AN ABSTRACT OF THE THESIS OF

Thomas G. Chastain for the degree of Doctor of Philosophy in
Crop Science presented on November 3, 1987
Title: SPRING ESTABLISHMENT OF ORCHARDGRASS AND TALL FESCUE SEED CROPS WITH CEREAL COMPANION CROPS
Abstract approved: Redacted for Privacy
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Orchardgrass and tall fescue seed crops are commonly spring-planted in Oregon, but do not produce a marketable crop during the first growing season. Establishing orchardgrass and tall fescue with cereal companion crops would provide income during the seeding year and could increase seed production profits. This study was conducted to evaluate the feasibility of establishing orchardgrass and tall fescue seed crops with spring wheat, barley, and oats, and to examine the morphological, physiological, seed yield, and economic responses to competition with cereals. 'Hallmark' orchardgrass and 'Bonanza' tall fescue were interplanted with 'Waverly' wheat, 'Steptoe' barley, and 'Cayuse' oats in 15- and 30-cm rows at right angles to grass rows in March 1985 and 1986 near Corvallis, OR.

Spring cereals reduced the photosynthetic photon flux density (PPFD) available for grass seedling growth, causing transient increases in chlorophyll content and lower soil temperatures. Soil water content was also depleted, causing increased stomatal resistance and lower transpiration rate. Reductions in PPFD and soil water were responsible for poor stand establishment and grass crop growth. The negative effects on seedling establishment persisted after cereal harvest and delayed grass regrowth until the following spring, resulting in low fertile tiller populations. Consequently, first-year orchardgrass seed yields were reduced by 40 and 53% in the two trials, whereas first-year tall fescue seed yields were reduced by 61% in both trials. First-year seed yields were similarly reduced by all three cereals. Second-year orchardgrass seed yield was not influenced by companion cropping, but second-year tall fescue yield increased by 15%. Cereal row spacing had no effect on grass seed crop growth, physiology, or seed yield.

Seeding orchardgrass with spring wheat in 30-cm rows increased net income by $212 per hectare over a 3-year period under average crop market conditions while tall fescue planted with spring oats in 30-cm rows earned $139 per hectare more than planting alone. Drier than normal conditions increased competitive effects of cereals, reducing first-year seed yields and economic return. Irrigation or fall planting may be the key to more favorable returns from companion cropping of orchardgrass and tall fescue.

Spring Establishment of
Orchardgrass and Tall Fescue Seed Crops
with Cereal Companion Crops

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed November 3, 1987

Commencement June 1988

APPROVED:

Redacted for Privacy

Professor of Agronomy in charge of major

Redacted for Privacy

Head of Department of Crop Science

Redacted for Privacy

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Date thesis is presented November 3, 1987

ACKNOWLEDGEMENT

I would like to thank Dr. Don F. Grabe for his invaluable contribution to this study, for guiding me through my graduate training, and for his generous support of innovative research. I would like to express my gratitude to Dr. H.W. Youngberg, Dr. K.L. Chambers, Dr. R.G. Petersen, and Dr. R.L. Stebbins for serving on my graduate committee.

I am indebted to Dr. T.M. Ching for her contribution to the physiological part of this investigation and the use of her laboratory facilities. I have greatly appreciated the creative discussion and technical advice provided by Dr. F.E. Bolton.

My special thanks go to Carol Garbacik and Daryl Erhensing for their assistance in conducting this investigation. Finally, I wish to thank my wife, Donna, for spending many weekend hours counting tillers and for her moral support during my graduate training.

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INTRODUCTION

The production of high quality orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.) seed is an important component of the agricultural economy of Oregon. These perennial grass seed crops are usually spring seeded in the Pacific Northwest (Van Keuren and Canode, 1963a), and do not produce a marketable crop in the year a new seed field is planted. Poor seed production during the establishment year has been attributed to the absence of environmental conditions required for vernalization of the crop (Gardner and Loomis, 1953; Templeton et al., 1961). Consequently, Oregon growers receive no income from orchardgrass or tall fescue seed crops in the year of planting. In some European countries, however, grass seed crops are commonly established with annual companion crops such as the cereals, flax (*Linum usitatissimum* L.), and winter rape (*Brassica napus* L.). A companion crop provides these growers with a cash crop during the establishment year. This cropping system could be employed in Oregon to increase the profitability of grass seed production.

Recently, the focus of agricultural research has shifted from maximizing crop yields to increasing the profitability of farm enterprises and improving the quality of farm commodities. The companion cropping system could potentially increase the profitability of seed production without increasing grass seed crop yield.

European studies of companion cropping report both success and failure in establishing grass seed crops, but only offer speculative reasons for these results. Certainly, competition for resources between companion crops and grass seed crops must play an important role in the relative success of stand establishment. The companion crop affects stand establishment negatively by modifying the growth environment in which the grass seed crop is grown (Chastain and Grabe, 1988a). A fundamental understanding of the biological effects of companion crops on grass seed crop establishment is needed to adapt this cropping system to the unique climate and soils of Oregon. Moreover, the impact of companion crops on the economic return of grass seed production needs to be evaluated.

The objectives of this investigation were to (i) determine the influence of cereal companion crops and row spacing on spring establishment of orchardgrass and tall fescue seed crops in Oregon's Willamette Valley, (ii) to examine the competitive effects of spring cereal companion crops on physiology and morphology of orchardgrass and tall fescue, (iii) to study the effect of spring cereal companion crops on grass seed crop growth environment, and (iv) to evaluate the impact of spring cereal companion crops on the economic return of the cropping system.

LITERATURE REVIEW

Companion Cropping

Companion cropping is only successful when the companion crop produces more income than is lost due to lower seed yield as a consequence of intercrop competition. Therefore, the goal of the companion cropping system is to minimize losses in grass seed yield due to the competitive effects of companion crops, while maximizing companion crop income production.

Historically, small grain companion crops have been used to establish forages (Kilcher and Heinrichs, 1960). Increased income, weed control, and erosion control were the principle benefits of establishing slow growing forages with companion crops (Decker and Taylor, 1985). The availability of effective and economical herbicides made seeding forages alone a viable alternative, and as a result, the practice of companion cropping has declined in the United States. During the 1930's and 40's, growers began planting forage grasses solely for seed production instead of harvesting seed from a forage stand (Cowan, 1956). This change coincided with the introduction of herbicides in forage establishment and hastened the decline of companion cropping. In contrast, the reluctance of European seed producers to lose one season's income when a seed field is planted has resulted in the persistence of companion cropping in Europe (Evans, 1951).

