological station (New Zealand Meteorological Service, Kairanga) approximately 1000 metres from the trial site. The site was ploughed, rotary hoed and rolled prior to the first sowing. Thereafter prior to each sowing the plots to be sown were rotary hoed and rolled. There were seven monthly sowing dates from October to April, replicated four times in a randomised block design. Complete experimental details are given in Table 3.1.

Plant numbers were counted seven weeks after sowing and the number of tillers counted 16 weeks after sowing from six one-metre lengths of row from each plot. Spring tiller numbers, tiller weight and dry matter m^{-2} were determined on 12 September 1990. Three one-metre row samples were cut to ground level from each plot. The total bulked sample was weighed fresh and a 100 g sub-sample taken for dry weight; tillers were counted in another 100 g subsample; 100 dried tillers were weighed to determine tiller dry weight; ten tillers were measured for tiller length (from bottom of cut tiller to tip of longest extended leaf).

During anthesis a growth analysis was made in late-November (Table 3.1) when three one-metre row lengths were cut from each plot and reproductive tillers counted from each sample. Their dry weight was determined from 100 randomly selected tillers from the bulked samples. Spikelets and florets were counted on 20 seed heads selected randomly from each bulked sample. Florets were counted from a spikelet taken from the base, middle and top of each seed head.

Table 3.1. Experimental field data

	Trial 1 (1989/90) Time of sowing	Trial 2 (1991) Autumn trial
Sowing	11 October, 1989 6 November, 1989 8 December, 1989 9 January, 1990 9 February, 1990 9 March, 1990 4 April, 1990	4 March, 1991 25 March, 1991 15 April, 1991
Seeding rate and row width	7 kg ha^{-1}, 30 cm rows	7 kg ha^{-1}, 30 cm rows
Sowing method	Drilled using an Aitchison Seedmatic drill and chain-harrowed to cover the seed	Hand-sown into furrows and soil raked over the top of the seed
Plot size	2.5 m x 14 m	6 m x 3 m
Replications	4	3
Design	Randomised block	Randomised block
Defoliation	1990. Cut with a rotary mower 5 cm above ground level, 30 April only 1991. Topped monthly from April until July	nil defoliation
Post-harvest Management	January 1991 stubble burnt and left to regrow until April topping	
Herbicides and fungicides (all applied by a small gas-sprayer in 160 litres water ha^{-1} at 300 kPA)	2,4-D (2.14 kg ai ha^{-1}) + dicamba (200 g ai ha^{-1}) applied on 15 November 1989. 2,4-D (2.14 kg ai ha^{-1}) + bromoxynil (200 g ai ha^{-1}) + ioxynil (200 g ai ha^{-1}) on 25 January 1990. Ethofumesate (3 kg ai ha^{-1}) + 2,4-D (2.14 g ai ha^{-1}) on 26 June 1990. Propiconazole (250 g ai ha^{-1}) on 16 November 1990, 5 December 1990 and 1 November 1991. Atrazine (1.5 kg ai ha^{-1}) on 26 April 1991.	2,4-D (1.8 kg ai ha^{-1}) + dicamba (900 g ai ha^{-1}) + ethofumesate (1 kg ai ha^{-1}) 7 weeks after sowing. Dicamba (750 g ai ha^{-1}) + 2,4-D (750 g ai ha^{-1}) +bromoxynil (200 g ai ha^{-1}) + ioxynil (200 g ai ha^{-1}) + ethofumesate (1 kg ai ha^{-1}) to 1st and 2nd sowings only on 24 May 1991 Propiconazole (250 g ai ha^{-1}) on 11 October and 15 November 1991.
Nitrogen (applied by hand)	120 kg N ha^{-1} 6 September 1990 40 kg N ha^{-1} 19 April 1991 100 kg N ha^{-1} 5 September 1991	40 kg N ha^{-1} 3 weeks after sowing 100 kg N ha^{-1} 5 September 1991.
Growth analysis	28 November 1990	2 December 1991
Seed Harvest	1st Harvest 19 December 1990 2nd Harvest 23 December 1991	1st Harvest 27 December 1991

At seed harvest, three one-metre row lengths of seed heads were hand-cut from each plot, bulked, air dried, threshed and cleaned, and seed yields and thousand-seed weights (T.S.W.) (adjusted to 14% moisture) were determined.

The time to harvest was determined when samples of seed bulked from all plots were between 46 and 50% seed moisture content. Seed moisture content was determined when duplicate 10 gram samples were weighed, dried under an infra-red lamp for 20 minutes and reweighed. The seed heads were dried by placing them in hessian bags, hanging them for approximately two weeks on a fence next to the field trial and then transferring the bags to hang on wires inside a large shed for one month. The dried seed was separated from the seed heads by putting the seed heads through a locally made stationary belt thresher. The threshed seed was cleaned by passing twice over an air-screen separator (screen sizes were, top screen 1.6 mm wide x 12 mm long slots, bottom screens 1.6 mm round holes), and then once through a small locally made air-blast cylinder. T.S.W. was determined by weighing 4 x 50 seeds from each seed yield sample. Seed moisture content of cleaned seed was determined by drying duplicate samples of 10 grams fresh weight at 130°C for one hour (high constant temperature oven method, International Seed Testing Association, 1985).

Seed was also harvested in the second summer (23 December 1991) when three one-metre row lengths were hand cut from each plot and processed as for the first summer harvest.

The results were analysed as a randomised block design using the SAS statistical programme.

3.2.2 Autumn establishment field trial

An autumn sowing field trial was established at the AgResearch Grasslands plant breeding farm, Manawatu (40° 23' south) on a weakly leached, non-accumulating, well drained recent soil from quartzo feldspathic silty alluvium (Karapoti silt loam). Three tall fescue cultivars (Grasslands Roa, Grasslands Garland and G48) and three sowing dates (4 March, 25 March and 15 April 1991), replicated three times in a randomised block design made up the trial. The sowing rate of 7 kg ha^{-1} was adjusted to 100% viability following a tetrazolium test which gave 85% viability for G48 (8.24 kg ha^{-1}) and 98% viability for Roa and Garland (7.14 kg ha^{-1}). Seed used was harvested in late-December 1990.

Experimental details are given in Table 3.1. Rainfall and soil temperatures (10 cm depth) were recorded at a meteorological station (New Zealand Meteorological Service, Palmerston North), approximately 50 metres from the trial site.

Plant numbers were counted six weeks after sowing, (6 x 1 m rows per plot). Twelve weeks after sowing tiller numbers were counted (6 x 1 m rows per plot) and one one-metre row per plot was cut at this time to ground level to determine tiller dry weight (100 tillers weighed) and tiller length (20 tillers) (see 3.2.1). On 4 June, 5 August and 1 October, two one-metre rows per plot were cut and bulked for dry weight, tiller number (100 g subsample), tiller dry weight (100 tillers) and tiller length measurements (20 tillers) - although tiller lengths were not measured on 1 October.

Growth analysis measurements and seed yields were taken as in the previous trial (see 3.2.1). At harvest the number of cleaned seeds per spikelet were calculated by dividing T.S.W. by 1000 to get the weight of one seed and dividing the seed weight into seed yield per m^2 to get cleaned seed number per m^2. Cleaned seed number per m^2 were then divided by spikelet number per m^2 (spikelets per tiller at anthesis multiplied by reproductive tiller number at anthesis) to get seed number per spikelet.

The results were analysed as a randomised block design using the SAS statistical programme.

3.3. RESULTS

3.3.1 Time of sowing trial

Meteorological data (Appendix 1.1) Sowings from October 1989 to February 1990, (with the exception of December 1989) experienced 1 to 2°C warmer temperatures than normal, while in November, December and February rainfall was lower. October 1989 received twice the normal rainfall and February 1990 only received 20% of the normal rainfall. March and April 1990 were almost 2°C warmer than normal and March received double the normal rainfall. Overall, seed was established in soil with temperatures some 1-2°C warmer than normal, and which were drier than normal, except for October 1989 and March 1990 which received twice the normal rainfall.

Plant establishment By seven weeks after sowing, three to four times more plants had established in the summer- (Dec-Feb) and autumn-sown (Mar-Apr) plots than in the spring-sown plots (Oct/Nov) (Table 3.2). An exception was the January sowing which had lower plant numbers than other summer/autumn sowings. By sixteen weeks after sowing there were no significant differences in tiller numbers among the November- to April-sown plots (Table 3.2). The October-sown plots had significantly ($P<0.05$) more tillers at sixteen weeks after sowing than the November-, February-, March- and April-sown plots.

By the beginning of September, October- and November-sown plots had produced significantly more herbage dry matter than December- and January-sown plots (360 kg ha^{-1} more dry matter) and February-, March- and April-sown plots (730, 790 and 960 kg ha^{-1} more dry matter respectively) (Table 3.2). October- and November-sown plots also produced 960 more tillers m^{-2}, 0.32 g heavier tillers and 43 cm longer tillers than March- and April-sown plots by September 1990 (Table 3.2). December- to January-sown plots mostly produced significantly more dry matter and tillers than March- or April-sown plots (Plate 3.1).

Seed Production Lodging was observed in October- to February-sown plants in early-December, during anthesis. Stem rust (*Puccinia graminis* Persoon.) was also present on stems and leaves in these plots before propiconazole was applied on 16 November 1990. Reproductive tillers at anthesis were greater from the earlier sowings, with October- and November-sown plots producing between five and seven times more tillers than March- and April-sown plots (Table 3.3). Time of sowing had no effect on spikelets per tiller but florets per spikelet were significantly ($P<0.05$) lower at earlier sowing dates (Table 3.3) in that floret numbers increased at all spikelet positions as sowing was delayed. This meant that autumn-sown plots produced on average nearly one more floret per spikelet than earlier-sown plots. More florets were produced by the middle and top spikelets than by the basal spikelets. At first seed harvest (December 1990), the October- to January-sown plots produced between 700 and 800 kg ha^{-1} more seed than the April-sown plots (Table 3.3). Seed yields of February-sown plots did not differ from October-sown plots but March- and April-sown seed yields were significantly lower than October-sown seed yields. Time of sowing did not affect T.S.W..

At harvest in the second year (December 1991) there were no significant differences among treatments, which averaged 850 kg seed ha^{-1}, a seed weight of 2.14 g and 540 reproductive tillers m^{-2} (Appendix 1.2).

Relationships between vegetative tiller weights, first season seed yields and first season seed yield components at anthesis. Linear correlation coefficients were calculated to determine if DW (dry weight) of vegetative tillers as measured in September were related to first season seed yield components and hence seed yield (Table 3.4). Highly significant ($P<0.001$) positive coefficients were obtained for DW of vegetative tillers in September with seed yield and reproductive tiller numbers. Reproductive tiller numbers were also highly significantly ($P<0.001$) correlated to seed yield. Florets per spikelet were negatively correlated with both vegetative tiller numbers in September and seed yield in December. It was therefore the number of reproductive tillers at anthesis, not spikelet or floret numbers, that had the most influence in determining seed yield in this time of sowing trial; the higher the reproductive tiller numbers the higher the seed yield, and the higher the number of florets per spikelet the lower the seed yield (Table 3.3).

3.3.2. Autumn sowing trial

Meteorological data (Appendix 1.1). March 1991 received 70% less rain than normal while April received 170% more rain than normal. Autumn soil temperatures did not differ markedly from normal soil temperatures and so the seed was planted into average temperature soil for the area, but the soil was very dry in March and then very wet in late-April.

Plant establishment. Plant numbers for Roa and Garland six weeks after sowing were significantly greater from the second and third sowings than the first sowing (Table 3.5). However, G48 produced significantly more tillers at the second sowing compared to the first sowing but there were no differences between the G48 tiller numbers from the first and third sowing and the second and third sowing. There was no difference in plant numbers among cultivars from the first sowing. G48 established better than Roa at the second sowing, but not at the third sowing, at which Garland produced significantly more plants than G48.

By twelve weeks after sowing, Roa and Garland tiller numbers, dry weight and tiller length were generally greater from the first and second sowing compared to the third sowing (Table 3.5), except for Garland tiller dry weights which did not significantly differ between the second and third sowings. G48, however, produced significantly more tillers from the second sowing compared to the third sowing, and produced heavier and longer tillers from the first two sowings compared to the third sowing. Garland produced significantly more tillers from the first sowing compared to Roa and G48, but Garland tillers were shorter and lighter than the other two cultivars from all three sowings. There were no differences in tiller production between G48 and Roa by twelve weeks after sowing, except for the second sowing where G48 had more tillers than Roa. G48 was therefore showing no overall significant establishment advantage over Roa at twelve weeks after sowing.

Winter and spring production. By 5 August, more dry matter had been produced from March- than April-sown plots (on average, earlier-sown plots produced more dry matter than later-sown plots), but there were no differences among cultivars in dry matter production (Table 3.6). By 1 October, all March sowing date plots had similar dry matter production except for G48 where there was more dry matter in plots from the first than the second sowing. The 15 April-sown plots had significantly less dry matter than the two earlier sowings (Table 3.6), except for Roa which only produced significant differences between the first and third sowings.

Table 3.2. Effect of time of sowing on establishment.

Time of sowing	Plant number m^{-2} 7 weeks after sowing	Tiller number m^{-2} 16 weeks after sowing	Spring production (September 12)			
			Herbage dry weight (g m^{-2})	Tiller number m^{-2}	Tiller weight (g/tiller)	Tiller length (cm)
October	37	585	1030	1636	0.56	68
November	18	408	1067	1607	0.47	65
December	96	518	720	1415	0.42	51
January	57	438	655	1271	0.47	48
February	86	352	321	920	0.29	37
March	99	414	256	876	0.22	26
April	109	374	85	439	0.17	21
LSD ($P<0.05$)	17.2	167	202	369	0.12	15.9

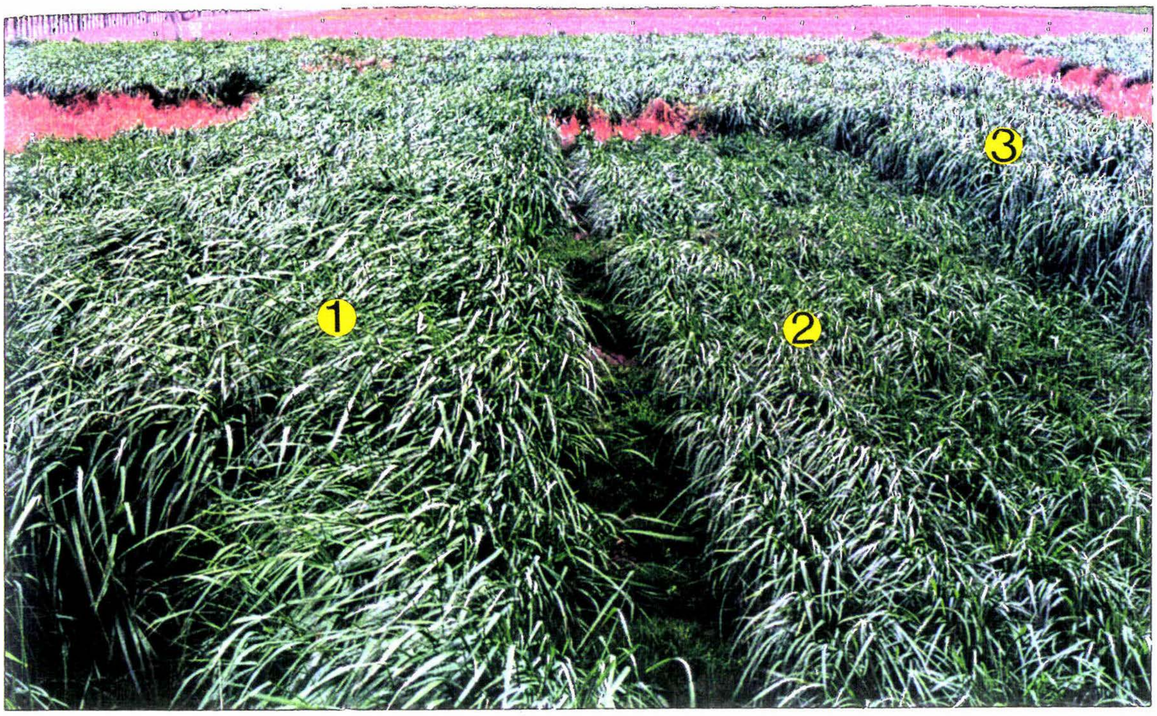

Plate 3.1 Growth of plots in September 1990.

1. Plots were sown in October 1989
2. Plots were sown in April 1990
3. Plots were sown in November 1989

Plate 3.2 Stages of growth of autumn-sown cultivars on 4 June 1991.

1.	G48 sown 4 March	2.	Garland sown 4 March
3.	G48 sown 15 April	4.	Garland sown 15 April
5.	G48 sown 25 March	6.	Roa sown 25 March

Table 3.3 Effect of time of sowing on seed production.

Time of sowing	Anthesis						Seed harvest	
	Reproductive tillers m^{-2}	Spikelets per tiller	Florets per spikelet				Seed yield (kg ha^{-1})	T.S.W. (g)
			* B	* M	* T	* Av.		
October	631	92.0	5.0	6.4	6.3	5.9	1223	2.73
November	695	95.7	5.4	6.5	6.3	6.1	1036	2.76
December	476	94.7	4.9	6.9	6.6	6.1	1096	2.81
January	327	83.0	5.6	7.2	7.1	6.6	1068	2.66
February	203	85.4	6.0	6.8	6.8	6.5	993	2.84
March	136	84.0	6.3	7.2	7.0	6.9	813	2.74
April	83	86.0	6.6	7.5	7.2	7.1	370	2.73
LSD ($P<0.05$)	101	n.s.	0.74	0.75	0.83	0.65	320	n.s.

* B = Base of tiller
* M = Middle of tiller
* T = Top of tiller
* Av. = Average per spikelet.

Table 3.4. Coefficients of linear correlation (r) (I) for dry weight per vegetative tiller in September and (II) seed yield harvested in December with seed yield components at peak anthesis.

	Dry weight (g) vegetative tillers in September		Seed yield ($kg\ ha^{-1}$) in December	
Component				
Seed yield ($kg\ ha^{-1}$)	0.61	***	-	
No. reproductive tillers m^{-2}	0.79	***	0.65	***
No. spikelets / tiller	0.37	*	0.19	n.s.
No. florets / spikelet	- 0.55	**	- 0.63	***

Table 3.5. Effect of time of autumn sowing on plant numbers and tiller production of three tall fescue cultivars six and twelve weeks after sowing respectively.

Sowing date	G48	Roa	Garland	LSD (P<0.05)
		Plant number m^{-2} (6 weeks after sowing)		
4 March	106	98	117	n.s.
25 March	165	141	152	15.5
15 April	123	146	160	28.0
LSD (P<0.05)	41	35	34	
		Tiller number m^{-2} (12 weeks after sowing)		
4 March	433	410	567	97
25 March	579	512	593	33
15 April	350	285	324	n.s.
LSD (P<0.05)	166	101	91	
		DW (g) per tiller (12 weeks after sowing)		
4 March	0.043	0.039	0.027	0.007
25 March	0.043	0.036	0.025	0.006
15 April	0.026	0.020	0.016	0.008
LSD (P<0.05)	0.013	0.007	0.010	
		Tiller length (cm) (12 weeks after sowing)		
4 March	16.5	15.3	11.6	3.9
25 March	13.8	12.8	9.8	1.8
15 April	9.5	8.5	6.5	1.7
LSD (P<0.05)	1.6	1.5	2.6	

All interactions n.s.

Table 3.6. Effect of time of autumn sowing on winter and spring dry matter production (g m^{-2}) in three tall fescue cultivars.

	Dry matter (g m^{-2})			
Time of sowing	G48	Roa	Garland	LSD (P<0.05)
		5 August		
4 March	217	156	196	n.s.
25 March	135	117	89	n.s.
15 April	25	17	20	n.s.
LSD (P<0.05)	38	56	71	
		1 October		
4 March	781	654	565	n.s.
25 March	646	555	501	n.s.
15 April	323	295	176	114
LSD (P<0.05)	125	331	122	

All interactions n.s.

All cultivars at this time (1 October) had similar dry matter production except for Garland at the third sowing which had produced less dry matter than Roa and G48. It was therefore time of sowing, not cultivar, which had the most influence on dry matter production in August and in October. A three week delay in sowing between 25 March and 15 April significantly reduced dry matter production by late-winter and by mid-spring (Table 3.6).

Garland produced significantly more tillers per m^2 from each sowing than Roa or G48 by 1 October (Table 3.7). Earlier (4 June and 5 August), Garland had more tillers than Roa and G48 from the 4 March sowing date, but not from the 15 April sowing date. There were

Table 3.7. Effect of time of autumn sowing on winter and spring tiller numbers in three tall fescue cultivars.

	Tiller no m^{-2}			
Time of sowing	G48	Roa	Garland	LSD (P<0.05)
			4 June	
4 March	433	410	567	97
25 March	444	368	493	49
15 April	167	158	214	n.s.
LSD (P<0.05)	62	49	102	
			5 August	
4 March	2425	1903	3732	1703
25 March	1840	2240	2345	n.s.
15 April	700	598	669	n.s.
LSD (P<0.05)	431	1086	1605	
			1 October	
4 March	2825	2444	5390	2323
25 March	2263	2232	4120	1028
15 April	1824	2305	3370	917
LSD (P<0.05)	n.s.	n.s.	1712	

Interactions n.s. for 4 June and 1 October
Interaction (P<0.05) Time of sowing x cultivar on 5 August

no differences in tiller numbers between Roa and G48 by 5 August and 1 October further showing that G48 had no establishment advantage over Roa.

On 5 August, all cultivars had significantly fewer tillers from the last sowing date compared with earlier sowing dates. There was a significant interaction (P<0.05) between time of sowing and cultivar tiller numbers on 5 August, due to Garland producing more tillers than Roa and G48 when sown early (4 March) but not when sown later (Table 3.7). Delaying sowing by three weeks in the autumn, 25 March to 15 April, reduced tiller numbers in all cultivars by 4 June and 5 August, but by 1 October spring tillering had eliminated any tiller differences between plots sown on 25 March and 15 April.

Table 3.8. Effect of time of autumn sowing on winter and spring tiller dry weights in three tall fescue cultivars.

	Tiller dry weight (g)			
Time of sowing	G48	Roa	Garland	LSD (P<0.05)
		4 June		
4 March	0.043	0.039	0.027	n.s.
25 March	0.029	0.029	0.019	0.065
15 April	0.014	0.011	0.010	0.003
LSD (P<0.05)	0.015	0.012	0.004	
		5 August		
4 March	0.075	0.066	0.038	0.028
25 March	0.062	0.043	0.026	0.014
15 April	0.026	0.020	0.017	0.005
LSD (P<0.05)	0.023	0.009	0.006	
		1 October		
4 March	0.285	0.247	0.104	n.s.
25 March	0.292	0.241	0.112	0.109
15 April	0.177	0.124	0.049	0.062
LSD (P<0.05)	n.s.	0.109	0.026	

Interactions n.s. for 4 June and 1 October
Interaction (P<0.03) Time of sowing x cultivar on 5 August

March-sown plots had produced heavier tillers than April-sown plots by 4 June and 5 August (Table 3.8). By 1 October, however, much of this advantage had disappeared, there being no differences in tiller weight between the March-sown plots, but April-sown plots still had lighter tillers than March-sown plots, except in G48. At nearly all times Garland had lighter tillers than G48. In June and October there were no differences in tiller weight between Roa and G48 at all sowing dates. However, in August, G48 had significantly heavier tillers than Roa in the plots sown on 25 March and 15 April. On 5 August there was a significant interaction (P<0.03) between time of sowing and cultivar.

Tiller length decreased as sowing was delayed (Plate 3.2) (Table 3.9). Garland tillers were generally significantly shorter than Roa and G48 which did not differ (with the exception of the April sowing at 4 June where G48 had longer tillers than Roa). Garland was therefore behaving as a turf cultivar with fine, short and numerous tillers while Roa and G48 were behaving as pasture cultivars and producing heavier and longer tillers than Garland.

Table 3.9. Effect of time of autumn sowing on winter and spring tiller lengths in three tall fescue cultivars.

	Tiller length (cm)			
Time of sowing	G48	Roa	Garland	LSD (P<0.05)
		4 June		
4 March	16.5	15.3	11.6	3.88
25 March	14.2	12.1	9.5	2.86
15 April	9.3	8.0	7.0	0.95
LSD (P<0.05)	4.11	2.23	1.73	
		5 August		
4 March	20.4	19.7	13.1	n.s.
25 March	18.5	14.4	10.9	4.32
15 April	11.0	9.4	7.7	2.2
LSD (P<0.05)	3.96	4.18	2.79	

All interactions n.s.

Seed production. At anthesis, the early-March-sown plants had produced significantly more reproductive tillers than the April-sown plants, but there was no significant difference in spikelet and floret production between the early- March- and April-sown plants (Table 3.10). Reproductive tillers from the 25 March-sown plants did not differ from the first and last sowings. However, Roa plants sown on 25 March did produce significantly more florets per spikelet than plants sown either earlier or later.

Garland produced more (P<0.05) reproductive tillers than G48 and Roa, and significantly fewer spikelets than G48. Roa only produced significantly more spikelets and florets than Garland when plants were sown on 25 March. Roa and G48 did not differ significantly in reproductive components from any of the autumn sowings.

Time of sowing in the autumn significantly affected seed yields (Table 3.10). Plants from both the March sowings produced similar seed yields which were on average, three times greater than the seed yields obtained from April-sown plants. Garland produced more seed than the two other cultivars, particularly when sown in March. There was no significant difference in seed yield between Roa and G48.

Overall, there were no significant differences in T.S.W. except for the earlier-sown Garland which produced lighter seed than later-sown plants (Table 3.10). Seed number m^{-2} was significantly reduced by sowing in April compared to March sowing. Garland produced more seeds m^{-2} than either G48 or Roa when sown in March (Table 3.10). There was no significant difference in seed number per spikelet (calculated) from either time of sowing or different cultivars (Appendix 1.3). Seed numbers per spikelets across the three autumn sowing dates averaged 3.1 for G48, 3.0 for Roa and 2.5 for Garland.

Relationships between reproductive tillers and winter/spring vegetative tillers. Linear correlation coefficients were calculated to determine if vegetative tiller numbers in June, August and October were related to reproductive tiller numbers at anthesis (Table 3.11). Vegetative tillers numbers in June were highly significantly ($P<0.001$) correlated to reproductive tiller numbers (Table 3.11). August and October tillers were not related to reproductive tiller numbers. It was therefore the number of June tillers than influenced subsequent reproductive tiller numbers and thereby seed yield and not the number of tillers in August or October.

Table 3.10. Effect of time of autumn sowing on reproductive components at anthesis and seed yield and T.S.W. of three tall fescue cultivars.

Sowing date	G48	Roa	Garland	LSD (P<0.05)
		Reproductive tillers (m^{-2})		
4 March	212	242	529	190
25 March	172	151	393	108
15 April	68	90	224	24
LSD (P<0.05)	117	102	186	
		Spikelets per tiller		
4 March	130	105	87	32
25 March	132	116	94	21
15 April	119	107	81	33
LSD (P<0.05)	n.s.	n.s.	n.s.	
		Florets per spikelet		
4 March	6.5	6.7	6.4	n.s.
25 March	6.9	7.2	6.4	0.5
15 April	6.8	6.7	6.5	n.s.
LSD (P<0.05)	n.s.	0.2	n.s.	
		Seed yield (kg ha^{-1})		
4 March	973	1119	1633	320
25 March	865	1016	1618	519
15 April	384	339	565	n.s.
LSD (P<0.05)	311	482	325	
		T.S.W. (g)		
4 March	1.488	1.593	1.420	n.s.
25 March	1.364	1.549	1.530	n.s.
15 April	1.408	1.675	1.589	n.s.
LSD (P<0.05)	n.s.	n.s.	0.126	
		Seed numbers m^{-2}*		
4 March	63972	70541	115320	37210
25 March	64933	65099	105669	39530
15 April	27681	20813	35842	n.s.
LSD (P<0.05)	24205	32428	19283	

All interactions n.s.

