AN ABSTRACT OF THE THESIS OF

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Title: EFFECT OF CEREAL COMPANION CROPS ON THE ESTABLISHMENT OF RED FESCUE (FESTUCA RUBRA L.) FOR SEED PRODUCTION

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Some perennial grass seed crops such as red fescue (Festuca rubra L.) do not produce a profitable seed crop during the first growing season. The present establishment method in Oregon for red fescue seed crops generally entails spring planting which does not satisfy vernalization requirements for seed production in the year of planting. This establishment procedure relies on the amortization of establishment costs over the seed producing life of the stand. In Europe, perennial grass seed crops are often established with annual companion crops such as winter rape, flax, peas and cereals. Companion crops provide income in the year of establishment, thereby increasing the profitability of the seed production venture over the life of the stand. However, the companion crop competes with the grass seed crop for light, soil moisture and nutrients which often causes unsatisfactory establishment.

The primary objective of this study was to determine the feasibility of establishing red fescue with cereal companion crops in Oregon's Willamette Valley. The second objective was to examine the influence of cereal companion crops, cultivars and row spacings on the growth and environment of red fescue. This was investigated to identify companion cropping methods that would be the least competitive with the

establishing seed crop. The third objective was to evaluate the effect of companion cropping on subsequent red fescue seed production and income relationships over a two-year period.

Two experiments were initiated in October 1982 and October 1983 at the Oregon State University Hyslop Crop Science Field Laboratory. 'Pennlawn' red fescue was established with two winter wheat cultivars, 'Hill 81' and 'Yamhill', and two winter barley cultivars, 'Hesk' and 'Scio', as companion crops. Cereal companion crops were drilled in 15-, 30-, 45-, and 60-cm row spacings, perpendicular to red fescue rows. Red fescue was also established without a companion crop as a control.

Companion crop tiller height, tillers m^{-2} and leaf area $tiller^{-1}$ were measured to determine their influence on red fescue growth and development during establishment. The effect of cereal companion crops on red fescue environment was investigated by measuring photosynthetic photon flux density (PPFD) incident on red fescue plants and by determining soil moisture levels. Red fescue tiller height, leaf area, dry matter production, and tillers m^{-2} were examined to evaluate the effect of companion crops on red fescue growth. Companion crop grain yields were obtained to calculate additional revenues from establishment with companion crops. First-year red fescue seed yield and yield components were measured to determine the seed production capability of red fescue established with cereal companion crops. Finally, a partial budgeting technique was employed to evaluate the economic feasibility of companion cropping in Oregon.

Cereal companion crops markedly reduced PPFD incident on red fescue plants. This greatly decreased red fescue tiller m^{-2}, dry matter m^{-2}, individual tiller weight, and increased the height of tillers.

Leaf area tiller^{-1} was generally unaffected by companion crops. Increasing companion crop row spacing resulted in more red fescue tillers m^{-2}, dry matter m^{-2}, and reduced etiolation of tillers because of higher PPFD availability. Soil moisture content was not decreased by establishment with cereal companion crops.

Although companion crops adversely affected red fescue growth during the establishment year, first-year seed yield was not significantly reduced. Red fescue seed yields ranged from 490 kg ha^{-1} when planted with Hill 81 wheat to 654 kg ha^{-1} with Scio barley. The seed yield of red fescue planted without a companion crop was 589 kg ha^{-1}. Establishment with Yamhill wheat in 15-cm rows increased net income over a two-year period by $416 ha^{-1} over monocultural red fescue. Establishment with Hesk barley proved to be the least successful in terms of income. Establishment with companion crops was shown to be most profitable when cereal market prices were high and red fescue prices low. The results of this research clearly indicate the potential for increased profits by establishment of red fescue seed crops with cereal companion crops.

Effect of Cereal Companion Crops on the Establishment of Red Fescue (*Festuca rubra* L.) for Seed Production

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INTRODUCTION

The production of forage and turf grass seed requires special management practices to obtain a quality product with equitable profits for the grower. Several perennial grass seed crops do not produce marketable seed yields during the summer after establishment. These include red fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), and orchardgrass (*Dactylis glomerata* L.). In Oregon, the current method of establishing red fescue generally involves planting the crop in spring. Spring plantings do not produce a seed crop in the first growing season because the environmental conditions required to vernalize the crop are not satisfied. Planting the red fescue crop in the autumn will satisfy the environmental requirements but only insignificant quantities of seed are produced. This lack of income in the year of sowing, coupled with the increasing costs of production, requires the identification of a more cost-effective establishment method. Intercropping the grass seed crop with a cereal crop during the establishment year may be the solution to this problem.

Intercropping is defined as the production of two or more crops, such that most, if not all, of their growth overlaps in time and space. The intercropping method of grass seed crop establishment is commonly known as undersowing, covercropping, and companion cropping. The cereal crop is often referred to as a companion crop, nurse crop or cover crop, whereas the grass seed crop is known as the undersown crop. In this thesis, the term companion crop will be used to denote the cereal crop. In a grass seed production scheme, the cereal crop is present only during the establishment year, and in subsequent years, the grass seed crop is managed in a monocultural manner. The use of this system enables the grower to obtain an income in the establishment year by producing a cereal grain crop. European and some Canadian grass seed producers have embraced this method because they are eager to ensure a quick economic return rather than to rely on subsequent seed harvests to offset lost income in the establishment year (Peto, 1962; Griffiths et al., 1978). Forage crops in North America have been established with cereal crops (Kilcher and Heinrichs, 1960), but grass seed crops are infrequently established in this manner.

Griffiths et al. (1967) have indicated depressed seed yields from the initial harvest due to competition by the cereal crop in the establishment year. This minor loss in seed yield was readily counterbalanced by revenues generated by the cereal crop. Yields in subsequent years were normal.

The primary objective of this study was to investigate the feasibility of establishing red fescue with cereal companion crops in Oregon's Willamette Valley. The second objective was to determine the influence of companion crops on red fescue growth and environment in the year of planting. The third objective was to study the effect of companion crops on the first-year seed yield of red fescue and on net income received during the two-year period.

LITERATURE REVIEW

Intercrop Competition

When two or more crops are grown simultaneously in a cropping system, it is inevitable that competition will occur between the constituents of that system for factors that have profound effects on vital plant processes. Competition for light and moisture between companion crops and undersown crops during establishment was recognized early by Evans (1951).

Light

One of the problems associated with the use of cereal companion crops in establishing grass seed crops is the reduction in the amount of light received by the undersown grass due to shading by the companion crop. This shading can result in deviations from the normal quantity, quality, and duration of incident photosynthetically active radiation (PAR) that can result in adverse effects on vital plant processes in the undersown crop. Reductions in incident PAR due to shading incurred in intercrop competition can have significant ecological implications, especially when the quantity of incident PAR is reduced to 20% of normal sunlight (Daubenmire, 1974). The lower limit for vascular plant survival is attained when relative PAR quantities reach 1-2% (Larcher, 1975). Blackman and Black (1959), showed that the maximum growth rates for orchardgrass, perennial ryegrass (*Lolium perenne* L.), and meadow fescue (*Festuca pratensis* Huds.), occurred at 80-100% of full sunlight with reduction in growth rates noted below this level. In experiments exploring the effect of shade- reduced PAR incidence on weeds, it was shown that 10% of PAR found in normal sunlight resulted in height reduction in *Celosia argentea* L. and *Tridax procumbens* L. (Shetty et al.

1982). Also at the same PAR level, the leaf area index of Digitaria ciliaris L. decreased 70 to 80% and dry matter production was reduced up to 80% at higher shading levels.

Increases in incident PAR quantity are accompanied by greater dry matter production in grasses (Alberda, 1966). Low PAR incidence was found to inhibit tiller production resulting in lower final tiller number and reduced rate of leaf primordia accumulation on the shoot apices of meadow fescue and perennial ryegrass (Ryle, 1967). Swards of downy brome (Bromus tectorum L.) grown below a Kentucky bluegrass canopy exhibited greater biomass production and increased survival rates when exposed to supplemental light than those plants that did not recieve this treatment (Bookman and Mack, 1983). Water soluble carbohydrates, plant weight and tiller number of orchardgrass were all reduced as plants were increasingly shaded (Auda et al., 1966).

In studies where subterranean clover (Trifolium subterraneum L.) was undersown with a wheat (Triticum aestivum L.) companion crop, a positive linear relationship was seen between PAR availability and clover dry matter production (Santhirasegaram and Black, 1968). Van Keuren and Canode (1963), reported decreases in crested wheatgrass (Agropyron desertorum (Fisch.ex Link) Schult.) seed yield when established with a barley (Hordeum vulgare L.) companion crop. Competition for soil moisture here is assumed not to be a limiting factor because irrigation was provided, thus shading by the barley was suggested as a possible reason for the reduction in seed yield.

The duration that PAR of favorable quantity or quality is available to undersown crops is controlled by the cereal companion crop. The point in the life cycle of the plant competitors at which competition occurs is of paramount importance (Donald, 1961). As wheat companion crops increase in stature and leaf area during elongation of their culms, the quantity of PAR available to undersown Kentucky bluegrass steadily decreased (Meijer, 1979b). Plant canopies can alter the light quality incident on plants below them, thus the relative proportion of red light is increased while the proportion of blue and violet light tends to be lower (Daubenmire, 1974).

Intercrop competition for light can influence plant growth and development. Plants that are subjected to low light availability experience a lowering of the photosynthetic rate and reductions in the net assimilation rate (Donald, 1961). Milthorpe (1961), in reporting work done by Blackman and Wilson (1951), stated that the growth rates of plants are seldom lessened before incident light levels fall to 100-150 cal cm^{-2} day^{-1}. The growth and yield of beans (Phaseolus vulgaris L.) was lower when intercropped with corn (Zea mays L.) than when monoculture was utilized, with the decreases being attributed to shading by the corn (Gardiner and Craker, 1981). Growth rate, leaf area index, and the net assimilation rate of beans decreased with reductions in light availabilty.

Transmitted light is that which is found at a given level above the soil surface in the crop community, including that which is reflected, penetrates and passes through foliage (Anderson, 1966). Many factors influence light transmission through a cereal canopy to the undersown grass seed crop. These include leaf area, leaf arrangement, leaf angle, plant height, plant density and the type or cultivar of companion crop involved.

Soil Moisture

The successful use of a cereal companion crop is dependent on an adequate supply of soil moisture for both the grass seed crop and the companion crop. In Europe, this system of establishment is a common practice due, in part, to the availability of ample summer precipitation. In contrast with European climate, the Willamette Valley is characterized as having mild, wet winters interrupted by summer drought that results in a soil moisture deficit. Competition for soil moisture during this period between the two crops can, in some instances, result in failure of the undersown grass seed crop to establish properly. Griffiths and Roberts (1974), illustrated this point by stating that a recent spring drought in Wales caused failures in undersown grass seed crop stands. Unpublished research in Oregon by de Haas (1983) indicated that soil water potential was actually greater when Kentucky bluegrass was undersown with a winter wheat companion crop than when established alone.

Soil moisture stress is responsible for a number of effects on perennial grass seed crop growth. Brown and Blaser (1970), in studying the effect of soil moisture stress on orchardgrass showed increasing soil moisture stress reduced tiller number and tiller weight. Norris (1982) found that tiller number and tiller weight in perennial ryegrass and tall fescue (*Festuca arundinacea* Schreb.) were also reduced by soil moisture stress, but orchardgrass tiller numbers were not reduced.

Interactions Between Factors

Evaluation of the influence of light in intercrop competition can be a difficult matter because other environmental factors such as wind, relative humidity, soil moisture, and temperature all vary concomitantly with reductions in light availability (Daubenmire, 1974). In competition studies between downy brome and Kentucky bluegrass, shading by Kentucky bluegrass was the initial cause for decreased productivity of the downy brome, but the inability of roots to grow and obtain available resources was the ultimate cause of mortality (Bookman and Mack, 1983). The interrelationship of light availability, soil temperature, and soil moisture was noted by Larson and Willis (1957), when using corn to establish an alfalfa (Medicago sativa L.) and red clover (Trifolium pratense L.) mixed forage crop. In areas where the forages were shaded by corn, they found soil temperatures were lower and soil moisture was in greater supply. Better alfalfa-clover stands were found in these shaded areas resulting in greater dry matter production. Contradictory to the findings of Larson and Willis were those obtained by Cooper and Ferguson (1964) while establishing alfalfa, orchardgrass and birdsfoot trefoil (Lotus corniculatus L.) with a barley companion crop. Here soil temperatures were also lower under the shade of the companion crop but soil moisture content was reduced by the barley.

Strategies for Minimizing Intercrop Competition

The impact of competition between the companion crop and the grass seed crop can be minimized by cultural practices and cultivar or crop selection. When red fescue and Kentucky bluegrass are undersown, adaptations in the management of the companion crop need to be utilized in order to enhance the growth environment of these grasses (Meijer, 1984).

Cultural Practices

In experimentation with undersown subterranean clover, growth and dry matter yield of the undersown clover was greater when the wheat companion crop was planted in north-south oriented rows than in east-west rows due to greater light availability (Santhirasegaram and Black, 1968). Light availability increased with wider companion crop row spacing, with a slight decrease observed for the widest row spacing possibly due to increased tillering of the wheat at this spacing. Studies conducted by Tanner and Peterson (1960), showed that corn drilled in east-west rows provided more uniform light to interseeded alfalfa than north-south rows, resulting in greater transmission during morning and afternoon hours when there was less available light than at noon. Cloudy conditions caused a 25% relative increase in light transmitted through north-south corn rows but not in east-west drilled rows. Meijer (1979b) found by increasing the row width of a winter wheat companion crop from 12.5cm to 37.5cm, light transmission and tiller number increased in Kentucky bluegrass. Bor and Vreeke (1974), recommended 25cm to 37.5cm row spacings be used for the wheat companion crop when undersowing Kentucky bluegrass.

Crested wheatgrass seed yields in Canada were not different when the wheat companion crop was sown parallel to the grass rows, across the grass rows or without the companion crop, although yields were slightly better when planted parallel (Lawrence, 1970). Wheat row spacings of 30.5, 61, and 91.5cm in right angle seedings and in 15.2, 30.5, and 91.5cm rows drilled parallel to crested wheatgrass rows had no effect on seed yield. In an earlier study, Lawrence (1967), reported that wheat companion crops, whether sown parallel or across, reduced Russian wild ryegrass (*Elymus junceus* Fisch.) seed yields greatly. Row spacing of the companion crop had a greater effect on seed yield, because the narrowest wheat row spacings gave the lowest Russian wild ryegrass seed yields. Unpublished work at Oregon State University (1983) has shown when winter wheat was sown in rows parallel to the grass seed crop row, seed yields were greater for orchardgrass than when the wheat was sown across the rows. Kentucky bluegrass seed yields were markedly decreased by a winter wheat companion crop regardless of row orientation.