Grass seed crops have exhibited a variety of seed yield responses to establishment with companion crops. The following is a survey of the research on establishment of grass seed crops with companion crops.

European Studies

Much of the early companion cropping research was conducted by the staff of the Welsh Plant Breeding Station at Aberystwyth, Wales. Roberts (1964) showed that spring oats (*Avena fatua* var. *sativa* (L) Haussk.) reduced first-year (2nd year after planting) orchardgrass seed yield. Low fertile tiller populations were caused by establishment with oats and were responsible for the reduction in seed yield. Second-year (3rd year after planting) fertile tiller numbers and seed yield were not affected by seeding with oats. Giffiths et al., (1978) reported that first-year tall fescue and orchardgrass seed yields were reduced by barley (*Hordeum vulgare* L.) companion crops, whereas second-year seed yield was not affected. Establishing orchardgrass with barley produced 20% greater economic returns than planting orchardgrass alone (Griffiths et al., 1967).

In Sweden, barley companion crops caused minimal reductions in first-year red fescue (*Festuca rubra* L.) seed yield, whereas Kentucky bluegrass (*Poa pratensis* L.) first-year yields were very poor when planted with barley (Cedell, 1975). Both seed crops exhibited low first-year seed yields when established with winter wheat (*Triticum aestivum* L.).

More recently, Anton Nordestgaard of Denmark has conducted extensive studies on cultural practices used in establishing grass seed crops with companion crops. Nordestgaard (1979) found that fertile tiller number and first-year seed yield of Kentucky bluegrass were reduced by establishment with winter wheat, spring wheat, field bean (*Phaseolus vulgaris* L.), and flax, but not by winter rape.

North American Studies

Few studies have been conducted in North America to determine the feasibility of planting grass seed crops with companion crops. Orchardgrass seed yield was not affected by spring establishment with barley or peas (*Pisum sativum* L.) under irrigation in central Washington (Van Keuren and Canode, 1963b). Crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.) seed yield was reduced by barley, but not by peas. Pardee and Lowe (1963) reported that winter wheat, barley, or spring oat companion crops had no effect on timothy (*Phleum pratense* L.) and orchardgrass seed yield in New York. Pardee and Lowe advised that seeding the grass seed crops alone was not economical because there would be no cash returns for a full year.

In Oregon, Chastain and Grabe (1988b) showed that red fescue seed yield was somewhat depressed by establishment with wheat companion crops, but net income was increased by \$508 ha^{-1} over a 3-year period. If only half of the experimentally obtained income is earned by Oregon growers, then the profitability of red fescue seed production would be substantially increased.

Lawrence (1967) found that Russian wild ryegrass (*Elymus junceus* Fisch.) seed yield was markedly reduced by wheat companion crops in Saskatchewan, Canada. In contrast, wheat companion crops did not reduce crested wheatgrass seed yield although seedling vigor was negatively affected (Lawrence, 1970).

Growth Environment

The competitive effects of companion crops on grass seed crops are mostly due to modifications of the seedling growth environment. Seedlings grown in the microenvironment under companion crops must compete for light, water, nutrients, and space. In addition, it is possible that allelopathic agents are produced by some companion crops and could inhibit seedling growth and development. Therefore, an understanding of grass growth under adverse environmental conditions is very important. Knowledge of grass seed production physiology is limited and the following studies are primarily concerned with the physiological and morphological responses of forage grasses to environmentally induced stress.

Shading

The light environment under a companion crop canopy is characterized by reduced light intensity, increased far-red radiation, and is not uniformly distributed due to the presence of sunflecks.

Cowan (1956) discussed the poor competitive ability of tall fescue seedlings when shaded by weeds. Nittler et al. (1963) showed that low light intensity greatly reduced the number of tillers per orchardgrass seedling. Shading reduced orchardgrass plant weight and tiller number (Auda et al., 1966). Ryle (1967) found that shading reduced tiller production and the rate of leaf primordia accumulation on shoot apices of meadow fescue (*Festuca pratensis* Huds.) and perennial ryegrass (*Lolium perenne* L.). Chastain and Grabe (1988a) reported that companion crop shading on red fescue seed crops reduced tiller numbers, dry matter production, and caused etiolation of tillers.

Deregibus et al. (1983) concluded that ryegrass (Lolium spp.) tillering was impaired as a result of increased exposure to far-red radiation as under a plant canopy. This effect was counteracted by an exposure to red radiation. This finding suggests that the tillering response of grasses to light may be mediated by phytochrome and that light quality, as well as quantity, may be important in determining tiller number.

Forde (1966) observed that reduced light (20% of full sun) increased orchardgrass lamina length and decreased lamina width. Shading was responsible for an increase in the number of epidermal cells lengthwise along the lamina and decreased cell number across the width of the lamina. Taylor et al. (1968) found that orchardgrass grown under 10.8 kLux light had greater leaf area than plants under 16.1 kLux.

Tall fescue leaves have more stomata in full sun than under 23% full sunlight (Woledge, 1971). Consequently, the CO_2 flux into the leaf could be impaired as a result of fewer stomata under shade and is indicative of possible reductions in seedling dry matter production. Grass root growth was increased more than shoot growth as light intensity was increased (Cooper and Tainton, 1968). The sensitivity of grass root sytems to shading suggests that possible reductions in the extent of roots in the soil could result in lessened ability to take up water and nutrients.

Woledge (1971) found that tall fescue plants grown in full sunlight had higher photosynthetic and respiration rates than plants grown in 23% sunlight. She observed that shaded tall fescue plants had 6% more chlorophyll than plants grown in full sun. The photosynthetic rate of heavily shaded perennial ryegrass leaves declined faster with age than unshaded leaves (Woledge, 1972). Heavy shading also reduced the longevity of leaves.

Orchardgrass photosynthetic rates did not increase appreciably as light availability increased from 30 to 100%; however, ribulose diphosphate carboxylase activity increased as shading was reduced (Singh et al., 1974). Usually, photosynthetic rates and ribulose diphosphate carboxylase activity in C_3 grasses increase as light intensity increases as was indicated for tall fescue. However, the lack of change in orchardgrass photosynthetic rate over a range of light intensities suggests an adaptive mechanism for competition under shade. Shading was reponsible for reductions in water soluble carbohydrate content of orchardgrass plants (Auda et al., 1966)

Sunflecks lasting 1 minute may make significant contributions to the daily carbon gain of plants, whereas sunflecks less than 5 seconds in duration contribute little carbon to the shaded plant (Gross and Chabot, 1979).