* Calculated

Table 3.11. Coefficients of linear correlation (r) for reproductive tiller numbers at anthesis with vegetative tiller numbers in June, August and October.

No vegetative tillers m^{-2} in:	No reproductive tillers m^{-2}
June	0.64 ***
August	0.07 n.s.
October	0.10 n.s.

3.4 DISCUSSION

The main objective of these establishment trials was to see if tall fescue could produce a seed crop following autumn sowing. In both field trials, all sowings and all three cultivars, produced seed yields similar or greater than the 1990 New Zealand average of 343 kg ha^{-1} for Grasslands Roa (Agriseeds; head licensee seed company for Grasslands Roa, pers. comm.)(Tables 3.3 and 3.10). The spring- and summer-sown Roa produced no more seed than February-sown Roa and only the October-sown Roa significantly outyielded the March-sown Roa (Table 3.3). Furthermore, the seed yields in the first trial would probably have been even higher were it not for the infestation of stem rust (*Puccinia graminis* Persoon). In the previous year, a similar trial at Aorangi in the absence of stem rust produced seed yields of well over 2000 kg ha^{-1} (Hare, 1992). Based on the number of reproductive tillers, spikelets and florets at anthesis (Table 3.3) this trial should also have produced similar yields. Unfortunately the stem rust was not noticed until it was quite advanced, suggesting that fungicide should have been applied at ear emergence, i.e. three weeks earlier, for maximum benefit (Hare, 1993). This incident of stem rust was also the first reported case in a tall fescue seed crop in New Zealand.

It is therefore possible to obtain good seed yields from autumn sowings, provided sowing is in early-autumn (February - March) and soil moisture is not deficient and autumn temperatures are warm (above 15°C), to allow vegetative tiller growth to continue from establishment to the early-winter. Hill, Pearson and Kirby (1985) showed that tall fescue had very slow germination and tillering at low temperatures (10 to 15°C) and high temperatures (24°C and above). Optimum establishment of tall fescue was at day temperatures of between 18 and 21°C. Charlton, Hampton and Scott (1986) also showed that the most favourable temperatures for tall fescue germination were between 15 and 25°C with lower or higher temperatures significantly lowering germination rates. Tall fescue must have time to establish and tiller strongly before the onset of low winter temperatures. Tillers present in June had a highly significant ($P<0.001$) correlation with reproductive tiller numbers (Table 3.11), whereas August and October vegetative tiller numbers were not correlated with reproductive tiller numbers. Tiller numbers by early-winter are therefore extremely important to ensure adequate duration of vernalization (Bean, 1970) and subsequently increased reproductive tillers in the spring (Hare, Rolston, Falloon and Hickson, 1988).

It has been suggested that tall fescue tillers must undergo sufficient vernalization during winter before they can be initiated by long days in the spring (Bean, 1970). The more tillers vernalized and available for spring long-day initiation, the greater the reproductive tiller numbers and subsequent seed yield. Even though the autumn sowings produced more florets per spikelet, within tiller productivity can not fully compensate for lack of reproductive tiller numbers (Hare *et al.*, 1988). It has previously been shown in prairie grass (*Bromus willdenowii*) (Hare *et al.* 1988) and in tall fescue (Hare, 1992) that florets per spikelet at anthesis are negatively correlated with seed yield, whereas reproductive tiller numbers at anthesis are positively correlated with seed yield.

The autumn establishment trial showed that time of sowing is critical, as a three week delay in sowing in the autumn significantly reduced seed yields eight months later in all three cultivars (Table 3.10). While there was no significant difference between seed yields from plants sown three weeks apart in March, the plants sown six or three weeks later in April produced significantly less seed (Table 3.10). Again it was the number of reproductive tillers that determined seed yields. Throughout the winter and into the early-spring (Plate

3.2; Tables 3.5 and 3.7) April-sown plants produced significantly fewer tillers than March-sown plants. Even though they had similar tiller numbers by October (Table 3.7; Roa and G48) these new tillers may not have undergone sufficient vernalization to be initiated by the longer spring days.

Even though April-sown plants established as well as earlier-sown plants (Table 3.5), subsequent tillering was not as rapid as the tillering rate of larger, early-sown plants. Plants from March-sowings always had more tillers in the winter which were heavier than April-sown plants. Therefore, plants must be well-established before the onset of mild winter temperatures (May to August; 6 to 10°C). Larger plants appear to have more ability to tiller than smaller plants under mild winter temperatures.

The ability to tiller under mild winter temperatures is another factor in determining successful seed yields from autumn-sowings. In the South Island of New Zealand, April-sown Roa tall fescue produced only 170 kg ha^{-1} of seed compared to 940 kg ha^{-1} from April-sowings in the North Island (Hare *et al.*, 1990). In the US in Bozeman and Moccasin, Montana, Kenmont tall fescue only produced seed yields of 108 and 141 kg ha^{-1} at two sites from late-summer sowings (Wichman *et al.*, 1991). The NZ South Island and the US Montana sites are considerably colder than the North Island sites in these trials. Average 10 cm soil temperatures in mid-winter are 3.9°C at the South Island site (*Summaries of Climatological Observations. N.Z. Meteorological Service*), -0.7°C at the two Montana sites (D. Wichman, Montana Agricultural Experimental Station, pers. comm.) and 6.7°C at the two North Island sites (Appendix 1.1). Therefore, despite successful establishment in the South Island and in Montana, the colder winters at these sites prevented tall fescue from building up sufficient early-winter tillers for reproduction in the spring. Successful autumn establishment therefore appears to be dependent on mild winters in order to ensure that enough tillers are developed to become reproductive in the spring. Tall fescue tillering rate is reduced when temperatures fall from 15 to 10°C (Hill *et al.*, 1985). Temperatures below 10°C would presumably reduce the rate of tillering even more, as performance is further impaired. For example, Charlton *et al.* (1986) found that tall fescue seeds took 65 days at 5°C to reach 75% germination compared to 12 days at 10°C.

The autumn field trial showed that there was no difference in seed production between Roa and G48 tall fescues. Only at 10 and 12 weeks after sowing (Table 3.7 and 3.5) did G48 have more tillers than Roa. Thereafter, there were no significant differences in tiller production and tiller weight between the two cultivars. Despite the claim that G48 was bred for quicker establishment than Roa, no evidence for this was shown in the autumn field trial. Garland, however, did show that its very fine tillers (compared to Roa and G48) were sufficiently numerous by mid-winter to produce more seed than the other two cultivars in the autumn field trial. Garland produced 56, 72 and 56 percent more seeds from the 4 March, 25 March and 15 April sowings respectively than the two pasture cultivars (Table 3.10). It is therefore the number of tillers that establish in the autumn and survive the winter, and not their weight, which is of most importance for winter vernalisation.

The number of reproductive tillers per unit area is the most important factor for high seed yields in tall fescue. Garland, a turf-type tall fescue, by producing more reproductive tillers per m^2 in the field trial shows that it is a cultivar that is very well suited to autumn establishment in parts of the North Island of New Zealand. In areas where the autumns are dry and cold and the winters cold, spring-summer sowing of tall fescue would be still recommended in order to get good first harvest seed yields (Hare *et al.*, 1990; Wichman *et al.*, 1991).

Chapter 4

Undersowing tall fescue with a barley cover crop

4.1 INTRODUCTION

When tall fescue is spring-sown (October) in New Zealand, the first seed crop is not harvested until 15 months later (December). The lack of income in the establishment year supports the identification of a more cost-effective planting method; i.e. if tall fescue was sown with an annual cover crop farmers would obtain an income from the latter crop in the estabiishment year. Factors affecting the success or failure of the cover crop system have not been examined in New Zealand. Most such studies have been conducted in Europe and the US where this system is frequently used. Furthermore, many of the systems establish grass seed and cereals in the autumn rather than the spring, further extending the time before a grass seed crop is taken. Chastain and Grabe(1988b and 1989) and Nordestgaard(1984) reported that it is more profitable to grow grass seed crops under cereal cover crops than to grow the grass alone.

In the US seed yields of timothy (*Phleum pratense* L.), smooth bromegrass (*Bromus inermis* Leyss.) and cocksfoot (*Dactylis glomerata* L.) have not been reduced when grown under winter wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.) and spring oats (*Avena fatua* var. *sativa* (L.) Haussk.) (Pardee and Lowe, 1963). Similarly red fescue (*Festuca rubra* L.) seed yields were also not lowered by cover crops of winter wheat and winter barley (Chastain and Grabe, 1988b). However, seed yields of spring-sown turf-type tall fescue have been reduced by 61% in the first year when grown with a spring cereal cover crop (Chastain and Grabe, 1989).

In the UK, first year seed yields of cocksfoot were reduced by cover crops of spring oats and barley (Roberts, 1964; Bean, 1978). Timothy, meadow fescue (*Festuca pratensis* Huds.) and tall fescue also suffered first year seed yield reductions, but bent grass (*Agrostis tenuis* Sibth.) and perennial ryegrass (*Lolium perenne* L.) were not affected (Bean, 1978) when sown with cover crops. Undersowing perennial ryegrass with barley in the spring decreased ryegrass seed yields in one trial but not in two other trials (Hebblethwaite and Peirson, 1983).

In Denmark, Nordestgaard (1984) found that cocksfoot, red fescue and meadow fescue seed yields were better when established under an early ripening, rather than under a late ripening barley cultivar. However, Kentucky bluegrass (*Poa pratensis* L.) seed yields have been depressed by sowing with winter wheat and spring barley in Sweden (Cedell, 1975) and winter wheat, spring wheat, field beans (*Phaseolus vulgaris* L.) and flax (*Linum usitatissimum* L.) in Denmark (Nordestgaard, 1979). Pure stands of tall fescue have produced higher seed yields in the first harvest season in the Ukraine than when grown under a cover crop of barley (Mikhailichenko and Svetlichnyi, 1987).

The objectives of this research were therefore:

i) to investigate the influence of a cereal cover crop and row spacing on the growth, development and seed production of undersown tall fescue.

ii) to investigate the gross margins for tall fescue seed crops sown alone compared with sowing with cereal cover crops.

4.2 MATERIALS AND METHODS

Two trials were conducted at the AgResearch Grasslands 'Aorangi' farm, Manawatu, New Zealand (40° 23' S) on a weakly leached, slowly accumulating, poorly drained, recent gley soil from quartzo-feldspathic silty alluvium (Kairanga silt loam). Rainfall was recorded at a meteorological station (New Zealand Meteorological Service, Kairanga) approximately 1000 metres from the trial sites. Each trial was conducted on a new site from the previous year's trial.

4.2.1 **Trial 1**

The field site was ploughed, disced and rotary hoed during August and September 1989. Grasslands Roa tall fescue and Triumph barley were sown on 29 September 1989 with an Aitchison Seedmatic drill followed by chain harrows. The barley was drilled first at 5-6 cm depth in a north-south direction and the tall fescue drilled over the top at 1-2 cm depth in an east-west direction. The field was rolled after the tall fescue was sown. The treatments were as follows (barley row spacings and seeding rates are in brackets);

1) Barley alone (15 cm, 150 kg ha^{-1})
2) Barley alone (15 cm, 75 kg ha^{-1})
3) Tall fescue alone
4) Tall fescue and barley (15 cm, 37.5 kg ha^{-1})
5) Tall fescue and barley (15 cm, 75 kg ha^{-1})
6) Tall fescue and barley (30 cm, 37.5 kg ha^{-1})
7) Tall fescue and barley (30 cm, 75 kg ha^{-1})

Low barley sowing rates were chosen to allow the tall fescue to develop well within a partially closed cover canopy.

The tall fescue was drilled in 30 cm rows at a seeding rate of 7.5 kg ha^{-1}. The treatments were replicated three times in a randomised block design. Plots were 8 m long (east to west) and 3 m wide (north to south).

In both trials estimates of canopy cover development were determined by infra-red photographs (de Ruiter and Brooking, 1990) at two positions within each of the barley alone plots and returning to the same positions over time. Photographs were taken at four days after emergence through to 75 to 80% cover. Paper positive (10 x 7 cm) images were captured and digitised by image processing software and determinations made of the relative proportions of leaf cover to bare soil. Estimates of barley cover above 75% were determined by difference between photosynthetically active radiation (PAR) detected at the soil surface by a one-meter line quantum sensor (Li-Cor) relative to a point quantum sensor

(Li-Cor) positioned above the canopy. A daily soil water balance (Kerr, de Ruiter and Hall, 1986) was calculated from inputs of daily mean air temperature, solar radiation and rainfall in both trials. This was used to derive soil water deficits throughout barley growth. These data, canopy cover and soil water deficits, are not presented in this thesis as the work was mainly by de Ruiter but the results (de Ruiter pers. comm.) are discussed.

200 kg ha^{-1} of 30% potassic super (0, 7, 15, 8) was applied at sowing; 50 kg N ha^{-1} (Urea) was applied on 17 October 1989 and 120 kg N ha^{-1} (Urea) was applied on 6 September 1990. All fertiliser was applied by hand.

Herbicides and fungicides were applied as follows through a small gas-pressure sprayer in 160 litres water ha^{-1} at 300 kPa:

17 October 1989. Dicamba (0.48 kg ai ha^{-1}) + 2,4-D (0.43 kg ai ha^{-1}) for control of willow weed *(Polygonum persicaria)* and fathen *(Chenopodium album)*.

31 May 1990. Ethofumesate (1.6 kg ai ha^{-1}) + MCPA (1.13 kg ai ha^{-1}) for control of twin cress (*Coronopus didymus*), willow weed and *Poa annua*.

25 July 1990. Ethofumesate (2.0 kg ai ha^{-1}) + 2,4-D (1.13 kg ai ha^{-1}) for control of *Poa annua* and broadleaf weeds.

16 November 1990. Propiconazole (0.123 kg ai ha^{-1}) to control stem rust (*Puccinia graminis* Persoon) in tall fescue.

Tall fescue plants were counted seven weeks after seeding, with six one-metre rows counted in each plot. Barley was hand harvested on 6 February 1990 from two one m^2 areas per plot, threshed and cleaned (seed yields adjusted to 14% moisture content) (see 3.2.1). The whole plot area was machine harvested to 10 cm height on 26 February after two weeks of wet weather and the threshed straw and stubble were left and either blew or rotted away because the residue was so light.

Tall fescue tiller dry weights (100 tillers from bulked samples per plot) and numbers after barley harvest were counted from three one-metre rows cut to ground level from each plot on 9 February 1990.

All the plots were topped with a rotary mower to 5 cm above ground level on 30 April 1990. No other cutting or grazing took place during this year. On 18 September 1990 a one-metre row was cut to ground level, weighed and herbage dry weight (100 g sub-sample), tiller numbers (whole sample) and tiller dry weight (100 tillers) determined. As there were no vegetative tiller number differences between treatments in September no reproductive analysis was done during anthesis. In an identical trial the previous season (Hare *et al*., 1990) no differences in seed yield components were found at anthesis, and in that trial no vegetative tiller differences were found in September. Tall fescue seed harvest was on 19 December 1990 with three one-metre rows of seed heads cut from each plot. The cut seed heads were bulked for each plot, dried, threshed and cleaned (see 3.2.1).

The results in both trials were analysed as a randomised block design by the SAS statistical programme.

4.2.2 Trial 2

This trial was first sown on 1 October 1991, but was abandoned at the end of October, due to the unsuspected effects of a residual chemical (chlorimuron) which seriously impaired plant growth.

Grasslands Roa tall fescue and Triumph barley were resown in a new field on 9 November 1990 with an Aitchison Seedmatic drill followed by chain harrows. The field had been in wheat for two years and was fallowed over the winter then ploughed, disced and harrowed. The barley was first drilled at 5-6 cm depth in 15 cm rows in a north-south direction and the tall fescue immediately drilled over the top at 1-2 cm depth in 30 cm rows in an east-west direction. The field was rolled after the tall fescue was sown. Three barley seeding rates (100, 150 and 200 kg ha^{-1}) with and without tall fescue and two tall fescue seeding rates (7.5 and 15 kg ha^{-1}) with and without barley were used. The treatments were as follows:

1. Barley alone 100 kg ha^{-1}

2. Barley alone 150 kg ha^{-1}

3. Barley alone 200 kg ha^{-1}

4. Barley (100) + tall fescue 7.5 kg ha^{-1}

5. Barley (150) + tall fescue (7.5)

6. Barley (200) + tall fescue (7.5)

7. Barley (100) + tall fescue 15 kg ha^{-1}

8. Barley (150) + tall fescue (15)

9. Barley (200) + tall fescue (15)

10. Tall fescue alone 7.5 kg ha^{-1}

11. Tall fescue alone 15 kg ha^{-1}

In this trial commercial barley sowing rates were chosen as the tall fescue had survived very well under the two previous trials (Hare *et al*., 1990 and Trial 1). Two tall fescue sowing rates were chosen in case the lower sowing rate did not survive under more severe barley competition, but the higher sowing rate (pasture rate, Hume and Fraser, 1985) may be more competitive.

The treatments were replicated three times in a randomised block design. Plots were 11 m long (north to south) and 3.5 m wide (east to west). No fertiliser was applied at sowing.

Herbicides, insecticides and fungicides were applied as follows (gas sprayer, as in trial 1):

5 December 1990. 2,4-D (0.72 kg ai ha^{-1}) and bromoxynil (0.1 kg ai ha^{-1}) plus ioxynil (0.1 kg ai ha^{-1}) to control fathen and willow weed.

16 November 1990. Phorate (2 kg ai ha^{-1}) to control aphids and prevent the spread of Barley Yellow Dwarf Virus (BYDV). The granules were spread by hand.

2 April 1991. Ethofumesate (2 kg ai ha^{-1}), 2,4-DB (2.4 kg ai ha^{-1}) and dicamba (0.2 kg ai ha^{-1}) to control barley growth, *Poa annua*, docks (*Rumex* sp.) and thistles (*Cirsium vulgare*). Ethofumesate (3 kg ai ha^{-1}), 2,4-DB (2.4 kg ai ha^{-1})

and dicamba (0.2 kg ai ha^{-1}) on 6 June 1991 to control *Poa annua* and broadleaf weeds.

1 November 1991. Propiconazole (0.250 kg ai ha^{-1}) to control stem rust.

Tall fescue establishment was determined 17 days after planting and barley 10 days after planting by counting all plants within six one-metre rows in each plot. On 12 December 1990, 28 December 1990 and 30 January 1991, one 0.25 m^2 area was cut in each plot and barley and tall fescue tiller numbers counted, and dry weight of vegetation and dry weight per tiller calculated from whole sample. Barley and tall fescue establishment was more rapid in trial 2 compared to trial 1 so plant counts were earlier and more frequent. Barley was hand harvested on 21 February 1991 (2 m^2 area per plot) and tall fescue length (see 3.2.1.), dry matter and tiller numbers measured from 2 x 50 cm rows cut from each plot and bulked on 22 February 1991. The barley was threshed and cleaned as in trial 1.

The remaining barley and stubble were topped with a forage harvester (material removed from field) on 25 February 1991 to 10 cm above ground level and removed. The autumn regrowth was topped to approximately 15 cm above ground level (cut material left in field) on 25 March, 10 May and 9 July 1991. Nitrogen (urea) was applied by hand on 27 March (40 kg N ha^{-1}) and on 5 September 1991 (100 kg N ha^{-1}).

On 11 June and 17 September 1991, two one-metre rows were cut and bulked from each plot. Herbage dry weight (whole sample), tiller number (100 g sub-sample) and tiller dry weight (100 tillers) were measured.

During anthesis, a growth analysis was made on 29 November 1991 as detailed in the previous chapter (see 3.2.1). Seed harvest on 27 December followed the same procedures as in the time of sowing trial (see 3.2.1). After seed harvest the stubble was cut and burnt on site. The seed heads were dried, threshed and cleaned (see 3.2.1.). Seed yields and T.S.W. were corrected to 14% seed moisture content.

4.3 RESULTS

Meteorological data (Appendix 2.1)

Soil temperatures (10 cm) were 0.6 to 2°C warmer during establishment (November-December) in the second trial compared to the first trial. Thereafter, soil temperatures were similar in both trials. The second trial received over 100 mm of rain in November compared to only 33 mm in the first trial. Both trials received adequate autumn-winter rainfall. Seed was therefore sown into warm, moist soil in both trials and received adequate moisture during the establishment period which was normal for the area (Appendix 1.1). After barley harvest in both trials there was sufficient moisture not to warrant any irrigation for the undersown tall fescue.

Tall fescue plant growth from establishment to barley harvest

(NOTE: In trial 2 there were no interactions between undersowing and tall fescue sowing rate for any of the data. All the data presented for trial 2 are the means of each undersown barley rate treatment, tall fescue alone treatments and each tall fescue sowing rate treatment.)

Barley sowing rate did not affect tall fescue plant establishment in the second trial but did decrease plant numbers in three treatments in the first trial (Table 4.1). In the first trial, 103 plants m^{-2} had established seven weeks after sowing and at the same sowing rate (7.5 kg ha^{-1}) in the second trial, 160 plants m^{-2} had established 17 days after sowing. Increasing the tall fescue sowing rate from 7.5 to 15 kg ha^{-1} virtually doubled the plant numbers by 17 days after sowing in trial 2.

Table 4.1 Establishment of tall fescue(Tf) and barley(B).

Trial 1

Treatment	B row spacing (cm) / sowing rate(kg ha^{-1})	Tall fescue plant no m^{-2} (7 weeks after sowing)
Tf alone		115
Tf + B	(15/37.5)	110
Tf + B	(15/75)	98
Tf + B	(30/37.5)	100
Tf + B	(30/75)	92
LSD (P<0.05)		10.7

Trial 2

Tf alone and Tf + B(kg ha^{-1})	Tall fescue plant no m^{-2} (17 days after sowing)	Barley sowing rate (kg ha^{-1})	Barley plant no m^{-2} (10 days after sowing)
Tf alone	224	100	217
Tf + B(100)	234	150	299
Tf + B(150)	240	200	388
Tf + B(200)	225		
LSD (P<0.05)	n.s.		29

Tall fescue sowing rate (kg ha^{-1})	Tall fescue plant no m^{-2} (17 days after sowing)	B alone and with Tf(kg ha^{-1})	Barley plant no m^{-2} (10 days after sowing)
7.5	160	B alone	311
15	301	B + Tf(7.5)	291
		B + Tf(15)	303
LSD (P<0.05)	23		n.s.

Interactions n.s.

Table 4.2 **Tall fescue(Tf) and barley(B) growth following establishment until three weeks before barley harvest (trial 2).**

(a) Tall fescue

Treatment	Tiller no m^{-2}			DW per tiller (g)			DW ($g\ m^{-2}$)		
Tf alone and Tf + B($kg\ ha^{-1}$)	12 December 1990	28 December 1990	30 January 1991	12 December 1990	28 December 1990	30 January 1991	12 December 1990	28 December 1990	30 January 1991
Tf alone	322	986	1882	0.02	0.05	0.21	6.5	53.5	395
Tf + B(100)	255	314	310	0.02	0.04	0.09	4.7	14.1	29
Tf + B(150)	273	269	235	0.02	0.04	0.06	4.2	11.2	15
Tf + B(200)	241	270	206	0.02	0.04	0.06	4.6	10.4	14
LSD (P<0.05)	62	172	206	n.s.	0.008	0.02	1.9	14.2	40
Tall fescue sowing rate ($kg\ ha^{-1}$)									
7.5	168	312	624	0.02	0.05	0.11	3.2	15.4	115
15	377	607	691	0.02	0.04	0.10	6.9	29.2	111
LSD (P<0.05)	48	122	n.s.	n.s.	n.s.	n.s.	1.3	10.0	n.s.

(b) Barley

Barley sowing rate ($kg\ ha^{-1}$)									
100	726	1061	913	0.13	0.37	1.31	97	389	1196
150	768	1159	1093	0.14	0.41	1.35	109	477	1465
200	888	1217	1049	0.16	0.39	1.35	138	474	1405
LSD (P<0.05)	154	135	145	0.019	n.s.	n.s.	29	72	205
B alone and with Tf($kg\ ha^{-1}$)									
B alone	854	1227	1063	0.15	0.38	1.35	136	460	1433
B +Tf(7.5)	765	1099	1023	0.13	0.38	1.28	104	417	1300
B + Tf(15)	764	1110	969	0.13	0.42	1.38	105	464	1334
LSD (P<0.05)	n.s.	n.s.	n.s.	0.019	n.s.	n.s.	29	n.s.	n.s.

All interactions n.s.

However, once plants started tillering, barley, regardless of sowing rate, significantly reduced tall fescue tiller numbers, tiller dry weight and dry matter production compared to tall fescue grown alone in trial 2 (Table 4.2), particularly from the end of December to the end of January. In this trial, the three barley sowing rates had similar effects on tiller numbers and dry matter production of the undersown tall fescue. The higher tall fescue sowing rate produced nearly twice the number of tillers and dry matter that the lower tall fescue sowing rate in December. By the end of January there were, however, no significant differences in tiller and dry matter production between the two tall fescue sowing rates. Pure stands of tall fescue had produced nearly six times the number of tillers, three times heavier tillers and twenty times more dry matter than undersown tall fescue by the end of January in trial 2.

At barley harvest, tall fescue grown alone produced more tillers and more dry matter in both trials and heavier tillers in trial 2, compared to undersown tall fescue (Table 4.3). In trial 2 at barley harvest, the higher sowing rate of tall fescue produced 1.5 times the number of tillers that the lower sowing rate of tall fescue did. Undersown tall fescue at barley harvest produced similar numbers of tillers, regardless of the sowing rate of barley, but the 200 kg ha^{-1} barley sowing rate did suppress tiller weights (Table 4.3).

Barley establishment and growth

Barley sowing rate significantly affected early barley plant establishment, with the higher sowing rates having more plants m^{-2} than lower sowing rates (Table 4.1). Undersowing tall fescue had no effect on early barley establishment.

Table 4.3 Effect of barley(B) cover crops on tall fescue(Tf) vegetative growth at barley harvest.

Trial 1

Treatment	B row spacing (cm)/sowing rate(kg ha^{-1})	Tiller no m^{-2}	Herbage dry wt (g m^{-2})	Tiller DW (g)
Tf alone		1650	420	0.27
Tf + B	(15/37.5)	667	205	0.37
Tf + B	(15/75)	583	170	0.30
Tf + B	(30/37.5)	716	198	0.32
Tf + B	(30/75)	394	109	0.31
LSD (P<0.05)		445	54	n.s.

Trial 2

Treatment	Tiller no m^{-2}	Herbage dry wt (g m^{-2})	Tiller DW (g)
Tf alone and Tf + B(kg ha^{-1})			
Tf alone	1464	423	0.296
Tf + B(100)	298	39	0.146
Tf + B(150)	306	44	0.157
Tf + B(200)	248	29	0.119
LSD(P<0.05)	122	44	0.029
Tall fescue sowing rate (kg ha^{-1})			
7.5	455	124	0.196
15	703	143	0.162
LSD (P<0.05)	87	n.s.	0.021
Interactions n.s.			

Following establishment, barley sown at 100 kg ha^{-1} on 12 and 28 December had fewer tiller numbers than the 200 kg ha^{-1} sowing rate (Table 4.2). By the end of January barley plants sown at 100 kg ha^{-1} had fewer tillers than plants sown at 150 kg ha^{-1}. Tiller weights did not vary between barley sowing rates during late December and January, but there was a decrease in dry matter production at the 100 kg ha^{-1} sowing rate compared to the higher rates. Undersown tall fescue had no effect on barley tiller numbers, tiller weight and dry matter production from December to the end of January (Table 4.2).

Barley grain yields

Low barley sowing rates, rather than row spacing, had the greatest effect on grain yield, especially in the first year (Table 4.4). The 75 kg ha^{-1} seeding rate produced more grain than the 37.5 kg ha^{-1} seeding rate. Barley Yellow Dwarf Virus (BYDV) was more evident in plots sown at the lowest density. In the second trial, barley sowing rates and undersown tall fescue had no significant effect on barley grain yields. There was no BYDV evident in this trial.