Kopriva (1961), noted that the seeding rate of the cereal companion crop should be reduced by one-fourth under dry conditions. When undersowing Kentucky bluegrass, a winter wheat seeding rate of 100 kg ha^{-1} was regarded as beneficial to the grass seed crop. Seeding rates of 50.4 and 100.8 kg ha^{-1} for the winter wheat companion crop had no adverse effects on timothy (*Phleum pratense* L.) seed yields, but both seeding rates reduced bromegrass (*Bromus inermis* Leyss) seed yields in New York (Pardee and Lowe, 1963). First year orchardgrass and Kentucky bluegrass seed yields were not influenced by winter wheat seeding rates of 67 and 100 kg ha^{-1} in unpublished research conducted at Oregon State University (1983). Orchardgrass seed yield reductions over a three year period were lessened by reducing the number of spring oat (*Avena fatua* var. *sativa* (L.) Haussk.) rows by one-fifth in Wales (Roberts, 1964). Meijer (1981), in the Netherlands, reported Kentucky bluegrass yields in the first year were greater when the winter wheat companion crop was sown at an 80 kg ha^{-1} rate than at 165 kg ha^{-1}. Similar results were obtained for red fescue where greatest seed yields were attained using an 80 kg ha^{-1} winter wheat seeding rate (Meijer, 1979a).

Grass seed crops can be established with cereal companion crops by employing one of two basic methods. Using the first method, simultaneous sowing of the companion crop with the grass seed crop can be done either in fall or spring. The delayed sowing method entails drilling the companion crop in fall, then seeding in the grass seed crop in spring (Sicard, 1984). Griffiths et al. (1978), suggest simultaneous planting, because this method allows the undersown crop the greatest opportunity to establish and survive under a competitive environment. Planting Kentucky bluegrass and red fescue seed crops at the same time as the winter wheat companion crop was regarded by Liefstingh and Vreeke (1971) as the superior method under the conditions that exist in the Netherlands. Sicard (1984), favors spring seeding of grass seed crops into fall planted cereals in the continental climate regions of France. In these areas, fall plantings are more susceptible to the direct action of frost and soil heaving than are spring planted grasses.

Cultivar or Crop Selection

Properly selecting a companion crop with attributes that lessen the impact of competition can contribute to better stand establishment and subsequent seed yields. In commenting on the effects of intercrop competition, Donald (1961) stated that overstory crops with leaves that express upright angles increase the relative amount of light received by the understory crop. The leaf water potential of soybeans (*Glycine max* (L.) Merr.) intercropped with sorghum (*Sorghum bicolor* (L.) Moench) was greater when a tall variety of sorghum was utilized than when monoculture or a shorter sorghum variety was employed, with the difference being attributed to increased shading by the taller sorghum variety (Wahua and Miller, 1978).

When spring barley and oats are used to establish forage legumes, those cultivars with fewer and shorter tillers allowed more light transmission to undersown forages (Flanagan and Washko, 1950). Evans (1951) considered the most beneficial attributes of cereal companion crops used to establish grass seed crops to be lodging resistance, low leaf area and early uniform maturity. Kopriva (1961) concurred with these views by stating that a short growing period and reduced tendency of the cereal crop to lodge was necessary when undersowing grass seed crops.

There are qualities of the grass seed crop that can make them better suited for establishment with a companion crop. Roberts (1960), listed those qualities a grass seed crop must possess for sucessful establishment with a companion crop. These include the capacity to tiller under shaded conditions, form new tillers after removal of the companion crop, and the ability to tiller under the low soil temperature regime of autumn and winter. The drought tolerance and competitive ability of crested wheatgrass were regarded as contributing factors in reducing the persistance of influence of the wheat companion crop on dry matter and seed yield (Lawrence, 1970).

The type of companion crop and the crop to undersow must be considered in order to insure adequate yields from both crops. Undersowing orchardgrass and meadow fescue with spring barley resulted in better seed yields than those obtained using winter wheat as a companion crop (Schoberlein, 1980). In Sweden, Cedell (1975), found that when establishing red fescue with barley, the first year seed yields were slightly reduced when compared to red fescue established alone, while Kentucky bluegrass seed production was severly reduced by a barley companion crop. Both seed crops suffered substantial yield losses when undersown with a winter wheat crop. Seed yield of Kentucky bluegrass when established with winter turnip rape (Brassica napus L.) or broadbean (Vicia faba L.) experienced no decreases.

In Romania, the average seed yield of meadow fescue over a three period was 723 kg ha^{-1} when sown with spring oats compared to 780 kg ha^{-1} when sown alone (Popovici and Ciubotariu, 1978). Similar results were noted for timothy undersown with spring oats. First year seed yields of Kentucky bluegrass were 1080 kg ha^{-1} when undersown with flax (Linum usitatissimum L.), 1000 kg ha^{-1} with winter wheat, and 570 kg ha^{-1} with spring barley (Liefstingh and Vreeke, 1971). Red fescue yields in the year after sowing were reported to be 1290 kg ha^{-1} with flax, 990 kg ha^{-1} with winter wheat and 850 kg ha^{-1} with spring barley.

Winter rape, winter wheat, spring wheat, barley, field bean and oil flax were evaluated to determine their capability as companion crops for establishing Kentucky bluegrass in Denmark (Nordestgaard, 1979). All the companion crops tested reduced the number of Kentucky bluegrass fertile tillers for the first harvest year somewhat with spring wheat showing significant reductions. With the exception of winter rape, companion crops were found to depress first year seed yields and over a two-year period, yield reductions ranged from 15-34%, depending on the companion crop in question. Nordestgaard (1981) noted that undersowing Italian ryegrass (Lolium multiflorum Lam.) and perennial ryegrass with spring barley was superior to sowing alone in terms of seed yield.

Griffiths et al. (1967), in Wales, reported that barley companion crops reduced first year seed yields of timothy, meadow fescue, tall fescue, and orchardgrass, whereas bentgrass (Agrostis tenuis Sibth.) and perennial ryegrass were not adversely affected. In the second year, all seed crops established with barley did not yield differently than those established alone. Undersowing orchardgrass with spring oats as a companion crop decreased first year seed yields, but subsequent harvests were equivalent to that obtained by monocultural methods (Roberts, 1964). Pardee and Lowe (1963) found no differences in the mean yields for the first two harvests of timothy, smooth bromegrass, and orchardgrass, with or without companion crops of winter wheat, barley or spring oats in the humid conditions of the northeastern United States. In Washington state, crested wheatgrass exhibited losses in yield over a three-year period when established with barley, but no losses were detected when peas (*Pisum sativum* L.) were used as a companion crop (Van Keuren and Canode, 1963).

Special Practices

Weed Control

Weed control practices that result in fields that are essentially weed-free are a prerequisite for successful grass seed crop production. This success can be attributed to increases in seed quality, reduction in competition, and increased marketability of the product. Establishing grass seed crops with cereal companion crops can present special weed control problems because this system requires herbicides that are selective in two crops simultaneously during the establishment year. Early use of companion crops relied upon cultivation and shading produced by the companion crop to control weeds (Evans, 1951). With the advent of modern herbicides, the role of the companion crop has shifted from an agent of weed control to cash crop. There are critical points in the process of grass seed crop establishment with cereal crops where herbicide applications are essential. These include applications at planting to control annual grass and broadleaved weeds, broadleaved weed control in spring and finally, volunteer cereal control after the grain is harvested.

In Belgium, the least amount of damage in orchardgrass, Kentucky bluegrass and meadow fescue was obtained when isoproturon or isoproturon with neburon was applied shortly after planting the winter wheat companion crop when undersowing the grasses in April (Himme et al., 1983). Sicard (1984), in France, obtained similar results with orchardgrass where herbicide applications could be made at the tillering stage of the wheat and at least three weeks before the grass seed crop is undersown. Neburon and isoproturon are used to control annual grass and broad leaved weeds in winter wheat, spring and winter barley, but are not available for usage in the United States. Also using the delayed seeding method in France , control of annual grass weeds was obtained with diclofop-methyl after emergence of red fescue and orchardgrass (Debrand, 1981).

No information was available for herbicides utilized in simultaneous fall plantings in Europe. In the United states, the carbon-seeding method outlined by Lee (1973) is usually used when fall seeding valuable perennial grass seed crops without a companion crop. This method entails the application of a charcoal band over the grass seed at planting which absorbs an herbicide such as diuron (similar in weed control capability to isoproturon and neburon), thus protecting the seed from the herbicide and controlling the weeds at the time of planting.

In delayed spring seeding of orchardgrass, tall fescue, meadow fescue, red fescue and timothy into fall planted winter wheat, good post emergence control of broadleaved weeds was obtained by applications of tetrabutryn and nitrofen, allowing at least four months between the time of application and planting the grass seed crop (Sicard, 1984). Broadleaved weeds were controlled in simultaneous seedings of crested wheatgrass and a wheat companion crop by spraying 2,4-D (Lawrence, 1970).

In the year following establishment, shattered cereal seed becomes the source of a weed problem that demands serious consideration. Control of volunteer cereals is difficult because an herbicide must be used that will control one member of the grass family (the cereal), but not another (the grass seed crop). Volunteer winter wheat can be controlled in Kentucky bluegrass and red fescue in the Netherlands by applying 5 kg ha^{-1} TCA between mid-September and mid-October when the wheat has germinated (Liefstingh and Vreeke, 1971; Bor and Vreeke, 1974). Volunteer spring barley can best be controlled in Kentucky bluegrass and red fescue by 4 l endothal and 1 l wetting agent ha^{-1} (Liefstingh and Vreeke, 1971). Nordestgaard (1976) suggested that when volunteer cereal from the companion crop interferes with the growth of the undersown crop, cutting the field would be considered an appropriate control measure. Volunteer winter cereals can be controlled in red fescue by sethoxydim and ethofumesate will control these in perennial ryegrass, tall fescue and Kentucky bluegrass in the United States (Whitson et al. 1985).

Post Cereal Harvest Residue Management

After the cereal companion crop is harvested, much cereal stubble and straw remains in the field which can interfere with light interception and growth of the grass seed crop. Removal of the crop residue following cereal harvest is essential for the use of soil-applied herbicides because these applications can be rendered ineffective if the soil surface is covered with crop residue. Van Keuren and Canode (1963) removed grain straw after harvesting of barley companion crops used to establish crested wheatgrass and orchardgrass.

Nordestgaard (1973, 1982) conducted extensive studies on removing barley companion crop straw used in undersowing orchardgrass, perennial ryegrass, meadow fescue and red fescue. Nordestgaard compared removal of straw immediately after harvest, two weeks after harvest, and four weeks after harvest with not removing the straw. Delaying removal of barley residue greatly reduced first year seed yields in all of the grass seed crops evaluated. For example, if barley straw was removed immediately, then first year red fescue seed yields of 820 kg ha^{-1} were obtained whereas if removal was delayed four weeks or not removed, then red fescue yielded only 640 kg ha^{-1}. Increasing the fall nitrogen application did not overcome non-removal of straw. Field burning the straw reduced fertile tillers and first year seed yield for all grass species with red fescue experiencing a 75% decline in yield. Where straw was immediately removed after barley harvest, the average yields over a two-year period were 990 kg ha^{-1} compared with 750 kg ha^{-1} for field burning the straw. Field burning red fescue residue in subsequent years was found to increase seed yields. Temperatures generally appeared to be lower in red fescue where barley straw was removed.

Fertilization

Special fertilizer requirements are needed to successfully use companion crops to establish grass seed crops. Roberts (1964) reported that when orchardgrass was established with spring oats, an additional fall application of an ammonium nitrate and limestone mixture resulted in a greater number of fertile tillers but an additional spring application improved seed weight per panicle and seed yield in the first year. Van Keuren and Canode (1963) speculated that reductions in crested wheatgrass yields may have been due, in part, to insufficient quantities of nitrogen available to aid in the breakdown of the roots and stubble of the barley companion crop. In studies conducted by Nordestgaard (1980), the effect of timing of autumn nitrogen applications in the year of undersowing on red rescue was examined. Applications of nitrogen at a 62 kg ha^{-1} rate were made on August 1, August 15, September 1, and September 15 after removal of the barley companion crop. He concluded that the greatest number of fertile tillers and seed yield of first year red fescue were obtained by delaying nitrogen applications to September 15.

Economic Implications

The primary motivation for establishing grass seed crops with companion crops is financial in nature. Roberts (1964) illustrated the economic benefits of establishing orchardgrass with spring oats as a companion crop. In general, over a three-year period, orchardgrass seed yield was not reduced by establishment with a cereal crop and when income from the cereal crop was considered, this method earned 10-15% greater annual financial return. Similar results were reported by Griffiths et al. (1967), using barley as a companion crop for orchardgrass, where 20% greater mean annual income was attained for an equivalent time period. In Canada, crested wheatgrass yields were not decreased by establishment with a wheat companion crop; therefore, it was noted that the combinations of reasonable seed yields and income from the wheat crop could make this cropping system attractive to the grower (Lawrence, 1970).

MANUSCRIPT I

EFFECT OF CEREAL COMPANION CROPS ON ESTABLISHMENT OF RED FESCUE FOR SEED PRODUCTION

ABSTRACT

Red fescue (*Festuca rubra* L.) seed crops are characterized by slow establishment and unprofitable seed yields during the first year. In Europe, planting red fescue with cereal companion crops permits the grower to avoid the lack of income during the establishment year. However, the companion crop competes for light, soil moisture and nutrients which may retard initial growth of the seed crop.

The objectives of this study were to determine the feasibility of establishing red fescue seed crops with cereal companion crops in Oregon's Willamette Valley and to examine the influence of cereal companion crops, cultivars and row spacings on the growth and environment of red fescue. 'Pennlawn' red fescue was established in 1982 and 1983 on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil near Corvallis, OR with 'Yamhill' and 'Hill 81' winter wheat (*Triticum aestivum* L.), and 'Hesk' and 'Scio' winter barley (*Hordeum vulgare* L.) as companion crops. The cereals were drilled in 15-, 30-, 45- and 60-cm rows perpendicular to the red fescue rows.