Water Stress

The responses of grass seed crops to water stress induced by competition with companion crops have not been well documented. In addition to possible competition for water, companion crops reduce wind speed, soil temperature, and increase the relative humidity of the grass crop growth environment. All of these factors could have a significant impact on the grass plant's water status.

Spring barley companion crops shaded orchardgrass seeded for forage and, in turn, reduced the extent of the seedling root system (Cooper and Ferguson, 1964). Orchardgrass growth was impaired by the direct effects of shading and indirectly by water stress induced as a result of poor root growth. Soil water deficit was responsible for reductions in orchardgrass tiller number and plant weight (Brown and Blaser, 1970). Conversely, Norris (1982) found that orchardgrass tiller numbers were not affected by soil water deficit. Tall fescue and perennial ryegrass tiller populations were reduced by low soil water content.

Winter cereal companion crops shaded red fescue seed crops and reduced soil temperature, but did not compete for soil moisture (Chastain and Grabe, 1988a). Companion crops reduce wind movement under their canopies which lessens the evaporative demand on the grass plants. Reduced wind movement causes a thickening of the boundary layer air on the lamina of the seedling which results in lower tranpiration rates. Lower soil temperatures in companion crop shade reduces the evaporation rate from the soil surface. Reduced wind movement, coupled with lower soil temperature, resulted in greater soil water conservation under cereals as the soils dried in spring than for monoculturally planted red fescue. Obviously, the cereal crops used some water, but this loss was compensated for by the greater water conservation under cereals. The net result was that there was no competition for water between cereal and grass seed crop.

Feldhake and Boyer (1986) showed that evapotranspiration was higher for unshaded orchardgrass as soil temperature increased, but tall fescue was not affected similarily.

Stomatal closure in response to water stress is the primary cause for reduced transpiration rate (Hsiao, 1973). Apparently, at higher light intensities, more intense water stress is required to induce stomatal closure. Consequently, plants that are shaded by companion crops may experience increased stomatal resistance under only mild water stress conditions. Stomatal closure due to water stress also reduces CO_2 assimilation because of restricted CO_2 flux (Hsiao, 1973). Finally, water stress has been implicated in reducing the chlorophyll content of leaves (Hsiao, 1973).

Cultural Practices to Maximize Economic Return

It is clear that the companion crop has a negative effect on stand establishment of the grass seed crop. Certain strategies have been employed by grass seed producers in an attempt to reduce the competitive effects of the companion crop. These include alterations in companion crop row spacing, seeding rate, row direction, and by using weakly competitive companion crops.

Spring barley and oat cultivars having fewer and shorter tillers increased the amount of light incident on forage legume seedlings (Flanagan and Washko, 1950). Wicks et al. (1986) indicated that wheat cultivars less than 78-cm tall were poor competitors with weeds, whereas cultivars at least 83-cm tall had greater competitive ability. Thus, short cultivars are needed for companion cropping because they intercept less light (weaker competitors) and could improve grass crop stand establishment. Kentucky bluegrass seed crops received more light and produced more tillers when winter wheat companion crops were planted in 37.5-cm rows instead of 12.5-cm rows (Meijer, 1979). Winter cereals planted in 60-cm rows provided much more light for red fescue growth than 15-cm rows; however, seed yield was not improved as a result of greater fescue growth under 60-cm rows (Chastain and Grabe, 1988b).

Crested wheatgrass seed yields were similar when wheat companion crop rows were drilled parallel to grass rows, across grass rows, or without wheat (Lawrence, 1970). Wheat row spacings ranging from 15.2 to 91.5 cm, had no effect on subsequent wheatgrass seed yield. Increased orchardgrass, red fescue, and meadow fescue seed yields were obtained when barley companion crops were seeded at 90 kg ha^{-1} rather than 180 kg ha^{-1} (Nordestgaard, 1984a). Seed yield was simliar whether the seed crops were established under 12- or 24-cm barley rows, and greater when an early-maturing barley cultivar was used. Kentucky bluegrass fertile tiller populations and seed yields were greater when winter wheat was seeded at 100 kg ha^{-1} instead of 200 kg ha^{-1} (Nordestgaard, 1984b). The direction in which wheat rows were drilled did not affect bluegrass seed yield.

The plant growth regulator, chlormequat chloride, was applied on winter wheat to reduce lodging and to improve the growth environment for Kentucky bluegrass seedlings, but did not increase seed yield (Nordestgaard, 1984b). Another growth regulator, paclobutrazol, increased light transmission through a wheat canopy by reducing tiller height, but had no effect on subsequent red fescue seed yield (Chastain and Grabe, unpublished).

Other special management practices are required for successful establishment of grass seed crops with companion crops. Weed control, fertilization, and post-harvest residue management practices in companion cropping systems were discussed by Chastain (1986).

Griffiths et al. (1978) stated that "one of the major problems with the establishment of first class seed production stands under a cereal crop is that of ensuring the survival of an adequate population of grass seedlings that will grow vigorously and quickly after the cereal crop is removed". Managing the seed crop so as to produce the maximum numbers of fall tillers is required to obtain the greatest seed yield in the following spring. This means selecting a companion crop that is not a strong competitor and/or encouraging regrowth of the grass seed crop in late summer and early fall. This may entail using additional fertilizer and irrigation, or other practices that facilitate regrowth of the grass crop.

Wider companion crop row spacings have generally improved grass crop growth by providing a more favorable growth environment, but have not been as effective as reduced companion crop seeding rates in alleviating the competitive effects on seed yield.

Companion crops usually, but not always, reduce first-year seed yields. It is evident that grass seed crops have differential abilities to tolerate shading and water stress. Differential ability of grasses to tolerate stress induced by companion crops may be due to physiological or morphological plasticity. The ability to adapt to a modified environment depends on the genetic makeup of the grass and is expressed as alterations in metabolic function or growth habit. Forcella (1987) found that tall fescue genotypes that have high leaf area expansion rates have superior competitive ability. Grasses having this characteristic would be among the most suitable candidates for companion cropping. The possible adaptations of orchardgrass to shade (Singh et al., 1974) have been discussed.