Tall fescue autumn, winter and spring growth

Trial 2 was the only trial in which the autumn and the winter growth were measured. By 11 June 1991, fifteen weeks after barley harvest, the undersown tall fescue had shown good recovery during autumn (Table 4.5) with no significant differences in tiller numbers among treatments. However, the undersown tall fescue tiller weights were significantly lighter than tillers in plots sown without barley. Dry matter production was still less in the undersown tall fescue plots compared to tall fescue sown alone plots.

Table 4.4 Effect of undersowing tall fescue(Tf) on barley(B) grain yields (14% moisture).

Treatments	B row spacing(cm)/ sowing rate(kg ha^{-1})	Barley grain yield (t ha^{-1}) Trial 1
B alone	(15/150)	4.32
B alone	(15/75)	3.56
Tf + B	(15/37.5)	3.13
Tf + B	(15/75)	3.77
Tf + B	(30/37.5)	2.64
Tf + B	(30/75)	3.79
Above treatments significant at:		P<0.005
<u>Contrasts</u>		
	1 vs 2	n.s.
	2 vs 4	n.s.
	3, 5 vs 4, 6	0.001
	3, 4 vs 5, 6	n.s.
	3 vs 4	0.02
	5 vs 6	0.01

Treatments	Trial 2
Barley sowing rate (kg ha^{-1})	
100	5.81
150	5.89
200	6.27
LSD (P<0.05)	n.s.
B alone and with Tf(kg ha^{-1})	
B alone	5.97
B + Tf(7.5)	6.10
B + Tf(15)	5.89
LSD (P<0.05)	n.s.
Interactions n.s.	

Table 4.5 Effect of barley(B) cover crops on undersown tall fescue(Tf) autumn tiller production following barley harvest (Trial 2)

Treatment	Autumn growth 11 June 1991 Tiller no m^{-2}	DW per tiller (g)	Herbage DW m^{-2} (g)
Tf alone and Tf + B(kg ha^{-1})			
Tf alone	2648	0.123	356
Tf + B(100)	2744	0.085	259
Tf + B(150)	2662	0.088	250
Tf + B(200)	2573	0.073	208
LSD (P<0.05)	n.s.	0.024	61
Tall fescue sowing rate (kg ha^{-1})			
7.5	2527	0.093	251
15	2786	0.091	286
LSD (P<0.05)	n.s.	n.s.	n.s.
Interactions n.s.			

Plants in the lower sowing rate plots of tall fescue had recovered during the autumn, so that by June there were no significant differences in tiller number, tiller dry weight and herbage dry weight between the 7.5 and 15 kg ha^{-1} sowing rates.

In trial 1, by spring (September) there were no differences in tiller number, dry matter and tiller dry weight among tall fescue treatments (Table 4.6). In trial 2 there were no differences in tiller numbers and dry matter among treatments but tiller weights were heavier in the sown alone and lower tall fescue sowing rate plots compared to undersown and higher tall fescue sowing rate plots respectively.

In trial 1, spring tiller numbers were c 1000 per m^2 fewer than those in trial 2, but these tillers were three times heavier than tillers in trial 2. In trial 1 there had been no topping after 30 April, but in trial 2 topping had been done on 10 May and 9 July.

Table 4.6 Effect of barley(B) cover crops on spring tiller and vegetative production of tall fescue(Tf).

Trial 1 18 September 1990

Treatment B row spacing (cm)/sowing rate(kg ha-1)	Tiller no m^{-2}	Tiller dry wt (g)	Herbage dry wt (g m^{-2})
Tf alone	1722	0.55	858
Tf + B (15/37.5)	1858	0.48	862
Tf + B (15/75)	1781	0.48	827
Tf + B (30/37.5)	1978	0.44	867
Tf + B (30/75)	2124	0.47	962
LSD (P<0.05)	n.s.	n.s.	n.s.

Trial 2 17 September 1991	Tiller no m^{-2}	Tiller dry wt (g)	Herbage dry wt (g m^{-2})
Tf alone and Tf + B(kg ha^{-1})			
Tf alone	2567	0.186	551
Tf + B(100)	3097	0.161	575
Tf + B(150)	2902	0.166	525
Tf + B(200)	2647	0.161	487
LSD (P<0.05)	n.s.	0.022	n.s.
Tf sowing rate (kg ha^{-1})			
7.5	2577	0.178	523
15	3029	0.158	546
LSD (P<0.05)	416	0.015	n.s.

Interactions n.s.

Tall fescue seed yields

Sowing barley and tall fescue together had no effect on tall fescue seed yields in the first trial (Table 4.7). Seed weight was higher in seed from pure sown plots compared to the weight of seed from the Tf + B(30/75) plots which produced the highest seed yields.

In the second trial all the undersown tall fescue, regardless of barley sowing rate, produced significantly less seed, but heavier seed, than tall fescue sown alone. Tall fescue undersown with barley at 150 and 200 kg ha^{-1} produced fewer reproductive tillers than tall fescue sown alone. There were no significant differences in spikelets and florets among all treatments. Tall fescue sowing rate had no significant effect on seed yield, seed weight or reproductive components at anthesis.

4.4 DISCUSSION

The growth and development of tall fescue under a barley cover crop will depend upon a satisfactory environment in terms of water, light and nutrients, and the barley sowing rate, until the removal of the barley harvest stubble. In the first trial and a trial in the previous year (Hare *et al.*, 1990) the barley sowing rates used were below the commercially recommended rate of 150 kg ha^{-1} and allowed the tall fescue to develop well under a partially closed canopy. However, recent work has shown that tall fescue can suffer up to a 61% decrease in first season seed yields when undersown at commercial barley sowing rates (Chastain and Grabe, 1989). In the second trial, barley sowing rates of up to 200 kg ha^{-1} were chosen to see if tall fescue would survive and still produce an acceptable seed crop the following summer.

Table 4.7 **Effect of barley(B) cover crops on tall fescue(Tf) seed yields and seed yield components (14% moisture).**

Trial 1

Treatment B row spacing (cm)/sowing rate (kg ha^{-1})		Seed Yield (kg ha^{-1})	T.S.W.
Tf alone		1497	2.94
Tf + B	(15/37.5)	1577	2.79
Tf + B	(15/75)	1626	2.82
Tf + B	(30/37.5)	1367	2.82
Tf + B	(30/75)	1718	2.67
LSD (P<0.05)		n.s	0.17

Trial 2

	Seed Yield (kg ha^{-1})	T.S.W.	Reproductive tillers m^{-2} at anthesis	Spikelets per tiller at anthesis	Florets per tiller at anthesis
Tf alone and Tf + B (kg ha^{-1})					
Tf alone	1018	1.88	355	84	6.3
Tf + B(100)	754	2.08	257	81	6.2
Tf + B(150)	831	2.06	204	79	6.5
Tf + B(200)	725	2.09	170	80	6.5
LSD (P<0.05)	118	0.15	99	n.s.	n.s.
Tf sowing rate (kg ha^{-1})					
7.5	860	2.00	256	82	6.5
15	805	2.07	237	80	6.3
LSD (P<0.05)	n.s.	n.s.	n.s.	n.s.	n.s.
Interactions n.s.					

In both trials there was good soil moisture from establishment through to barley harvest and there was no nitrogen limitation to tall fescue growth under the barley cover crop (de Ruiter pers. comm.). In the first trial the low barley sowing rates developed incompletely closed canopies which allowed ample light to reach the tall fescue (de Ruiter pers. comm.). In the second trial, sowing rates of barley at or greater than 100 kg ha^{-1} developed a completely closed canopy cover and intercepted more than 90% of the light by 49 days (28 December 1991) after sowing (de Ruiter pers. comm.). This meant that in the second trial competition for light was severe until after barley harvest when stubble was removed. This was in contrast to previous work with spring-sown tall fescue and barley (Chastain and Grabe, 1989) where as much as 40% of the incident light still reached the tall fescue plants at barley maturity with a barley sowing rate of 117 kg ha^{-1}. However, in winter-sown red fescue and wheat (140 kg ha^{-1} sowing rate) 95% of the light was intercepted by the time of wheat ear emergence (Meijer, 1987).

Once full canopy cover developed, the tall fescue stopped tillering. There was no increase in tall fescue tiller numbers from the end of December (Table 4.2) to barley harvest (Table 4.3) in the second trial. Meijer (1987) also found that red fescue and meadow fescue stopped tillering at the time the cover crop intercepted more than about 85% of the light. By being able to receive light up until barley harvest, undersown tall fescue in trial 1 had more and heavier tillers and produced more dry matter than tall fescue in trial 2 at barley harvest(Table 4.3). Lack of light, therefore, was the most limiting factor to growth of tall fescue under the barley cover crop.

Tall fescue sowing rate significantly affected tiller production of tall fescue up until barley harvest in trial 2. The advantage of the 15 kg ha^{-1} sowing rate over the 7.5 kg ha^{-1} was, however, short-lived, and by the middle of winter there were no significant differences in tiller numbers, tiller weights or dry matter production overall between the two (Table 4.5).

The presence or absence of tall fescue had no major significant effect on barley growth and development (Table 4.2) and no influence on grain yield (Table 4.4). Up to a 100 kg ha^{-1} sowing rate of barley, grain yields increased with sowing rate (Table 4.4). But above 100 kg ha^{-1}, barley sowing rate had no significant effect on grain yields even though the trend was towards higher yields from higher sowing rates. At the low barley sowing rates (75 and 37.5 kg ha^{-1}), the barley crop did produce low grain yields, 2.6 - 2.8 t ha^{-1}, as found in a previous trial on the same farm (Hare *et al.*, 1990).

Once the barley harvest stubble was removed the undersown tall fescue resumed tillering confirming Langer's (1972) statement that grasses that have been shaded tiller at the same rate as unshaded grasses once shade is removed. However, in these trials undersown tall fescue must have tillered at nearly eight times the unshaded tall fescue rate in order to reach equal tiller numbers by June in trial 2 (Table 4.5). This massive increase in tillering capacity was, however, accompanied by reduced tiller weight compared with tillers of tall fescue sown alone, a situation which persisted to September in trial 2 but not in trial 1 (Table 4.6). In trial 1, in early spring (September), while there were no major differences in tall fescue production among undersown and sown alone treatments (Table 4.6), tiller numbers were considerably less but heavier than those found in trial 2.

At anthesis in trial 2, reproductive tiller numbers were reduced 40% by undersowing compared to tall fescue sown alone and by seed harvest undersown tall fescue treatments yielded 24% less seed than tall fescue sown alone (Table 4.7). In a similar trial sown the year previous to trial 1 (1988), barley sowing rates of 75 kg ha^{-1} or less had no effect on tall fescue reproductive tiller numbers (Hare and de Ruiter, unpubl. data) or on seed yield (Hare *et al.*, 1990). Seed yields also did not differ significantly in trial 1 due to low barley competition. All barley sowing rates of 100 kg ha^{-1} and above in trial 2 reduced tall fescue seed yields to a similar level, significantly below yields produced by tall fescue sown alone.

The fact that no vegetative tiller number differences occurred among undersown treatments and tall fescue sown alone in June and September in trial 2, but that significant differences in reproductive tiller numbers were recorded at anthesis needs explanation.

Firstly, tall fescue tillers that form in winter and spring are often short-lived and only survive for a few days or weeks (Robson, 1968). It is the older tillers that form in the summer and early autumn that contribute most to seed yield in tall fescue (Robson, 1968). The lighter vegetative tillers in undersown treatments in trial 2 in June (Table 4.6) and September (Table 4.7) may have been very short-lived and had no chance to become reproductive.

Secondly, inadequate vernalization of young, vegetative tillers in undersown tall fescue may be another reason for the significant reduction in reproductive tiller numbers at anthesis and subsequent lower seed yield than tall fescue sown alone in trial 2. In contrast in trial 1, all tillers were of an equal weight in September, and therefore could have been of the same age and to have all received an equal amount of vernalization. It therefore appears that the larger and more numerous tillers found in undersown tall fescue at barley harvest in trial 1 compared to those in trial 2, enabled them to grow more rapidly before the onset of winter. Where the barley sowing rates were substantially increased in trial 2, the undersown tall fescue at barley harvest was considerably less vigorous than tall fescue at a similar stage in trial 1.

The results from these trials show that tall fescue seed crops can be successfully established under a spring-sown barley cover crop and produce seed the following summer. At sowing rates of 75 kg ha^{-1} or less tall fescue seed yields did not differ between undersown and pure-sown tall fescue crops. But, once the barley sowing rate increased above 100 kg ha^{-1}, shading significantly reduced tall fescue tiller numbers and their size to such an extent that even though tiller numbers did recover quite quickly during autumn and winter, they were unable to produce the number of reproductive tillers that pure-sown swards did. However, seed yields were only reduced by 24% by undersowing in trial 2, a considerably smaller reduction than the 61% decline in undersown tall fescue seed yields reported by Chastain and Grabe (1989).

Table 4.8 Gross margin analysis comparing undersown tall fescue and barley with tall fescue sown alone in 1992 from trial 2.

		$ ha⁻¹ Undersowing	Tall fescue
Gross revenue ha⁻¹*			
Tall fescue alone	1018 kg ha⁻¹ @ $2.30 kg⁻¹	—	2341
Undersowing			
Tall fescue	770 kg ha⁻¹ @ $2.30 kg⁻¹	1771	
Barley	5.99 t ha⁻¹ @ $260 t⁻¹	1,557	
Total income ha⁻¹		3328	2341
Direct costs ha⁻¹			
Cultivation		160	160
Seed			
Tall fescue	7.5 kg ha⁻¹ @ $6.50 kg⁻¹	49	49
Barley	150 kg ha⁻¹ @ $0.80 kg⁻¹	120	—
Drilling		60	30
Herbicides			
Combine	0.5 ℓ ha⁻¹ @ $38 ℓ⁻¹	19	19
2,4-D	1 ℓ ha⁻¹ @ $9 ℓ⁻¹	9	9
Nortron	4 ℓ ha⁻¹ @ $115 ℓ⁻¹	460	460
Dicamba	1 ℓ ha⁻¹ @ $19 ℓ⁻¹	19	19
2,4-D	1 ℓ ha⁻¹ @ $9 ℓ⁻¹	9	9
Spraying	2 x $19 ha⁻¹	38	38
Insecticide			
Phorate	$10 kg ha⁻¹ @ $8 kg⁻¹	80	—
Spraying	$18 ha⁻¹	18	—
Fungicide			
Tilt	1 ℓ ha⁻¹ @ $124 ℓ⁻¹	124	124
Spraying	$18 ha⁻¹	18	18
Fertiliser			
Cropmaster at sowing		75	—
Urea autumn and spring		150	150
Harvesting	$160 ha⁻¹	320	160
Seed cleaning			
Tall fescue only	$12 kg⁻¹ per 100 kg F.D.	120	180

	$ ha^{-1}	
	Undersowing	Tall fescue
Sacks for tall fescue		
$1.20 per sack 30 kg per sack	30	41
Barley cartage to malting company	50	-
Total costs ha^{-1}	1922	1460
Gross margin ha^{-1}	1406	881

* Prices in June 1992 from seed and agricultural trading companies.

Yields based on:

1. Undersown tall fescue yields in Table 4.7 (Trial 2). Mean of the three barley rates which were undersown.
2. Tall fescue alone yield from Table 4.7 (Trial 2).
3. Barley yields mean of the three sowing rates from Table 4.4 (Trial 2).

Chastain and Grabe (1988 and 1989) reported that it was more profitable to grow grass seed crops under cereal cover crops than to grow the grass alone. The profitability of undersowing tall fescue with barley was examined using data from trial 2. If the undersown tall fescue and barley yielded 770 kg ha^{-1} and 5.99 t ha^{-1} respectively and the tall fescue alone yielded 1018 kg ha^{-1} there is a gross margin advantage to undersowing of $525 ha^{-1} (Table 4.8) which makes undersowing particularly economic. Furthermore, the price and yield of malting barley and the yield of undersown tall fescue have to decline considerably before there is a disadvantage in undersowing tall fescue (Appendix 2.2a, 2.2b). Undersown tall fescue seed yields would have to decline to 50% lower than yields from pure sown stands before undersowing becomes less profitable than sowing tall fescue alone (Appendix 2.2b) Based on the tall fescue seed yields obtained above and considering that undersown tall fescue seed yields were 24% lower than yields from pure sown plots, undersowing still has a considerable economic advantage over sowing tall fescue alone.

In their economic analysis, Chastain and Grabe(1989) used data over a three year period, and because of compensatory second year seed yield increases in undersown tall fescue they were able to show that undersowing was more profitable than pure stands by US$130 ha^{-1}. However, if only first year seed yields are economically analysed then Chastain and Grabe(1989) may have recorded uneconomic returns from undersowing, particularly as first year seed yields were 61% less in undersown crops. They also failed to explain why second year seed yields of undersown tall fescue were greater than pure stands, a situation which is unlikely to occur normally. If the management of seed crops are idential after the first harvest then they usually produce approximately the same second year seed yield (Hare, 1992).

If moisture in the autumn is limiting, then undersown tall fescue would probably suffer a far larger seed yield reduction than the 24% found in trial 2. A reduction close to 61% as found by Chastain and Grabe (1989) in undersown tall fescue would be more likely. This is because the main tall fescue seed growing area in New Zealand (Canterbury), is a region considerably drier than the region where the present trials took place and unless irrigation is used tall fescue will most likely suffer during establishment from moisture stress caused by the competing cover crop. The tall fescue must have sufficient moisture and nutrients to rapidly grow and tiller before cover crop canopy shading stops tillering. Once the barley harvest stubble has been removed there must be adequate available moisture so that the undersown tall fescue can start to 'catch up' to the pure swards. Chastain and Grabe (1989) concluded that irrigation after the cereal harvest is needed to maximise the undersown grass tiller numbers in the autumn. If irrigation is used this does increase the costs of undersowing compared to sowing pure stands of tall fescue. Pure stands of tall fescue established in the spring are not likely to require any substantial period of irrigation to promote growth unless there was a summer drought.

The current research has shown that barley cover crops sown at sowing rates up to 75 kg ha^{-1} have no effect on undersown tall fescue seed yields but once barley sowing rates are above 100kg ha^{-1} undersown tall fescue seed yields are depressed.

Farmers may still prefer to sow tall fescue alone rather than undersow, so as to be guaranteed successful establishment, even though these studies have shown that undersowing only becomes uneconomic when seed yields decline by more than 50% compared to sowing tall fescue alone (Appendix 2.2b). However, the cash flow income from barley sowing rates above 100 kg ha^{-1} in the first summer may be attractive enough for many farmers to take the risk of undersown tall fescue first year seed yield depression by knowing that they will be compensated for by an increased income from the cover crop and undersowing tall fescue combination. The recommendation from the current research is that undersowing is an economic management practice for farmers to establish tall fescue seed crops.

Chapter 5

Post-harvest, autumn and winter management of tall fescue seed fields

5.1 INTRODUCTION

Field management after harvest is extremely important for perennial grass seed production in the following season because reproductive tillers for the next harvest are produced in the autumn and early winter, and accumulated straw, debris or stubble can seriously impair tiller development, thereby lowering seed yields (Youngberg and Wheaton, 1979).

In the US burning stubble and straw as soon as possible after harvest has increased tall fescue seed yields by more than 20% when compared with baling and removing only the straw (Youngberg, 1980). In perennial ryegrass, continuous burning was the only post-harvest treatment capable of maintaining seed yield over several years (Young *et al*. 1984). Burning or close cutting increases seed yield by removing the shading effect from post-harvest residue accumulation and allowing sunlight penetration into the grass canopy (Ensign *et al*. 1983), which results in a more rapid tiller emergence before the autumn. Ryle (1961) demonstrated that tillers of timothy that were shaded to less than 50% full sunlight either failed to initiate or their fertility was reduced by one half. In further studies, Ryle (1966) found that few cocksfoot tillers produced ears in less than 50% natural light.

The more open canopy created after post-harvest burning or close cutting allows more vigourous tillering in perennial grasses, better flower induction and many more panicles in the spring (Chilcote *et al.*, 1980). However, in the US and European seed growing areas livestock are usually not available. Sheep can graze stubble and post-harvest residue to ground level, and in New Zealand trials, Hare and Archie (1990) have shown that grazing was just as effective as burning in red fescue seed crops.

In the US and Europe there has been increasing concern about smoke pollution from crop stubble burning and it is increasingly likely that field burning will be banned. Yet studies have shown that in seed crops that are harvested for many years, cutting is not as effective as burning (Young *et al*., 1984a). Grazing sheep can get much closer to ground level than close cutting, effectively removing nearly as much stubble as burning. Post-harvest grazing therefore offers an alternative to burning.

In most trials reported on post-harvest management no cutting other than at post-harvest takes place. Furthermore, in some reported papers (e.g. Chilcote *et al*., 1980) it is not stated how soon after harvest the post-harvest cutting is done. In New Zealand, providing adequate moisture is available, the warm temperate climate allows the grass to grow vigorously after harvest. New Zealand farmers use sheep to control excessive autumn and winter growth and to provide additional income from grazing. Closing management studies have shown that tall fescue seed crops can be grazed until late winter (July - August) without depressing seed yields (Brown, Rolston, Hare and Archie, 1988).

Autumn cutting of perennial grass seed fields has increased both fertile tiller numbers and seed yields by allowing better light penetration to the tillers and increased survival of later spring elongating reproductive tillers (Meijer and Vreeke, 1988a). In these trials cutting after harvest was only done once. There has been no report on the combination of immediate post-harvest management, i.e. burning or cutting, followed by autumn and winter defoliation.

Grazing removes all the defoliated vegetation, whereas cutting can leave the defoliated vegetation on the seed field. This vegetation will decompose, but in the process light penetration to the base of the grass plants may be inhibited, preventing tiller development. In this study the combinations of immediate post-harvest burning, grazing and cutting, with autumn and winter grazing and cutting (no residue removal) were examined, to determine their effects on tiller development and seed yields.

Following rain in the autumn atrazine is used by many tall fescue seed growers to remove annual grasses, ryegrass and other broadleaf weed seedlings (Rolston and Archie, 1990). Atrazine also prevents the stand from becoming too dense and clumpy by removing tall fescue seedlings developing from shed seed. However, there may be different field reactions to atrazine depending on the type of post-harvest management and autumn-winter management used. This study also investigated the effect of atrazine and field management on tiller development and seed yield.

5.2 MATERIALS AND METHODS

The field trial was conducted at the AgResearch Grasslands farm 'Aorangi', Manawatu, New Zealand (latitude 40° 23' south) on a weakly leached, slowly accumulating, poorly drained, recent gley soil, from quartzo-feldspathic silty alluvium (Kairanga silt loam). The 'Grasslands Roa' tall fescue seed field was established in October 1988 at 7 kg ha^{-1} in 30cm rows. Before the field trial commenced seed harvests had been taken in December 1989 and January 1991 by combine harvester. Rainfall and soil temperatures (10 cm depth) were recorded at a meteorological station approximately 1000 metres from the trial site.

The trial was a randomised block design with the main plots (six post-harvest management treatments) 24 m x 3 m and the sub-plots (three autumn and winter management treatments) 8 m x 3 m, in right angle strips across the main plots. The treatments were replicated three times and the sub-plot strips randomised within each replication. The data were analysed as a randomised block design using the SAS statistical programme.

After the seed was combine harvested on 8 January 1991 the burnt plots were burnt to ground level on 9 January (fuel load was approximately 5600 kg DM ha^{-1} as determined from 2 x 0.25m^2 plots cut to ground level prior to burning). Sheep (1000 ha^{-1}) grazed the grazed plots to ground level in one day on 10 January.

The main plot treatments were:

1. Straw removed (10 cm stubble left) by a fine chop forage harvester on 9 January. (Plate 5.1a, b)
2. Straw removed (as above) and atrazine, 3 kg ai ha^{-1}, applied 26 April using a small powered gas sprayer with a 3 m boom width in 160 litres water ha^{-1}.
3. Straw removed by hand and the plot then hard grazed by sheep to 3-5 cm above ground level. (Plate 5.2a, b)
4. Straw removed by hand and the plot then hard grazed by sheep to 3-5 cm above ground level; atrazine applied on 26 April.
5. Stubble and residue burnt. (Plate 5.3)
6. Stubble and residue burnt; atrazine applied on 26 April.

The straw removal was to simulate baling of the combine harvester tailing straw. The main plots were then split three ways for autumn and winter grazing (Plate 5.4), autumn and winter cutting (residue left on the plot) (Plate 5.5) and no further grazing or cutting after post-harvest treatments (Plate 5.6). The designated plots were grazed on 28 February or cut on 5 March (**G.C.1.**); grazed on 23 March or cut on 26 March (**G.C.2.**); final grazed on 9 May or final cut on 10 May (**G.C.3.**). Grazing (500 sheep ha^{-1}) and cutting were done in one day and were not to ground level. Tiller lengths before and after each defoliation are recorded in the results. Nitrogen was applied by hand on 19 April (40 kg N ha^{-1}) and on 5 September 1991 (100 kg N ha^{-1}). Propiconazole (0.25 kg ai ha^{-1}) was applied on 1 November 1991 using a small gas powered sprayer which delivered 160 litres water ha^{-1}.

(a)

(b)

Plate 5.1 Removing straw (a) and stubble cutting to 10 cm (b)

(a)

(b)

Plate 5.2 **Sheep grazing harvest stubble (a) and stubble grazed down to 3-5 cm (b)**

Plate 5.3 Harvest stubble immediately after burning

Plate 5.4 **Sheep grazing autumn regrowth**

Plate 5.5 **Cutting autumn regrowth**

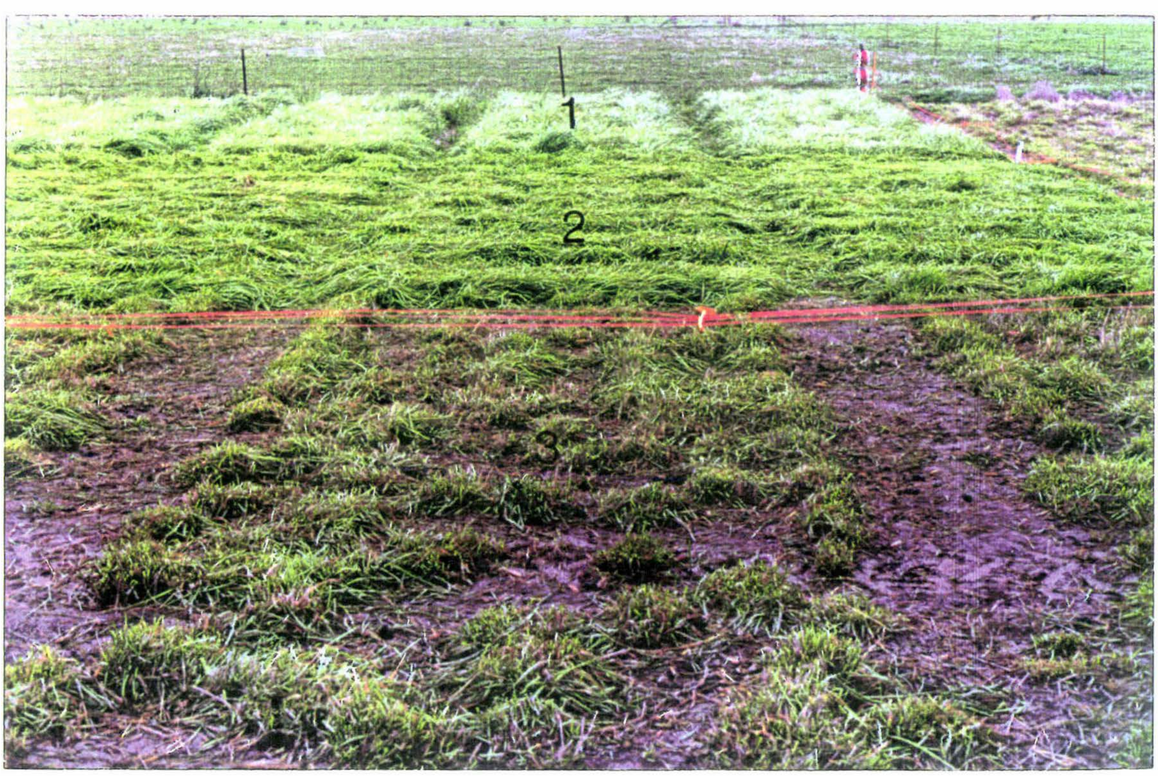

Plate 5.6 **Autumn defoliation showing undefoliated plots (1), cut plots (2) and grazed plots (3)**

Plate 5.7 **Grazed plots, two months after atrazine application. Sprayed plots (left) and unsprayed plots (right.)**

The following measurements were made:

1. Tiller number, tiller weight, tiller base diameter, tiller length and herbage dry weight were measured before each grazing and cutting and on 9 July and 2 September 1991. A 0.25 m^2 quadrant was cut to ground level from all plots and the following subsamples taken for the above measurements at all of the above times: tiller number from 100g fresh weight; tiller weight from 100 dried tillers; tiller diameter from 15 tillers (measured by Mitutoyo digimatic calipers); tiller length from 15 tillers (see 3.2.1.), dry weight from 100g fresh material.
2. Tiller length (as above) and dry matter (as above) were measured after each grazing and cutting, using subsamples from a 0.25 m^2 quadrant in each plot cut to ground level.
3. The percentage of light transmission to the plant base was measured by determining the difference between photosynthetically active radiation (PAR) detected at the soil surface by a one meter line quantum sensor (Li-Cor) relative to a point quantum sensor (Li-Cor) positioned above the canopy. Four measurements were made per plot, before and after each grazing and on 9 July and 2 September.
4. During anthesis a growth analysis was made on 27 November as detailed in Chapter 3 (see 3.2.1). At seed harvest on 23 December 1991 all seedheads from within 4 x 0.25 m^2 areas from each plot were cut, dried, threshed and cleaned (see 3.2.1). After cleaning, seed yields and one thousand seed weights (T.S.W.) were recorded (see 3.2.1) and both corrected to 14% seed moisture content.