The influence of wheat and barley on red fescue environment and growth was monitored until the cereals were harvested. Companion crops markedly reduced photosynthetic photon flux density (PPFD) incident on red fescue plants. This greatly decreased red fescue tillers m^{-2}, dry matter m^{-2}, individual tiller weight and increased the height of tillers. Leaf area $tiller^{-1}$ was generally unaffected. There were no differences in red fescue growth under wheat or barley or under their respective cultivars. Increasing row spacing resulted in more red fescue tillers m^{-2}, dry matter m^{-2} and reduced etiolation of tillers

because of higher PPFD availability. Soil moisture content was not decreased by establishment with cereals. Competition with companion crops for PPFD was more important than soil moisture in determining red fescue growth during the establishment year.

Additional index words: Grass seed production, Intercrop competition, Wheat, Barley, Photosynthetic photon flux density, Soil moisture content, Growth analyses, *Festuca rubra* L.

Effect of Cereal Companion Crops on Establishment of Red Fescue for Seed Production

INTRODUCTION

Red fescue (Festuca rubra L.) is a perennial turf grass adapted to cool temperate regions. The present establishment method in Oregon for red fescue seed crops generally entails spring planting which does not satisfy vernalization requirements for seed production in the year of planting. Intercropping red fescue with cereal companion crops during the establishment year may alleviate this income deficit by the production of a cereal grain crop. Unfortunately, intercrop competition between red fescue and the cereal companion crop for light, moisture and nutrients is an inevitable consequence of this establishment method. Minimizing the impact of intercrop competition is the primary objective of an establishment program that includes the use of cereal companion crops.

Companion cropping has gained wide acceptance among European grass seed producers because of the immediate income generated by the grain crop (Peto, 1962; Griffiths et al., 1978). In addition, greater long-term income may be realized by the grower. Cereal companion crops have been used to establish forage crops in North America (Kilcher and Heinrichs, 1960), but grass seed crops are seldom established in this manner.

Light interception by the cereal companion crop reduces the amount of light received by the grass seed crop and influences its growth and development. In perennial grass seed crops such as orchardgrass (Dactylis glomerata L.), perennial ryegrass (Lolium perenne L.) and meadow fescue (Festuca pratensis Huds.), the maximum rate of growth occurred in 80 to 100% of full sunlight, while reductions in growth rate were noted below these levels (Blackman and Black, 1959). Ryle (1967) reported that shading inhibited tiller production and reduced the rate of leaf primordia accumulation on the shoot apices of meadow fescue and perennial ryegrass. Shading reduced plant weight, water soluble carbohydrates and tiller number of orchardgrass (Auda et al., 1966). Supplemental light increased biomass production and survival of downy brome (Bromus tectorum L.) shaded by a Kentucky bluegrass (Poa pratensis L.) canopy (Bookman and Mack, 1983).

A cereal companion crop may possibly compete with the grass seed crop for soil moisture during periods of soil moisture depletion, adversely affecting establishment of the grass. Soil moisture stress reduced tiller number and the weight of individual tillers in orchardgrass (Brown and Blaser, 1970). Investigations of soil moisture stress by Norris (1962) revealed similar results for perennial ryegrass and tall fescue (Festuca arundinacea Schreb.), but contrary to the findings of Brown and Blaser, tiller numbers were not decreased by moisture stress in orchardgrass.

Various strategies that have been implemented to minimize competition by cereal companion crops include manipulation of row spacing, row orientation, seeding rate and the use of companion crops that are not strong competitors. Meijer (1979b) noted that winter wheat (Triticum aestivum L.) planted in 37.5-cm rows made more light available for a Kentucky bluegrass seed crop than wheat planted in 12.5-cm rows, resulting in greater numbers of Kentucky bluegrass tillers.

Lawrence (1970) found that crested wheatgrass (Agropyron desertorum (Fisch. ex Link) Schult.) seed yields were similar whether a wheat companion crop was planted parallel to the grass rows, across the grass rows, or when a companion crop was not used. In addition, when wheat was seeded in 30.5-, 61-, and 91.5-cm rows parallel to wheat-grass rows, there were no detectable adverse effects on subsequent seed yields. Using the same wheat companion crop planting arrangements, Lawrence (1967) reported that seed yield of Russian wild ryegrass (Elymus junceus Fisch.) was markedly reduced.

Pardee and Lowe (1963) found that timothy (Phleum pratense L.) seed yield was not affected when a winter wheat companion crop was drilled at 50.4 and 100.8 kg ha^{-1}, but these same rates reduced bromegrass (Bromus inermis Leyss) seed yield. Meijer (1981) reported that first-year Kentucky bluegrass seed yields were greater when the seeding rate of the winter wheat companion crop was reduced from 165 to 80 kg ha^{-1}. Lowering the wheat seeding rate to 80 kg ha^{-1} also gave the best red fescue seed yields (Meijer, 1979a).

Certain companion crop cultivars contribute to better stands and seed yields than do others. Flanagan and Washko (1950) found that when spring barley (Hordeum vulgare L.) and oat (Avena fatua var. sativa (L.) Haussk.) cultivars had fewer and shorter tillers, greater amounts of light were transmitted to forage legumes. Evans (1951) considered the most beneficial attributes of cereal companion crops to be lodging resistance, low leaf area and early uniform maturity. Roberts (1960) concluded that a grass seed crop in a successful companion cropping system must possess the capacity to tiller under shaded conditions, form new tillers after removal of the companion crop, and have the ability to tiller under low soil temperatures.

The objectives of this research were to determine the feasibility of establishing red fescue seed crops with cereal companion crops in Oregon's Willamette Valley and to examine the influence of cereal companion crops, cultivars and row spacings on the growth and environment of red fescue.

MATERIALS AND METHODS

Two experiments were initiated on 11 October 1982 and 5 October 1983 at the Oregon State University Hyslop Crop Science Field Laboratory near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil. 'Pennlawn' red fescue was established with two winter wheat cultivars, 'Hill 81' and 'Yamhill', and two winter barley cultivars, 'Hesk' and 'Scio', as companion crops. The cereals were drilled in north-south rows in 15-, 30-, 45-, and 60-cm row spacings using an Ojyord plot drill at seeding rates of 118, 118, 79, and 59 kg ha^{-1}, respectively. Red fescue was planted in 30.5-cm rows in an east-west direction at a 11.2 kg ha^{-1} seeding rate.

Activated charcoal was applied in a band over the red fescue rows at a 28 kg ha^{-1} rate. An application of 2.24 kg ha^{-1} diuron [3-(3, 4-dichlorophenyl)-1,1-dimethylurea] was made immediately following planting. Bromoxynil (3, 5-dibromo-4-hydroxybenzonitrile) was applied for general broadleaved weed control on 6 April 1983 and on 22 March 1984 at a 0.56 kg ha^{-1} rate. Dinoseb amine (2-sec-butyl-4,6-dinitrophenol, alkanolamine salt) was applied on the second experiment on 31 January 1984 at a 1.68 kg ha^{-1} rate to control speedwell (<u>Veronica</u> spp.). Fertilizer was incorporated into the seedbed before planting at 36 kg ha^{-1} N and 20 kg ha^{-1} P rates. Spring fertilizer applications were made 22 March for each experiment at 88 kg ha^{-1} N and 17 kg ha^{-1} S rates.

The experimental design was a split-plot replicated in six randomized blocks. The main plots consisted of cereal row spacings and the subplots were cereal cultivars and red fescue established alone (control) that were randomly arranged within the main plot. Each subplot was 6.71-m in length and 1.83-m in width.

Cereal growth parameters were measured on several dates in the spring by using 30.5-cm sections of row randomly selected from each subplot. The number of tillers in each section was counted and the number of tillers m^{-2} was calculated using these values. Each 30.5-cm section of row was subdivided into 10 equal subsections from which a tiller was obtained in a random manner. The height of these 10 tillers was measured and their leaf area was determined using a Li-Cor Model Li-3000 portable area meter.

Red fescue tiller height, leaf area, and tiller m^{-2} were obtained by the same methods employed for the cereals. Above-ground dry matter production of red fescue was determined after oven-drying the entire row section for 36 hours at $85^{o}C$. The individual tiller weight was calculated by dividing the dry weight of the sample by the number of tillers.

Photosynthetic photon flux density (PPFD) received by the red fescue was measured by using a Li-Cor Model Li-1776 Solar Monitor with a line quantum sensor. One reading was made parallel to the red fescue rows above the cereal canopy to determine total incident PPFD. A second reading was taken by placing the sensor parallel to the red fescue row below the cereal canopy and on the same level as the fescue plants. The percentage of PPFD transmission through the cereal canopy was calculated by dividing the amount of PPFD at the level of the red fescue plants by the total PPFD above the cereal canopy. Two observations were made for each subplot on 11 dates in 1983 and on 9 dates in 1984.

Soil moisture was determined gravimetrically from samples taken with an Oakfield soil corer during the spring and early summer, beginning after excessive soil moisture was no longer apparent. In 1983, segments of the soil profile were sampled at 0 to 15, 15 to 30, 30 to 45, and 45 to 60-cm depths. In 1984, samples were obtained from 0 to 20, 20 to 40, and 40 to 60-cm depths. Two observations were made for each portion of the profile in each subplot.

Soil temperature was measured in 1984 using a Weather Master Model T 601 recording soil thermograph with two soil temperature probes. The probes were buried 5-cm deep in subplots containing red fescue alone (control) and Hill 81 companion crops. One probe was placed in each of the Hill 81 subplots in 7-day intervals while the other probe remained in the control.

Statistical analyses were conducted using the Statistical Interactive Program System (Oregon State University). Analysis of variance (ANOVA) was used to test the effects of cereal row spacings, cereal cultivars and the interaction of these factors. Comparisons between monocultural establishment and establishment with companion crops, as well as comparisons between companion crop cultivars, were made utilizing orthoganol contrasts. The separation of treatment means was accomplished by Fisher's protected least significant difference (LSD) values. The 30-cm row spacing treatment was deleted from analyses of the first experiment due to mechanical difficulties at the time of planting which resulted in poor stands of cereals.

RESULTS AND DISCUSSION

Cereal Growth Parameters

In general, barley produced more tillers m^{-2} than wheat (Table I.1). The most tillers m^{-2} were produced by Hesk barley while Yamhill wheat produced the least. Yamhill wheat tillers were taller than those of Hill 81 wheat and both barley cultivars. Leaf area tiller^{-1} was greater for wheat than for barley. The earlier maturation of barley was reflected by the rapid decrease in leaf area in the latter part of May in each year. In wheat, Yamhill had a greater leaf area until the time maximum leaf area was reached, but the leaves of Hill 81 remained green and functional for about a month longer.

The number of cereal tillers m^{-2} decreased as the row spacing increased (Table I.2). The row spacing of the companion crops did not substantially affect the height of their tillers or the leaf area of those tillers in 1983, but inconsistent effects were noted in 1984.

Influence of Companion Crops on Red Fescue Environment

The amount of PPFD available for use by red fescue plants was greatly reduced by the cereal companion crops (Fig. I.1). The transmission of PPFD through companion crop canopies was lowest at 15-cm row spacings and increased with increases in row spacing in a linear fashion. The PPFD incident on red fescue plants was reduced proportionally by increases in tiller height and leaf area tiller^{-1} of companion crops.

The amount of PPFD transmitted through the canopies of companion crops was greater in barley than in wheat (Fig. I.2). Greater PPFD transmission through barley can be related to the shorter stature and smaller leaf area of barley. Prior to the latter part of May when maximum leaf area was attained by the wheat cultivars, lower PPFD transmission was observed under Yamhill canopies than under Hill 81. This was due to the greater tiller height, leaf area and the lax leaves of Yamhill. After this time, however, the transmission of PPFD through Hill 81 canopies was markedly lower than Yamhill due to the longer leaf area duration possessed by Hill 81. By early July, the differences in PPFD transmission between cultivars was minimized because all leaves had senesced. The number of tillers m^{-2} possessed by a particular cultivar did not influence PPFD transmission as greatly as leaf area or tiller height.

Soil water content was equivalent to or, under some cultivars, greater when red fescue was established with companion crops (Tables I.3, I.4). It was initially hypothesized that the companion crop would deprive the red fescue plants of soil moisture. However, the shading of the soil surface by the companion crop greatly reduced the daily maximum temperature at a 5-cm depth (Table I.5), which could contribute to the greater soil moisture contents noted for the upper portion of the soil profile. This reduction in soil temperature, coupled with the inhibition of air movement by the companion crop canopy, could result in a lowering of the rate of evaporation from the soil surface.

Soil moisture content was generally greater under barley companion crops than under wheat. Among wheat cultivars, soil moisture was greater under Yamhill, probably due to the higher level of shading noted early in spring under Yamhill. Later, as maturity was approached, the longer leaf area duration of Hill 81 would suggest that this cultivar actively extracted water from the soil for a longer time period. The row spacing of the cereal crop was not as influential in determining the amount of soil moisture as was the cultivar.

Effect of Companion Crops on Red Fescue Growth Parameters

Cereal companion crops greatly reduced the number of spring-formed red fescue tillers m^{-2} (Fig. I.3). This reduction was partly attributable to the physical displacement of red fescue plants by cereal plants where companion crop and fescue rows intersected. No substantial differences were detected in tillers m^{-2} produced under wheat or barley or by their respective cultivars. The dry matter m^{-2} produced by red fescue was also much lower when established with companion crops (Fig. I.4). In general, red fescue dry matter m^{-2} was not different when established with wheat or barley or either of their cultivars.

Differences between 1983 and 1984 in red fescue tiller and dry matter production were primarily due to the differing weather conditions of each year. Red fescue growth parameters responded to companion crop cultivars and row spacings in a similar fashion in both experiments despite these differences.

Competition with cereals for soil water was not responsible for reducing tillers m^{-2} and dry matter m^{-2} of red fescue. The soil under all treatments was saturated during April 1983 and 1984 and significantly lower tillers m^{-2} and dry matter m^{-2} were already apparent where red fescue was planted with companion crops and before any soil moisture stress was observed. No real differences in soil moisture existed between the companion crop row spacings, but PPFD availability was greater as row spacing increased. Thus most of the reduction in red fescue tillers m^{-2} and dry matter m^{-2} was accounted for by decreases in the quantity of PPFD under companion crop canopies.