If the success of companion cropping depends on the ability of the grass to recover from stress and regrow, then grasses that store greater amounts of non structural carbohydrates would be probable candidates for companion cropping. Finally, fall planting may be superior to spring planting (used in this study) because fall seeded grasses are older and possibly better able to withstand the intercrop competition that occurs in spring.

MANUSCRIPT I

SPRING ESTABLISHMENT OF ORCHARDGRASS SEED CROPS WITH CEREAL COMPANION CROPS

ABSTRACT

When orchardgrass (Dactylis glomerata L.) seed crops are spring-planted, a seed crop is not produced during the first growing season because environmental conditions required to promote flowering are absent. Income produced by establishing orchardgrass seed crops with cereals could offset revenue lost when a seed field is planted. This investigation was conducted to ascertain the feasibility of establishing orchardgrass seed crops with cereal companion crops and to examine the morphological, physiological, seed yield, and economic responses of orchardgrass to competition with cereals.

'Hallmark' orchardgrass was interplanted with 'Waverly' spring wheat (Triticum aestivum L.), 'Steptoe' spring barley (Hordeum vulgare L.), and 'Cayuse' spring oats (Avena fatua var. sativa (L.) Haussk.) in 15- and 30-cm rows at right angles to grass rows. The crops were planted in March 1985 and 1986 on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil near Corvallis, OR. Interspecific competition for light and water was monitored during the growing season to evaluate the competitive effects of cereals on orchardgrass establishment.

Cereals reduced photosynthetic photon flux density (PPFD) incident on orchardgrass seedlings, resulting in lower soil temperature and transitory increases in chlorophyll content. Cereal crops reduced soil moisture content, causing water stress in orchardgrass seedlings as indicated by greater stomatal resistance and lower transpiration rate. The severity of water stress was intensified by shading, resulting in reduced orchardgrass tiller and dry matter production. The negative effects on growth persisted into the fall and winter, reducing fertile tiller production during the following spring. Consequently, spring cereals reduced first-year seed yields by 40% in Trial 1 and 53% in Trial 2. Seedling growth and first-year seed yields were similarly reduced by companion crops regardless of cereal crop or row spacing used. Second-year seed yield was not influenced by the cereals.

Although orchardgrass seedlings were adversely affected during establishment, net income was increased by \$212 ha^{-1} over a 3-year period in Trial 1 when planted with wheat in 30-cm rows. Extremely dry conditions in Trial 2 caused low cereal and seed yield, making establishment with cereals unprofitable. This study demonstrated the negative effects of spring cereals on orchardgrass stand establishment and the potential for increased profitability of orchardgrass seed crops planted with wheat.

Additional index words: Grass seed production, Cropping system, *Dactylis glomerata* L., Physiological responses, Growth analyses, Water stress, Wheat, Barley, Oats, Net income

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Spring Establishment of Orchardgrass Seed Crops with Cereal Companion Crops

INTRODUCTION

When orchardgrass (Dactylis glomerata L.) seed crops are spring-planted in the Pacific Northwest, few seed are produced during the first growing season because environmental conditions required to promote flowering are absent (Gardner and Loomis, 1953). Since one season's income is lost when a new seed field is planted, it would be advantageous to develop a more cost-effective alternative to monoculture establishment. Planting red fescue (Festuca rubra L.) with winter wheat (Triticum aestivum L.) companion crops generated \$508 ha^{-1} more than monoculture establishment over a 3-year period in Oregon (Chastain and Grabe, 1988b), and similar beneficial results could be possible for orchardgrass.

In Wales, Roberts (1964) concluded that first-year orchardgrass seed yield was reduced by spring oat (Avena fatua var. sativa (L) Haussk.) companion crops as a result of low fertile tiller number. Fertile tillers and seed yields in subsequent years were not reduced by establishment with spring oats. Griffiths et al. (1978) found that barley (Hordeum vulgare L.) companion crops also decreased first-year orchardgrass yield, but had no effect on second-year yields. Conversely, Van Keuren and Canode (1963) reported that orchardgrass seed yield was not affected by spring establishment with barley under irrigation in central Washington.

A fundamental understanding of the biological effects of cereal companion crops on orchardgrass is needed to adapt this cropping system to the unique climate and soils of Oregon. No studies to date have evaluated the physiological responses of grass seed crops to establishment with companion crops. The objectives of this study were to ascertain the agronomic feasibility of establishing orchardgrass seed crops with cereal companion crops and to examine the morphological, physiological, seed yield, and economic responses to competition with cereals.

MATERIALS AND METHODS

'Hallmark' orchardgrass was planted with cereals on 13 March 1985 (Trial 1) and 27 March 1986 (Trial 2) at the Oregon State University Hyslop Crop Science Field Laboratory, near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil. 'Waverly' spring wheat, 'Steptoe' spring barley, and 'Cayuse' spring oats were drilled in 15- and 30-cm rows. Cereal seeding rates were 117 kg ha^{-1} for wheat and barley, and 134 kg ha^{-1} for oats. Orchardgrass was planted in 45-cm rows at right angles to cereal rows at a 9 kg ha^{-1} seeding rate. The experimental design was a split-plot replicated in four randomized blocks. Main plots were cereal row spacings, and subplots were cereal species and orchardgrass monoculture (Control). Each subplot was 6.7 m by 1.8 m.

Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was sprayed on the experiment site at 0.45 kg ha^{-1} before seedbed preparation. Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) was applied at 0.45 kg ha^{-1} to control broadleaved weeds, 22 to 24 days after planting. Late germinating broadleaved weeds in Trial 2 were controlled with 0.56 kg ha^{-1} MCPA [(4-chloro-2-methylphenoxy) acetic acid] on 9 May 1986. Fall broadleaved weeds were controlled with 1.12 kg ha^{-1} MCPA in late October. Annual bluegrass (*Poa annua* L.) was controlled with 2.24 kg ha^{-1} simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine) applied on 5 November 1985 and 28 October 1986 for Trial 1 and 2, respectively.

Ethofumesate [($\pm$)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] was sprayed at a rate of 1.12 kg ha^{-1} on 20 November 1985 and 24 October 1986 to control volunteer cereals. Spring broadleaved weeds were controlled with 0.56 kg ha^{-1} MCPA and 0.28 kg ha^{-1} dicamba (3,6-dichloro-2-methoxybenzoic acid) in mid-March 1986 and 1987.