5.3 RESULTS

5.3.1 Meteorological data

Rainfall and soil temperatures (10cm) for the trial year 1991 and the ten year farm average (1980 - 1990) are presented in Appendix 3.1. 1991 experienced a wetter than normal February, April and August, but March, May and June were drier than normal. Soil temperatures for April to August in 1991 were about 1°C warmer than normal, but for

November and December were nearly 2°C colder than normal.

Table 5.1 Dry matter before and after each defoliation in the autumn.

Autumn defoliation		Dry matter (kg ha^{-1})			
		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.1*	Before grazing	7370	5923	5162	1982
	After-grazing	5892	5010	4127	1327
G.C.2*	Before defoliation				
	No defoliation	9067	11717	9130	ns
	Cut	3965	9736	6275	3916
	Grazed	6441	6840	5161	ns
	LSD (P0.05)	2180	3908	3285	
	After defoliation				
	Cut	4548	4377	3445	ns
	Grazed	4187	3388	1855	2280
	LSD (P<0.05)	ns	ns	692	
G.C.3*	Before defoliation				
	No defoliation	11253	9859	8981	ns
	Cut	5972	6977	4962	ns
	Grazed	4715	3392	3753	ns
	LSD (P<0.05)	1759	ns	ns	ns
	After defoliation				
	Cut	6092	5916	4669	ns
	Grazed	5191	3061	3408	ns
	LSD (P<0.05)	ns	ns	ns	ns

* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

5.3.2. Autumn growth of tall fescue.

Dry matter *(Table 5.1)*

Following post-harvest treatments in early January over 5000 kg DM ha^{-1} grew in seven weeks (c. 100 kg DM ha^{-1} day^{-1}) until the first grazing at the end of February (G.C.1.). Before the first grazing (G.C.1.) significantly more dry matter was available in the straw removed plots compared to burnt plots. After autumn grazing, significantly ($P<0.05$) more dry matter was left on the plots that had straw removed compared to burnt plots, but these differences had disappeared by the second grazing (G.C.2.). The autumn cut plots were not measured after cutting at the first defoliation (G.C.1).

By the second defoliation (G.C.2.) over 9000 kg DM ha^{-1} had accumulated in the undefoliated plots. Before defoliation (G.C.2) the cut plots that had received different post-harvest treatments had significant differences in dry matter due to the uneven deposit of cut vegetation from the rotary slasher at G.C.1. At G.C.2. autumn cutting was more carefully done so that after defoliating by cutting the plots had similar amounts of vegetation left. The burnt plots were grazed harder than other plots, because significantly less dry matter (mainly residual stalks) was left on them compared to the other post-harvest treatments.

Growth was slower between the second and third defoliations. There were no significant differences in the amount of dry matter among the post-harvest treatments before or after the final defoliation (G.C.3). Even though the undefoliated plots had more dry matter on them by G.C.3. only in the straw removed treatment was this difference significant from that of the autumn cut or autumn grazed plots.

Tiller numbers *(Table 5.2)*

Burnt-autumn-cut plots at the second defoliation had significantly more tiller numbers than the straw removed- and grazed-autumn-cut plots. These differences had disappeared by the third defoliation where all treatments had similar tiller numbers. The undefoliated straw removed plots had fewer tillers before the second defoliation (G.C.2.) than undefoliated grazed and burnt plots, but these differences had also disappeared by the third defoliation (G.C.3.).

Table 5.2 **Tiller numbers before each defoliation in the autumn.**

Tiller numbers (m^{-2})					
Autumn defoliation		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.1*	No defoliation	2797	2834	2493	ns
G.C.2*	No defoliation[1]	2450	3324	3334	868
	Cut[1]	1959	2216	2665	243
	Grazed[1]	2312	2935	2561	ns
	LSD (P0.05)	ns	694	ns	
G.C.3*	No defoliation[2]	2429	3017	2614	ns
	Cut[2]	2941	2965	2678	ns
	Grazed[2]	3123	3460	3323	ns
	LSD (P<0.05)	ns	ns	ns	

1 treatments applied at G.C.1: data recorded before G.C.2
2 treatments applied at G.C.2: data recorded before G.C.3
* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

***Tiller length** (Table 5.3)*
With the exception of the grazed post-harvest plots, undefoliated plots had reached a maximum tiller length of over 50 cm before the first defoliation. This length remained fairly constant up to the third defoliation. Sheep grazed the burnt plots to a shorter height each time, but differences were only significant before the second defoliation. Grazing at G.C.1. was more lax compared to the harder grazing intensities at G.C.2. and G.C.3., with longer tillers remaining after G.C.1. than either G.C.2. or G.C.3..

The tillers in the defoliated plots were significantly shorter in length than undefoliated tillers before the second and third defoliation. Tillers in the burnt-autumn-grazed plots were half the length of the tillers in the burnt-autumn-cut plots following the second defoliation. After the third autumn-grazing tillers in the grazed autumn-grazed plots were significantly shorter than grazed autumn-cut plots.

Tiller weight *(Table 5.4)*

Immediate post-harvest treatments had no effect on tiller weight. After G.C.1. and before G.C.2. autumn-cut plot tiller weights were significantly less than undefoliated plot tiller weights in the straw removed and burnt post-harvest plots. The first defoliation (G.C.1.) did not significantly lower tiller weight in the autumn-grazed plots compared to undefoliated plot tiller weights, when measured before the second defoliation (G.C.2.).

After G.C.2. tiller weights in the autumn-cut and autumn-grazed plots before G.C.3. were between quarter to half the weight of tillers in the undefoliated plots.

Tiller diameter *(Table 5.5)*

Before the second defoliation, tillers from grazed post-harvest plots which had not been autumn defoliated were significantly smaller in diameter than tillers from grazed post-harvest autumn-grazed plots. Before the second defoliation tillers from grazed post-harvest plots that had been autumn-grazed were greater in diameter than tillers from undefoliated plots, while before the third defoliation tillers from grazed post-harvest plots that had been autumn-cut, were significantly greater in diameter than tillers from grazed post-harvest plots that had been autumn-grazed.

Table 5.3 Tiller length before and after each defoliation in the autumn.

Tiller length (cm)					
Autumn treatments		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.1*	Before grazing	53.4	42.9	53.7	9.5
	After grazing	36.9	23.6	20.8	5.9
G.C.2*	Before defoliation				
	No defoliation	56.1	59.3	51.9	ns
	Cut	29.4	35.8	32.0	ns
	Grazed	37.0	40.8	30.3	8.6
	LSD (P0.05)	7.8	5.3	13.3	
	After defoliation				
	Cut	23.7	14.1	19.2	ns
	Grazed	14.6	13.9	7.6	ns
	LSD (P<0.05)	ns	ns	8.1	
G.C.3*	Before defoliation				
	No defoliation	56.1	53.1	54.4	ns
	Cut	29.5	31.0	34.8	ns
	Grazed	27.5	21.0	21.7	ns
	LSD (P<0.05)	5.9	10.3	9.7	
	After defoliation				
	Cut	20.9	19.1	15.3	ns
	Grazed	14.0	8.5	7.6	ns
	LSD (P<0.05)	ns	3.5	ns	

* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

Table 5.4 Tiller weight before each defoliation in the autumn.

Tiller weight (g)					
Autumn treatments		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.1*	No defoliation	0.280	0.217	0.210	ns
G.C.2*	No defoliation[1]	0.302	0.277	0.247	ns
	Cut[1]	0.129	0.197	0.146	ns
	Grazed[1]	0.201	0.194	0.171	ns
	LSD (P0.05)	0.141	ns	0.086	
G.C.3*	No defoliation[2]	0.436	0.281	0.302	ns
	Cut[2]	0.176	0.181	0.164	ns
	Grazed[2]	0.119	0.089	0.100	ns
	LSD (P<0.05)	0.070	0.144	0.096	

1 treatments applied at G.C.1: data recorded before G.C.2
2 treatments applied at G.C.2: data recorded before G.C.3
* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

Table 5.5 **Tiller diameter before each defoliation in the autumn.**

		Tiller diameter (mm)			
Autumn treatments		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.2*	No defoliation[1]	2.39	2.05	2.59	0.45
	Cut[1]	2.55	2.60	2.64	ns
	Grazed[1]	2.30	2.70	2.31	ns
	LSD (P0.05)	ns	0.65	ns	
G.C.3*	No defoliation[2]	3.42	2.70	2.90	ns
	Cut[2]	2.59	3.13	2.84	ns
	Grazed[2]	2.90	2.30	2.33	ns
	LSD (P<0.05)	ns	0.71	ns	

1 treatments applied at G.C.1: data recorded before G.C.2
2 treatments applied at G.C.2: data recorded before G.C.3
* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

5.3.3 Winter growth of tall fescue

Dry matter *(Table 5.6)*

Nearly 13 tonnes ha^{-1} of dry matter had accumulated in the undefoliated plots by 9 July. Defoliated plots had one-half to one-third less dry matter than undefoliated plots, and there was no significant difference between autumn-cutting and autumn-grazing. Autumn-cut plots without atrazine produced significantly more dry matter than autumn-cut plots with atrazine (Table 5.7), but atrazine did not affect dry matter production in undefoliated or autumn-grazed plots (Plate 5.7; Table 5.7).

Tiller numbers *(Table 5.6)*

There were no significant differences in tiller numbers among treatments, but there was a significant interaction ($P<0.02$) with tiller numbers being reduced by atrazine in autumn-defoliated plots (Table 5.7). In the autumn-cut plots tiller numbers increased from 2860 in May (Table 5.2; G.C.3.) to 4660 in July (Table 5.7), but with atrazine, numbers declined to 2790 (Table 5.7). Likewise, in the autumn-grazed plots tiller numbers increased from 3300 in May (Table 5.2; G.C.3.) to 4700 in July, but with atrazine numbers declined to 2390 in July (Table 5.7).

Tiller weight *(Table 5.6)*

Defoliated plots had significantly lighter tillers than undefoliated plots. Atrazine did not affect tiller weights (Appendix 3.2).

Tiller length *(Table 5.6)*

Defoliated plots were still significantly shorter in tiller length than undefoliated plots. In the two months following the last defoliation, autumn-cut plots grew 8 cm in length and autumn-grazed plots grew 9.6 cm in length. Atrazine did not affect tiller lengths (Appendix 3.2).

Tiller diameter *(Table 5.6)*

Undefoliated plots had significantly thicker tiller diameters than in defoliated plots. Atrazine did not affect tiller diameter (Appendix 3.2).

Table 5.6 **Percentage light interception, dry matter, tiller numbers, tiller weight, tiller length and tiller diameter of tall fescue, 9 July 1991.**

Defoliation	Post-harvest management			LSD (P<0.05)
	Straw removed	Grazed	Burnt	
		Dry matter (kg ha^{-1})		
No defoliation	12855	12858	13147	ns
Cut	5867	6195	5300	ns
Grazed	5030	3542	3637	ns
LSD (P<0.05)	3442	3570	3400	
		Tiller number m^{-2}		
No defoliation	2400	3057	3139	ns
Cut	4202	3606	3365	ns
Grazed	4208	3202	3242	ns
LSD (P<0.05)	ns	ns	ns	
		Tiller weight (g)		
No defoliation	0.364	0.319	0.392	ns
Cut	0.106	0.119	0.110	ns
Grazed	0.070	0.079	0.064	ns
LSD (P<0.05)	0.111	0.084	0.168	
		Tiller length (cm)		
No defoliation	58.9	57.9	61.2	ns
Cut	26.0	27.4	36.4	ns
Grazed	21.3	20.2	17.4	ns
LSD (P<0.05)	9.7	12.8	12.8	
		Tiller diameter (mm)		
No defoliation	3.28	3.25	3.68	ns
Cut	2.54	2.71	2.56	ns
Grazed	2.34	2.39	2.18	ns
LSD (P<0.05)	0.45	0.84	0.66	
		% light interception		
No defoliation	97.9	95.6	97.6	ns
Cut	87.4	82.7	84.8	ns
Grazed	43.5	36.6	36.0	ns
LSD (P<0.05)	13.6	11.6	11.2	

Table 5.7 Effect of atrazine upon dry matter and tiller numbers of tall fescue 9 July 1991.

	Atrazine		
Autumn defoliation	Nil	Applied	LSD (P<0.05)
		Dry matter (kg ha^{-1})	
No defoliation	14060	11847	ns
Cut	6414	5160	1242
Grazed	4860	3279	ns
LSD (P<0.05)	3206	2025	
		Tiller numbers m^{-2}	
No defoliation	3015	2715	ns
Cut	4659	2790	1292
Grazed	4708	2393	1133
LSD (P<0.05)	1387	ns	

5.3.4 Light interception during autumn, winter and spring

By the time of the first defoliation light interception was over 90% in the undefoliated plots (Table 5.8). This interception increased slightly by the second defoliation in late-March but was not recorded in the undefoliated plots for the next two defoliations, as dry matter and tiller length remained constant (Tables 5.1 and 5.2 respectively).

Grazing let more light reach the plant base than cutting after the third defoliation (G.C.3.). Significantly more light reached the plant base following grazing in the burnt plots than grazing in the post-harvest grazed and straw removed plots after the first and third grazing and before the second and third grazing.

By early-July (Table 5.6), the cut plots were becoming increasingly shaded with no significant difference between undefoliated plot light interception and cut plot light interception. Grazed plots were still very open and were allowing over 50% of the light to reach the plant bases at this time.

Table 5.8 **Percentage of light intercepted before reaching the tall fescue plant base before and after each defoliation.**

		Light Interception (%)			
Autumn defoliation		Post harvest management			
		Straw removed	Grazed	Burnt	LSD (P<0.05)
G.C.1*	After defoliation				
	No defoliation	95.0	92.0	91.3	ns
	Cut	70.4	68.9	73.2	ns
	Grazed	77.4	72.1	53.7	15.67
	LSD (P<0.05)	5.68	ns	17.05	
G.C.2*	Before defoliation				
	No defoliation	96.0	94.2	93.1	ns
	Cut	84.5	79.3	78.0	ns
	Grazed	87.7	87.5	81.5	5.48
	LSD (P0.05)	5.94	7.70	8.52	
	After defoliation				
	Cut	70.6	68.9	60.8	ns
	Grazed	40.8	37.0	24.2	ns
	LSD (P<0.05)	ns	ns	24.4	
G.C.3*	Before defoliation				
	Cut	81.1	85.6	89.5	ns
	Grazed	86.8	74.2	65.7	12.8
	LSD (P<0.05)	ns	ns	17.7	
	After defoliation				
	Cut	70.9	72.3	73.0	ns
	Grazed	22.3	18.6	10.0	7.3
	LSD (P<0.05)	18.2	32.9	29.2	

* G.C.1. Grazed 28 Feb., cut 5 Mar.
G.C.2. Grazed 23 Mar., cut 26 Mar.
G.C.3. Grazed 9 May, cut 10 May.

5.3.5 Early spring growth of tall fescue (Table 5.9)

Table 5.9 **Dry matter, tiller numbers, tiller weight, tiller length, tiller diameter and light interception % of tall fescue, 2 September 1991**

Autumn Defoliation	Post-harvest management			LSD (P<0.05)
	Straw removed	Grazed	Burnt	
		Dry matter (kg ha^{-1})		
No defoliation	14947	13907	12358	ns
Cut	7045	6433	8630	1213
Grazed	7192	6837	8218	ns
LSD (P<0.05)	3137	4153	ns	
		Tiller number m^{-2}		
No defoliation	2871	3307	2938	ns
Cut	4094	3061	4135	ns
Grazed	4782	6021	4934	ns
LSD (P<0.05)	895	1350	1415	
		Tiller weight (g)		
No defoliation	0.413	0.310	0.332	ns
Cut	0.147	0.181	0.171	ns
Grazed	0.128	0.094	0.141	ns
LSD (P<0.05)	0.119	0.110	0.121	
		Tiller length		
No defoliation	58.1	48.4	56.6	ns
Cut	41.0	46.9	44.4	ns
Grazed	38.5	34.2	39.2	ns
LSD (P<0.05)	11.7	10.8	10.4	
		Tiller diameter (mm)		
No defoliation	3.39	2.97	3.19	ns
Cut	2.37	2.47	2.61	ns
Grazed	2.32	1.91	2.17	0.35
LSD (P<0.05)	0.62	0.52	0.56	
		% light interception		
No defoliation	98.2	97.1	96.3	ns
Cut	94.7	92.8	95.3	3.4
Grazed	84.1	73.4	69.2	ns
LSD (P<0.05)	6.6	7.9	13.2	

By the beginning of September the effects of atrazine had disappeared and there were no significant differences among atrazine treatments (Appendix 3.3). There were also only some very minor differences between post-harvest management treatments. Burnt plots that had been autumn-cut had more dry matter than straw removed or grazed plots which had been autumn-cut.

Plots that had not been autumn-defoliated had more dry matter, but a smaller number of heavier, longer and larger diameter tillers than defoliated plots, particularly those plots that had been autumn-grazed. Tillers from the autumn-grazed tall fescue plots were similar to those from the autumn-cut tall fescue, except for the grazed post-harvest plots, where tiller numbers were greater and tiller lengths shorter in autumn-grazed tall fescue compared to autumn-cut tall fescue. By September, autumn-grazed tall fescue was also still allowing more light to reach the base of the tillers than either the non-defoliated or autumn-cut plots, in which there was almost total light interception further up the plant canopy.

5.3.6 Seed yield components and seed yield.

At anthesis the post-harvest treatments only affected reproductive tiller numbers in plots that had been cut in the autumn (Table 5.10). Reproductive tillers in plots that had straw removed after harvest and were then later autumn-cut, produced 30% fewer reproductive tillers than plots that had been burnt and then autumn-cut later. Autumn defoliation significantly reduced the number of spikelets per tiller at anthesis compared to undefoliated plots, but had no effect on reproductive tillers and florets per spikelet.

At seed harvest post-harvest treatments had no effect on seed yields and T.S.W. or seeds per spikelet (Table 5.11). Seed yields were only reduced in one autumn treatment where the plots had straw removed at harvest and were then later autumn-cut. Autumn-grazing had no significant effect on seed yields.

Table 5.10 Reproductive components at anthesis.

Autumn treatments	Post-harvest management			LSD (P<0.05)
	Straw removed	Grazed	Burnt	
		Reproductive tillers m^{-2}		
No defoliation	513	551	593	ns
Cut	426	504	619	115
Grazed	510	574	540	ns
LSD (P<0.05)	ns	ns	ns	
		Spikelets per tiller		
No defoliation	99	96	103	ns
Cut	80	83	85	ns
Grazed	83	76	77	ns
LSD (P<0.05)	17	11	17	
		Florets per spikelet		
No defoliation	6.5	6.3	6.2	ns
Cut	6.5	6.1	6.3	ns
Grazed	6.2	6.2	6.2	ns
LSD (P<0.05)	ns	ns	ns	

Table 5.11 Seed yield, one thousand seed weight (T.S.W.) and seeds per spikelet.

Autumn treatments	Post-harvest management			LSD (P<0.05)
	Straw removed	Grazed	Burnt	
		Seed yield (kg ha^{-1})		
No defoliation	652	662	646	ns
Cut	574	663	610	ns
Grazed	675	582	703	ns
LSD (P<0.05)	89	ns	ns	
		T.S.W. (g)		
No defoliation	2.17	2.07	2.17	ns
Cut	2.04	2.12	2.12	ns
Grazed	1.99	2.02	2.05	ns
LSD (P<0.05)	ns	ns	ns	
		Seeds per spikelet		
No defoliation	1.68	1.65	2.05	ns
Cut	1.21	1.34	1.83	ns
Grazed	1.25	1.51	1.21	ns
LSD (P<0.05)	ns	ns	ns	

There was a significant interaction (P<0.01) with atrazine and autumn defoliation on reproductive tillers with atrazine lowering the number of reproductive tillers in autumn-grazed plots by 28%. However, atrazine did not significantly reduce seed yield and the other seed components (Table 5.12).

Table 5.12 Effect of atrazine upon reproductive tillers, spikelets and florets at anthesis and seed yield at harvest.

Autumn treatments	Atrazine		
	Nil	Applied	LSD (P<0.05)
	Reproductive tillers m^{-2}		
No defoliation	527	579	ns
Cut	523	510	ns
Grazed	629	453	109
	Spikelets per tiller		
No defoliation	97	102	ns
Cut	82	83	ns
Grazed	75	82	ns
	Florets per spikelet		
No defoliation	6.3	6.3	ns
Cut	6.1	6.4	ns
Grazed	6.1	6.2	ns
	Seed yield (kg ha^{-1})		
No defoliation	645	662	ns
Cut	634	594	ns
Grazed	660	645	ns
	T.S.W. (g)		
No defoliation	2.12	2.15	ns
Cut	2.13	2.04	ns
Grazed	2.05	1.98	ns
	Seeds per spikelet		
No defoliation	1.68	1.92	ns
Cut	1.44	1.45	ns
Grazed	1.46	1.14	ns

5.4 DISCUSSION

All three post-harvest management treatments, i.e. burning, grazing and cutting (with straw removal) produced the same seed yields 11 months later. This result is best explained by the growth of tall fescue after post-harvest treatments and the climate of the region.

From 9 January (post-harvest treatments) to 28 February 1991, when the first measurements of regrowth were taken, 160 mm of rain fell and the soil temperature averaged a warm 19°C. Under these conditions regrowth was very rapid with over 7000 kg DM ha^{-1} produced in the plots which were cut, nearly 6000 kg DM ha^{-1} in grazed plots and just over 5000 kg DM ha^{-1} in burnt plots (Table 5.1). Tiller numbers averaged 2700 m^{-2} at 28 February (Table 5.2) and over 90% of the light was being intercepted before reaching the plant base (Table 5.8).

In Oregon, where most of the published work on post-harvest management has been carried out, the dry summer results in little growth of perennial grasses after harvest. The grasses are almost dormant (Youngberg, 1980). It is therefore not until the autumn when rain falls that tillering commences in Oregon, whereas in the North Island of New Zealand tillering can commence in mid-summer, immediately after harvest.

Burning did remove significantly more harvest stubble than grazing or cutting, but the warm moist weather probably allowed any debris remaining on the grazed and cut plots to decompose quickly and not impede tiller development. A treatment of leaving all the straw on the field was not chosen because farmers in New Zealand always remove the straw by either grazing, baling or burning. However, a comparison of these three methods had not been done before.

There was no advantage in burning compared to cutting, which is in contrast to results found in the US (Chilcote *et al.,* 1980; Youngberg, 1980; Young *et al.*, 1984a). Immediate post-harvest grazing was just as effective as burning or cutting, a result also found earlier in red fescue seed crops at the same locality (Hare and Archie, 1990). Therefore in this region of New Zealand if burning was outlawed because of smoke pollution, grazing or baling off the straw would remain very effective post-harvest management treatments. And indeed, there are probably many farmers in New Zealand who have never burnt their tall fescue seed harvest stubbles. Rather, baling the straw for either their own use or resale, and then grazing the stubble has been their main management practice.

The autumn to early-winter defoliations were investigated because it was believed that shading from the large bulk of tall fescue regrowth from harvest would impede tiller growth and also make tillers less receptive to vemalization (Chilcote *et al.*, 1980; Ensign *et al.*, 1983). And indeed, a large amount of vegetation did grow in the undefoliated plots; 6000 kg DM ha^{-1} by the end of February, nearly 10000 kg DM ha^{-1} by the end of March (Table 5.1) and nearly 13,000 kg DM ha^{-1} by early July (Table 5.6). There was also by the end of February almost total shading at the plant bases in undefoliated plots (Table 5.7). Ryle (1961, 1966, 1967) predicted that under these shaded conditions new tillers would either fail to initiate or their reproductive fertility would be reduced by one half. However, this did not happen as undefoliated plots produced the same number of reproductive tillers as defoliated plots and these tillers produced more spikelets. The reason for this is that the fertile tillers were probably produced in mid-summer, January to February, when they received full sunlight prior to canopy closure in late-February, and through the autumn and winter their leaves and stems were receiving sunlight in the upper canopy.

Tiller numbers in undefoliated plots from the end of January (Table 5.2) to September (Table 5.9) showed very little variation, averaging between 2500 and 3000 tillers per m^2. Because of the shaded conditions in the undefoliated plots new tillers did not appear, whereas in the defoliated plots, which received plenty of autumn and winter sunlight down to the plant bases, over 4000 tillers per m^2 had been produced in most plots by September (Table 5.9).

However, there was absolutely no advantage in producing these high number of winter tillers, as only approximately 12% of tillers present in the spring became reproductive

(Table 5.10). This was probably because the new tillers had not received a sufficient length of vernalization to become reproductive (Chapter 6), or were devernalized, or died (Robson,1968). Young, new winter tillers die most frequently in the spring, up to 4.5 tillers per plant per day (Robson, 1968). However, if this was the case, why didn't all the 2500 - 3000 tillers per m^2 in the undefoliated plots in March (Table 5.2) become reproductive, because all of these tillers should have received the full period of winter vernalization? Instead only between 18% - 22% became reproductive (c. 550 reproductive tillers per m^2, Table 5.10).

This may be explained in two ways. Firstly, Ryle (1961) stated that if cocksfoot tillers were shaded to less than 50% full sunlight they may fail to initiate. In the undefoliated plots many of the 2500 or more tillers may have been shaded by other tillers so that perhaps only a proportion of tillers may have received full sunlight throughout the winter and then initiated. Secondly, tillers were not identified and there may have been some tiller death and tiller renewal (Robson, 1968; Hill and Watkin, 1975). Robson(1968) found that over 50% of all tall fescue tillers produced died without flowering, and many tillers died within only a few days or weeks after they first appeared. The reproductive tillers in the undefoliated plots at anthesis would probably have been the older tillers formed back in January and February. Because of their longer period of differentiation they were likely to produce more spikelets per tiller (Robson, 1968; Hill and Watkin, 1975; Chilcote *et al.*, 1980; Young *et al.*, 1984a). However, this needs to be confirmed.