The weight of individual red fescue tillers was usually lower when planted with cereal crops (Table I.6). Cereal companion crops increased tiller height of red fescue due to the reduction of PPFD under these crops (Fig. I.5). Etiolation was greatest immediately adjacent to the cereal row and was the least where the lowest companion crop shading occurred. Red fescue tiller height was not differentially affected by either companion crop or their cultivars. Red fescue leaf area $tiller^{-1}$ was not affected by cereal companion crops (Table I.7).

Effect of Row Spacing on Red Fescue Growth Parameters

Greater etiolation of red fescue tillers occurred in 15-cm rows than in 60-cm rows (Fig. I.6). This was a direct result of reductions in PPFD transmission as row spacing decreased. By increasing the width of companion crop rows, greater tillers m^{-2} and dry matter m^{-2} resulted from the increase in PPFD availability, but these values remained far below that observed when red fescue was planted without a companion crop (Figs. I.7 and I.8). Altering the row spacing of the companion crop had no appreciable effect on red fescue leaf area $tiller^{-1}$ or on tiller weight. In general, no interactions of companion crop row spacing and cultivar were found that influenced red fescue growth.

The years in which these experiments were conducted were characterized by higher than average precipitation during the period of intercrop competition between March and July . Thus the growth and development of red fescue, especially with the companion crop drilled in narrow rows, might have been further impaired had serious moisture stress conditions been present. Cereal companion crops inhibited red fescue tiller production, caused tiller etiolation and reduced dry matter m^{-2}. There were no distinct advantages in establishment with wheat or barley or their cultivars since all seemed to adversely affect red fescue growth parameters to the same extent.

Increasing companion crop row spacing resulted in more red fescue tillers m^{-2}, dry matter m^{-2} and reduced etiolation of tillers, but had no effect on leaf area $tiller^{-1}$ or tiller weight. Increasing the width of companion crop rows alleviated some of the negative effects on red fescue development caused by reduced PPFD. Planting the companion crop in wider rows could have a significant effect on first-year seed yields. The grain yields of the companion crops and the effect of companion crops on first-year red fescue seed yield are presented in a companion paper.

Table I.1. Growth parameters of cereal companion crop cultivars interplanted with red fescue. Means of growth parameters are averaged over row spacings on each sampling date.

Growth parameter	Year	Date	Companion crop cultivar: Hesk	Scio	Yamhill	Hill 81	LSD 0.05
			tillers m^{-2}				
Tiller number							
	1983	6 Apr.	720	699	473	477	266
		20 Apr.	552	483	302	409	250
		4 May	369	520	251	365	178
		17 May	513	463	307	369	264
	1984	4 Apr.	730	636	545	567	224
		26 Apr.	522	475	345	364	124
		21 May	543	460	322	395	132
			cm				
Tiller height							
	1983	6 Apr.	35.18	41.87	58.51	49.93	9.62
		20 Apr.	54.17	57.43	74.64	61.13	2.58
		4 May	65.90	78.07	92.70	62.23	10.56
		17 May	85.64	84.92	107.83	79.42	11.20
	1984	4 Apr.	36.24	35.65	53.88	46.66	8.69
		26 Apr.	57.80	60.73	80.91	69.16	7.71
		21 May	89.68	83.73	112.93	98.92	9.47
			cm^{-2} $tiller^{-1}$				
Leaf area							
	1983	6 Apr.	42.18	58.88	73.29	62.83	10.91
		20 Apr.	63.32	67.93	112.09	84.34	21.66
		4 May	63.40	68.54	92.08	81.20	19.27
		17 May	47.85	44.01	88.16	96.46	35.08
	1984	4 Apr.	56.83	67.13	95.71	70.29	18.58
		26 Apr.	93.77	99.97	142.34	106.97	18.76
		21 May	67.01	66.49	129.78	133.79	19.76

Table I.2. Influence of row spacing on cereal companion crop growth parameters. Growth parameter means are averaged over cultivars on each sampling date.

Growth parameter	Year	Date	Row spacing, cm 15	30	45	60	LSD 0.05
Tiller number			tillers m^{-2}				
	1983	6 Apr.	959	--	446	371	374
		20 Apr.	589	--	395	326	269
		4 May	535	--	365	249	367
		17 May	614	--	351	274	605
	1984	4 Apr.	954	688	476	360	152
		26 Apr.	564	486	360	294	157
		21 May	586	475	377	283	121
Tiller height			cm				
	1983	6 Apr.	43.21	--	48.32	47.58	NS
		20 Apr.	55.43	--	64.48	63.58	NS
		4 May	71.34	--	80.90	74.96	NS
		17 May	88.30	--	91.07	88.98	NS
	1984	4 Apr.	36.36	43.45	45.48	47.15	12.18
		26 Apr.	64.58	68.99	66.74	68.28	5.75
		21 May	98.55	96.73	96.61	92.46	8.04
Leaf area			cm^{-2} $tiller^{-1}$				
	1983	6 Apr.	49.02	--	66.64	62.23	14.20
		20 Apr.	71.78	--	89.18	84.81	NS
		4 May	77.21	--	73.79	77.92	NS
		17 May	70.55	--	60.61	76.20	NS
	1984	4 Apr.	58.21	70.02	77.81	83.92	10.04
		26 Apr.	102.57	105.72	116.38	118.39	NS
		21 May	98.27	93.38	106.13	99.29	16.37

Table I.3. Influence of cereal companion crops on soil water content in 1983. Soil water content values are averaged over sampling dates and row spacings.

Depth in profile	Companion crop cultivar: Hesk	Scio	Yamhill	Hill 81	Control	LSD 0.05
cm	mg kg^{-1}					
0-15	189.6	194.3	194.6	189.9	174.5	10.0
16-30	179.5	188.5	186.8	179.1	170.6	9.9
31-45	184.0	192.4	180.2	175.4	180.5	11.4
46-60	208.8	220.0	201.2	193.1	213.4	26.6

Table I.4. Influence of cereal companion crops on soil water content in 1984. Soil water content values on each sampling date are averaged over row spacings.

Depth in profile	Date	Companion crop cultivar				Control	LSD 0.05
		Hesk	Scio	Yamhill	Hill 81		
cm		mg kg^{-1}					
0-20	17 May	263.5	263.5	262.7	256.2	259.1	8.7
	13 June	254.8	253.2	263.6	254.3	251.6	13.8
	27 June	249.8	252.8	253.8	237.5	236.2	11.1
	5 July	217.6	226.4	226.2	202.1	190.4	11.7
21-40	17 May	260.2	258.9	253.4	249.3	257.5	8.8
	13 June	264.4	264.5	264.4	250.1	268.4	NS
	27 June	244.9	249.6	243.0	221.8	240.5	13.0
	5 July	226.2	233.8	230.3	206.9	202.4	10.9
41-60	17 May	301.5	296.0	285.8	285.0	283.3	22.3
	13 June	289.8	296.2	289.0	284.4	299.4	NS
	27 June	266.3	270.4	250.0	240.9	277.4	25.9
	5 July	250.5	248.8	230.3	214.5	217.2	32.6

Table I.5. Effect of a Hill 81 wheat companion crop on soil temperatures at a depth of 5 cm. Soil temperatures for each comparison between red fescue planted with Hill 81 wheat and planted alone (control) are averaged over two 7-day intervals between 7 May and 8 July 1984.

Row spacing	Temperature Max.	Temperature Min.
cm	°C	
15	15.8	12.3
Control	18.1	12.9
30	13.0	11.5
Control	17.8	12.0
45	17.4	11.1
Control	21.4	11.7
60	17.4	13.3
Control	20.0	14.2

Table 1.6. Dry weight per tiller of red fescue established with cereal companion crops. Tiller dry weight values are averaged over companion crop row spacings on each sampling date.

Year	Date	Companion crop cultivar				Control	LSD 0.05
		Hesk	Scio	Yamhill	Hill 81		
		mg tiller^{-1}					
1983	6 Apr.	9.8	9.6	7.3	9.3	10.6	NS
	20 Apr.	26.2	28.3	19.1	25.3	32.0	9.8
	4 May	43.9	38.9	26.3	43.6	51.3	17.0
	17 May	54.8	60.9	42.4	52.0	94.0	26.0
	1 June	66.9	51.6	52.7	57.8	69.0	NS
	14 June	79.0	74.7	59.7	57.6	74.0	20.0
1984	4 Apr.	4.6	4.1	4.8	4.8	5.3	1.1
	17 Apr.	6.0	5.3	6.3	6.0	6.8	1.1
	10 May	14.5	13.5	19.3	15.5	17.1	NS
	31 May	21.2	20.4	20.9	21.3	28.9	6.6
	14 June	33.4	28.3	27.3	30.2	39.6	7.4

Table I.7. Leaf area per tiller of red fescue interplanted with cereal companion crops. Leaf area means are averaged over companion crop row spacings on each sampling date.

Year	Date	Companion crop cultivar				Control	LSD 0.05
		Hesk	Scio	Yamhill	Hill 81		
		cm^{-2} $tiller^{-1}$					
1983	6 Apr.	2.40	3.06	2.26	3.00	2.82	1.14
	20 Apr.	4.82	5.24	3.74	4.69	4.79	1.35
	4 May	5.79	5.90	4.27	5.95	5.22	1.88
	17 May	5.87	6.86	5.31	5.81	6.72	NS
	1 June	5.94	4.80	5.25	5.43	5.26	NS
	14 June	5.55	5.82	4.84	4.75	5.14	1.35
1984	4 Apr.	0.89	0.80	0.97	0.92	0.98	NS
	17 Apr.	1.58	1.52	1.79	1.62	1.74	0.34
	10 May	3.33	3.10	3.68	3.33	3.19	NS
	31 May	4.19	3.71	4.30	3.96	4.21	NS
	14 June	4.88	4.76	4.98	4.86	5.66	1.20

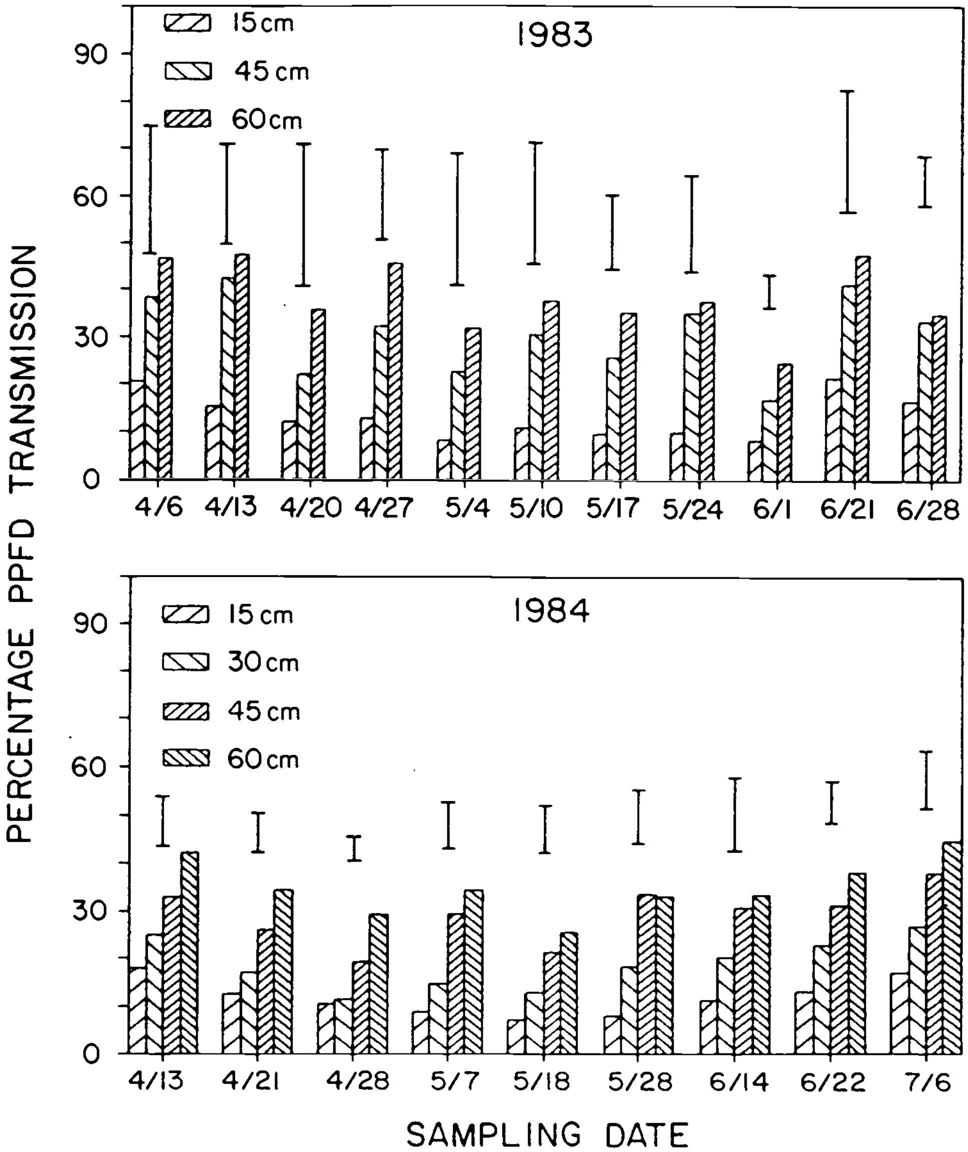

Fig. I.1. Effect of companion crop row spacing on the percentage of PPFD transmitted to red fescue. Means of PPFD transmission are averaged over cultivars. Vertical lines denote LSD 0.05 values for each sampling date.