Fertilizer was incorporated into the seedbed before planting at 56 kg ha^{-1} N and 27 kg ha^{-1} P. Additional fertilizer was applied in mid-April at 28 kg ha^{-1} N and 4 kg ha^{-1} S. Fall N was applied in early October at 50 kg ha^{-1}. Spring fertilizer applications were made in March of the harvest year at 112 kg ha^{-1} N and 15 kg ha^{-1} S.

Cereal tiller number, tiller height, and leaf area index (LAI) were measured at peak cereal leaf area. Orchardgrass tiller number, tiller height, dry matter, and LAI were measured during the growing season and in November (Chastain and Grabe, 1988a).

Stomatal resistance (L_r), leaf temperature (L_t), and transpiration rate (TR) were determined with a Li-Cor Model 1600 steady state porometer. Porometer measurements were made between 1200 and 1400 h on abaxial and adaxial leaf surfaces, and L_r values were calculated assuming the two leaf surfaces acted in parallel. Chlorophyll was extracted from 1 g samples of fresh orchardgrass leaves taken between 1100 and 1200 h. Leaf samples were homogenized in 80% (v/v) acetone at 4^oC in darkness. The homogenate was placed in a refrigerated centrifuge for 10 min at 10000 X g. Chlorophyll content in the supernatant was determined with a spectrophotometer (Bruinsma, 1963).

The percentage of photosynthetic photon flux density (PPFD) incident on orchardgrass seedlings was measured with a Li-Cor Model Li-1776 Solar Monitor and line quantum sensor (Chastain and Grabe, 1988a). Soil water content was determined gravimetrically from samples taken in the top 15 cm of the soil profile. Soil temperatures were measured at a 5-cm depth between 1200 and 1400 h on 2 July 1985 and 26 June 1986.

Oat and barley companion crops were harvested with a Hege plot combine on 23 July 1985 and 24 July 1986, while wheat was harvested on 5 August 1985 and 1 August 1986. Cereal stubble was flail-chopped and removed in mid-August.

Fertile and vegetative tiller populations were measured at peak anthesis on two 30-cm samples of grass row taken from each subplot on 2 June 1986 and 16 May 1987. First-year seed crops were harvested with a plot harvester and bagged for drying on 23 June 1986 and 16 June 1987. The second-year seed crop was harvested on 16 June 1987. The dried grass crop was threshed and seed was cleaned with a Clipper M2-B air-screen cleaner before weighing. Plots were burned in August after the first seed harvest.

The effect of cereals on net income from seed production was evaluated by the partial budgeting technique described by Chastain and Grabe (1988b).

Analysis of variance (ANOVA) was used to test the effect of row spacing, companion crops, and possible interaction of these factors. Orthogonal contrasts were used to compare establishment of orchardgrass with cereals against orchardgrass monoculture (Control) and to detect possible differential effects among cereal crops. Treatment means were separated by using Fisher's protected least significant difference (FLSD) values.

RESULTS AND DISCUSSION

Intercrop competition

Between early April and July, precipitation was 10 and 16% lower than normal in Trials 1 and 2, respectively. Intercrop competition occurred during this period and was increased in severity because the low rainfall was irregularly distributed.

Barley tillers were taller than wheat or oat tillers (Table I.1) and were prone to lodging. Row spacing did not influence tiller height in Trial 1, whereas cereals planted in 15-cm rows had taller tillers in Trial 2. Oats produced more tillers and attained greater LAI than other cereals. Cereal tiller number and LAI were unaffected by row spacing in both trials. No row spacing X cereal interactions were evident for cereal growth characteristics in Trial 2, however, more oat tillers and greater LAI were produced in 15-cm rows in Trial 1.

Grain yield was not influenced by row spacing X companion crop interaction (Table I.1). Row spacing effects on grain yield were not evident in Trial 1, whereas yield was greater in 15-cm rows in Trial 2. Barley and oat yields were not different from wheat in Trial 1, but were greater in Trial 2. Barley yield was greater than oats in Trial 1, however, oat yields were greater than barley in Trial 2. Grain yield was greater in 1985 (Trial 1) as a result of very dry conditions in the spring of 1986 (Trial 2).

Companion crops reduced PPFD incident on orchardgrass seedlings by as much as 85% (Table I.2). There were no significant row spacing X cereal effects on PPFD transmission. PPFD transmission was not influenced by row spacing in Trial 1. In contrast, orchardgrass under

15-cm cereal rows received less PPFD than 30-cm rows in Trial 2 because 15-cm rows had taller tillers (Table I.1). No differences in PPFD transmission were evident among cereal crops in Trial 1. However, barley shaded orchardgrass seedlings more than oats in Trial 2 because barley tillers attained greater height.

Less soil water was present in orchardgrass plots spring-planted with cereals (Table I.3). By comparison, Chastain and Grabe (1988a) showed that winter cereals did not compete with red fescue for soil water. Spring cereal canopy development was slower and covered less soil surface than winter cereals. Unlike winter cereals, spring cereal roots were initially located at the same depth as seedling grasses when the soil dried in the spring. Soil temperature was reduced by cereal shading, but this reduction did not alleviate the evaporative demand from the soil exhibited by winter cereal companion crops. Row spacing had no effect on soil water content and temperature. No row spacing X cereal interactions were detected for soil water content and temperature.

The competition for light and water combined to reduce the number of orchardgrass tillers and dry matter production (Table I.4). Nittler et al. (1963) observed that low light intensity greatly reduced the number of tillers per orchardgrass seedling and Norris (1982) found that soil moisture deficit reduced orchardgrass growth rate. Spring barley shaded orchardgrass seeded for forage, reducing the extent of the seedling root system (Cooper and Ferguson, 1964). Therefore, orchardgrass growth under cereals was not only impaired by the direct effects of shading, but also indirectly by water stress induced as a result of poor root growth. Orchardgrass photosynthetic rate did not appreciably increase as PPFD availabilty was increased from 30 to 100%; however, ribulose diphosphate carboxylase activity increased as shade was reduced (Singh et al., 1974). Growth reductions under shade could have been increased by water stress if photosynthetic enzyme activity was inhibited.

The poor light environment under cereals caused significant etiolation of seedling tillers in Trial 1 and caused minor ($P>0.05$) effects in Trial 2. Cereals caused a marked reduction in orchardgrass LAI (Table I.4). Orchardgrass growth characteristics were unaffected by cereal row spacing in Trial 1, but early growth was improved under 30-cm rows in Trial 2. There was little difference in orchardgrass growth regardless of row spacing and cereal crop.