There may also be a ceiling to the number of reproductive tillers per m^2 that tall fescue plants can produce and support. In this trial and the trials in Chapters 3 and 4, the average number of reproductive tillers per m^2 was approximately 500. It appears that numbers above this figure are difficult to achieve, possibly because the nutrient resources are just not sufficient to support 1000 or 2000 reproductive tillers per m^2. The maximum number of tall fescue reproductive tillers per m^2 reported from trials overseas has been between 400 and 600 per m^2, e.g. 404 (Watson and Watson, 1982, U.S), 417 (Albeke, Chilcote and Youngberg, 1983, U.S.), 504 (Suzuki, 1989, Japan) and 598 (Chastain and Grabe, 1989, U.S.).

In detailed studies on spaced potted plants of S170 tall fescue Robson, (1968) showed that only about 30% of all vegetative tillers flowered. Very few tillers flowered that had formed during the winter and Robson (1968) suggested that this was either due to insufficient vernalization or devernalization by higher spring temperatures. Furthermore, Robson (1968) found that many tall fescue tillers died in early spring, particularly secondary tillers. These secondary tillers presumably died either from a lack of light or from starvation because they were short of carbohydrates and other nutrients such as nitrogen, and could not obtain an adequate supply from the parent tillers to which they are organically connected (Robson, 1968).

Robson (1968) argued that it would be difficult to use management to increase the number of late-summer formed tillers after seed harvest in order to increase reproductive tillers and thereby increase seed yields at the next seed harvest. An increase in vegetative tiller population in late-summer would lead to an increase in the number of deaths in the autumn due to competition for light and nutrients (Robson, 1968). It appears there is a ceiling to the number of reproductive tillers tall fescue can support, and this number can not be increased easily without changing the genetic constitution of tall fescue (Robson, 1968). Robson (1968) found that no tillers in tall fescue lived on average more than one year. Therefore, of the 2500 - 3000 tillers present in undefoliated plots in late-February in the present study (Table 5.2), it seems likely that many would presumably have died (to be replaced by new tillers) in the autumn, after living only a few days or a few weeks.

While undefoliated plots produced more spikelets per tiller they tended to produce lighter seed possibly because of insufficient nutrients to support larger seed numbers. This does, however, remain speculation at this stage.

There was no advantage from cutting or grazing during the autumn and early winter in this trial. While more light was received at the plant base in cut and grazed plots and more vegetative tillers did emerge, no more reproductive tillers were produced at anthesis, and seed yields were no greater than in any of the undefoliated plots.

However, there was also no disadvantage from cutting (except in one treatment) or grazing and it therefore may be an advantage for farmers to graze until the autumn and early-winter (Green and Evans, 1957) as extra income would be provided from grazing animals. Grazing will also control volunteer growth around fence lines and headlands. Also, grazing will almost certainly result in less bulk to cut at harvest, which may mean quicker field drying before harvesting. Later winter grazing does, however, reduce seed yields, particularly if the crop is grazed close to ground level (Roberts, 1961; Williams and Boyce, 1978; Brown *et al.*, 1988).

Cutting in the autumn and early winter could be an economic disadvantage as running machinery across the field and using fuel would increase field costs without any increase in seed yields but there would be less bulk to thresh at harvest.

In environments similar to the trial site, growers therefore have an option to graze their fields until early-winter without fearing any loss of seed yield, or, they can let the tall fescue seed crop grow after immediate post-harvest management until the next seed harvest knowing that seed yields will not suffer. However, these results are from a single trial and results may differ from year to year and indeed from site to site. The trial is being repeated in identical form during 1992 at the same site and until these results are known, firm recommendations cannot be made.

Of major concern to seed growers in New Zealand is the amount of ryegrass seed contamination in their tall fescue seed crops. Atrazine, while not giving total control, can reduce ryegrass seed contamination levels in tall fescue seed to levels which allow seed lots to meet the certification standards required for Second Generation seed in New Zealand (Rolston and Archie, 1990). Furthermore, on heavier soils and under good rainfall, Roa tall fescue has tolerated atrazine rates of up to 4.5 kg ai ha^{-1} on a site near that used for these post-harvest trials (Rolston and Archie, 1990). In the present trial a lower atrazine rate of 3 kg ai ha^{-1} was chosen in case a dry winter occurred, in which case severe damage can occur to mature tall fescue plants (Rolston and Archie, 1990). This rate, however, was still almost twice that commonly used in Roa tall fescue seed crops (W. Archie, pers. comm.).

Atrazine initially removed the small tall fescue seedlings in defoliated plots so that by July 1991 (Table 5.7), cut and grazed plots with atrazine had approximately 2000 fewer tillers per m^2. These plots visually appeared to be more open and slightly yellow compared to non-sprayed plots (Plate 5.7). The lack of damage in undefoliated plots was probably because the shading effect of vegetation prevented seedling development from fallen seed so only strong mature tillers were present at the time of atrazine application. These strong tillers were apparently not susceptible to the root absorbed herbicide probably because of their deeper root depth than small seedlings. In contrast, the cut and grazed plots had many small tillers and seedlings present which were killed by the atrazine.

By allowing the field to become more open and less clumpy it was believed that more fertile reproductive tillers would emerge in atrazine treated plots than in untreated plots because of less competition from a mass of vegetative tillers. This did not happen. Rather, atrazine applied to autumn-grazed plots lowered reproductive tiller numbers by 28% but at the same time increased spikelets per tiller and seeds per spikelet by 9% and 16% respectively. Even though the increased spikelets per tiller and seeds per spikelet were insignificant, the increases may have been enough to compensate for low reproductive tiller numbers and allow, surprisingly, similar seed yields to be produced between atrazine treated and untreated plots that were autumn-grazed. Also the large number of reproductive tillers in the untreated plots may have produced a lot of light seed which separated off during seed cleaning.

Applying up to 3 kg ai ha^{-1} of atrazine is probably in excess of what can safely be applied in many seed growing regions, where drier autumns and winters can cause atrazine to severely damage tall fescue (Rolston and Archie, 1990). A reduction of 28% in reproductive tiller numbers could, without spikelet and seed number compensation, lower seed yields and so a lower rate would be recommended. In order to overcome problems from volunteer seedlings and other perennial grasses, it may also be advisable to leave the tall fescue seed crops undefoliated after immediate post-harvest management. The shading effect from the mid-summer to autumn growth of tall fescue may prevent many new tall fescue seedlings and other grass seedlings from growing and causing seedlot contamination. However, this theory remains speculative at this stage.

In the present trial, other grass contaminants were not present in the unsprayed plots. Atrazine therefore did not offer any advantages to non-spraying in this trial. However, if grass contaminants are present there would be an advantage in applying atrazine but there is no advantage in trying to increase seed yields from atrazine application.

This study has clearly shown that immediate post-harvest management is important for tall fescue seed crops and that either burning, grazing or straw removal can be used. However, subsequent autumn defoliation is not important for tall fescue seed production.

Chapter 6

Vernalization and juvenility in tall fescue

6.1 INTRODUCTION

It is commonly believed that tall fescue seedlings following seed sowing must pass through a juvenile stage during which the seedlings are unable to respond to vernalization and then reach a certain vegetative maturity before they can be vernalized. Bean (1970) showed that 4 - 5 week old tall fescue plants needed to produce about four leaves before they were able to respond to low temperature induction. Unfortunately in this experiment Bean (1970) did not state the temperatures used, though Langer (1972) and Calder (1966) both suggested that the most effective vernalizing temperature lay between 0 and 10°C. In another experiment Bean (1970) also implicated the existence of a juvenile phase by finding that 2 and 4 week old tall fescue seedlings took longer to be vernalized than 6 and 8 week old seedlings. However, the size of seedlings, number of leaves, and tiller length and weight were not mentioned. If the juvenile phase in tall fescue could be clearly defined in easily measurable botanical growth stages this would have implications for autumn sowing and autumn-winter defoliation of tall fescue. By knowing the length of the juvenile stage, the time of autumn sowing could be adjusted to allow plants to grow and pass through the juvenile stage before the onset of winter vernalizing conditions. Similarly, the timing of autumn-winter defoliation could be manipulated to ensure that tillers have time to regrow and pass through the juvenile stage in time to be vernalized before the winter ends.

The objectives of this trial were to attempt to more clearly define the juvenile phase in Grasslands Roa tall fescue in terms of easily measurable botanical growth stages and to study the duration of vernalization required at various growth stages to induce tillers to become reproductive.

6.2 MATERIALS AND METHODS

6.2.1 General

Grasslands Roa tall fescue plants were established in a potting mixture in 15 cm diameter pots at two week intervals from 13 June to 1 August 1991. The potting mixture used comprised 60% peat and 40% coarse sand with osmocote fertiliser (slow release fertiliser over 3-4 months, 1.5 kg cu m^{-1}, N (19), P (3), K (10); long release fertiliser over 12-14 months, 2.4 kg cu m^{-1}, N (18), P (2), K (9); dolomite lime, 3 kg cu m^{-1}; single superphosphate 1.5 kg cu m^{-1}; frittered trace elements 125 g cu m^{-1}). Three seeds were sown per pot, and, following establishment, plants (1st leaf stage) were hand-thinned to one plant per pot. The plants were grown in a heated glasshouse (average maximum daily temperature 30.6°C, average minimum daily temperature 12°C, average mean daily temperature 21.3°C) and on 15 August were transferred to a vernalization room (see 6.2.2).

The treatments were as follows:

1. **Plant age**

Seeds were sown in 50 pots at each time on 13 June, 27 June, 11 July, 25 July, and 8 August, to produce plant ages of 9, 7, 5, 3 and 1 week at time of transfer to the vernalization room (15 August).

2. **Vernalization time**

Plants were held in the vernalization room for 0, 10, 20, 30 or 40 days (0, 240, 480, 720 or 960 hours respectively).

3. **Replications**

At the time of vernalization the plants were divided into 7 replicates, with 1 plant constituting a replicate. (7 reps x 5 plant age x 5 vernalization times = 175 plants). The 35 plants from each plant age group were selected at random from the original 50 plants established per age group.

Beginning at plant emergence and continuing until plants had completed their vernalization treatment, the main stem and every tiller on each plant was tagged as it emerged from the leaf sheath using a different coloured rubber ring. Following vernalization, plants were removed to the glasshouse and tagging was discontinued. All tillers that emerged and were exposed to vernalization conditions were therefore identified.

Immediately prior to the vernalization treatment seven plants from each of the five plant age groups were destructively harvested. The number of tillers per plant were counted and measurements were made of tiller length (tip of longest extended leaf to the point where the lowest leaves were attached at soil level), tiller base diameter (using calibers) and tiller dry weight. Each of the five plant age groups were also categorised using a decimal code as for the cereal growth stages described by Zadoks, Chang and Konzak (1974) and further illustrated by Tottman and Broad (1987)(Plate 6.1; Table 6.1). This was in order that the growth stage of each plant group could be recognised by internationally accepted growth codes and illustrations.

Once they were returned to the heated glasshouse, vernalized plants and the control (unvernalized) plants were grown through until tillers reached anthesis. The plants received 0.2 g per pot of N, P, K, S, fertilizer (15, 10, 10, 7) and 0.1 g per pot of urea (46% N) on the 30 September 1991 and 7 November 1991. On 30 September 1991 the plants were sprayed with propinconazole (equivalent to 0.5 kg ai ha^{-1}) to prevent the spread of powdery mildew (*Blumeria graminis*). Plants were watered daily.

At their time of anthesis (Plate 8.2) individual reproductive tillers on each plant were cut and the number of spikelets per tiller and florets per spikelet determined (one spikelet at the base, middle and top of each tiller was counted to estimate floret numbers).

By the end of January all the reproductive tillers had flowered and had been harvested. The plants were then removed from the glasshouse and the trial ceased.

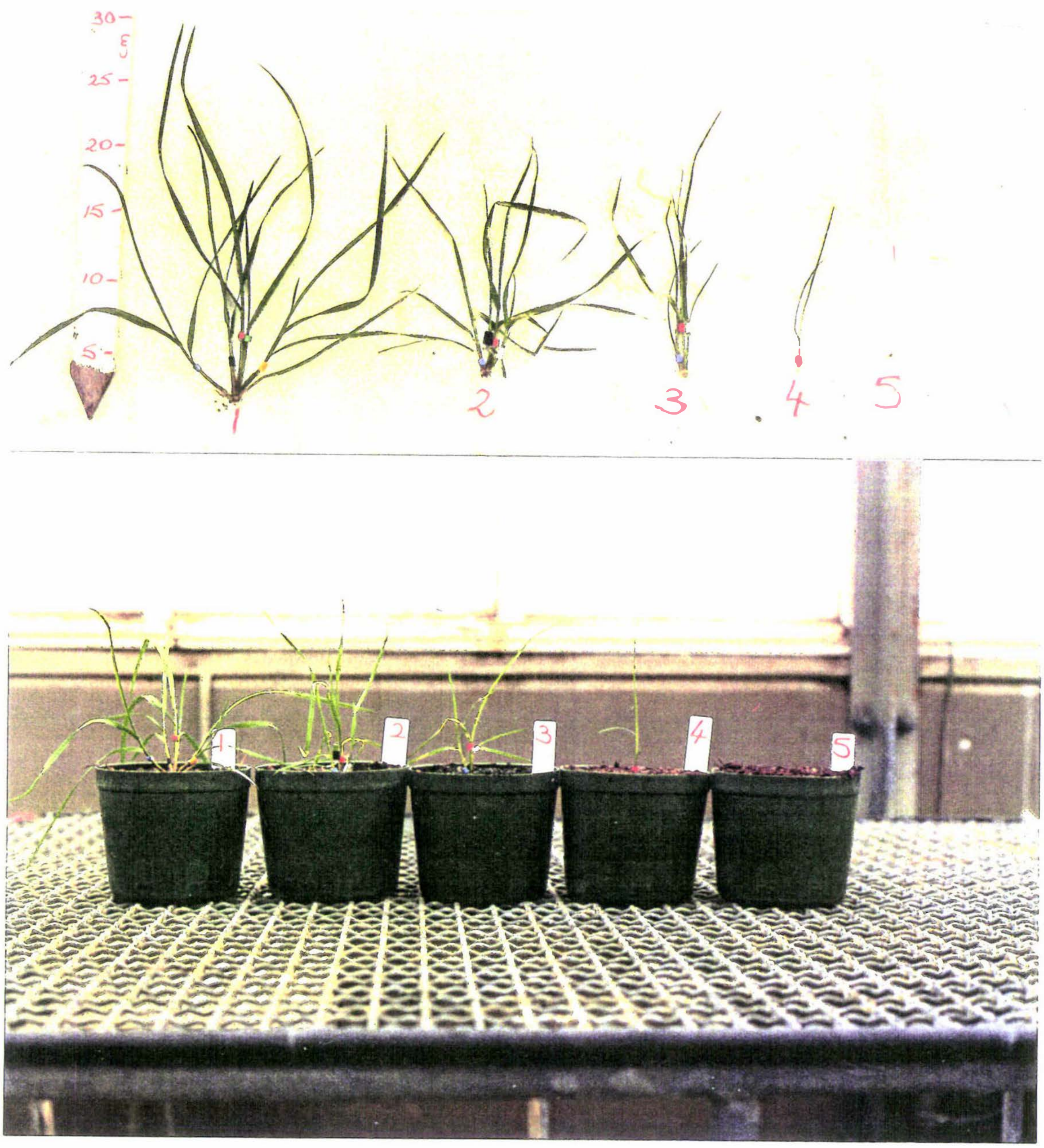

Plate 6.1 **Growth stages of tall fescue plants immediately prior to vernalization.**

1. 9 weeks after sowing
2. 7 weeks after sowing
3. 5 weeks after sowing
4. 3 weeks after sowing
5. 1 week after sowing

Table 6.1 Plant age and dry weight, cereal decimal code, botanical description number of tillers, length of tillers and weight and diameter of tillers prior to vernalization.

Growth stage	Plant age (weeks)	Decimal code*	Botanical description*	Plant dry weight grams	Tiller			
						Length (cm)	diameter (mm)	weight (g)
1	9	19, 27	Main shoot 7 tillers, 9 leaves unfolded	0.39	Main shoot	30.7	2.53	0.097
					Tiller 1	28.0	2.35	0.075
					2	25.9	2.04	0.053
					3	20.7	1.87	0.036
					4	22.4	2.36	0.045
					5	18.7	2.03	0.035
					6	16.0	1.80	0.024
					7	18.0	1.90	0.025
2	7	14, 24	Main shoot 4 tillers, 4 leaves unfolded	0.21	Main shoot	28.3	2.66	0.082
					Tiller 1	22.9	2.28	0.048
					2	21.3	2.14	0.039
					3	16.2	1.68	0.022
					4	16.8	1.94	0.020
3	5	13, 22	Main shoot 2 tillers, 3 leaves unfolded	0.072	Main shoot	21.5	1.97	0.041
					Tiller 1	16.5	1.45	0.017
					2	14.6	1.39	0.014
4	3	11, 20	Main shoot first leaf unfolded	0.001	Main shoot	9.6	0.83	0.001
5	1	05	Radicle emerged from seed	-	-	-	-	-

* Refer to Zadoks, Chang and Konzark (1974) and Tottman and Broad (1987).

6.2.2 Vernalization room conditions

The environmental conditions in the vernalization room are summarised as follows:-

Temperature (± 0.5°C)		Humidity (± 5% R.H.)	
Day	8°C	Day	75
Night	4°C	Night	75
Day length	8 hours		

The temperature day/night and night/day changeovers were of 2 hour duration, with the light switching on mid-way through the night/day changeover and switching off mid-way through the day/night changeover.

Lighting was as follows:-

Photosynthetic photon flux density (PPFD) (μmol $m^{-2}s^{-1}$) 345. The lighting system used consisted of 4 x 1000 Sylvania 'Metal-Arc' high pressure discharge lamps, together with 4 x 1000W Phillips tungsten iodide lamps (Warrington, Dixon, Robotham and Rook, 1978). Photosynthetically active radiation (PAR) was measured at standard trolley height (1 m) using a Li Cor 185 meter with a LI-190SE flat response sensor (WM^{-2}) and a LI-190S quantum sensor was used to measure the PPFD (μmol $m^{-2}s^{-1}$).

The CO_2 level was monitored but was uncontrolled, remaining within 310 - 370 ppm (ambient conditions). Air flow down through the plants was 0.3 - 0.5m sec^{-1} as measured with an Alnor Instruments thermoanemometer.

6.3 RESULTS

6.3.1 Growth stage prior to vernalization

The five plant growth stages used in this study are illustrated in Plate 6.1 and described in Table 6.1. Plant growth ranged from unemerged seeds (1 week after sowing) to plants with a main shoot and 7 tillers (9 weeks after sowing).

6.3.2 Growth during vernalization

Tillers tagged before vernalization produced virtually no new growth during the vernalization period. New tillers on plants at each growth stage did appear in the vernalization room and these were also tagged. In the first three growth stages approximately 4-5 new tillers emerged during 40 days vernalization. In the fourth growth stage 1-2 new tillers appeared and in the fifth stage only the main shoot with no leaves unfolded developed after 40 days vernalization.

6.3.3. Reproductive development

The 40 day vernalization period enabled the greatest number of plants to become reproductive (Table 6.2), although plants at growth stage 5 produced no reproductive tillers during this time. In growth stages 1 to 4, the percentage of plants which produced reproductive tillers after 40, 30, 20 or 10 days vernalization were 64, 14, 3.6 and 7% respectively. Surprisingly, 10% of the untreated control plants also produced reproductive tillers (Table 6.2).

With the exception of one plant, all other plants that had been vernalized in the seed stage (growth stage 5) did not produce reproductive tillers. The one plant that did produce reproductive tillers after 30 days vernalization had only the main shoot emerged before the completion of the vernalization period.

A far greater number of reproductive tillers were produced by 40 days vernalization (156 reproductive tillers) than by 30 days vernalization (33 reproductive tillers), 20 days vernalization (2 reproductive tillers), 10 days vernalization (8 reproductive tillers) or 0 days vernalization (15 reproductive tillers) (Table 6.2). All these tillers, however, did produce a similar number of spikelets per tiller and florets per spikelet regardless of duration of vernalization exposure and growth stage prior to vernalization (Table 6.2). Even the control plants produced a similar number of spikelets per tiller and florets per spikelet as plants receiving vernalization.

Many of the tillers that became reproductive had not emerged before the onset of the vernalization period (Figure 6.1). From the total number of tillers that became reproductive from plants receiving 40 days of vernalization, 35.5% had emerged before vernalization, 28.4% emerged during vernalization and 36.1% emerged after vernalization. As the plants decreased in age, growth stage 2 to 3 to 4, a far greater proportion of reproductive tillers (53%) emerged after the vernalization period compared to growth stage 1 (6%) (Figure 6.1).

Emerged tillers that received the full 40 days vernalization produced 48% more spikelets per tiller, 24% more florets per spikelet and 84% more florets per tiller than reproductive tillers which had emerged after the vernalization period (Figure 6.2) but may have initiated under vernalization. Tillers that emerged during the vernalization period produced only 6% fewer spikelets per tiller, 6% fewer florets per spikelet and 11% fewer florets per tiller than tillers receiving the full 40 days vernalization (Figure 6.2).

Table 6.2 Reproductive development of plants vernalized at various growth stages.

Growth Stage	Vernalization period (days)					
	40	30	20	10	0	
	Total number of plants that produced reproductive tillers from 7 plants per treatment					
1	5	1	0	2	2	
2	4	0	1	0	1	
3	5	2	0	0	1	
4	4	1	0	0	0	
5	0	1	0	0	0	
	Total number of reproductive tillers from 7 plants per treatment					
1	53	1	0	8	7	
2	36	0	2	0	4	
3	45	17	0	0	4	
4	22	2	0	0	0	
5	0	13	0	0	0	
	Spikelets per reproductive tiller					
1	76	41	0	51	85	
2	76	0	72	0	97	
3	78	86	0	0	66	
4	99	83	0	0	0	
5	0	84	0	0	0	
	Florets per spikelet					
1	4.0	5.3	0	5.4	3.6	
2	5.2	0	3.2	0	3.7	
3	5.8	4.5	0	0	3.5	
4	5.8	3.5	0	0	0	
5	0	5.6	0	0	0	

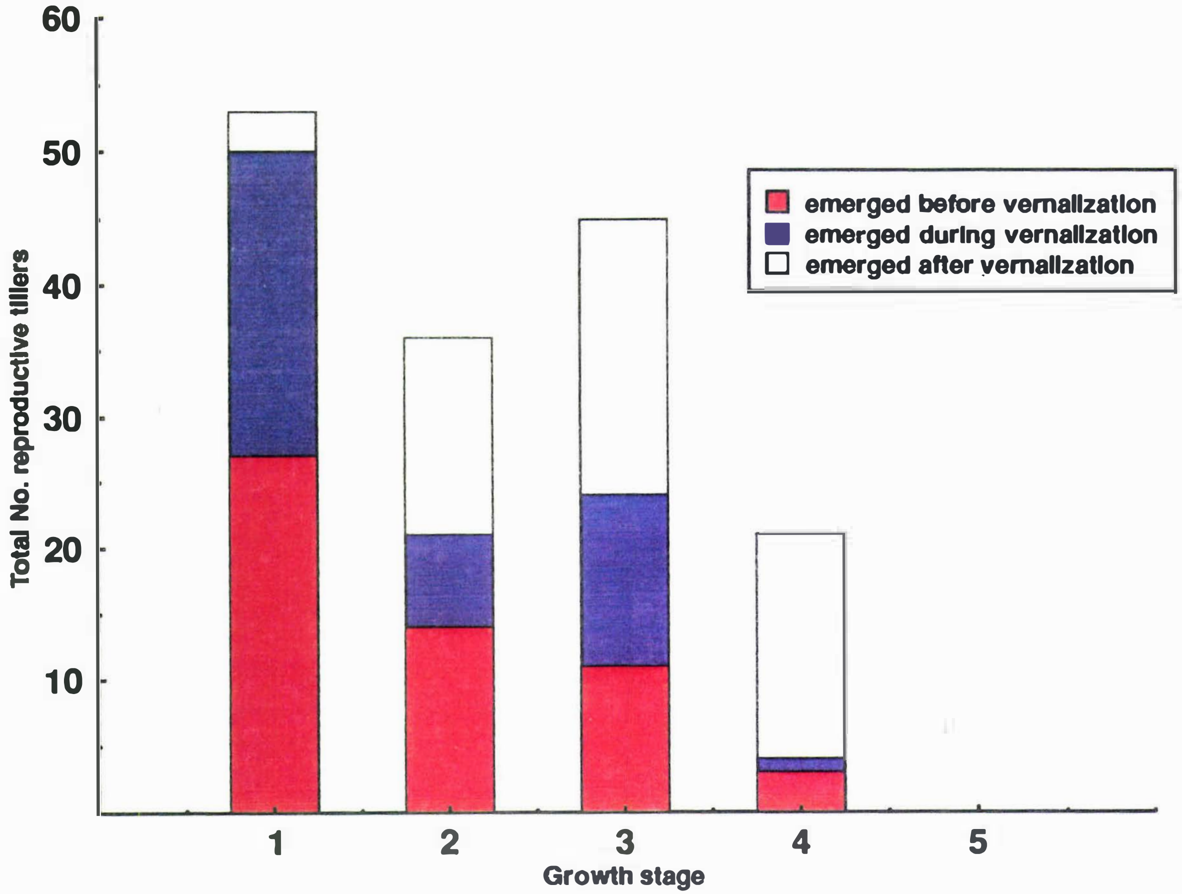

Figure 6.1 Proportion of reproductive tillers produced from plants receiving 40 days vernalization

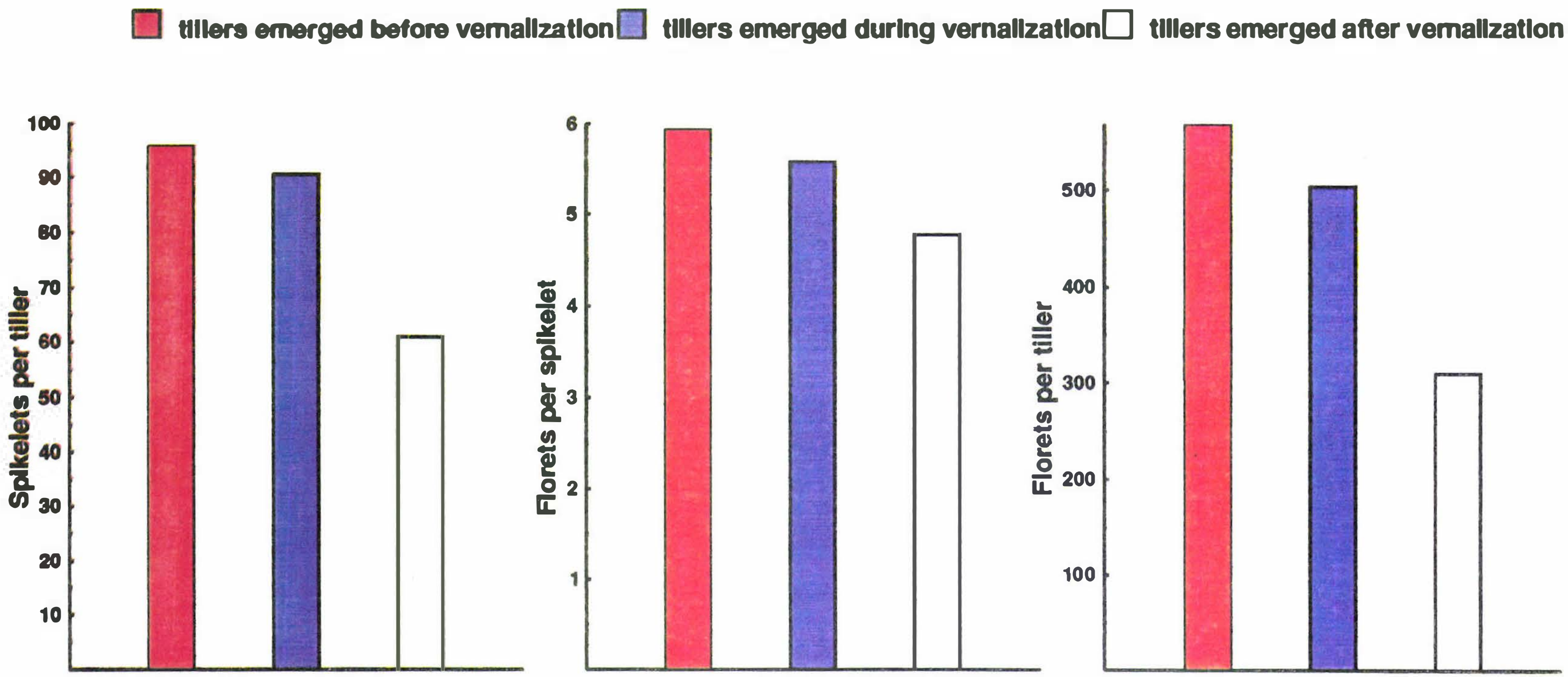

Figure 6.2 Comparison of spikelet and floret numbers from tillers that emerged before, during and after 40 days vernalization

6.4 DISCUSSION

A juvenile stage is present in plants when seedlings or even some larger plants are unabl to respond to vernalization (Cooper and Calder, 1964). A juvenile stage is not presen when seeds fail to respond to vernalization (Cooper and Calder, 1964). The results in thi study show that in up to 64% of plants no juvenile stage exists in Roa tall fescue. Sixty fou percent of plants at all growth stages from three week old seedlings with a main shoot an the first leaf unfolded (Table 6.1, Plate 6.1, decimal code 11, 20; Zadoks *et al.*, 1974 Tottman and Broad, 1987) through to nine week old seedlings with a main shoot, seve tillers and nine leaves unfolded (Table 6.1, Plate 6.1, decimal code 19, 27; Zadoks *et al.*, 1974; Tottman and Broad, 1987) were capable of producing reproductive plants after 4 days (960 hours) vernalization (Table 6.2). But when the germinating seed (Table 6.1 Growth stage 5, decimal code 05, Zadoks *et al., 1974;* Tottman and Broad, 1987) wa vernalized for 40 days none of these plants which later grew in the glasshouse produce reproductive tillers. Therefore, while ryegrass can be induced by cold or short-da treatments given to the germinating seed (Cooper and Calder, 1964) only one Roa tal fescue plant responded in this way, but this was after 30 days vernalization (Table 6.2). However, 36% of plants failed to produce seed heads after 40 days vernalization. It may be that they were still in the juvenile stage, but it is more probable that they had not received sufficient length of vernalization to become reproductive (Bean, 1970). All of Bean's (1970) plants produced seed heads after 23 weeks vernalization. Until further work is conducted on Roa, the juvenile stage in Roa cannot be ignored.