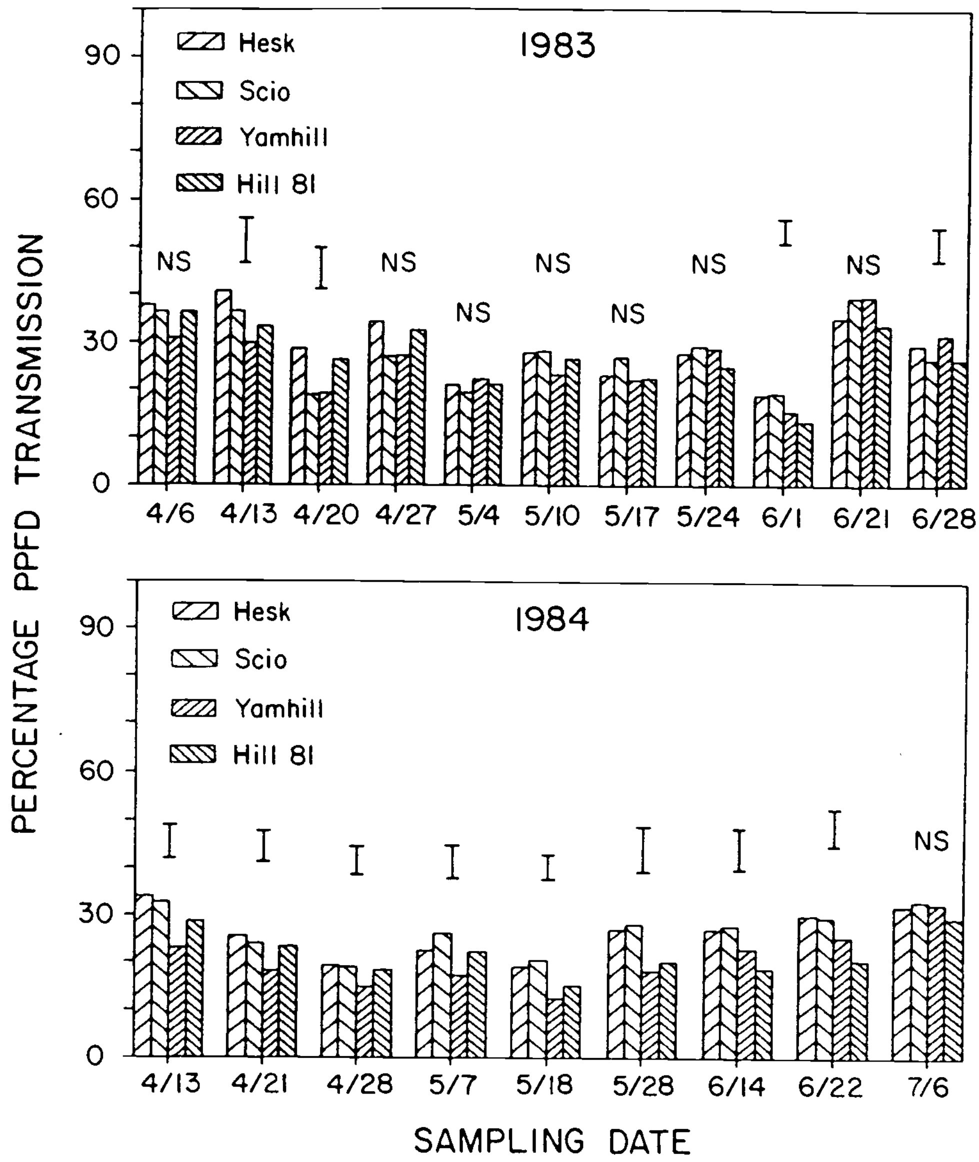

Fig. I.2. Influence of companion crop cultivars on percentage of PPFD transmitted to red fescue. Means of PPFD transmission are averaged over row spacings. Vertical lines denote LSD 0.05 values for each sampling date.

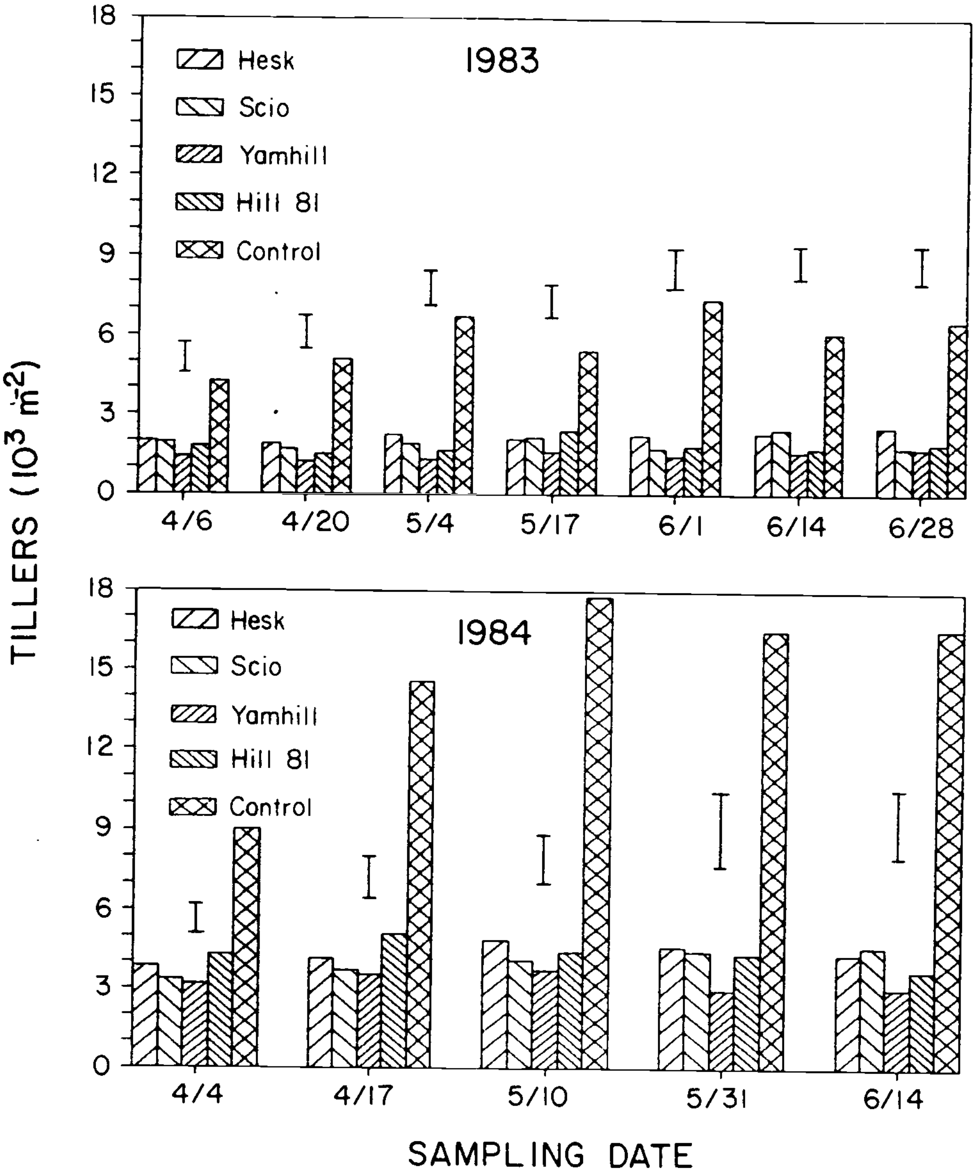

Fig. I.3. Influence of companion crop cultivars on red fescue tillers m^{-2}. Means of red fescue tillers m^{-2} are averaged over row spacings. Control indicates red fescue established without a cereal companion crop. Vertical lines denote LSD 0.05 values for each sampling date.

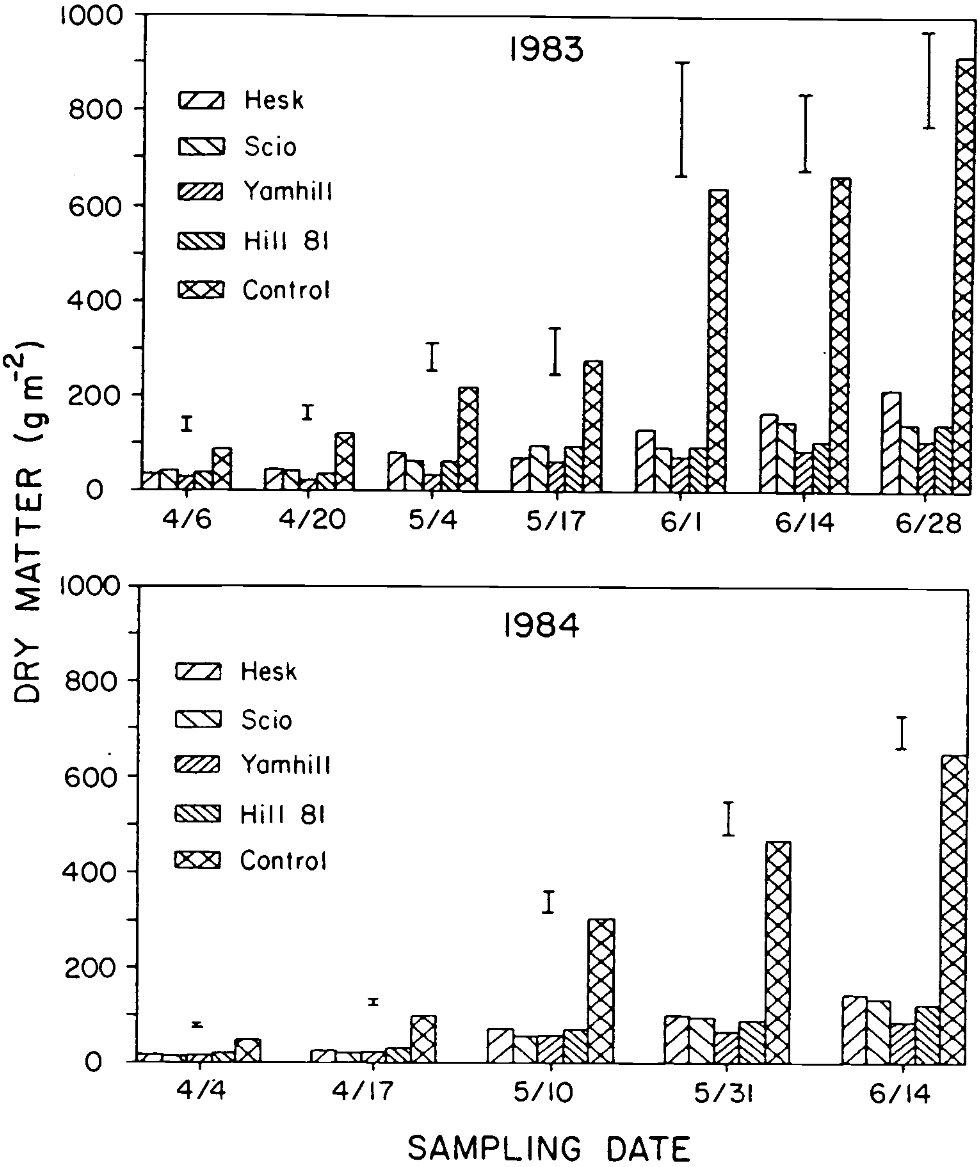

Fig. I.4. Effect of cereal companion crop cultivars on red fescue dry matter m^{-2}. Red fescue dry matter means are averaged over row spacings on each sampling date. Control indicates red fescue established without a cereal companion crop. Vertical lines denote LSD 0.05 values for each sampling date.

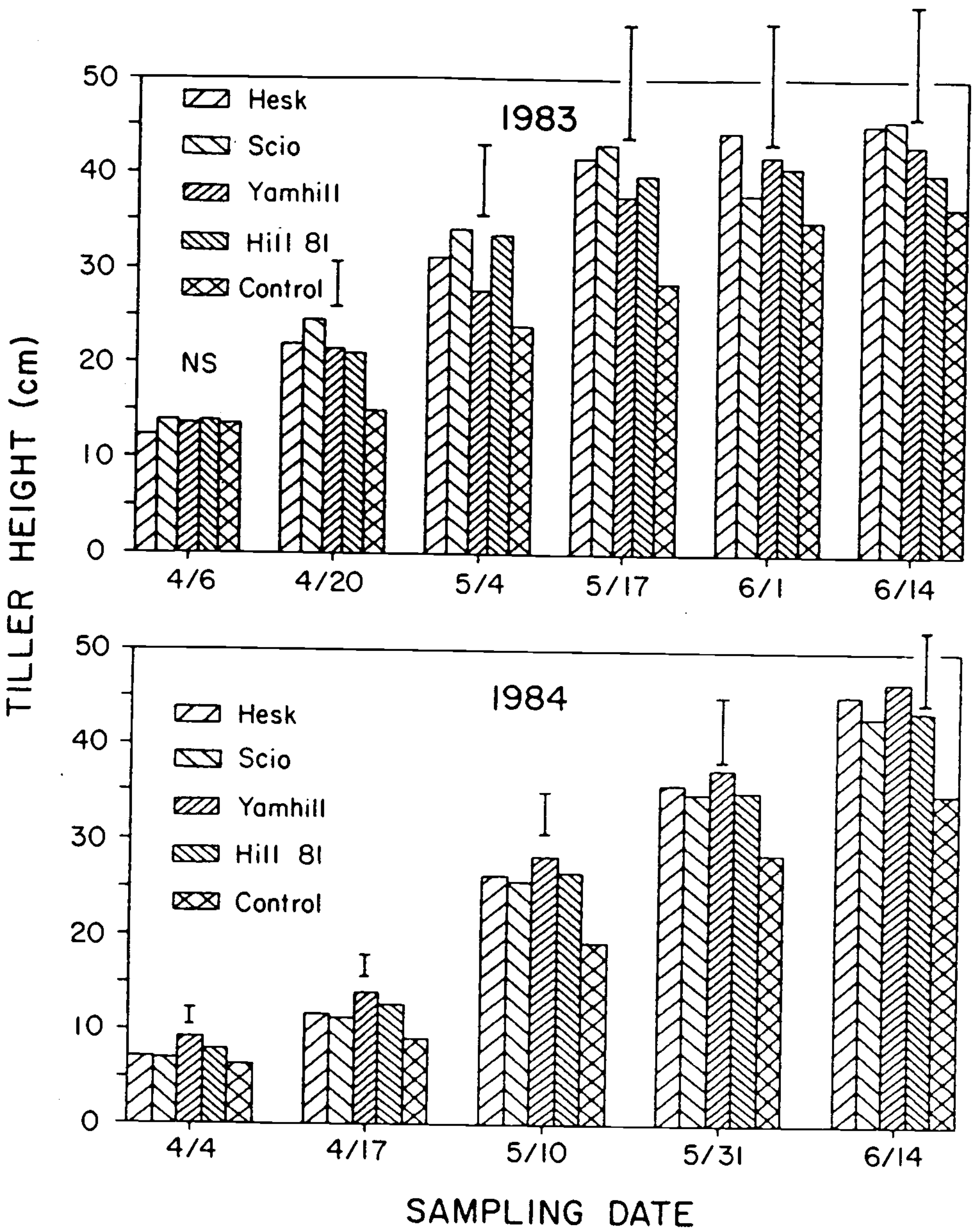

Fig. I.5. Red fescue tiller height as influenced by cereal companion crop cultivars. Red fescue tiller height means are averaged over row spacings on each sampling date. Control indicates red fescue planted without a cereal companion crop. Vertical lines represent LSD 0.05 values for each sampling date.