Reduction in soil water content by cereal crops caused mild water stress in orchardgrass seedlings as indicated by increased stomatal resistance (L_r) and reduced transpiration rate (TR) on 10 June 1986 (Table I.5). Somewhat greater ($P>0.05$) L_r and lower TR values were observed under cereals on 21 June and 8 July. L_r was considerably lower on 8 July due to a heavy rainstorm on 4 July. The stomatal closure and restricted CO_2 flux caused by high L_r may have been partly responsible for reduced dry matter production under cereals. Seedling leaf temperatures (L_t) under cereals were similar to those exposed to full sun in control plots because of reduced TR. Since L_t was not lower in shade as would be expected for unstressed plants, this result provides more evidence of water stress imposed by cereals. Orchardgrass water stress was not lessened by a particular cereal row spacing or combination of row spacing and cereal crop.

The shading of orchardgrass seedlings by cereals caused increased leaf chlorophyll content in June 1986 (Table I.5). However, water stress conditions intensified as the season progressed, resulting in reduced orchardgrass chlorophyll content under cereals. Examination of chlorophyll content revealed a transient effect of row spacing, causing increases due to shading under 15-cm rows on 27 June and decreases due to water stress on 11 July. More chlorophyll was found under 15-cm barley rows on 27 June.

Seed Production

The negative effect of cereals on orchardgrass growth persisted into November (Table I.6), resulting in fewer and stunted tillers and less dry matter. Poor seedling growth under cereals in spring retarded regrowth in fall, presumably as a result of shade-induced reductions in water-soluble carbohydrates (Auda et al., 1966). This meant fewer tillers were sufficiently mature to be receptive to short-day and low temperature stimuli required to promote flowering. Thus, cereals caused markedly fewer fertile tillers to be produced in the following spring (Table I.6). Planting with cereals, however, did not affect total tiller number (sum of fertile and vegetative tillers) at peak anthesis. Unfortunately, more vegetative rather than fertile tillers were produced by orchardgrass planted with cereals, indicating regrowth was delayed until after vernalization conditions were no longer present. Among cereal crops, oats caused the least reduction in fertile tiller populations.

First-year seed yield was reduced by establishment with cereal companion crops as a result of low fall and fertile tiller production (Table I.6). First-year seed yields were closely associated with fall (r = 0.82) and fertile (r = 0.76) tiller numbers (Table I.7). Reductions in first-year seed yield ranged from 34 to 48% in Trial 1, and from 42 to 58% in Trial 2. Griffiths et al. (1978) reported that spring barley reduced first-year orchardgrass seed yield by 70%. Cereals reduced first-year seed yield in Trial 2 more than Trial 1 because extremely dry conditions in Trial 2 caused increased competition for water. Seed yield was improved by the enhanced growth environment provided by 30-cm cereal rows in Trial 1, but not in Trial 2. Nordestgaard (1984) noted that barley row spacing had no effect on first-year orchardgrass seed yield.

All cereals reduced seed yield to the same extent in Trial 1, whereas establishment with oats severely depressed seed production in Trial 2. Nordestgaard (1984) showed that orchardgrass seed yield was improved by planting with a early-maturing barley cultivar. By comparison, no yield advantage was obtained by planting spring barley and oats which matured earlier than wheat. Second-year seed yield was not affected by cereals. The effect of establishment with cereals on orchardgrass seed yield concurs with results obtained by Roberts (1964) and Griffiths et al. (1978). Since no combination of cereal crop and row spacing was significantly more conducive to seed yield, cereals and row spacings must be chosen on the basis of grain income.

Economic Return

The effect of companion cropping on net income from orchardgrass seed production was determined by partial budget analysis (Table I.8). Although orchardgrass seedling growth was adversely affected in Trial 1, net income was increased by \$230 ha^{-1} over a 2-year period by planting with wheat in 30-cm rows. Net income production over a 3-year period was reduced to \$212 ha^{-1} by minor reductions in second-year seed yield. Precipitation was lower than normal in Trial 1. Extremely dry conditions in Trial 2 caused low cereal yields, and coupled with reduced first-year seed yield due to competition for water, made establishment with spring cereals unprofitable. Van Keuren and Canode (1963) demonstrated that orchardgrass seed yields were not decreased by spring barley under irrigated conditions. Thus, irrigation may be required to obtain profitable spring establishment with cereals in very dry years. Fall establishment of red fescue with cereals produced more favorable economic returns (Chastain and Grabe, 1988b) because fall-planted fescue plants were more mature and less susceptible to competition with cereals for light and water than spring-planted orchardgrass seedlings.

Given adequate precipitation, wheat was the superior companion crop due to greater economic returns. Barley and oats reduced seed yield to the same extent as wheat, but wheat income was markedly greater. More income was produced by establishment with wheat in 30-cm rows in Trial 1. This was attributed to greater first-year seed yield of orchardgrass planted under 30-cm wheat rows (Table I.6). Conversely, income production was lower from 30-cm row treatments in Trial 2 because grain yield was lower and was not accompanied by a corresponding increase in seed yield as in Trial 1. The best economic result over the range of market conditions was provided by wheat in 30-cm rows. Companion cropping would be most effective in increasing economic returns when wheat prices are high and orchardgrass prices are low due to stronger compensation for seed yield losses by wheat income.

This study showed that spring cereals adversely affected orchardgrass seedling morphology and physiology during stand establishment, causing reductions in first-year seed yield. Orchardgrass growth and first-year seed yields were not differentially reduced by spring wheat, barley, or oats, but more income was produced by wheat in 30-cm rows. Even with below normal rainfall, the economic return of orchardgrass seed production was increased in Trial 1. Companion cropping could provide growers with the additional benefit of an annual cash flow from their seed production enterprise. A better understanding of how lower cereal seeding rates and irrigation may affect stand establishment and seed yields is needed to obtain consistently profitable spring plantings of orchardgrass with cereals in Oregon.

Table I.1. Growth characteristics and grain yield of cereal companion crops used to establish orchardgrass seed crops.