Critical examination of Bean's (1970) experiment shows that the results also do not substantiate his suggestion that a juvenile stage exists in tall fescue. Firstly, different age groups of tall fescue plants (0, 2, 4, 6 and 8 weeks growth) were produced in a heated glasshouse (temperature not stated). It seems possible that the temperature may have fallen below 10°C which Evans (1960) Calder (1966) and Langer (1972) state is the critical maximum temperature for effective vernalization. If this in fact occurred some vernalization may have been possible prior to plants being transferred to an unheated glasshouse (temperature also not stated).

Also in Bean's (1970) experiment maximum temperatures in the unheated glasshouse may still have been quite warm, i.e. above 10°C. This is suggested by the fact that tall fescue plants probably continued to grow in the unheated glasshouse, since the longer Bean (1970) kept the young plants in the unheated glasshouse, the better their subsequent production of inflorescences. Plants kept in an unheated glasshouse for 18 and 23 weeks all produced similar numbers of inflorescence, regardless of age, when put back into a warm glasshouse.

Bean's (1970) experiment shows that young plants may take longer to be vernalized than older plants (Evans 1960), but the conclusion that a juvenile stage exists in tall fescue cannot be substantiated. Nevertheless, results in the present study and those of Bean (1970) both demonstrate that there is a wide divergence in vernalization requirement of genotypes of tall fescue cultivars. In the present experiment several control plants (0 days vernalization) produced reproductive tillers as did one plant from growth stage five (Table 6.1) after 30 days vernalization. These plants either did not require vernalization (control) or responded to vernalization in the seed stage (growth stage 5). Bean (1970) showed that ecotypes from Mediterranean environments will flower when placed in conditions continuously above 8°C. Roa tall fescue was bred entirely from overseas material, particularly from 12 Mediterranean seed lines (Anderson, 1982). The seed used in the present study was breeders seed. The inconsistent reproductive response of plants to periods of 30 days or less vernalization (Table 6.2) must be due to the fact that many of the Mediterranean genotypes still present in Roa tall fescue do not require any vernalization at all. And it probably these plants which are still in Roa tall fescue seedlines that often produce seed heads in the first summer after a spring sowing (Hare, unpubl. data).

It may be a useful plant breeding exercise to select out the tall fescue plants that do not require vernalization and breed a tall fescue cultivar that does not have a vernalization requirement. This cultivar would probably be far more productive from autumn sowings than the present Roa cultivar (Chapter 3). Autumn-sown crops of this cultivar that did not have to be vernalized would only have to have a large number of tillers present in the spring in order to produce a high yielding seed crop.

Tillers which had not visibly emerged during the vernalization period also became reproductive. How then did these tillers become reproductive without vernalization? Calder (1966) states that each grass tiller must be vernalized independently, since there is no translocation of the vernalized state. If this is true then these tillers either must have been vernalized while still in the leaf sheath or as a very young bud at the base of the tiller, as the site of vernalization is the growing point (Langer, 1972), or maybe these tillers did not require any vernalization at all to become reproductive.

In addition, these plants and tillers may have received enough vernalization exposure from the short daylengths (10 to 12 hours) during July, August and September and from glasshouse temperatures which sometimes fell to 10°C and averaged 12°C minimum temperatures during these months. These conditions particularly apply to older plants in the control groups (growth stage 1,2 and 3) which were growing for a longer period in the glasshouse and were the only control plants to become reproductive (Table 6.2). When the study was first planned, controlled environment rooms, with long daylengths (16 hr days) and 15°C minimum temperatures, were going to be used to grow the plants in outside the vernalization periods. However, the cost of these rooms at NZ$1000 per week made the study too expensive and the warm glasshouse was used instead. This may have been a limitation to the study in that there may have been just enough cold exposure and short daylengths to allow some control plants (10%) to become reproductive. However, as discussed already these control plants may not have required any vernalization at all.

The present study shows that the longer the vernalization exposure, the stronger the reproductive response. However, because some plants did produce reproductive tillers after only 10, 20 or 30 days vernalization exposure shows that the response in Roa tall fescue is not an obligate one. Rather it appears to be a quantitive response that strengthens as the exposure to vernalization conditions increases.

In this study the maximum period for vernalization was 40 days or 960 hours. This maximum period was chosen as it was thought that Roa tall fescue would not need a longer period for maximum vernalization. This may have not been long enough as only 4 to 5 out of 7 plants per growth stage treatment became reproductive.

In previous trials (Chapters 3, 4 and 5), it was thought that perhaps those young tillers which had emerged from either autumn sowing, in undersown barley, or following autumn defoliation had not passed through their juvenile stage in time to be adequately vernalized. However, it is more likely it is the length of vernalization exposure that determines how many reproductive tillers emerge (Bean, 1970). Furthermore, the longer tillers are vernalized, the more spikelets and florets they will produce (Figure 6.2, Table 6.2) since they have undergone a longer period of differentiation (Robson, 1968; Hill and Watkin, 1975). If only partial vernalization has been achieved it seems likely that later exposure to higher spring temperatures may very well reverse the vernalized state as suggested by Purvis and Gregory (1952).

It is also possible that if the temperature change from the vernalization room to the heated glasshouse in the above trial had been more gradual, (over several days for example) with increasing temperatures, perhaps more plants would have become reproductive. The sudden temperature change which took place may have reversed the vernalized state in some plants vernalized for only 30, 20 or 10 days.

Hourly grass minimum temperatures at the Aorangi farm where trials in Chapter 3, 4 and 5 were conducted were not available in 1990 and 1991. However, these temperatures were available in 1992. Grass minimum temperatures are chosen because they are taken right at ground level where the growing point of the reproductive tiller would be. The number of hours per month that temperatures were below 8°C at Aorangi in 1992 were May 252, June 337, July 304, and August 351. From these data it can be seen that tillers must be formed before the end of June in order to receive no less than 960 hours vernalization at temperatures below 8°C. Any tillers formed in July or early August would not receive sufficient length of vernalization to produce a strong reproductive response in the spring. Furthermore, meteorological data from the Aorangi research station shows that the winter of 1992 has had temperatures 1°C colder than the 20 year average. Thus, in an average year tillers may have to be formed by early June to receive sufficient grass minimum temperatures to induce a strong vernalization response. However, this only applies to the plants that require vernalization because there are still a large number of Roa tall fescue plants that require between 10 to 30 days vernalization.

Chapter 7

The effects of fungicides on tall fescue seed production

7.1 INTRODUCTION

Fungicide application has been found to increase seed yields in perennial ryegrass in the UK (Hampton and Hebblethwaite, 1984) New Zealand (Hampton, 1986; Latch and Christensen, 1988) and the Netherlands (Horeman, 1989), in cocksfoot in New Zealand (Rolston *et al.*, 1989) and the US (Welty, 1989a) and in prairie grass in New Zealand (Rolston, *et al.*, 1989). Prior to this research commencing in 1990, fungicides had not been shown to increase seed yields of tall fescue in the US (Welty, 1989b), but recently Nyirenda (1992) in New Zealand obtained a significant yield increase following control of stem rust in three New Zealand and three US tall fescue cultivars.

Seed yield increases following fungicide application to grasses have been reported to result from control of leaf and stem diseases (Hampton, 1986; Horeman, 1989) and increased green leaf area duration. Even in the absence of disease, fungicides also appear to delay leaf senescence and maintain green leaf area during seed development and maturation. The response recorded has been a reduction in seed abortion and an increase in the number of seeds per spikelet (Hampton and Hebblethwaite, 1984; Hampton, 1986; Rolston *et al.*, 1989).

Even though Welty (1989b) did not get a significant seed yield increase in tall fescue following fungicide application, some of the treatments did result in seed yields larger than the non-sprayed controls. In Welty's (1989b) trials there was little leaf or stem disease and the tall fescue did not lodge. Lodging creates a favourable microclimate for the growth of fungi (Griffiths,1969), and in recent New Zealand trials, tall fescue crops have lodged prior to anthesis (Hare, 1992).

Various fungicides have been used in grass seed production research with varying efficacies. For example, chlorothalonil was more effective than propiconazole in cocksfoot

(Welty, 1989a), propiconazole was very effective in prairie grass and cocksfoot (Rolston *et al.*, 1989) and ryegrass (Horeman, 1989), and chlorothalonil was also effective in ryegrass (Welty, 1989b). Earlier studies with ryegrass successfully used triadimefon plus carbenodazim plus captafol (Hampton and Hebblethwaite, 1984; Hampton, 1986). Triadimefon by itself was more effective than either carbendazim and captafol (Hampton, 1986) and has also been used to successfully increase seed yields of prairie grass and cocksfoot (Rolston *et al.*, 1989).

Timing of fungicide application is also important. A single application before anthesis has given protection against disease and increased seed yields (Hampton, 1986; Rolston *et al.*, 1989). Further applications of these systemic fungicides did not usually increase seed yields (Hampton, 1986).

Propiconazole has been registered and used successfully in ryegrass seed crops in New Zealand. Tebuconazole, another triazole fungicide, has recently been successfully used in France (Clinkspoor, 1991), and currently is available in New Zealand. These two fungicides were evalulated for use in tall fescue seed crops.

7.2 MATERIALS AND METHODS

The trials were conducted at the AgResearch Grasslands farm 'Aorangi', Manawatu, New Zealand (latitude 40° 23' south), on a weakly leached, slowly accumulating, poorly drained, recent gley soil from quartzo-feldspathic silty alluvium (Kairanga silt loam) on a Grasslands Roa tall fescue stand which had been established in 1988. Management information since establishment is presented in Table 7.1.

7.2.1 TRIAL 1 (1990)

Propiconazole (Tilt) at 250 g ai ha^{-1} in 160 litres water ha^{-1}. was applied using a small pressure sprayer at 300 kPa at the following times; during ear emergence (2 November), during anthesis (22 November), both of the above times and nil (control). Ear emergence was when around 60% (i.e. 200-300 heads m^{-2}) were at the stage shown in Plate 8.1 and anthesis was when around 60% (i.e 200-300 heads m^{-2}) were at the stage shown in Plate 8.2. The treatments were replicated four times in a randomised block design, with each treatment plot measuring 2 m x 10 m. The results were analysed as a randomised block design using the SAS statistical programme.

Table 7.1 Field Management

Sowing date:	30 September 1988
Seeding rate:	7 kg ha^{-1}
Row spacing:	30 cm
Herbicides:	2, 4-D (2.14 kg ai ha^{-1}) + dicamba (200 g ai ha^{-1}) applied on 5 December 1988, 8 March and 13 June 1989. Ethofumesate (2 kg ai ha^{-1}) on 13 June and 18 September 1989. Atrazine, 1.5 kg ai ha^{-1} on 24 April 1990 and 3 kg ai ha^{-1} on 26 April 1990.
Defoliation:	1989 Cut with a rotary mower 5cm above ground level, 4 April and 7 July. 1990 Lightly grazed with bulls, March to July. 1991 Grazed to 3 - 4 cm above ground level on 28 February, 23 March and 9 May.
Nitrogen:	90 kg N ha^{-1} 8 September 1989 30 kg N ha^{-1} 10 May 1990 100 kg N ha^{-1} 6 September 1990 40 kg N ha^{-1} 19 April 1991 100 kg N ha^{-1} 5 September 1991.
Seed harvest:	Machine harvested in December 1989 and after experimental hand harvesting in December 1990.
Post harvest management:	January 1990 and 1991. Stubble burnt.

During anthesis (26 November) three, one-metre rows were cut from each plot and the numbers of reproductive tillers counted. Spikelets per tiller and florets per spikelet (from one spikelet from the base, middle and top of each tiller) were then counted from 20 tillers randomly selected from the bulked material. A further 20 reproductive tillers were randomly cut from each plot for spikelet and floret counts on 10 December and 17 December (two days before seed harvest). A count was made on 10 December in order to see if spikelet and floret numbers changed during seed development as a result of disease.

At seed harvest (19 December) three, one-metre rows were cut from each plot, air dried in hessian sacks, threshed and cleaned (see 3.2.1.). Seed yields and one thousand seed weight (T.S.W.) were corrected to 14% seed moisture content. Four x 50 seeds per plot were germinated following treatment with 0.2% KNO_3, chilling the imbibing seeds (5 days) and placing the seeds in a growth cabinet for 14 days at 15°C (16 hr dark) and 25°C (8 hr light) (International Seed Testing Association, 1985). An interim germination count was made at 7 days and a final count at 14 days.

At harvest the number of cleaned seeds per spikelet were calculated by dividing T.S.W. by 1000 to get the weight of one seed and dividing the seed weight into seed yield per m^2 to get cleaned seed number per m^2. Cleaned seed number per m^2 was then divided by spikelet number per m^2 (spikelets per tiller on 17 December multiplied by reproductive tiller number at anthesis) to get seed numbers per spikelet.

On 26 November, 10 December and 17 December, 20 reproductive tillers from each plot were examined and scored for percentage of leaf senescence and lesions on the flag leave (FL), and the next two leaves, referred to as leaf 2 (L2) and leaf 3 (L3). Scoring was done following illustrated keys for leaf rust of cereals prepared by James (1971). Key No 1.2 and key No 1.3 were used. Scoring was done three times in order to follow the course of disease infection (if any) in the crop.

7.2.2 TRIAL 2 (1991)

Propiconazole at 250 g ai ha^{-1} and 125 g ai ha^{-1} and tebuconazole (Folicur) at 188 g ai ha^{-1} in 160 litres water ha^{-1} were applied using a small pressure sprayer at 300 kPa during ear emergence (1 November) or during anthesis (26 November). There was also an untreated control. The treatments were replicated four times in a randomised block design on the same field as trial 1, with each treatment plot measuring 2 m x 7 m. The results were analysed as a randomised block design using the SAS statistical programme.

Reproductive analysis (4 December) and leaf scoring (4, 13, 23 December) for disease was done as in Trial 1 (see 7.2.1.). Spikelets and florets were counted on 30 tillers randomly selected per plot at the above dates. Seed harvest was on 23 December, and harvest, threshing and cleaning was done as described in 7.2.1. (Trial 1) following the methods given in 3.2.1. Seed yields, T.S.W. and germinations were determined as in 7.2.1. above. Seeds per spikelet were calculated as above, except that reproductive tiller numbers counted at harvest were used for the calculation.

7.3 RESULTS

7.3.1 Trial 1 (1990)

Leaf disease and senescence

Stem rust (*Puccinia graminis*) was first observed in the untreated plots on 10 November 1990. By the time of seed development (10 December) and before harvest (17 December) a significantly ($P<0.05$) greater percentage of green leaf area of the flag and second leaf of the untreated plots was infected with stem rust lesions compared to the propiconazole-treated plots (Table 7.2), but when assessed on a whole leaf basis, rust lesions appeared low in all treatments. However, these data are misleading as no attempt was made to determine the cause of leaf senescence. However, by observation, senescence was accelerated by stem rust lesioning of leaf tissue.

The application of propiconazole at ear emergence and at both ear emergence and anthesis (double application) significantly ($P<0.05$) reduced leaf senescence after anthesis (Table 7.3), compared with the application during anthesis only and the untreated plants. By harvest the untreated plots had significantly ($P<0.05$) more completely senesced leaves than propiconazole-treated plots (Table 7.4). The third leaves had senesced completely in all plots by the middle of seed development (10 December).

Table 7.2. **Effect of propiconazole (250 g ai ha^{-1}) and time of application on % green leaf area with stem rust lesions assessed during anthesis (26 November), during seed development (10 December) and just before harvest (17 December) (Trial 1).**

Percentage of green leaf area and total leaf area(in brackets) with stem rust lesions

Treatment	26 November		10 December		17 December	
	FL	L2	FL	L2	FL	L3
untreated	6.3(4.4)	7.5(3.8)	18.3(4.0)	18.7(2.6)	17.8(2.8)	25.8(2.3)
ear emergence	4.1(3.2)	5.3(2.9)	1.5(0.8)	5.1(2.0)	2.7(1.0)	8.0(1.8)
anthesis	18.5(12.8)	7.0(2.9)	4.0(1.01)	5.2(1.3)	4.7(0.9)	6.8(0.9)
both times	4.6(3.4)	8.5(4.9)	1.9(1.1)	4.6(1.9)	3.4(1.3)	5.7(1.4)
LSD (P<0.05)	ns	ns	8.0	9.2	3.7	11.9
CV%	143	72	81	71	33	61

Table 7.3. **Effect of propiconazole (250 g ai ha^{-1}) and time of application on leaf area senescence (%) assessed during anthesis (26 November), during seed development (10 December) and just before harvest (17 December) (Trial 1).**

Leaf area senescence (%)

Treatment	26 November			10 December		17 December	
	FL	L2	L3	FL	L2	FL	L2
untreated	30	49	95	78	86	84	91
ear emergence	23	46	85	47	60	62	78
anthesis	31	58	92	74	75	80	87
both times	26	42	95	43	57	61	75
LSD (P<0.05)	ns	ns	9	18	17	14	12
CV%	28	29	6	18	16	13	10

Table 7.4. Effect of propiconazole (250 g ai ha^{-1}) and time of application on percentage of completely senesced leaves assessed during seed development (10 December) and just before harvest (17 December) (Trial 1).

Percentage of completely senesced leaves

Treatment	10 December		17 December	
	FL	L2	FL	L2
untreated	35.0	55.1	57.0	80.3
ear emergence	17.3	28.8	22.5	50.8
anthesis	22.7	39.3	48.8	67.0
both times	15.2	26.5	18.8	46.5
LSD (P<0.05)	ns	ns	21.6	25.4
CV%	58	55	38	27

Seed yield and components

Propiconazole significantly (P<0.05) increased seed yields compared to untreated plots (Table 7.5), particularly in plots sprayed at ear emergence.

Table 7.5. Effect of propiconazole (250 g ai ha^{-1}) and time of application on seed yield, T.S.W., and seed germination.

Treatment	Seed yield (kg ha^{-1})	T.S.W. (g)	Germination %
untreated	967	2.716	85.5
ear emergence	2012	2.920	91.3
anthesis	1521	2.869	86.1
both times	1690	2.998	89.0
LSD (P<0.05)	437	0.254	ns
CV%	18	6	4

The ear emergence treated plots produced over 1000 kg more seed per ha than untreated plots and 490 kg more seed per ha than plots treated during anthesis only. Heavier seed (T.S.W.) was recorded in double treated plots compared to untreated plots, but there were no differences in seed germination (Table 7.5).

Table 7.6. **Effect of propiconazole (250 g ai ha^{-1}) and time of application on yield components at anthesis (Trial 1).**

Treatment	Reproductive tillers (no m^{-2})	Spikelets per tiller	Florets per spikelet			
			B	M	T	$\bar{x}$
untreated	399	76.2	5.8	6.9	6.5	6.4
ear emergence	390	72.8	6.0	6.9	6.5	6.4
anthesis	385	71.2	6.0	7.1	6.4	6.5
both times	328	76.2	6.4	7.3	6.6	6.8
LSD (P<0.05)	ns	ns	ns	ns	ns	ns
CV%	30	8	10	7	8	7

Propiconazole had no effect on seed yield components during anthesis (Table 7.6) or during seed development (10 December) (Table 7.7). However, propiconazole applied at ear emergence and at both times produced 107% and 100% more cleaned seeds per spikelet respectively at harvest than untreated plots (Table 7.7).

7.3.2 Trial 2 (1991)

Leaf disease and senescence

Up to 5% stem rust infestation was scored on stems in untreated plots at seed harvest. No stem rust reached the leaves and no stem rust was observed or scored during anthesis (4 December) or during seed development (13 December).

Leaf senescence at anthesis in the flag and second leaf (Table 7.8) was significantly reduced by propiconazole application at ear emergence compared to untreated plots. There were no significant differences between the propiconazole and tebuconazole treatments and rate of propiconazole also did not affect leaf senescence (Table 7.8).

Table 7.7 **Effect of propiconazole (250 g ai ha^{-1}) and time of applications on spikelet and floret numbers during seed development (10 December) and just before harvest (17 December) (Trial 1).**

	10 December					17 December					
Treatment	Spikelets per tiller	Florets per spikelet				Spikelets per tiller	Florets per spikelet				Seeds per spikelet*
		B	M	T	$\bar{x}$		B	M	T	$\bar{x}$	
untreated	64.7	5.1	5.5	4.7	5.1	64.0	3.7	3.4	2.1	3.0	1.4
ear emergence	69.3	4.7	5.3	4.6	4.9	65.5	4.3	4.1	3.0	3.8	2.9
anthesis	67.6	5.2	5.8	4.7	5.3	69.4	4.0	3.1	2.0	3.0	2.2
both times	69.1	4.7	5.1	4.3	4.7	67.7	4.2	4.2	2.5	3.6	2.8
LSD (P<0.05)	ns	ns	ns	ns	ns	ns	ns	1.05	ns	ns	1.3
CV%	18	13	13	21	14	11	15	17	38	21	36

* calculated

Table 7.8 **The effect of propiconazole and tebuconazole on leaf senescence (%) assessed during anthesis (4 December), during seed development (13 December) and at harvest (23 December) (Trial 2).**

	Leaf area senescence (%)					
Treatment (g ai ha^{-1})	4 December		13 December		23 December	
	FL	L2	FL	L2	FL	L2
untreated	54	77	44	74	83	91
ear emergence						
Propiconazole (250)	34	53	39	69	55	80
Propiconazole (125)	27	51	42	68	59	88
Tebuconazole (188)	47	58	45	60	61	91
anthesis						
Propiconazole (250)	35	69	57	76	65	90
Propiconazole (125)	39	74	54	74	66	88
Tebuconazole (188)	50	68	58	72	72	89
LSD (P<0.05)	19	21	ns	ns	ns	ns
CV%	30	22	29	20	22	10

Table 7.9 **Effect of propiconazole and tebuconazole on percentage of completely senesced assessed during anthesis (4 December), during seed development (13 December) and at harvest (23 December) (Trial 2).**

	Percentage completely senesced leaves					
Treatment (g ai ha^{-1})	4 December		13 December		23 December	
	FL	L2	FL	L2	FL	L2
untreated	13	53	11	33	52	59
ear emergence						
Propiconazole (250)	6	24	10	33	19	66
Propiconazole (125)	5	24	11	38	30	78
Tebuconazole (188)	14	21	18	29	20	65
anthesis						
Propiconazole (250)	9	39	20	36	28	70
Propiconazole (125)	9	46	18	41	29	64
Tebuconazole (188)	13	35	21	44	33	72
LSD (P<0.05)	ns	28	ns	ns	27	ns
CV%	80	55	72	67	60	30

At anthesis, all plots treated with fungicide during ear emergence had significantly fewer second leaves (L2) that had completely senesced compared to the untreated plots (Table 7.9). At harvest the ear emergence applications of propiconazole (250 g ai ha^{-1}) and tebuconazole produced fewer completely senesced flag leaves than untreated plots. After anthesis to harvest all fungicide treated plots showed no significant difference in second leaves (L2) that had 100% senescence (Table 7.9).

Seed yield and components

During anthesis, the number of reproductive tillers, spikelets and florets did not differ among treatments (Table 7.10). At seed harvest (Table 7.11), time and application of fungicides had no significant effect on seed yield, T.S.W., spikelets/tiller or florets/spikelet.

Table 7.10 Effect of propiconazole and tebuconazole on reproductive tillers, spikelets and florets during anthesis (Trial 2).

Treatment (g ai ha^{-1})	Reproductive tillers m^{-2}	Spikelets/tiller	Florets/spikelet
untreated	605	69.7	5.9
ear emergence		68.1	5.7
Propiconazole (250)	642		
Propiconazole (125)	599	76.7	5.8
Tebuconazole (188)	619	72.3	5.8
anthesis			
Propiconazole (250)	579	71.1	5.8
Propiconazole (125)	643	76.3	5.6
Tebuconazole (188)	665	72.3	5.8
LSD (P<0.05)	ns	ns	ns
CV%	22	14	11

Table 7.11 **The effect of propiconazole and tebuconazole on seed yield, T.S.W., spikelets and florets at harvest (Trial 2).**

Treatment (g ai ha^{-1})	Seed Yield (kg ha^{-1})	T.S.W. (g)	Spikelets/tiller	Florets/ spikelet
untreated	530	1.95	66.2	5.6
ear emergence				
Propiconazole (250)	581	2.10	65.2	5.8
Propiconazole (125)	495	1.97	70.4	5.9
Tebuconazole (188)	541	2.11	72.3	5.9
anthesis				
Propiconazole (250)	449	2.07	67.0	5.1
Propiconazole (125)	520	2.19	76.0	5.8
Tebuconazole (188)	513	2.17	76.7	5.4
LSD (P<0.05)	ns	ns	ns	ns

7.4 DISCUSSION

Stem rust (*P. graminis*) as a pathogen in tall fescue seed crops in New Zealand was first recorded in 1990 in the first trial of this study, but had been observed the previous season (1989) in roadside tall fescue (M.J. Christensen, pers. comm.). Since 1990 the incidence of stem rust in tall fescue seed crops has increased although no quantitative data yet exists. In Canterbury, New Zealand, where most of the 3000 ha of tall fescue seed crops are grown, stem rust has rapidly increased from isolated recordings in 1990 to numerous outbreaks in 1991 and 1992 (J. McKenzie and W. Archie, pers. comm.).

Outbreaks of stem rust seem to occur sporadically. For example, in 1991 in the second tall fescue trial in this study (see 7.2.2.) stem rust did not affect leaf tissue and reached a maximum of 5% of stems infected by harvest, yet in another trial 20 km way stem rust severely infected six cultivars of tall fescue (Nyirenda, 1992) and the three autumn-sown tall fescue cultivars (see 3.2.2) which were planted adjacent to Nyirenda's (1992) trial. These three autumn-sown cultivars had to be sprayed twice against rust infection (Table 3.1).