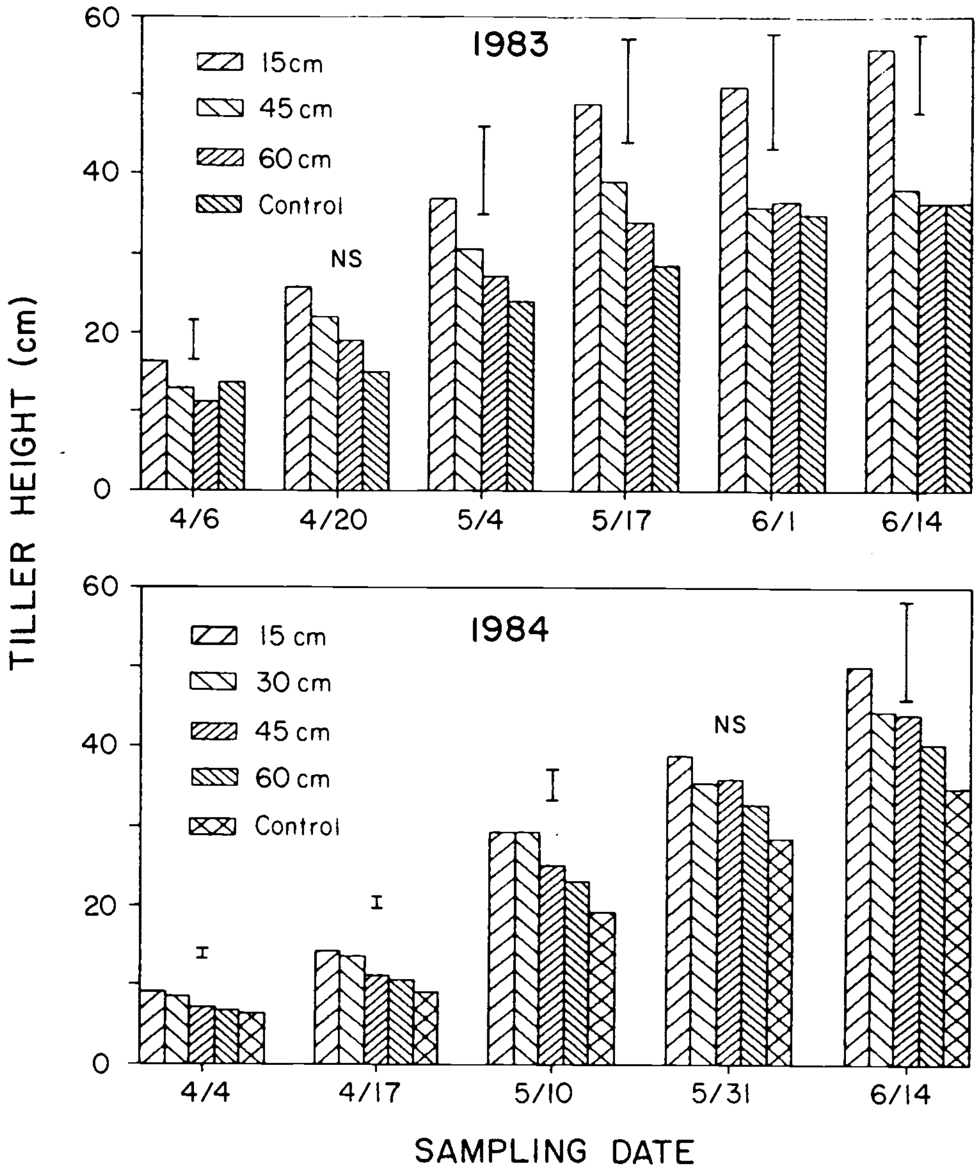

Fig. I.6. Effect of companion crop row spacing on red fescue tiller height. Red fescue tiller height means are averaged over companion crop cultivars on each sampling date. Control indicates red fescue planted without a cereal companion crop. Vertical lines represent LSD 0.05 values for each sampling date.

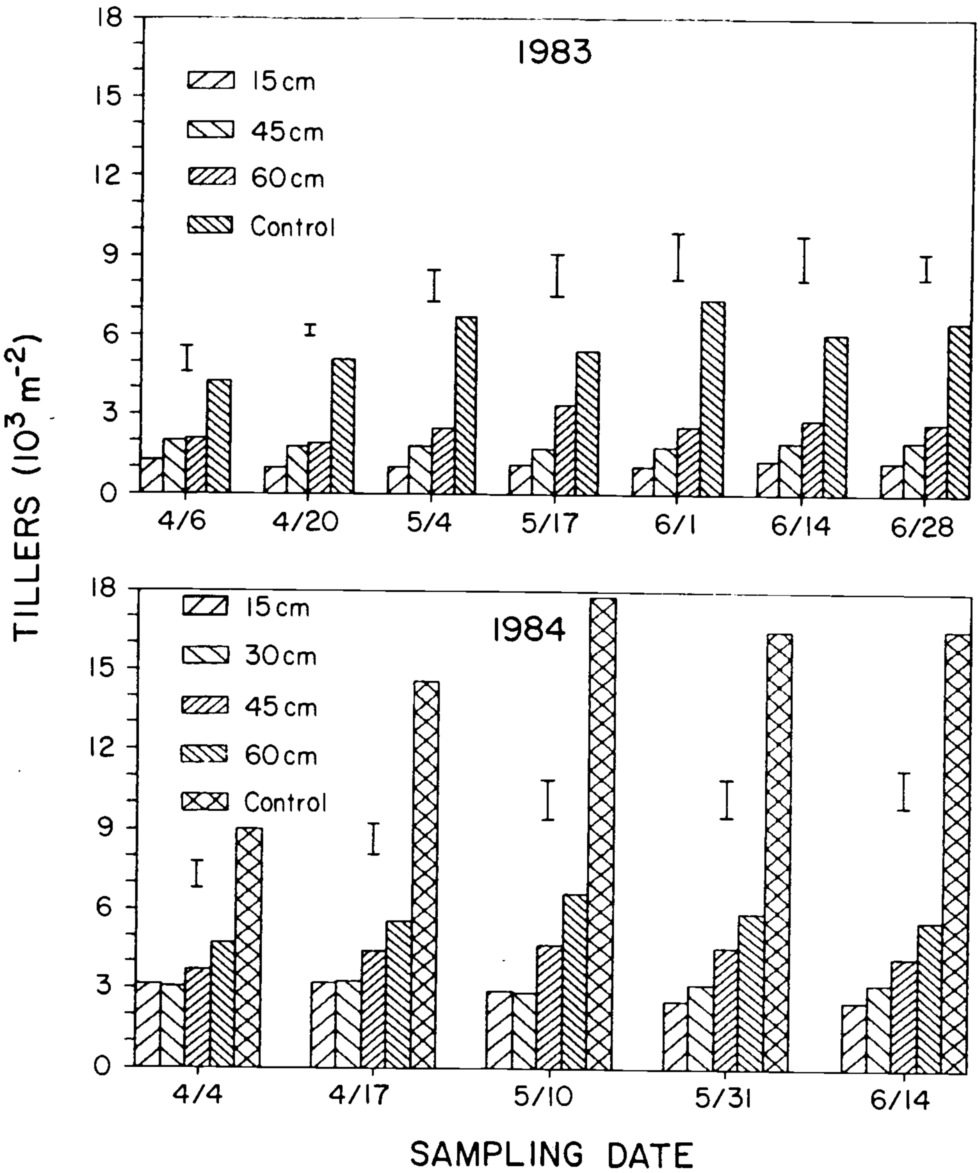

Fig. I.7. Influence of companion crop row spacing on red fescue tillers m^{-2}. Means of red fescue tillers m^{-2} are averaged over companion crop cultivars. Control indicates red fescue planted without a cereal companion crop. Vertical lines represent LSD 0.05 values for each sampling date.

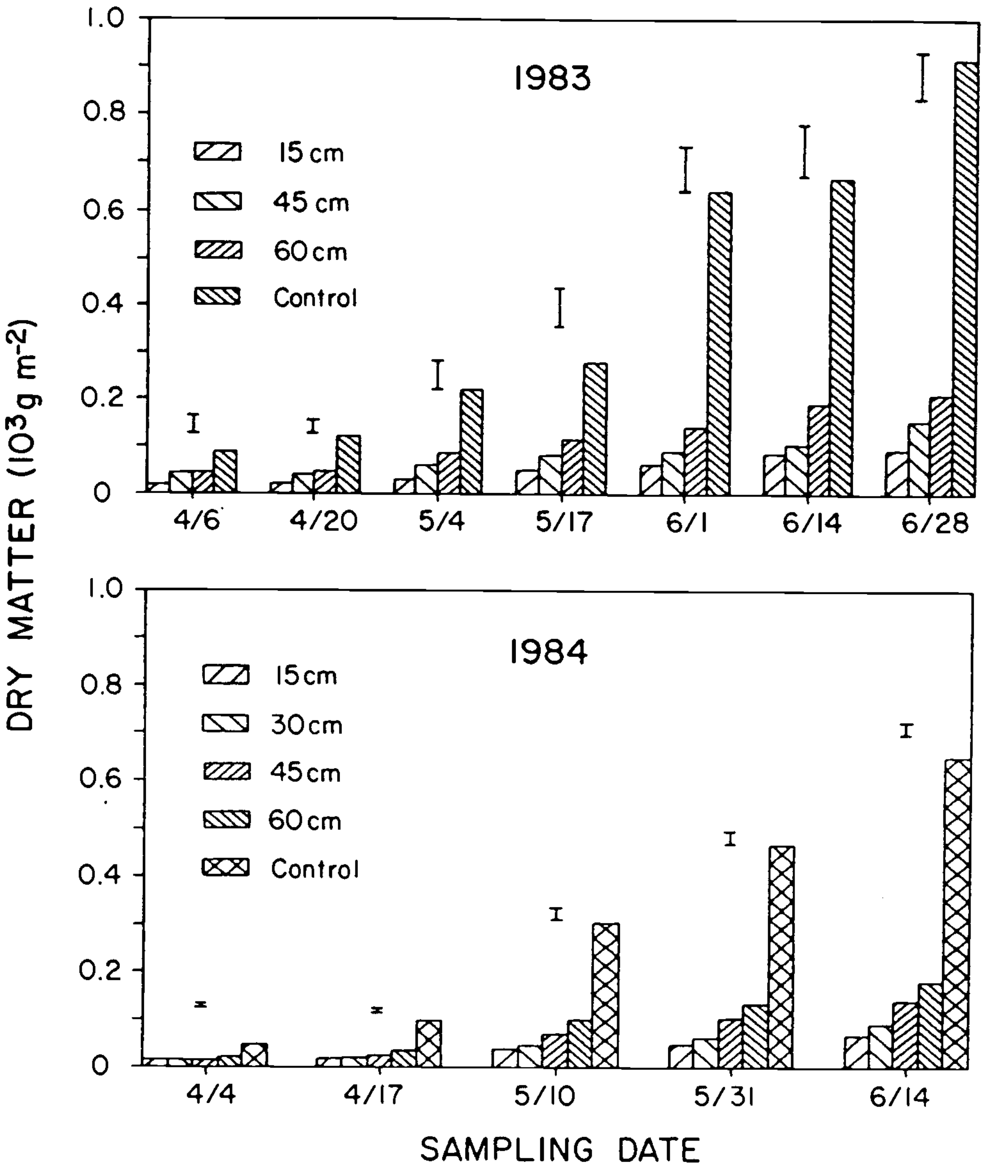

Fig. I.8. Influence of companion crop row spacing on red fescue dry matter m^{-2}. Red fescue dry matter means are averaged over companion crop cultivars. Control indicates red fescue established without a cereal companion crop. Vertical lines represent LSD 0.05 values for each sampling date.

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MANUSCRIPT II

SEED PRODUCTION CAPABILITY OF RED FESCUE ESTABLISHED WITH CEREAL COMPANION CROPS

ABSTRACT

Red fescue (Festuca rubra L.) is a perennial grass seed crop that is not harvested in the year of planting due to unprofitable yields. Oregon red fescue seed producers receive no revenue during the first growing season whereas those in Europe establish red fescue with companion crops thereby generating income in the first season.

The influence of companion crops on subsequent red fescue seed production and net income over a two-year period was investigated. 'Pennlawn' red fescue was interplanted in 1982 and 1983 with cereal companion crops near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil. 'Yamhill' and 'Hill 81' winter wheat (Triticum aestivum L.), and 'Hesk' and 'Scio' winter barley (Hordeum vulgare L.) were planted in 15-, 30-, 45- and 60-cm row spacings perpendicular to red fescue rows.

Although companion crops adversely affected red fescue growth during the establishment year, first-year seed yield and yield components were not significantly reduced by this method. Red fescue seed yields ranged from 490 kg ha^{-1} when established with Hill 81 wheat to 654 kg ha^{-1} with Scio barley. Red fescue seed yield without a companion crop was 589 kg ha^{-1}. Establishment with companion crops increased net income over a two-year period by as much as $416 ha^{-1} over monocultural red fescue establishment when Yamhill wheat companion crops were planted in 15-cm rows. Establishment with Hesk barley proved to be the least successful in terms of income. Establishment with companion crops was most profitable when cereal market prices were high and red fescue prices low. This study demonstrates the potential for profitable

establishment of red fescue seed crops with cereal companion crops in Oregon.

Additional index words: Seed yield components, Grain yield, Wheat, Barley, Economic analyses, Festuca rubra L.

Seed Production Capability of Red Fescue Established with Cereal Companion Crops

INTRODUCTION

The net economic return of Oregon grass seed crops fluctuates on an annual basis depending on market conditions, seed yield levels and production costs. Thus growers may encounter the situation where the costs of producing the seed crop outweigh the revenues received in that year. The cost of establishing red fescue (_Festuca rubra_ L.) seed crops is amortized over the life of the stand, which is usually about five years, and therefore constitutes a portion of the annual production costs. Establishment with cereal companion crops would provide a cash income during the establishment year, thereby increasing the profitability of the venture over the life of the stand.