Companion Crop	Cereal row spacing	Tiller Height		Tiller number		LAI		Grain Yield	
		Trial 1†	Trial 2‡	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
	cm	cm		tillers m^{-2}				kg ha^{-1}	
Wheat	15	65.9	67.3	813	495	2.58	1.87	5185	3935
	30	66.7	69.5	619	382	2.33	1.60	5085	3566
Barley	15	75.1	80.6	716	420	3.21	2.31	6061	4345
	30	75.6	76.3	708	307	3.49	1.63	5720	3854
Oats	15	68.7	72.9	1136	581	5.22	3.20	5451	4919
	30	70.2	66.1	791	393	3.60	1.86	5252	3928
	LSD 0.05	NS	NS	147	NS	0.69	NS	NS	NS
Row spacing means									
	15	69.9	73.6	888	499	3.67	2.46	5565	4400
	30	70.8	70.6	706	361	3.14	1.70	5352	3783
	LSD 0.05	NS	1.7	NS	NS	NS	NS	NS	435
Companion crop means									
Wheat		66.3	68.4	716	439	2.45	1.73	5135	3751
Barley		75.3	78.4	712	363	3.35	1.97	5891	4100
Oats		69.4	69.5	963	487	4.41	2.53	5351	4423
Contrast§									
Wheat vs. barley & oats		**	**	*	NS	**	*	NS	**
Barley vs. oats		**	**	**	**	**	*	*	*

†Trial 1 was planted in 1985.

‡Trial 2 was planted in 1986.

§Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table I.2. Effect of cereal companion crops on photosynthetic photon flux density (PPFD) incident on orchardgrass seed crops.

Companion crop	Cereal row spacing	Trial 1†		Trial 2‡	
		13 June	25 June	10 June	13 July
	cm	% PPFD			
Wheat	15	35	44	18	42
	30	34	49	30	47
Barley	15	42	41	26	46
	30	36	43	31	53
Oats	15	36	39	15	25
	30	46	45	30	37
	LSD 0.05	NS	NS	NS	NS
<u>Row spacing means</u>					
	15	38	41	19	38
	30	39	46	31	45
	LSD 0.05	NS	NS	7	5
<u>Companion crop means</u>					
Wheat		35	47	24	44
Barley		39	42	29	50
Oats		41	42	23	31
<u>Contrast</u>§					
Wheat vs. barley & oats		NS	NS	NS	NS
Barley vs. oats		NS	NS	*	**

†Trial 1 was planted in 1985.

‡Trial 2 was planted in 1986.

§Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table I.3. Influence of cereal companion crops on soil water content and temperature.

Companion crop	Cereal row spacing	Soil water content† Trial 1‡ 13 June	Soil water content† Trial 1‡ 25 June	Soil water content† Trial 2§ 26 June	Soil Temperature Trial 1	Soil Temperature Trial 2
	cm	$mg\ kg^{-1}$			°C	
Wheat	15	174	100	77	22.7	28.6
	30	170	96	84	23.8	34.6
Barley	15	157	92	79	23.7	29.2
	30	162	91	85	24.0	33.3
Oats	15	152	91	71	22.8	26.3
	30	172	102	72	23.7	28.4
	LSD 0.05	13	NS	NS	NS	NS
Row mean spacing						
	15	161	95	76	23.1	28.0
	30	168	96	81	23.8	32.1
	LSD 0.05	6	NS	NS	NS	NS
Companion crop means						
Wheat		172	98	81	23.2	31.6
Barley		160	91	82	23.9	31.3
Oats		162	97	72	23.2	27.3
Control¶		173	144	135	25.1	37.1
Contrast#						
Control vs. cereals		*	**	**	**	**
Wheat vs. barley & oats		*	NS	NS	NS	NS
Barley vs. oats		NS	NS	*	NS	*

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† Soil water content was 278 and 128 $mg\ kg^{-1}$ at soil water potentials of -0.01 and -1.5 MPa, respectively.

‡ Trial 1 was planted in 1985.

§ Trial 2 was planted in 1986.

¶ Control indicates orchardgrass planted without cereals.

Orthogonal contrasts significant at $P = 0.05$ (*) and $P = 0.01$ (**) levels.

Table I.4. Growth characteristics of orchardgrass seed crops established with cereal companion crops.

Companion crop	Cereal row spacing	Tiller number				Dry matter				Tiller height				LAI
		Trial 1 †		Trial 2 ‡		Trial 1		Trial 2		Trial 1		Trial 2		Trial 2
		20 May	15 June	12 June	17 July	20 May	15 June	12 June	17 July	20 May	15 June	12 June	17 July	17 July
	cm	tillers m^{-2}				g m^{-2}				cm				
Wheat	15	280	336	475	486	8.31	21.31	23.95	28.16	11.4	30.3	22.9	23.8	0.33
	30	260	303	642	490	7.45	18.32	40.44	38.41	9.2	25.6	22.6	23.0	0.39
Barley	15	258	296	465	546	5.96	13.11	26.51	41.14	11.7	24.7	24.9	26.4	0.48
	30	258	269	585	511	7.23	14.68	34.81	39.11	10.4	25.3	23.7	23.9	0.41
Oats	15	224	300	511	522	6.14	14.70	24.47	30.96	10.7	27.7	23.1	25.3	0.41
	30	319	382	572	502	8.47	25.06	36.22	30.61	9.1	27.7	21.9	20.1	0.37
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing means														
	15	254	310	484	518	6.80	16.37	24.98	33.42	11.3	27.6	23.6	25.2	0.40
	30	279	318	600	501	7.71	19.35	37.15	36.04	9.5	26.2	22.7	22.3	0.39
	LSD 0.05	NS	NS	85	NS	NS	NS	6.68	NS	NS	NS	NS	NS	NS
Companion crop means														
Wheat		270	319	559	488	7.88	19.82	32.19	33.29	10.3	28.0	22.7	23.4	0.36
Barley		258	283	525	528	6.59	13.90	30.66	40.13	11.0	25.0	24.3	25.1	0.44
Oats		272	341	542	512	7.30	19.88	30.35	30.79	9.8	27.7	22.5	22.7	0.39
Control §		345	730	1005	1055	8.72	53.62	81.24	156.90	6.9	20.5	20.1	21.8	1.23

Table I.4. (cont'd.)

	Cereal	Tiller number				Dry matter				Tiller height				LAI
Companion	row	Trial 1		Trial 2		Trial 1		Trial 2		Trial 1		Trial 2		Trial 2
crop	spacing	20 May	15 June	12 June	17 July	20 May	15 June	12 June	17 July	20 May	15 June	12 June	17 July	17 July
	cm	tillers m^{-2}				g m^{-2}				cm				
Contrast[¶]														
Control vs. cereals		**	**	**	**	NS	**	**	**	**	**	NS	NS	**
Wheat vs. barley & oats		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Barley vs. oats		NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS

[†] Trial 1 was planted in 1985.
[‡] Trial 2 was planted in 1986.
[§] Control indicates orchardgrass planted without cereals.
[¶] Orthogonal contrasts significant at P = 0.05 (*) and P = 0.01 (**) levels.