Stem rust in ryegrass has also been reported to fluctuate markedly from season to season (Hampton, 1986). Because stem rust of tall fescue has not been studied in detail it is not absolutely clear what conditions favour its spread. There are many different races of stem rust and while the stem rust of ryegrass and tall fescue belong to the same species (*Puccinia graminis*), they probably belong to different races (G.C.M. Latch, pers. comm.). Stem rust on ryegrass is more acute under moist, warm conditions and is less severe under hot/dry or cool conditions (Walker, 1957). Stem rust is also more prevalent when heavy dews and high humidity in the mornings allow the stomata to open on the plants and the spores to enter (Walker, 1957).

The spores are spread by wind and insects (Walker, 1957). The spores over-winter on various hosts and then spread again in the spring. The autumn-sown tall fescue in Nyirenda's (1992) trial was adjacent to spring-sown tall fescue sown in 1991 which was never defoliated and became very tall and rank. Stem rust spores may have over-wintered on this material and then spread in the spring to the nearby autumn-sown tall fescue. The tall fescue in trial 1 (see 7.2.1) was next to a chicory seed field which had a lot of harvest stubble on the field during the autumn and winter and which grew very tall during October and November. Stem rust spores may have over-wintered on chicory harvest stubble, moved to the chicory seed crop and then onto the tall fescue. The tall fescue in trial 2 (see 7.2.2) was surrounded by grazed fields which may not have provided over-wintering stem rust hosts. Furthermore, after the 1991 trial (see 7.2.1) was harvested, the stubble was burnt (Table 7.1), which would also have destroyed many of the stem rust spores. This suggests that both favourable environmental conditions and over-wintering hosts are needed for the stem rust life cycle to continue and the disease to develop as also stated by Walker (1957).

Stem rust pustules can be found on leaves, sheaths, stems and seedheads of ryegrass (Latch, 1966; 1980) and tall fescue (Hare, own observations). Stem rust infection in ryegrass interferes with the translocation of nutrients to the developing seed, resulting in shrivelled and sometimes non-viable seed (Latch, 1966; 1980). In the untreated plots in trial 1 (see 7.2.1), heavily infected leaves of tall fescue turned yellow around the infected sites and the chlorosis then progressed through the leaves. Many leaves completely senesced (Table 7.4) and broke off the leaf sheath, and the infected stems became dry or shrivelled, giving the tall fescue the appearance of 'haying off'. Thus, green leaf area is considerably reduced by stem rust in tall fescue (Table 7.3), as previously reported for ryegrass (Hampton and Hebblethwaite, 1984; Hampton, 1986; Rolston *et al.*, 1989).

The invasion of stem rust lesions in trial 1 (Table 7.2) caused a significant (P<0.05) increase in leaf senescence compared to tall fescue leaves in plots sprayed with propiconazole during ear emergence. The effect of this leaf senescence was to probably reduce the assimilate supply to developing seeds, because of reduced photosynthetic capability of the senesing leaves. Many of the nutrients utilised in the final stages of seed development are derived from ear photosynthesis (Ong and Marshall, 1975) and if rust infects the ear once again assimilate supply may be reduced, leading particularly to reduced seed weights (Hampton, 1986). Though not measured, stem rust in trial 1 did invade tall fescue seed heads and along with reduced green leaf area (Table 7.3), seed yields were reduced in untreated plots (Table 7.5). Seed weight, however, was not drastically reduced.

During anthesis (Table 7.6) no differences in seed yield components existed between the treatments. However, by seed harvest, many developing seeds in untreated plots had either aborted or had failed to fill out (shrivelled seed as described by Latch (1966; 1980) in stem rust infected ryegrass) and were removed during seed cleaning, resulting in a reduced number of seeds per spikelet (Table 7.7). This result compares well with research on ryegrass where stem rust significantly reduced seeds per spikelet (Hampton 1986), and also lowered T.S.W. compared to double fungicide applications (Table 7.5) (Hampton, 1986; Latch and Christensen, 1988). Stem rust in Nyirenda's (1992) trial reduced Roa tall fescue seed yields by 36% (and by 25-50% in four other cultivars), seeds per spikelet by 12% and T.S.W by 28%. In trial 1 of this study, stem rust reduced seed yields by 52% (Table 7.5), seeds per spikelet by 52% (Table 7.7) and T.S.W. by 7% (Table

7.5) compared to tall fescue treated with propiconazole during ear emergence. Nyirenda's (1992) work is the only other reported work on tall fescue where stem rust has caused a significant reduction in tall fescue seed yields.

Propiconazole and tebuconazole belong to the triazole chemical group of fungicides which are systemic and are rapidly absorbed by leaves and stems (O'Connor, 1989). Triazoles quickly kill early formed rust and their residual effect gives the plants several weeks protection. In trial 1 (see 7.2.1) propiconazole applied during ear emergence was able to protect tall fescue against stem rust invasion right up to seed harvest six weeks later. Propiconazole prevented further rust invading the plants (Table 7.2) in all three treatments in trial 1. Fungicides have been shown to reduce leaf senescence in ryegrass (Hampton and Hebblethwaite, 1984; Hampton, 1986), prairie grass (Rolston *et al.*, 1989) and cocksfoot (Rolston *et al.*, 1989) even when the incidence of disease has been low (Hampton and Hebblethwaite, 1984; Rolston *et al.*, 1989). The way fungicides delay leaf senescence when disease is not present is not clear. It is likely that fungicides directly affect the leaf microflora which are actively involved in the process of leaf senescence (Dickinson, 1973), and because leaf senescence is reduced, when little or no disease is present, the fungicide treated plants are able to continue photosynthesis and support nutrient translocation to developing seeds. Thus, more seeds per spikelet are retained (Hampton and Hebblethwaite, 1984; Rolston *et al.,* 1989). However, although the successful use of fungicides in retaining more seeds per spikelet when little or no disease is present has been recorded in ryegrass (Hampton and Hebblethwaite, 1984), prairie grass (Rolston *et al.,* 1989) and cocksfoot (Rolston *et al.,* 1989), this has not occurred in tall fescue (Welty, 1989b). Where disease has been siight, fungicides have not increased seed yields of tall fescue (Welty, 1989b; Mellbye and Young, 1990; Mellbye, Young and Koepsell, 1991), a result also recorded in trial 2.

However, the data from trial 2 did show that in the absence of disease the degree of senescence was reduced in the flag leaves when some fungicides were applied during ear emergence (Table 7.8 and 7.9). Senescence in leaf two was equally severe for all treatments (Table 7.8 and 7.9).

Tall fescue therefore appears to behave differently to ryegrass, prairie grass and cocksfoot in its response to fungicides when no disease is present. There are possibly several explanations for this different response of tall fescue.

Firstly, ryegrass and prairie grass seed crops are usually heavily lodged at harvest time. Lodging creates a microclimate which is favourable to the growth of fungi (Griffiths, 1969) and may also increase the leaf microflora which contribute to senescence. In most tall fescue seed crops lodging is only slight to moderate (Mellbye and Young, 1990; Mellbye *et al.*, 1991) and so the microclimate necessary for microfloral buildup is not created.

Secondly, ryegrass, prairie and cocksfoot set seed later than tall fescue in New Zealand. In the Manawatu, where these trials took place, December is normally wet and humid. Tall fescue is usually harvested from mid- to late-December, ryegrass and prairie grass from late-December to early-January and cocksfoot in mid-January. Growing under a longer period of moist warm weather may mean that microflora have more time to develop on ryegrass, prairie grass and cocksfoot than tall fescue. Further study is therefore needed on the development of leaf microflora on various grass seed crops.

Thirdly, tall fescue has very large green stems and leaf sheaths which are still present at harvest and which are most likely still contributing to photosynthesis. In lodged ryegrass seed crops a large proportion of the stems and leaf sheaths have turned brown by seed harvest and may not contribute to photosynthesis. Again the degree of stem and leaf sheath senescence needs to be studied more in tall fescue seed crops to see whether this argument of stem and leaf sheath green area contribution to photosynthesis can be supported.

Whenever the incidence of stem rust has been low in tall fescue seed crops there has been no seed yield response to fungicides (Table 7.11) (Welty, 1989b; Mellbye and Young, 1990; Mellbye *et al.*, 1991). In tall fescue it is not clear how much leaf senescence must take place before seed yield is affected. In trial 2 during seed development the flag leaves of untreated tall fescue had only 44% senescence (Table 7.8) compared to 78% senescence the previous year in trial 1 (Table 7.3). At harvest in both trials leaf area senescence on the flag and second leaves were almost identical, 83 - 84% and 91% respectively. (Table 7.3 and 7.8). Therefore it is the leaf area senescence that occurs during seed development, that is important in determining seed yields. Tall fescue may be able to tolerate up to 60% flag leaf area senescence during seed development without suffering seed yield losses, but further work needs to be done in this area of leaf senescence in tall fescue.

Hampton (1986) recommended that one critically timed application of a triazole fungicide at ear emergence in perennial ryegrass gave the best economic response. In trial 1 the single application of propiconazole during ear emergence produced the highest seed yield (Table 7.5). Nyirenda (1992) applied propiconazole twice, during ear emergence and during anthesis. The autumn-sown trial (see 3.2.2.) which was down wind from Nyirenda's trial showed rust infection very early and had to be sprayed twice, before ear emergence and during ear emergence (Table 3.1).

Welty (1989b) and Mellbye *et al.*(1991) concluded that while fungicides do reduce disease in tall fescue seed crops it would not be economic to apply fungicides under low disease pressure, as no significant seed yield increases were recorded by them from fungicide treated plots compared to untreated plots. Trial 2 also showed that if a fungicide is applied in the absence of disease there is unlikely to be a seed yield response to fungicide. Mellbye *et al.*(1991) also concluded that fungicides would be more likely to produce significant yield increases under high disease pressure. Whenever there has been high disease, as in the trials of Nyirenda (1992) and in trial 1, there have been significant seed yield increases with fungicides.

Therefore fungicides should only be applied to tall fescue seed crops after disease is first observed. If disease is first observed just prior to anthesis or during seed development, then it is likely there will be an advantage in applying fungicides, especially if the disease incidence increases rapidly. However, from the middle of seed development until seed harvest (10 - 15 days) there would probably be no advantage in applying fungicides if disease is first observed during this time. Growers must therefore conduct regular seed crop inspections (three to four day intervals) from ear emergence to seed harvest to observe for disease incidence, and particularly stem rust infection.

How much disease pressure a tall fescue seed crop can tolerate before seed yields decline has still to be studied. Also the time of application of fungicides in tall fescue seed crops needs to be studied under controlled conditions. Under controlled glasshouse environments potted plants of tall fescue, at various growth stages including ear emergence, anthesis, seed development and just before harvest, could be inoculated with stem rust spores. Once the disease is first observed on the plants, they could be either treated or not treated with fungicides. Thus, the timing of fungicide treatment in response to disease outbreak and stage of development of the tall fescue seed crop could be studied in detail.

In neither trial in this study did fungicide improve reproductive tillers per m^2, spikelets per tiller or florets per spikelet. In heavy disease infection (Trial 1) seed yield was improved 100% due to more seeds per spikelet, while in low disease infection (Trial 2) seed yield was not increased. This suggests that the effect of fungicide is in improved seed set and seed development, or less seed abortion or less floret sterility, rather than being related to reproductive development generally.

Chapter 8

Frost effects on tall fescue seed production

8.1 INTRODUCTION

Some New Zealand farmers consider that late-spring frosts during ear emergence, anthesis or early seed development may cause low seed yields in some perennial grasses (e.g. tall fescue and ryegrass, W. Moore pers. comm.), because seed lots have contained light seed and high levels of empty or shrivelled seed. Some farmers are so conscious of the likely risk of frost damage that they are spraying their seed crops with horticultural frost protectants (A. Lill, pers. comm.), despite the lack of research data on frost effects on grass seed crops and without information on whether the chemicals they are using are effective in protecting grass seed crops from frost damage.

Frost effects on seed production of grasses have not been studied in New Zealand and indeed very little information is available elsewhere. Nikolaevskaya (1973) subjected flowering plants of cocksfoot to -3 or -6°C for 3.5 to 5 hours. The heavier frost destroyed pollen viability and stigmas and as a result no seed was formed. The lighter frost reduced pollen viability by 72%, delayed seed development and reduced seed germination by 30%. Similarly, Niemelainen (1989) treated cocksfoot plants during early reproductive tiller development to -3, -6 and -10°C for 17, 14 and 11 hours respectively. Panicle production at -10°C failed completely and at the other temperatures panicle numbers were reduced compared with no frost. Frost at ear emergence was more damaging than frosts at early tiller development (Niemelainen, 1989).

Many detailed studies have been made of frost damage to cereals and ice formation in cereal plant tissue after frost. An excellent review has been written by Single (1985). To overcome frost damage in cereals several strategies have been employed. Notably, the breeding of frost resistant cultivars and planting strategies developed to avoid frost periods (Single, 1985). In horticultural crops water, bactericides and biodegradable detergents have all been used in attempts to obtain frost protection (Wilson and Jones, 1983a,b; Lindow, 1983a).

In New Zealand most grass seed crops would not be able to be sprinkler irrigated to prevent frost because of the large areas involved and the water volumes needed. Bactericides and biodegradable detergents, however, could be used. Kocide (cupric hydroxide) controls ice nucleating bacteria (*Pseudomonas syringae* in particular) and by reducing those bacteria populations in light air frosts (up to -2°C), Kocide treated plants (eg. maize, beans, tomatoes and almonds) suffer less damage than untreated plants (Lindow, 1983b). A biodegradable detergent, Teric, has also been successfully used to reduce frost damage in blackcurrants (Wilson and Jones, 1983a,b) by altering the physical properties of water in the leaves during the freezing process so that more water remains unfrozen down to -6.25°C. Both Kocide and Teric have been used by some mid-Canterbury farmers on wheat, ryegrass and brassica seed crops (A. Lill, pers. comm.). However, no research has been done on grass seed crops to determine the effectiveness of these chemicals as frost protectants.

In the US it is recognised that late-spring frosts at the time of tall fescue inflorescence emergence can reduce seed yield (Youngberg and Wheaton, 1979). However, the type of damage frost causes to tall fescue seed heads and ways of preventing frost damage in tall fescue have not been studied.

The present frost study was designed to examine the effects of air frost at various stages of reproductive growth in tall fescue and at the same time to see whether frost protectants could prevent frost damage.

8.2 MATERIALS AND METHODS

8.2.1 Sowing, plant growth and harvest

Three seeds of 'Grasslands Roa' tall fescue per pot were planted into 300, 15cm diameter pots on 18 February 1991 in potting mix (see 6.2.1) and grown in an unheated glasshouse (minimum temperature 14°C). Plants were reduced by hand trimming to one per pot three weeks after planting. When plants reached 65cm in height they were cut to 5 cm before being transferred outside on 23 April 1991.

The plants remained outside until the day they received frosting. After each frost treatment the plants were transferred into a temperature controlled glasshouse (average temperature 20°C, minimum 12°C, maximum 35°C) where they remained until seed harvest.

Pots were watered daily in the glasshouse and at least weekly outside the glasshouse if no rain fell. Propiconazole (at a rate equivalent to 250 g ai ha^{-1}) was applied to all plants and 0.2 g of NPKS fertilizer (15, 10, 10, 7) was applied to each pot on 30 September. On 7 October 0.1 g of Urea (46%N) was also applied to each pot.

Tillers were harvested once the seeds turned brown and the seeds were firm when rubbed between the hands. Individual seed heads were harvested between 31 December, 1991 and 13 January 1992, labelled, and placed in paper bags to air dry.

In early-March the seeds were rubbed out of the seed heads, cleaned in a small air-flow seed cleaner and weighed to determine seed weight per tiller and one thousand seed weight (T.S.W.)(see 3.2.1). Seed weights were corrected to 14% seed moisture. Fifty seeds per treatment were placed on top of moist paper in a covered petri dish with 0.2% $KN0_3$, chilled for five days at 5°C and then germinated in a cabinet (8hrs, light, 25°C; 16 hrs, darkness, 15°C) for 7 days (first count) and 14 days (final germination count).

10 seeds each from the control, -2°C and -5°C frost treatments at ear emergence and anthesis (no fungicides) were X-Rayed to determine whether they contained caryopses. The seeds were placed in five rows of ten on top of one Polaroid 55 film and put on a metal tray and placed inside a 43804N X-Ray system Hewlett-Packard Faxitorn series for two minutes at 20 kilovolts.

8.2.2 Experimental details

The number of replications and treatments are detailed in Table 8.1.

Table 8.1 Experimental details

Treatments: Three frost treatments

Control (No frost)

-2°C for 6 hours

-5°C for 6 hours

Five plant growth stages

ear emergence

anthesis

4 days after anthesis

6 days after anthesis

8 days after anthesis

Three frost protectant treatments

Control (No protectant)

Teric

Kocide

Replications: Five plants per treatment combination.

Analysis: The results were analyzed as a factorial design by the SAS statistical programme.

1. Plant growth stages: Different plant growth stages were identified by tagging tillers with coloured plastic rings. At ear emergence (Plate 8.1) and at anthesis (Plate 8.2), tillers reaching these stages were tagged, treated or not treated with frost protectants and transferred to the frost rooms. For the stages after anthesis (4, 6 and 8 days), tillers were tagged on one group of plants which were transferred to the frost rooms on 19 December 1991.

2. Frost protectants: On the morning of the frost treatments those plants receiving frost protectants were either sprayed with Teric™ (1 litre product per ha; ethylene oxide

condensate) or with Kocide 101™ (2 kg product per ha; cupric hydroxide). The frost protectants were applied through a small gas pressure sprayer in 160 litres water ha^{-1} at 300 kPa. A set of unsprayed plants were used as a control.

3. Frost: The frost rooms are fully described by Robotham, Lloyd and Warrington (1978). For each air frost treatment plants were brought from outside the glasshouse to the frost room and the pots placed in insulated trays (1.0 x 0.7 x 0.2m deep, 15 pots per tray) filled with pumice for insulation (Robotham, *et al.*, 1978). The plants were then held for six hours at 12°C and 40% relative humidity with $150WM^{-2}$ photosynthetically active radiation (Warrington, *et al.*, 1978). Lights were then switched off and the air temperature slowly reduced over six hours to either -2°C or -5°C. Two frost rooms were used on each frost occasion, -2°C and -5°C. Frosting was maintained for six hours. During the frost period the relative humidity was 100% and the soil temperature in the pots was kept above 5°C with a simple soil heating system (Robotham, *et al.*, 1978). After six hours of frost exposure the room temperature was slowly raised to 12°C over the next six hours. The appearance of plants during -2°C or -5°C frost exposure are shown in Plates 8.3 and 8.4 respectively. The frost duration of six hours was chosen because six hour frosts have been the standard protocol used in the frost rooms (D. Greer, pers. comm.)

Plate 8.1 Roa tall fescue seed head at ear emergence.

Plate 8.2 Roa tall fescue seed head at anthesis

Plate 8.3 Roa tall fescue seed heads at ear emergence during exposure to a -2°C frost.

Plate 8.4 Roa tall fescue seed heads at anthesis during exposure to a -5°C frost.

8.3 RESULTS

Frost significantly affected seed production and germination of tall fescue at various plant growth stages (Table 8.2). Frost protectants used in this study did not prevent frost damage from occurring as shown by lower seed yield per tiller and reduced 7 day germination after exposure to a -2°C frost (Table 8.3). More extreme frosting (-5°C) dramatically reduced seed yield, seed weight and destroyed seed viability at all growth stages (Table 8.2), with or without frost protectants (Table 8.3, Plate 8.5). Those few seeds which were formed had a T.S.W. of 1 g but were non-viable after a -5°C frost. However, vegetative tillers did subsequently recover and continued growth following heavy frost exposure.

Visually, it appeared that tall fescue had not been affected by the -2°C frost (Plate 8.5). However, after seed harvest it was found that seed yield per tiller had decreased significantly by nearly 45%. Associated with this was a drop of 7% in T.S.W., a reduction of 17% in 7 day germination and 7% in final germination (Table 8.2, 8.3). More damage occurred when plants were exposed to a -2°C frost at ear emergence, anthesis or 4 days after anthesis compared to frost exposure during later seed development after anthesis(Table 8.2).

At ear emergence a -2°C frost reduced seed yield per tiller by 62%, T.S.W. by 22%, 7 day germination by 33% and final germination by 19% (Table 8.2). A similar exposure of seed heads 8 days after anthesis still reduced seed yield per tiller by 38% and 7 day germination by 12%, but did not affect T.S.W. or final germination (Table 8.2).

Neither of the frost protectants used in this study prevented frost damage from a -2°C frost (Table 8.3). However, Kocide treated seed heads produced more seed after a -2°C frost than untreated seed heads. Untreated seed heads declined 53% in seed yield while Kocide treated seed heads declined 39% in seed yield following a -2°C frost. T.S.W. did not significantly ($P<0.05$) decline after a -2°C frost when Kocide was applied, but did when Teric was applied (Table 8.3). Kocide treated seed heads were therefore more protected from a -2°C frost than untreated or Teric treated seed heads.

When the florets were X-Ray photographed both the unfrosted and -2°C frosted florets were shown to contain full seed embryos while all florets exposed to a -5°C frost were empty (Plate 8.6).

Table 8.2 Effect of frost at different plant growth stages, on seed yield and quality.

Plant growth stage	Frost			
	No frost	-2°C	-5°C	LSD (P<0.05)
		Seed yield/tiller (gms)		
Ear emergence	0.48	0.18	0.01	0.08
Anthesis	0.55	0.26	0.01	0.11
4 d.a.a*	0.48	0.25	0.02	0.09
6 d.a.a*	0.51	0.39	0.01	0.10
8 d.a.a*	0.55	0.34	0.02	0.14
LSD (P<0.05)	n.s.	0.06	ns	
		T.S.W.(g)		
Ear emergence	2.54	1.98	1.01	0.20
Anthesis	2.48	2.07	1.01	0.22
4 d.a.a*	2.61	2.46	1.01	0.23
6 d.a.a*	2.60	2.65	1.00	0.25
8 d.a.a*	2.56	2.67	1.01	0.21
LSD (P<0.05)	n.s.	0.24	ns	
		7 day germination (%)		
Ear emergence	88	59	0	15
Anthesis	90	76	0	8
4 d.a.a*	93	88	0	5
6 d.a.a*	92	83	0	5
8 d.a.a*	91	80	0	6
LSD (P<0.05)	n.s.	14	n.s.	
		Final germination (%)		
Ear emergence	90	73	0	14
Anthesis	93	87	0	5
4 d.a.a*	96	96	0	6
6 d.a.a*	95	95	0	4
8 d.a.a*	95	92	0	4
LSD (P<0.05)	n.s.	8	n.s.	

* days after anthesis

Table 8.3 Effect of frost and frost protectants on seed yield and quality.

Frost protectant	Frost			
	No frost	-2°C	-5°C	LSD (P<0.05)
		Seed yield/tiller (g)		
No protectant	0.53	0.25	0.03	0.07
Teric	0.49	0.29	0.02	0.09
Kocide	0.52	0.32	0.01	0.09
LSD (P<0.05)	n.s.	0.05	ns	
		T.S.W. (g)		
No protectant	2.55	2.39	1.02	0.16
Teric	2.60	2.36	1.05	0.18
Kocide	2.52	2.37	0.99	0.18
LSD (P<0.05)	n.s.	n.s.	n.s.	
		7 day germination (%)		
No protectant	93	79	0	7
Teric	88	76	0	7
Kocide	92	77	0	9
LSD (P<0.05)	n.s.	n.s.	n.s.	
		Final germination (%)		
No protectant	93	87	0	5
Teric	92	88	0	6
Kocide	95	87	0	8
LSD (P<0.05)	n.s.	n.s.	n.s.	

Plate 8.5 Roa tall fescue seed heads 4 days after ear emergence frosts, (left to right) no frost, -2°C frost and -5°C frost.

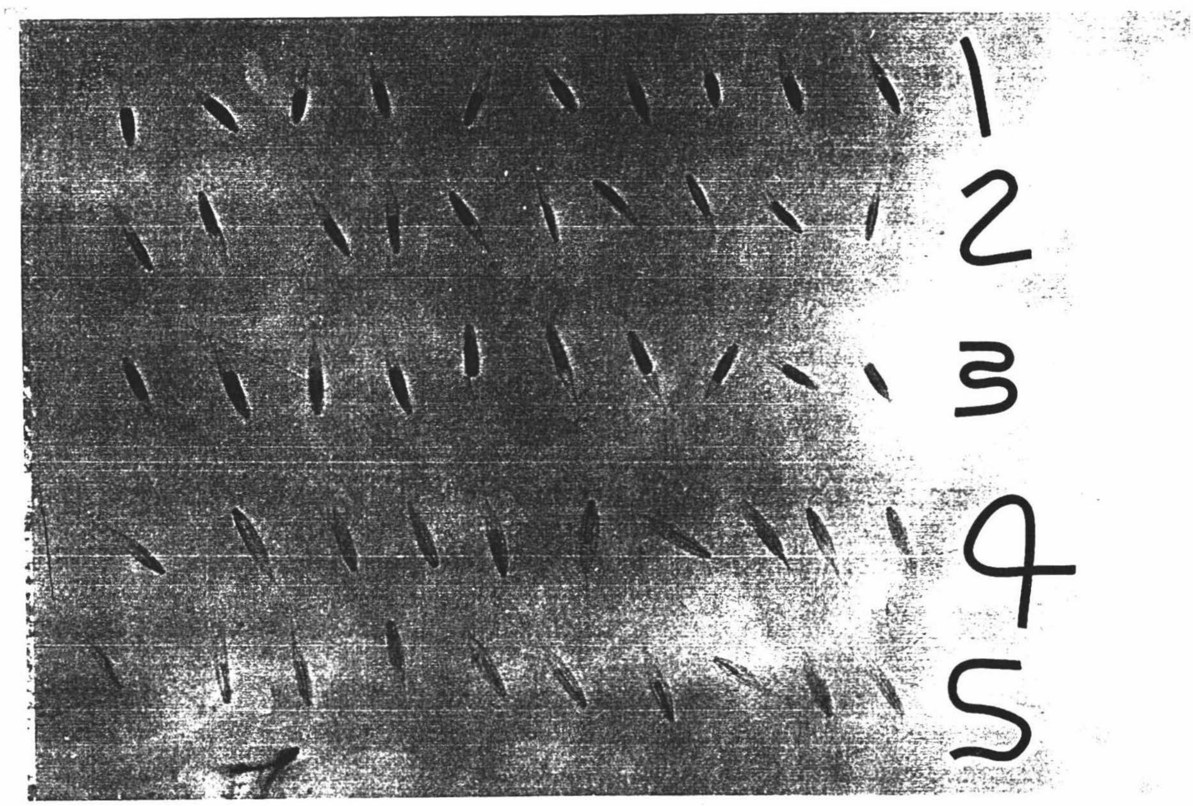

Plate 8.6 **X-Ray photograph of Roa tall fescue seeds exposed to different frost treatments (no frost protectants).**

1. No frost
2. -2°C at ear emergence
3. -2°C 8 days after anthesis
4. -5°C at ear emergence
5. -5°C 8 days after anthesis

8.4 DISCUSSION

This study has shown that tall fescue is sensitive to a -2°C and a -5°C air frost, particularly when seed heads are exposed at ear emergence and anthesis. A -5°C frost completely destroyed seed-bearing capacity and as a result no viable seed was formed, a result Nikolaevskaya (1973) also found in cocksfoot. At -2°C seed yield per tiller and 7 day germination declined after frosting at all growth stages, but T.S.W. and final germination were only reduced when plants were exposed at either ear emergence or anthesis.