The yield of perennial grass seed crops established with cereal companion crops is dependent on the characteristics of the companion crop and of the seed crop itself. Only a few studies have examined the factors governing the success of this method of seed production. The majority of these studies have been conducted in Europe where this establishment system is commonly employed.

Barley (_Hordeum vulgare_ L.) companion crops reduced the seed yield of crested wheatgrass (_Agropyron desertorum_ (Fisch. ex Link) Schult.) for a three-year period after establishment in eastern Washington (Van Keuren and Canode, 1963). Pardee and Lowe (1963) detected no differences in the seed yield of timothy (_Phleum pratense_ L.), smooth bromegrass (_Bromus inermis_ Leyss) and orchardgrass (_Dactylis glomerata_

L.) under companion crops of winter wheat (Triticum aestivum L.), spring oats (Avena fatua var. sativa (L.) Haussk.) and barley in New York.

In Wales, Roberts (1964) found that the first-year seed yield of orchardgrass was decreased by establishment with spring oats, but the yield in subsequent years was equivalent to that planted without a companion crop. The first-year seed yields of timothy, meadow fescue (Festuca pratensis Huds.), tall fescue (F. arundinacea Schreb.) and orchardgrass were depressed by barley companion crops in Wales (Griffiths et al. 1967), but bentgrass (Agrostis tenuis Sibth.) and perennial ryegrass (Lolium perenne L.) were not adversely affected. There were no apparent differences in second-year seed yield between the grass seed crops established with barley and those established alone. Of the grass seed crops evaluated over a two-year period, the seed yield of orchardgrass was reduced to the greatest extent by a barley companion crop, yet a 20% greater annual economic return was obtained with this method.

Cedell (1975) demonstrated the influence of companion crops on first-year seed production of red fescue and Kentucky bluegrass (Poa pratensis L.) in Sweden. Barley companion crops caused minimal reductions in red fescue yield while Kentucky bluegrass seed production was severely impaired. The first-year seed yield of both crops was substantially lower when established with winter wheat. In Denmark, Nordestgaard (1979) determined the feasibility of using winter wheat, spring wheat, winter rape (Brassica napus L.), field bean (Phaseolus vulgaris L.) and flax (Linum usitatissimum L.) as companion crops for the establishment of Kentucky bluegrass. Fertile tiller number and first-year seed yield were depressed by all the companion crops except winter rape. Over a two-year period, yield reductions ranged from 15 to 34% depending on the particular companion crop.

In Oregon, wheat and barley companion crops reduced red fescue tillers m^{-2}, dry matter m^{-2} and etiolated tillers during spring of the establishment year (Chastain and Grabe, 1985). In continuing this research, the objective of this investigation was to determine the influence of cereal companion crops on red fescue seed production and to determine the economic feasibility of this establishment method in Oregon's Willamette Valley.

MATERIALS AND METHODS

The experiments were conducted at the Oregon State University Hyslop Crop Science Field Laboratory near Corvallis, OR. 'Pennlawn' red fescue was established in 1982 and 1983 with 'Hill 81' and 'Yamhill' winter wheat, and 'Scio' and 'Hesk' winter barley. The experimental design was a split-plot replicated in six randomized blocks. Main plots consisted of 15-, 30-, 45-, and 60-cm cereal row spacings. Subplots consisted of the four cereal cultivars and a red fescue monocultural control. The details of planting and establishment-year management procedures were described previously (Chastain and Grabe, 1985).

Barley companion crops were harvested with a Hege plot combine on 22 July 1983 for the first experiment and on 16 July 1984 for the second. Wheat was harvested on 5 August 1983 and 1 August 1984 for the first and second experiments, respectively. Cereal stubble was flail-chopped and removed on 22 August 1983 and 23 August 1984.

Control of annual bluegrass (Poa annua L.) and other weedy grasses was achieved with simazine [2-chloro-4,6-bis(ethylamino)-s-triazine] applied at a 2.24 kg ha^{-1} rate on 21 October 1983 and on 30 October 1984. Control of volunteer cereals was obtained by applications of sethoxydim [2-(1-(ethoxyimion)butyl)-5-(2-(ethylthio)propyl)-3-hydroxy-2-cyclohexen-1-one] at a 0.43 kg ha^{-1} rate on 21 November 1983 and 15 November 1984. Broadleaved weeds were controlled with 0.56 kg ha^{-1} MCPA [(2-methyl-4-chlorophenoxy) acetic acid] and 0.28 kg ha^{-1} dicamba (3,6-dichloro-o-anisic acid) on 22 March 1984 and on 1 April 1985. Fall nitrogen was applied on 7 October 1983 and on 5 October 1984 at a 50 kg

ha^{-1} rate. Spring fertilizers were applied 22 March 1984 and 12 March 1985 at rates of 88 kg ha^{-1} N and 17 kg ha^{-1} S.

Potential yield components of red fescue were determined in two 30.5-cm sections of row from each subplot at peak anthesis on 19 June 1984. The fertile tillers in each subsample were counted and the number of fertile tillers m^{-2} was derived from these values. Before these tillers were counted, ten were randomly selected from each subsample from which the number of spikelets $tiller^{-1}$ was obtained. The number of florets $spikelet^{-1}$ was determined by counting the florets from representative spikelets on the upper, middle and lower portions of each of the ten subsampled inflorescences. The number of florets m^{-2} were calculated from the potential yield component estimates.

On 12 July 1984, 4.6 m^{-2} of each subplot was harvested with a plot harvester. The bagged plant material was dried and afterwards threshed by using a stationary thresher. Seed was cleaned with a Clipper M2-B air-screen cleaner before weighing. At the time of yield determination the seed moisture content was 10%. One-thousand seed weight was determined from 300 randomly selected seeds from cleaned subplot samples. The number of seed m^{-2} was calculated from the values for seed yield and 1000-seed weight.

A partial budgeting technique was employed to evaluate the changes in net income resulting from red fescue seed production with companion cropping (Castle et al. 1972). By using grain yields and red fescue seed yields obtained in this study, revenues were calculated for these crops on the basis of crop prices at the time of harvest. The cost of producing the crops was then estimated on the basis of local costs of performing the cultural operations on a farm-scale. The net change in income was determined by subtracting the decreased revenue and increased costs attributable to companion cropping from increases in revenue.

The statistical analyses for these experiments were conducted in the manner described by Chastain and Grabe (1985). The 30-cm row spacing in the first experiment was deleted from the analyses because of planting difficulties. Only the seed yield data for the first experiment are presented here as the results for the second experiment will not be available until a later date.

RESULTS AND DISCUSSION

Companion Crop Grain Yield

The grain yields of cereal companion crops in both 1983 and 1984 declined in a linear manner as the row width of the companion crop increased (Table II.1). The yield obtained from 45-cm row widths was not less than from 15-cm rows in 1983 but was significantly less in 1984. Grain yields averaged over cultivars ranged from 4185 kg ha^{-1} in 15-cm rows to 3175 kg ha^{-1} in 60-cm rows in 1983, and from 5667 kg ha^{-1} in 15-cm rows to 3415 kg ha^{-1} in 60-cm rows in 1984.

In both years, the yield of wheat was greater than that of barley. There were no differences in grain yield of barley cultivars in 1983, but the yield of Hesk surpassed that of Scio in 1984. Differences in yield between wheat cultivars were not significant in 1983, but Hill 81 yields were markedly superior to those of Yamhill in 1984. The grain yields of individual cultivars averaged over row spacings ranged from 3228 kg ha^{-1} for Hesk barley to 4110 kg ha^{-1} for Hill 81 wheat in 1983, and from 3306 kg ha^{-1} for Scio barley to 5706 kg ha^{-1} for Hill 81 wheat in 1984. No interactions were found between companion crop row spacing and cultivar for either year. Grain yields were markedly greater in 1984 than in 1983 due to more favorable weather conditions and reduced incidence of cereal diseases. While the yield of cereal crops may have been somewhat depressed by the presence of red fescue, no investigations determining the competitive effects of red fescue on cereal yield were made to verify this possibility because this was not an objective of this study.

Companion crop residues interfere with light interception and growth of red fescue resulting in reduced first-year seed yields. Removal of these residues from red fescue seed fields has been successful in alleviating these problems (Nordestgaard, 1982). In this study, cereal residues were flail-chopped and removed in accordance with these findings. In autumn following the harvest of the companion crops, sethoxydim was successful in completely controlling volunteer cereal plants. No other cultural practices were used that deviated from conventional methods of cereal and red fescue seed crop management.

Red Fescue Seed Yield and Yield Components

In a previous paper, Chastain and Grabe (1985) demonstrated the inhibition of tiller production, etiolation of tillers and reduced dry matter accumulation when red fescue was established with companion crops. These negative effects on red fescue were for the most part attributable to reductions in photosythetic photon flux density (PPFD) where companion crops were present. Despite the inhibited development of red fescue during the establishment year, the first-year seed yield was not significantly different from red fescue established without cereal companion crops (Table II.2). There were likewise no differences in potential yield components regardless of the establishment method employed. There were no interactions between companion crop row spacing and cultivar influencing red fescue potential yield components.

The lack of influence of cereal companion crops on red fescue seed yield may be comparable to the effect of field burning red fescue crop residue (Chilcote et al., 1980). They found that the number of tillers was lower during late summer and early autumn where red fescue was subjected to burning. During late autumn and winter, greater numbers of tillers were formed where red fescue was burned. The burned red fescue was exposed to an improved light and floral induction environment that ultimately resulted in greater seed yield than the non-burned plants. The tillers that are formed in the spring do not make major contributions to seed yield in red fescue (Meijer, 1984). The reduction in numbers of spring-formed tillers under companion crops was inconsequential because by the following harvest no differences in tiller number existed between red fescue established with or without companion crops. These findings would suggest that there was no direct relationship between tillers formed in spring under the companion crops and subsequent seed yields.

Greater red fescue seed yield occurred with barley companion crops than with wheat. The difference in seed yield may be attributable to greater PPFD transmission through barley canopies, utilization of less soil water by barley and the earlier date of maturation of barley (Chastain and Grabe, 1985). The yield of red fescue established with Scio barley was greater than with Hesk, while no differences in red fescue seed yield were observed between either of the wheat cultivars. Red fescue seed yields ranged from 490 kg ha^{-1} when established with Hill 81 wheat to 654 kg ha^{-1} with Scio barley. The seed yield of red fescue without a companion crop was 589 kg ha^{-1}.

Cereal companion crops, cultivars and row spacings did not influence 1000-seed weight. Therefore, the greater seed yield of red fescue established with Scio barley may best be explained by larger numbers of seeds m^{-2} rather than by differences in seed weight. This was the result of an increased proportion of florets subsequently producing seed where Scio was used.

Companion crop row spacing had no appreciable effect on first-year red fescue yield or yield components nor were there any interactions of companion crop row spacing and cultivar. Cereal companion crops did not alter the date of maturity of red fescue as indicated by the percentage seed moisture at the time of harvest.

Economic Implications

Using a partial budgeting technique, the effect of establishment with the four cereal companion crop cultivars on net income received during the year of establishment and the first seed production year was examined under the market conditions that existed during the experiment (Table II.3). Although the cost of establishing red fescue with cereal companion crops was greater, the increased revenue from the sale of cereal grain would have readily compensated for these added costs. These additional costs include the cost of cereal seed, grain drilling, combining, grain hauling and companion crop residue removal. Slight decreases in red fescue revenue were noted because of small non-significant reductions in seed yield when planted with Hesk barley and Yamhill and Hill 81 wheat. When established with Scio barley, greater seed yield and revenue were obtained than with the monocultural establishment method. Averaged over row spacings, increases in net income over the two-year period ranged from \$32.44 ha^{-1} for red fescue planted with Hesk barley to \$305.49 ha^{-1} with Yamhill wheat.

The income received from establishment with companion crops was influenced by the row spacing of the crop. The best and worst net changes in income from the various combinations of cultivar and row spacing are shown in Table II.4. This analysis indicates that \$415.85 ha^{-1} greater net income was obtained over the two-year period when red fescue was established with Yamhill wheat in 15-cm rows than when red fescue was established alone. When Hesk barley in 60-cm rows was used as a companion crop, \$45.59 ha^{-1} less income was received than when the fescue was established alone.

The effect of changes in crop market prices on the decision of whether to establish red fescue with companion crops can be observed in Table II.5. Thus when red fescue prices are low, establishment with cereal companion crops is most advantageous. The least advantage is realized when high red fescue prices are accompanied by low market prices for cereal grain.

Red fescue growth during establishment was not differentially affected by wheat or barley or their respective cultivars (Chastain and Grabe, 1985) but net income over the two-year period was greater when wheat was used. Companion crops or cultivars must be chosen on the basis of revenue production capability rather than their relative effect on growth during establishment. The choice of companion crop row spacings must also be based on grain revenue despite the more favorable influence of wider row spacings on red fescue growth.

These experiments clearly indicate that red fescue can be successfully established with cereal companion crops in Oregon and that there were no detrimental effects on subsequent seed yield. Adoption of this method would allow the producer of red fescue seed to offset some of the costs incurred in establishment by generating income from the cereals during the establishment year.

Table II.1. The effect of row spacing and cultivar on grain yield of cereal companion crops used to establish red fescue. Companion crops harvested in 1983 and 1984 were planted with red fescue in 1982 and 1983, respectively.

Year	Companion crop	Cultivar	Companion crop row spacing (cm)				Cultivar mean
			15	30	45	60	
			kg ha^{-1}				
1983	Barley	Hesk	3860	--[†]	3407	2415	3228
		Scio	4112	--	3641	2931	3561
	Wheat	Yamhill	4769	--	3941	3579	4096
		Hill 81	3999	--	4556	3776	4110
		Row spacing mean	4185	--	3886	3175	
	LSD 0.05						
		Cultivar	655				
		Row spacing	988				
		Cultivar x row spacing	NS				
1984	Barley	Hesk	5474	4323	3660	3290	4187
		Scio	4756	3533	2866	2082	3306
	Wheat	Yamhill	5930	4976	4382	3445	4683
		Hill 81	6508	5974	5484	4845	5706
		Row spacing mean	5667	4697	4102	3415	
	LSD 0.05						
		Cultivar	619				
		Row spacing	523				
		Cultivar x row spacing	NS				

[†]30-cm row spacing treatments were not analyzed in 1983 because of planting difficulties.

Table II.2. The influence of companion crop cultivars and row spacings on red fescue seed yield and yield components in 1984. Red fescue was established with companion crops in 1982.

Companion crop	Cultivar	Row spacing	Fertile tillers m^{-2}	Spikelets $tiller^{-1}$	Florets $spikelet^{-1}$	1000-seed weight	Florets m^{-2}	Seeds m^{-2}	Seed yield
		cm	No.	No.	No.	g	No.	No.	kg ha^{-1}
Barley	Hesk	15	645	40.21	6.57	1.38	145513	39335	544
		45	743	33.66	6.63	1.44	169675	32782	471
		60	676	31.85	6.70	1.38	145214	36520	500
	Scio	15	814	34.22	6.46	1.35	181914	46234	617
		45	759	33.59	6.34	1.41	163851	41193	583
		60	710	33.76	6.62	1.45	157334	52568	761
Wheat	Yamhill	15	607	32.01	6.38	1.38	123978	38934	533
		45	841	34.59	6.25	1.34	180256	41429	559
		60	548	35.23	6.59	1.40	123568	31678	447
	Hill 81	15	736	34.91	6.06	1.44	153356	34933	501
		45	709	31.13	6.35	1.43	139455	33361	476
		60	681	35.58	6.48	1.36	152142	36209	493
	LSD 0.05		NS	NS	NS	NS	NS	NS	NS
				Mean over row spacings					
Barley	Hesk		688	35.24	6.63	1.40	153467	36212	505
	Scio		761	33.86	6.47	1.40	167700	46664	654
Wheat	Yamhill		665	33.94	6.41	1.38	142601	37347	513
	Hill 81		709	33.87	6.29	1.41	148318	34835	490
	Control†		637	34.36	6.51	1.43	141655	41712	589
	LSD 0.05		NS	NS	NS	NS	NS	12436	156
				Mean over cultivars					
		15	701	35.34	6.37	1.39	151190	39859	549
		45	763	33.24	6.39	1.41	163310	37191	522
		60	654	34.11	6.60	1.40	144564	39244	550
	LSD 0.05		NS	NS	NS	NS	NS	NS	NS

†Control indicates red fescue established without a cereal companion crop.

Table II.3. Partial budget for establishment of red fescue with cereal companion crops. Production costs, revenues, and net changes in income are averaged over row spacings for a two-year period. Control indicates red fescue established without a cereal companion crop.

Budget item	Companion crop cultivar				Control
	Hesk	Scio	Yamhill	Hill 81	
	dollars ha^{-1}				
Production costs					
Increased costs	189.40	195.83	209.24	209.57	0
Decreased costs	0	0	0	0	0
Revenue					
Increased revenue†	285.85	361.01	572.68	574.63	0
Decreased revenue‡	64.00	0	57.94	76.11	0
Net change in income	32.44	165.19	305.49	288.96	0

†Gross income from companion crops based on August 1983 grain prices: \$0.14 per kg for wheat and \$0.09 per kg for barley.

‡Loss in gross red fescue income due to companion crops based on August 1984 red fescue price: \$0.77 per kg.

Table II.4. Influence of cereal row spacing on net change in income when red fescue was established with cereal companion crops. Net change in income refers to the relative income change due to establishment with cereal companion crops compared with red fescue planted alone for a two-year period.

Companion crop cultivar	Row spacing	Net change in income
	—— cm ——	—— dollars ha^{-1} ——
Hesk	15	115.91
	45	22.58
	60	-45.59
Scio	15	190.98
	45	120.54
	60	194.81
Yamhill	15	415.85
	45	324.79
	60	182.71
Hill 81	15	287.75
	45	341.59
	60	245.40

Table II.5. Sensitivity of companion cropping to changes in crop prices illustrated by net changes in income. Net changes in income are averaged over row spacings for a two-year period.

Market conditions	Companion crop cultivar: Hesk	Scio	Yamhill	Hill 81	Control
	dollars ha^{-1}				
Five year average prices†	31.11	213.77	282.11	257.85	0
High cereal, low fescue prices‡	115.47	253.95	339.74	323.38	0
Low cereal, high fescue prices‡	-42.23	202.60	119.78	164.96	0

†Average prices for 1980-84: wheat = \$0.14 per kg, barley = \$0.10 per kg, and red fescue = \$1.10 per kg.

‡Highest cereal and lowest red fescue prices for 1980-84: wheat = \$0.15 per kg, barley = \$0.11 per kg, and red fescue = \$0.77 per kg.

‡Lowest cereal and highest red fescue prices for 1980-84: wheat = \$0.13 per kg, barley = \$0.09 per kg, and red fescue = \$1.54 per kg.

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CONCLUSION

The lack of an adverse impact of cereal companion crops on subsequent seed yields was unexepected given the negative effects on red fescue growth during establishment. The observation that cereal companion crops did not reduce the availability of soil water during red fescue establishment was genuinely suprising as well. Although no differences in soil water were apparent between the companion crop row spacings under the conditions of these experiments, in a drier environment or on excessively well drained soils there may be a need for wider row spacings in order to conserve moisture. In addition, the establishment of red fescue with barley rather than wheat companion crops would be preferred under restrictive soil moisture conditions.

A possible additional benefit of establishing red fescue with cereal companion crops is that they may reduce the incidence of soil erosion during establishment on hilly terrain while the fescue plants are still quite small.

In general, there were no differences in red fescue growth under wheat or barley or any of the cultivars evaluated. The net income earned over the two-year period was much greater when red fescue was planted with wheat than with barley due to substantially larger revenues received from wheat. The decision of which companion crop or cultivar to employ in establishing red fescue seed crops must be made on the basis of revenue rather than on the influence on growth during the first growing season. Wider companion crop row spacings provided a more favorable growth environment for red fescue during establishment but had no effect on first-year seed yields. The net income received from the cereals was influenced by row spacing in the year of establishment, thus revenue is more important than growth in the year of planting in determining which cereal row spacing to use.

The effect of improved grain crop growth and yield on subsequent red fescue seed yield remains to be seen. Higher seed yields using barley companion crops may have been achieved if the residue from the barley was removed at an earlier date as suggested by Nordestgaard (1982). The removal of these crop residues was delayed because the experimental design used would not allow flail-chopping operations to commence until after the harvest of the later maturing wheat.

In these experiments, the planting of companion crops and the red fescue was accomplished in two separate operations. Some savings in these planting costs could be obtained if the companion crop and the red fescue were planted simultaneously.

These experiments clearly illustrate the potential of this establishment system for Willamette Valley red fescue seed crops. But caution must be exercised in using these results and cultural practices as the basis for actual farm scale seed production because this study was conducted at only a single location in the valley. With the refinement of these cultural practices and experimentation at diverse locations within the valley, there is no doubt that this establishment method can become a viable component of red fescue seed production in this area.

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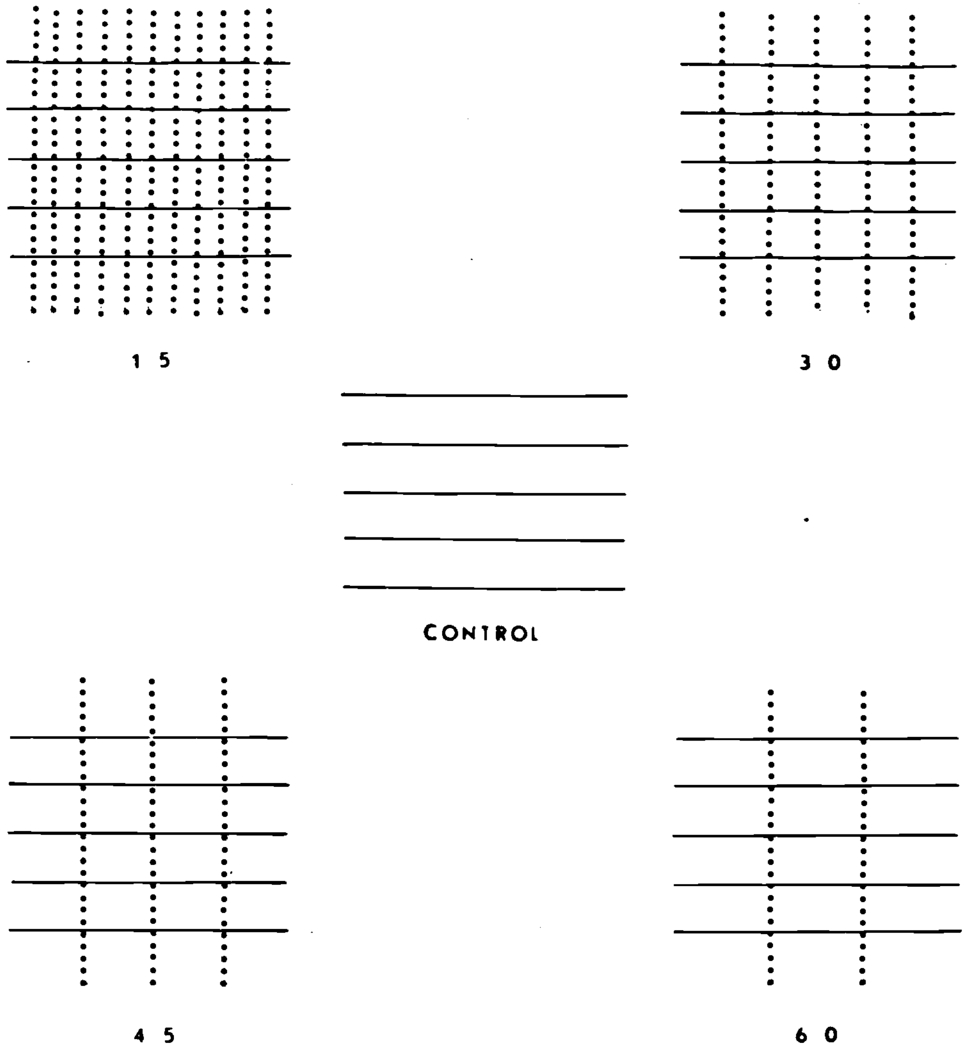
APPENDIX

Appendix Table 1. Cultural practices used to establish red fescue with cereal companion crops and to produce a first-year red fescue seed crop. Cultural practices for each experiment appear in chronological order.

Experiment 1			Experiment 2		
Date	Cultural Practice	Rate	Date	Cultural Practice	Rate
		kg ha^{-1}			kg ha^{-1}
10 Oct. 1982	Incorporated 16-20-0 into seedbed	224	4 Oct. 1983	Incorporated 16-20-0 into seedbed	224
11 Oct. 1982	Planted cereal crop	-	5 Oct. 1983	Planted cereal crop	-
	Carbon seeded red fescue crop	-	6 Oct. 1983	Carbon seeded red fescue crop	-
	Sprayed diuron	2.24	7 Oct. 1983	Sprayed diuron	2.24
22 Mar. 1983	Applied 42-0-0-8	208	31 Jan. 1984	Sprayed dinoseb amine	1.68
6 Apr. 1983	Sprayed bromoxynil	0.56	22 Mar. 1984	Applied 42-0-0-8	208
22 July 1983	Harvested barley	-		Sprayed bromoxynil	0.56
5 Aug. 1983	Harvested wheat	-	16 July 1984	Harvested barley	-
22 Aug. 1983	Removed cereal stubble	-	1 Aug. 1984	Harvested wheat	-
7 Oct. 1983	Applied 33-0-0	152	23 Aug. 1984	Removed cereal stubble	-
21 Oct. 1983	Sprayed simazine	2.24	5 Oct. 1984	Applied 33-0-0	152
21 Nov. 1983	Sprayed sethoxydim	0.43	30 Oct. 1984	Sprayed simazine	2.24
22 Mar. 1984	Applied 42-0-0-8	269	15 Nov. 1984	Sprayed sethoxydim	0.43
	Sprayed MCPA	0.56	12 Mar. 1985	Applied 42-0-0-8	269
	Sprayed dicamba	0.28	1 Apr. 1985	Sprayed MCPA	0.56
12 July 1984	First red fescue seed harvested	-		Sprayed dicamba	0.28

Appendix Table 2. Climatological data for Hyslop Crop Science Field Laboratory, October 1982 to October 1984.

Month	Precipitation	Departure from average	Temperature Max.	Departure	Min.	Departure
	mm	mm	°C	°C	°C	°C
1982						
Oct.	92.5	+ 6.4	18.0	0	5.8	+0.4
Nov.	140.0	- 16.8	9.7	-1.9	1.4	-1.5
Dec.	268.2	+ 70.9	8.2	+0.1	1.8	-0.4
1983						
Jan.	175.5	- 16.3	9.0	+1.7	2.4	+1.9
Feb.	261.9	+138.4	11.2	+1.0	4.0	+2.3
Mar.	223.0	+105.4	13.5	+1.4	5.7	+3.4
Apr.	76.5	+ 14.0	16.1	+0.9	4.1	+0.3
May	38.4	- 10.4	20.9	+1.9	7.0	+0.8
June	35.3	+ 4.8	21.1	-1.5	9.3	+0.2
July	64.8	+ 56.9	23.3	-3.8	11.2	+0.9
Aug.	56.1	+ 35.6	26.5	-0.5	12.0	+1.6
Sept.	13.5	- 24.1	22.8	-1.4	8.8	+0.1
Oct.	26.7	- 59.4	17.5	-0.5	4.7	-0.7
Nov.	252.2	+ 95.5	11.9	+0.3	5.5	+2.6
Dec.	186.7	- 10.7	4.8	-3.3	-0.5	-2.0
1984						
Jan.	82.8	-109.0	9.3	+2.0	1.7	+1.2
Feb.	175.8	+ 52.3	11.2	+1.0	2.1	+0.4
Mar.	97.0	- 20.6	14.4	+2.3	4.6	+2.3
Apr.	86.6	+ 24.1	14.0	-1.2	3.8	0
May	93.2	+ 44.5	17.6	-1.4	5.9	-0.3
June	110.2	+ 79.8	21.0	-1.6	8.1	-1.0
July	5.1	- 2.8	27.3	+0.2	10.6	+0.3
Aug.	T	- 20.6	27.4	+0.4	9.6	-0.8
Sept.	18.8	- 18.8	23.7	-0.5	8.6	-0.1
Oct.	118.1	+ 32.0	15.0	-3.0	5.4	0



Appendix Fig. 1. Planting patterns used to establish red fescue with cereal companion crops. Rows of vertical dots denote cereal rows and solid lines indicate red fescue rows. Numerals under planting patterns indicate companion crop row spacings in centimeters while the term control represents red fescue established without a companion crop.