The cereal plant is also particularly sensitive to frosts from ear emergence to grain development (Suneson, 1941; Langer and Olugbemi, 1970; Single and Marcellos, 1974), even when the frosts are only between -2°C and -2.5°C (Single, 1985). However, after anthesis and towards seed maturity, -3°C frosts have been found to lower seed weights but not damage germination in wheat (Single, 1985). In the present study, seed yield per tiller was reduced by a -2°C frost after anthesis, but not final germination (Table 8.2). T.S.W. was only reduced by a -2°C frost at ear emergence or anthesis. Tall fescue therefore reacts to frost in a similar way to cocksfoot (Nikolaevskaya, 1973) and cereals (Single, 1985). Heavy frosts (-5°C) destroy seed productivity, regardless of growth stage, while lighter frosts (-2°C) lower seed yield, seed weight and germination when seed heads are exposed between ear emergence and anthesis.

After anthesis, as the seeds increase in weight there will be a greater tolerance towards light frosts (-2°C) but seed yields can still significantly decline without loss of final germination. Even though -2°C frost exposed seeds at ear emergence in Plate 8.6 were visually as well developed as seeds not exposed to frost, the former were lighter, and seed yields were significantly reduced. T.S.W. of -2°C frost exposed seeds after anthesis did not differ from non-frosted seeds but seed yield per tiller did (Table 8.2), because light seed must have been removed during seed cleaning.

The two frost protectants used in this study did not prevent frost damage in tall fescue seed heads, even when they were exposed to a -2°C frost. However, Kocide treated seed heads suffered a lesser decline in seed yield than untreated seed heads (Table 8.3). Teric treated seed heads also suffered less damage than untreated seed heads at -2°C, but the difference was not significant at both $P<0.05$ and $P<0.10$. Kocide is apparently more effective in light frosts (-2°C) than heavy frosts when applied to horticultural crops (Lindow, 1983b) such as beans, squash, apricots, pears and tomatoes. In this study the -2°C air frost exposure for six hours may have been too severe for Kocide to work effectively. A shorter exposure of one to three hours may have increased the effectiveness of Kocide in preventing frost damage. Kocide also may not have had sufficient time to be effective before the frost treatments were applied. Research has shown that Kocide is more effective if it is applied two to five days before expected frosts occur (Lindow, 1983b). This is because the ice-nucleation-active bacteria while being rapidly killed by Kocide, only lose their ability to nucleate ice very slowly. This ice-nucleation activity is still associated with the dead bacterial cells (Lindow, 1983b). Therefore Kocide may have been more effective in preventing frost damage if it had been applied some days before the frost treatments were imposed. In this study this was not done as the time period between plant growth stages was thought to be critical and once a growth stage was reached the plants received frost treatments as soon as possible which was 16 hours after frost protectants were applied. However, in the field it is not possible to predict a frost several days in advance, and so if Kocide was applied, it would have to be applied at regular intervals during ear emergence, anthesis and seed development. And indeed Lindow (1983b) recommends that Kocide be applied at regular intervals, approximately 14 days (O'Connor, 1989), to be effective against light frosts (-1 to -2°C).

However, it must be emphasied that air frosts are equivalent to ground frosts several degrees colder. Examination of meteorological records (NZ Meteorological Service Summaries) shows that where an air frost occurs the associated ground frost is 2 to 4°C colder. This being the case then the -2°C air frost may have been too cold for the frost protectants to work, especially Kocide (Lindow, 1983b). But on the other hand Teric did prevent freezing damage in blackcurrant flowers down to temperatures near -6°C (Wilson and Jones, 1983b). A possible explanation for the ineffectiveness of Teric in preventing frost damage in tall fescue may be that Teric was not able to penetrate the seed tissue but could penetrate the larger vascular tissues of the blackcurrant flowers. Teric is reported (Wilson and Jones, 1983a,b) to prevent frost damage by penetrating blackcurrant flower tissues and altering the physical properties of tissue solutions during the freezing process so that tissue solutions do not freeze even at -6°C. Teric has only been reported to have been used on blackcurrant flowers (Wilson and Jones, 1983a,b) and tall fescue is only the second crop it has been evaluated on for frost protection.

Tall fescue seed heads are approximately 1 m above ground level during anthesis, a height at which air temperatures are measured in New Zealand. Air frost measurements are therefore more appropriate for recording for tall fescue seed crops than ground frost measurements. Only very heavily lodged tall fescue crops close to seed harvest have seed heads that are close to ground level and at this time the hardening seeds would be more resistant to sub-zero temperatures.

In the tall fescue seed growing regions of New Zealand, late spring air-frosts in November, the time tall fescue is growing from ear emergence to anthesis, are relatively common. At the research farm where the trials in Chapter 4, 5 and 7 were conducted, a -1.6°C air frost (-3.1°C ground frost) occurred on 27 November 1991, the time when tall fescue was in full flower. The seed yields obtained from these trials were 4 - 500 kg ha^{-1} lower than average and the T.S.W. of 1.9 to 2.2 grams considerably lower than the 2.4 to 2.8 grams obtained in previous trials. Other factors such as long periods of dull, overcast weather during seed filling in December may also have contributed to the low seed yields and T.S.W., but the fact that the -1.6°C air frost occurred during a sensitive growth stage in tall fescue, suggests that frost damage cannot be overlooked.

In the Canterbury region of New Zealand, where most tall fescue seed crops are grown, one or two air frosts of between -1 and -2°C can occur during November (NZ Meteorological Service Summaries). In 1991, severe November air frosts -1 to -2°C(-3 to -4°C ground frosts) did occur and tall fescue seed yields were considered lower (3 - 500 kg ha^{-1}) than normal with a lot of light seed being blown off in the combine harvester and removed by aspiration during seed cleaning (W. Moore, pers. comm.).

Frosts in the field may often be of a shorter duration than the six hour frost cycle used in this study. However, this study was concerned with the effect of sub-zero temperatures under controlled frosting on tall fescue seed production and not duration of frosting. Whether frost duration is of importance in affecting tall fescue seed heads is not known and would be an area of possible future research.

The results from this study show that tall fescue is particularly sensitive to frost damage at ear emergence and during anthesis. While a -5°C frost will destroy seed heads, the damage from a -2°C frost is more discreet and may not be immediately obvious. Only after harvest will it be noticed that seed yields have been reduced and seed weights and germination have decreased.

Increasing frost severity greatly increased floret sterility, particularly when frosting occurred at early growth stages, ear emergence and anthesis. A single exposure to a -2°C frost reduced seed yield by nearly 45% but had relatively less effect on T.S.W. and germination provided frost did not occur at ear emergence or anthesis. By the time seeds were a few days old some resistance to frost damage was evident. Despite some decrease in seed yield and a slight reduction in the rate of seed germination, 6 and 8 day old seed was less frost susceptible. Complete floret sterility occurred following a single -5°C frost irrespective of whether the two frost protectants used in this study were applied.

The ability of Kocide to reduce the degree of damage from the lighter frost can not be overlooked. More work needs to done on the timing of Kocide application under controlled light frost exposures in order to see if Kocide is more effective in preventing frost damage than this study showed. Teric also cannot be ignored and further work needs to be done to see if Teric can be as effective on grass seed crops as it was on blackcurrants (Wilson and Jones, 1983a,b).

The results of this study, where seed heads were only exposed to one frost cycle, have clearly shown the sensitivity of tall fescue to sub-zero temperatures. In field situations where successive frosts may occur, total infertility of florets which contain seed less than four days old will have a devastating and possibly cumulative effect in reducing seed yield and quality.

Chapter 9

General discussion, recommendations and conclusions.

For maximum seed production tall fescue seed crops require correct field management from planting to seed harvest (first year stands) and from harvest to harvest (second year stands). The experiments in Chapters three to six have shown that late-summer and autumn tillering is of extreme importance for subsequent reproductive development in the following spring and summer. The experiments in Chapters seven and eight have also shown that correct management of the crop must continue right up until seed harvest. The discussion in this chapter will link all these experiments together in order to develop a deeper understanding of the growth and development of tall fescue seed crops.

It has been over twenty years since Bean (1970) published his work on vernalization and juvenility in tall fescue. It has generally been accepted that a juvenile phase exists in tall fescue similar to the juvenile phase in cocksfoot (Calder, 1963) and phalaris (Ketellaper, 1960). Acceptance of the juvenile phase in tall fescue meant that low reproductive tiller numbers in seed crops could be explained with ease. If autumn-sown plants, or plants undersown with cover crops, or autumn to winter grazed crops failed to develop a sufficiently large number of reproductive tillers, then tiller juvenility was the usual explanation. That is, following autumn sowing, or cover cash crop harvest, or autumn to winter defoliation (grazing or close cutting), the plants would need to pass through a juvenile phase of some weeks before they could respond to winter cold vernalization. If tillers failed to become reproductive they had presumably not received the minimum hours of vernalization required because they had not grown out of their juvenile phase early enough.

The experiment in Chapter six has clearly shown that it is still not clear if a juvenile phase exists in Roa tall fescue. Other tall fescue cultivars may differ in terms of juvenility requirement and so it must be emphasised that the results from Chapter six apply to the cultivar Grasslands Roa. Most Roa tall fescue plants must still grow out of the seed stage and emerge with at least a main shoot with one leaf unfolded before they will respond to vernalization. However, some plants (10%), do not require any vernalization at all.

It was found, however, that it was the length of the vernalization exposure which increased the intensity of flowering (Table 6.2). But even when the Roa plants were exposed to 960 hours of temperatures below 8°C, only 55% to 70% plants produced reproductive tillers. The 960 hours of vernalization may not have been enough exposure to induce more plants. Either a longer period is needed to vernalize more Roa tall fescue plants, or perhaps a juvenile phase does exist in some plants (36%).

Unfortunately hourly grass minimum temperatures were not available from the sites where the field trials were conducted in 1990 and 1991. However, by using grass minimum temperatures from the main trial site, Aorangi, in 1992, tillers formed at the beginning of June would have received 992 hours of grass minimum temperatures below 8°C by the end of August and 1244 hours if formed before May. The winter of 1992 was colder than the 20 year average and therefore tiller formation before June would, in most years, be important in order for tillers to receive sufficient winter cold for vernalization.

If results from the field trials are examined it is found that total tiller numbers in June (Table 3.7, Table 4.7) and July (Table 5.6) are greater than the number of reproductive tillers that are produced at anthesis (Table 3.10, Table 4.7, Table 5.10). Either tiller death occurs and new tillers are formed, or tillers developing in June still did not receive sufficient vernalization exposure to be induced.

Hill and Watkin (1975) found that in ryegrass, timothy and prairie grass it was the early emerged heads after an autumn sowing or in the immediate post-harvest period that contributed nearly all the seed heads formed at seed harvest. Furthermore, Hill and Watkin (1975) found that the first tillers formed were highly persistent and became reproductive, whereas nearly all later formed tillers behaved as annual tillers and died. Tillers formed in winter and early spring showed a high mortality. This was also found by Robson (1968) in tall fescue where only 30% of all tillers flowered and many winter and spring formed tillers died after only a few days or a few weeks.

These results (Robson, 1968; Hill and Watkin, 1975), lend support to the present work on tall fescue. If the tillers in the tall fescue field trials had been tagged (identified), similar results to those of Robson (1968) and Hill and Watkin (1975) may have been found, with the first formed tillers from sowing or after immediate post-harvest management being the major contributors to seed yield. Thus, it seems very important that the first formed tillers are managed carefully in order to maximise their numbers and ensure their survival through the winter and spring to seed harvest.

With autumn-sown tall fescue crops, if it is vital that large numbers of tillers are established before June, the climate of the region becomes very important. The warm-moist Manawatu climate in March and April (Appendix 1.1) enabled early-autumn-established seed crops to produce satisfactory seed yields in the year of establishment (Table 3.3, 3.10). Also the choice of cultivar sown can contribute even more to successful autumn-sown crop seed yields. In Chapter three it was clearly shown that the turf-type tall fescue, Garland, tillered more rapidly in the autumn than the two pasture cultivars, Roa and G48 (Table 3.7), and was therefore able to produce more reproductive tillers and seed at seed harvest (Table 3.10). Tillers present in early-July also had the most significant correlation with reproductive tillers present at anthesis (3.11). This may be because early-formed tillers, late-summer and autumn, are the only tillers that survive until seed harvest.

Climate also plays an important role in ensuring that undersown tall fescue recovers well during late-summer and early-autumn and that the first-formed tillers survive. The moist-warm climate at the undersown trial sites (Appendix 2.1) enabled the numbers of undersown tall fescue tillers to 'catch up' to the numbers of tall fescue sown alone tillers by June (Table 4.5) so that at seed harvest, seed yields were only 24% below in undersown tall fescue compared to tall fescue sown alone (Table 4.7). The undersown tall fescue must also receive adequate early-autumn nitrogen (Meijer and Vreeke, 1988a) and in dry regions, irrigation (Chastain and Grabe 1989) to support the growth of the first-formed tillers. If these tillers are stressed and then die, the new tillers formed in the late-autumn and winter may not receive enough vernalization exposure (Chapter 6) to become reproductive or they may also not even survive until seed harvest (Robson, 1968).

The results from the vernalization experiment in Chapter six can also be applied to results found in the post-harvest management trials (Chapter 5). While autumn grazing and cutting did substantially increase vegetative tiller numbers in most plots (Table 5.9), many of these tillers may have either not received sufficient length of vernalization (at least 960 hours, Figure 6.1, Table 6.2) or they may have died before harvest and been renewed by more vegetative tillers (Robson, 1968). As tagging was not done some of these late-autumn and winter formed tillers may also have become reproductive but their contribution must have been small otherwise a far greater proportion of the 3000 to 4000 tillers present in July (Table 5.6) would have become reproductive.

The field recommendations that emerged from the establishment, undersowing, post-harvest management and vernalization trials would be as follows. Firstly, site is extremely important in determining the success of autumn-sowing and undersowing. The rapid emergence and subsequent tillering by autumn-sown plants and the recovery after severe shading of undersown plants by cover crops, is dependent on available soil moisture and mild temperatures at least above 15°C (Hill *et al.*, 1985; Charlton *et al.*, 1986) in the autumn. Production of commercial seed yields is dependent on many of the tillers forming before the onset of winter in order that these tillers receive full winter exposure to be vernalized.

Secondly, following the first seed harvest, burning, grazing or cutting the stubble immediately are all equally useful in enhancing second year seed yields. Also there is no advantage in terms of seed yield enhancement from either grazing, cutting or applying atrazine in the autumn to tall fescue seed crops, although there may be advantages in reducing ryegrass contamination. However, these recommendations apply to tall fescue seed crops grown at sites that receive good summer to autumn rainfall under mild temperature conditions. Where sites are dry and late-autumn and winters cold, buming harvest stubble has nearly always produced the best tall fescue seed yields in most trials (Youngberg, 1980).

The fungicide trial in November 1990 is the first report of the occurrence of stem rust in tall fescue seed crops in New Zealand. Although no stem rust was present in the fungicide trial area when propiconazole was first applied on 2 November 1990, this application was made to determine whether previous work on other grasses, which showed that in the absence of disease fungicides still increased seed yields because of increased green leaf area duration and less seed abortion (Hampton and Hebblethwaite, 1984; Hampton, 1986; Rolston *et al.*, 1989), would occur in tall fescue. This was despite Welty's (1986b) suggestion that fungicide did not increase tall fescue seed yields when little or no disease was present.

Stem rust did invade the first trial area (1990), and propiconazole was found to be highly effective against this disease (Table 7.3). Leaf senescence was lowered (Table 7.2) and seed yields increased by 1000 kg ha^{-1} following the use of propiconazole (Table 7.4). One propicicinazole application, at ear emergence, was found to be most effective.

In the second trial (1991), no visual symptoms of stem rust were present at ear emergence and anthesis and by the time of seed harvest only a trace of stem rust was found in untreated plants. No seed yield advantages were found from fungicide application in trial 2, supporting previous conclusions from research in the US that in the absence of disease it is not necessary to apply fungicides (Welty, 1989b; Mellbye and Young, 1990; Mellbye *et al.*, 1991). This suggests that tall fescue is unlike ryegrass (Hampton, 1986), in that even if flag leaf senescence is reduced by fungicides (Tables 7.7 and 7.8), the large green stems and green leaf sheaths are still capable of sufficiently supportive photosynthesis. The results further suggest that a significant invasion of disease affecting not only the leaves, but also leaf sheaths and stems would need to occur before seed yields decline in tall fescue seed crops.

The frost experiment was unique in that it quantified what had long been a grower opinion, that frost during seed head formation and seed development damages tall fescue seed crops by causing seed lots to have high levels of light, empty or shrivelled seed. Youngberg and Wheaton (1979) recommended that tall fescue not be grown in areas where late-spring frosts occur at the time of inflorescence emergence as seed yield will be reduced. Farmers in Canterbury, New Zealand, have been aware that frost damages tall fescue seed crops so they have attempted to overcome or reduce this problem by the application of frost protectants (A. Lill, pers. comm.) or frost damage insurance (W. Moore, pers. comm.). Until the present work was conducted (Chapter eight) there were no scientific data to support frost damage allegations or the value and effectiveness of materials applied as 'frost protectants' in tall fescue seed crops.

The research clearly showed that a -5°C air frost for six hours causes complete seed sterility (Tables 8.2 and 8.3, Plate 8.3). A less severe air frost of -2°C will lower seed yields and interim germinations, particularly when it occurs at ear emergence or anthesis (Table 8.2). The two materials applied as possible frost protectants, Teric and Kocide, were not able to prevent seed damage from air frosts. However, Kocide did reduce the level of seed yield loss to a lesser extent than the seed yield loss that occurred in untreated plants following a -2°C air frost.

The main conclusions arising from this study of agronomic aspects of tall fescue seed production are as follows:

1. Spring and summer sowings (October to February) gave the highest first season seed yields. Time of sowing in the autumn was critical as a delay of only three weeks from late-March to mid-April reduced seed yields by between 500 and 1000 kg ha^{-1}.

2. Undersown tall fescue seed yields were reduced at the first seed harvest when grown under barley sown at sowing rates above 100 kg ha^{-1} compared to tall fescue sown alone seed yields, but the economic return from growing tall fescue and barley together was $525

ha^{-1} more than sowing tall fescue alone.

3. Immediate post-harvest burning, grazing and straw removal of tall fescue all produced similar seed yields and autumn defoliation and atrazine had no effect on enhancing seed yields.

4. Vernalization increased the intensity of flowering of Roa tall fescue, but there were plants in the Roa tall fescue seed lot that did not require any vernalization at all.

5. Fungicides prevented seed yields declining in tall fescue but only when stem rust severely invaded the seed crop before anthesis.

6. Tall fescue seed heads were particularly sensitive to frost from ear emegence onwards. A -5°C air frost caused complete seed head sterility and a -2°C air frost reduced seed yield, but this reduction was lessened if a frost protectant, Kocide, was applied before frosting.

Suggested areas for future research arising as a result of the present study might include:

1. Vernalization: Further work must be carried out with longer periods of vernalization exposure used, 1000 to 2000 hours, to determine if longer exposure will make more tall fescue plants become reproductive. If possible, research on different tall fescue cultivar responses to vernalization should also be investigated. Those plants that do not require vernalization could be used in a plant breeding programme to breed a tall fescue cultivar without a vernalization requirement, which would perhaps be more suited to seed production from an autumn sowing than present tall fescue cultivars.

2. Establishment and cover crops: Although sufficient research has probably been done on time of establishment and undersown establishment with cover crops at warm-moist North Island sites, further work on these aspects needs to investigated in drier regions, where the effect of irrigation on autumn establishment and undersown tall fescue recovery would be worthy of future research, particularly as most commercial tall fescue seed production in New Zealand is carried out in drier regions.

3. Post-harvest management: The present trial is continuing for one more year. If the results again show no difference between immediate post-harvest management and subsequent autumn defoliation then research in this area need not continue in this region. However, with the large increase in the production of other tall fescue cultivars in Canterbury, the response of these cultivars to burning, grazing and cutting may not necessarily be the same as in Roa tall fescue. The dry, colder climate of Canterbury may also mean that post-harvest management and subsequent autumn defoliation results in a slower recovery of tall fescue seed crops than occurs under warm-moist North Island conditions. Therefore, different tall fescue cultivar responses to post-harvest management and autumn defoliation needs to be investigated in Canterbury.

4. Fungicides: At this stage it is not necessary to carry out more work with fungicides on tall fescue seed crops since the present study has clearly shown no advantage in fungicide application unless disease is present and that, in the presence of disease fungicides are capable of disease control. However, if new fungicides appear on the market or new disease strains develop, then further research may be required.

5. Frost: The current research was a preliminary investigation on the effects of frost on tall fescue seed production. Despite the fact that the results have clearly demonstrated the deleterious effect of air frost on seed yield and quality in tall fescue the use of less severe temperatures, different frost durations and repeated exposure were not studied and also given that Kocide did give some small protection to tall fescue seed heads during a light frost means that the use of chemical frost protectants can not be overlooked. These are areas which might be given more research attention.

6. Tiller development: Research on time of tiller formation, tiller survival and tiller fertility in tall fescue might be useful in identifying those tillers formed at particular times of the year which contribute most to the final crop of seed heads, and which should therefore be protected and enhanced by correct crop management.

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Appendices

Appendix 1.1 **Average monthly (0900 hrs) 10 cm depth soil temperature and rainfall for the period October 1989 to December 1990 (Aorangi) and March 1991 to December 1991 (Palmerston North) and average temperatures and rainfall (1980-90) for both sites.**

Month	Soil temperatures (°C)				Rainfall (mm)			
	Aorangi		Palmerston North		Aorangi		Palmerston Nort	
	1980/90	1989/90	1980/90	1991	1980/90	1989/90	1980/90	1991
October	12.7	13.7	-	-	67.9	125.2	-	-
November	15.2	16.8	-	-	67.3	33.3	-	-
December	17.3	16.9	-	-	66.4	56.7	-	-
January	18.5	19.0	-	-	71.7	102.5	-	-
February	18.0	20.9	-	-	54.5	11.5	-	-
March	16.2	18.0	15.6	16.2	71.6	169.2	91.2	28.7
April	12.7	14.1	13.1	12.7	52.3	47.1	60.4	162.7
May	9.7	10.8	10.3	10.4	62.	76.8	83.3	80.3
June	7.5	7.9	8.4	7.7	87.0	112.1	90.1	83.1
July	6.4	7.2	6.9	6.2	71.4	75.1	88.3	93.4
August	7.6	8.4	7.8	8.7	70.8	116.1	70.3	98.7
September	10.1	9.8	10.1	9.2	62.2	18.4	74.8	65.1
October	12.7	14.4	12.5	11.8	67.9	65.4	83.2	80.9
November	15.2	17.5	14.8	13.0	67.3	101.8	65.6	81.0
December	17.3	18.8	16.9	15.9	66.4	52.1	81.3	81.0

Appendix 1.2 **Effect of time of sowing on second harvest seed yield, T.S.W. and reproductive tillers.**

Time of Sowing	Seed Yield ($kg\ ha^{-1}$)	T.S.W. (g)	Reproductive tillers at anthesis
October	887	2.08	594
November	905	2.14	408
December	797	2.14	542
January	809	2.14	542
February	895	2.12	547
March	849	2.25	487
April	810	2.14	606
LSD (P<0.05)	n.s	n.s	n.s

Appendix 1.3 Effect of time of autumn sowing on seeds per spikelet.

Sowing Date	G48	Roa	Garland	LSD (P<0.05)
		Seeds per spikelet*		
4 March	2.83	2.83	2.62	n.s
25 March	2.98	3.86	2.88	n.s
15 April	3.61	2.33	2.11	n.s
LSD (P<0.05)	n.s	n.s	n.s	

Appendix 2.1 Average monthly (0900 h) 10 cm depth soil temperature and rainfall from October to September 1991.

Month	Soil temperatures (°C)		Rainfall (mm)	
	1989/90	1990/91	1989/90	1990/91
October	13.7	14.4	125.2	16.4
November	16.8	17.5	33.3	101.8
December	16.9	18.8	56.7	52.1
January	19.0	18.7	102.5	69.7
February	20.9	19.1	11.5	98.2
March	18.0	17.1	169.2	23.0
April	14.1	14.3	47.1	142.0
May	10.8	10.4	76.8	53.9
June	7.9	7.9	112.1	54.0
July	7.2	7.7	75.1	97.0
August	8.4	8.5	116.1	21.4
September	9.8	10.9	18.4	11.4

Appendix 2.2 Sensitivity analysis using parametric gross margins based on the data in Table 4.8.

(a) Gross margin ($ ha-1) advantage of undersown tall fescue over tall fescue alone*

Barley	Barley yield(t ha-1)				
$ tonne^{-1}	4.0	4.5	5.0	5.5	6.0
200	-232	-132	-32	68	168
240	-72	48	168	288	408
260	8	138	268	398	528

* Tall fescue undersown yield 770 kg ha^{-1} @ $2.30 kg^{-1}
Tall fescue alone yield 1018 kg ha^{-1} @ $2.30 kg^{-1}

(b) Gross margin ($ ha^{-1}) advantage of undersown tall fescue over tall fescue alone*

Undersown tall fescue yield kg ha^{-1}	Tall fescue alone yield (kg ha^{-1})				
	800	1000	1200	1400	1600
400	175	-285	-745	-1205	-1665
600	635	175	-285	-745	-1205
800	-	635	175	-285	-745
1000	-	-	635	175	-285
1200	-	-	-	635	175

* Barley yield 5.99 t ha^{-1} @ $260 t^{-1}
Tall fescue price $2.30 kg^{-1}

Appendix 3.1 Monthly rainfall and mean monthly 10cm (0900 hrs) soil temperatures.

Month	Rainfall (mm)		Soil temperature (°C)	
	1980-90[1]	1991	1980-90[1]	1991
January	71.7	67.9	18.5	18.7
February	54.5	105.9	18.0	19.1
March	71.6	23.0	16.2	17.1
April	52.3	135.9	12.7	14.3
May	62.0	49.9	9.7	10.9
June	87.0	54.0	7.5	7.9
July	71.4	85.6	6.4	7.7
August	70.8	114.9	7.6	8.5
September	62.2	72.6	10.1	10.9
October	67.9	76.6	12.7	11.4
November	67.3	66.4	15.2	12.7
December	66.4	81.4	17.3	15.5
Total	**805.1**	**933.6**		

[1] 10 year farm average

Appendix 3.2 Effect of atrazine upon tiller weight, tiller length and tiller diameter of tall fescue 9 July 1991.

	Atrazine		
Autumn defoliation	**Nil**	**Applied**	**LSD (P<0.05)**
	Tiller weight (g)		
No defoliation	0.379	0.337	n.s
Cut	0.106	0.116	n.s
Grazed	0.076	0.066	n.s
LSD (P<0.05	0.124	0.050	
	Tiller length (cm)		
No defoliation	60	59	n.s
Cut	26	27	n.s
Grazed	20	19	n.s
LSD (P<0.05)	10.7	6.0	
	Tiller diameter (mm)		
No defoliation	3.36	3.45	n.s
Cut	2.47	2.72	n.s
Grazed	2.36	2.24	n.s
LSD (P<0.05)	0.64	0.42	

Appendix 3.3 Effect of atrazine upon dry matter, tiller numbers, tiller weight, tiller length and tiller diameter, 2 September 1991.

	Atrazine		
Autumn defoliation	**Nil**	**Applied**	**LSD (P<0.05)**
	Dry matter ($kg\ ha^{-1}$)		
No defoliation	14770	12700	n.s
Cut	7839	6900	n.s
Grazed	7722	7109	n.s
LSD (P<0.05)	3738	3162	
	Tiller number (m^{-2})		
No defoliation	3225	2852	n.s
Cut	3782	3744	n.s
Grazed	5427	5064	n.s
LSD (P<0.05)	811	1340	
	Tiller weight (g)		
No defoliation	0.336	0.367	n.s
Cut	0.175	0.158	n.s
Grazed	0.122	0.120	n.s
LSD (P<0.05	0.073	0.108	
	Tiller length (cm)		
No defoliation	52	57	n.s
Cut	46	42	n.s
Grazed	38	37	n.s
LSD (P<0.05)	8.6	8.8	
	Tiller diameter (mm)		
No defoliation	3.18	3.18	n.s
Cut	2.49	2.47	n.s
Grazed	2.14	2.13	n.s
LSD (P<0.05)	0.39	0.38	