Table I.5. Effect of cereal companion crops on orchardgrass stomatal resistance (L_r), transpiration rate (TR), leaf temperature (L_t), and leaf chlorophyll content.

Companion crop	Cereal row spacing	Stomatal resistance (L_r)			Transpiration rate (TR)			Leaf temperature (L_t)			Leaf chlorophyll (a+b)†		
		10 June	21 June	8 July	10 June	21 June	8 July	10 June	21 June	8 July	19 June	27 June	11 July
	cm	s cm^{-1}			µg cm^{-2} s^{-1}			°C			g kg^{-1} FW		
Wheat	15	18.6	21.5	4.9	1.5	0.6	3.1	33.8	24.2	27.2	2.5	3.9	1.1
	30	19.9	16.9	5.9	1.4	0.8	2.9	34.0	24.7	28.5	2.6	3.8	1.8
Barley	15	22.5	17.4	9.0	1.2	0.8	1.8	34.3	25.0	28.3	3.1	4.2	1.4
	30	18.6	20.0	5.8	1.5	0.7	4.2	34.0	24.5	27.9	2.6	2.1	2.2
Oats	15	16.6	16.6	7.2	1.7	0.8	2.4	34.4	24.6	28.3	2.6	4.0	1.6
	30	18.5	23.4	7.1	1.5	0.5	2.8	34.3	23.4	28.1	2.8	4.0	1.5
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.9	NS
<u>Row spacing means</u>													
	15	19.2	18.5	7.1	1.5	0.7	2.4	34.2	24.6	28.1	2.7	4.0	1.4
	30	19.0	20.1	6.2	1.5	0.7	3.3	34.1	24.2	28.2	2.7	3.3	1.9
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.7	0.4
<u>Companion crop means</u>													
Wheat		19.2	19.2	5.4	1.5	0.7	3.0	33.9	24.5	28.1	2.6	3.8	1.5
Barley		20.6	18.7	7.4	1.4	0.8	3.0	34.1	24.8	28.1	2.8	3.1	1.8
Oats		17.6	20.0	7.2	1.6	0.7	2.6	34.4	24.0	28.2	2.7	4.0	1.6
Control‡		7.7	15.5	4.7	4.0	0.9	3.5	33.7	24.5	28.2	2.1	3.1	1.9

Table I.5. Effect of cereal companion crops on orchardgrass stomatal resistance (L_r), transpiration rate (TR), leaf temperature (L_t), and leaf chlorophyll content (cont'd).

Companion crop	Cereal row spacing	Stomatal resistance (L_r)			Transpiration rate (TR)			Leaf temperature (L_t)			Leaf chlorophyll (a+b)		
		10 June	21 June	8 July	10 June	21 June	8 July	10 June	21 June	8 July	19 June	27 June	11 July
	cm	$s\ cm^{-1}$			$\mu g\ cm^{-2}\ s^{-1}$			^{o}C			$g\ kg^{-1}\ FW$		
<u>Contrast</u> §													
Control vs. cereals		**	NS	NS	**	NS	NS	NS	NS	NS	**	**	**
Wheat vs. barley & oats			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	** **
Barley vs. oats		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	**

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† Mean of three 1 g leaf samples per subplot.

‡ Control denotes orchardgrass established without cereals.

§ Orthogonal contrasts significant at the P = 0.01 (**) level.

Table I.6. Effect of companion crops on fall and spring tiller populations and subsequent orchardgrass seed yield.

Companion crop	Cereal row spacing	Fall growth characteristics†						Spring growth characteristics‡					
		Tillers		Dry matter		Tiller height		Fertile tillers		Vegetative tillers		Total tillers	
		Trial 1§	Trial 2¶	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
	cm	— tillers m^{-2} —		—— g m^{-2} ——		—— cm ——		—— tillers m^{-2} ——					
Wheat	15	319	371	7.81	10.19	7.6	10.3	113	210	1026	829	1139	1039
	30	345	607	9.98	20.43	8.0	12.4	154	237	779	689	933	926
Barley	15	375	669	7.97	23.84	7.5	12.0	176	217	906	910	1082	1127
	30	380	660	12.92	25.44	8.5	13.2	190	307	719	822	909	1128
Oats	15	414	513	10.12	13.71	7.3	9.5	253	171	623	761	876	931
	30	436	606	13.17	20.10	8.6	11.9	318	172	689	748	1007	920
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Row spacing means</u>													
	15	370	518	8.63	15.91	7.4	10.6	181	199	852	833	1032	1032
	30	387	624	12.02	21.99	8.4	12.5	221	239	729	753	950	991
	LSD 0.05	NS	NS	1.82	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Companion crop means</u>													
Wheat		332	489	8.89	15.31	7.8	11.4	134	223	902	759	1036	982
Barley		378	665	10.44	24.64	8.0	12.6	183	262	813	866	996	1127
Oats		425	560	11.64	16.90	7.9	10.7	285	171	656	755	841	923
Control #		1258	1565	91.19	151.50	14.4	23.0	524	366	348	637	872	1003

Table I.6. Effect of companion crops on fall and spring tiller populations and subsequent orchardgrass seed yield (cont'd.).

Companion crop	Cereal row spacing	Fall growth characteristics						Spring growth characteristics					
		Tillers		Dry matter		Tiller height		Fertile tillers		Vegetative tillers		Total tillers	
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
	cm	tillers m^{-2}		g m^{-2}		cm		tillers m^{-2}					
Contrast[††]													
Control vs. cereals		**	**	**	**	**	**	**	**	**	*	NS	NS
Wheat vs. barley & oats		NS	**	NS	NS	NS	NS	**	NS	*	NS	NS	NS
Barley vs. oats		NS	*	NS	NS	NS	**	**	NS	NS	NS	NS	NS

[†] Fall growth characteristics were measured in early November.

[‡] Spring growth characteristics were measured at peak anthesis.

[§] Trial 1 was planted in 1985.

[¶] Trial 2 was planted in 1986.

[#] Control indicates orchardgrass established without cereals

[††] Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table I.6. Effect of companion crops on fall and spring tiller populations and subsequent orchardgrass seed yield (cont'd).

Companion crop	Cereal row Spacing	First-year seed yield Trial 1	First-year seed yield Trial 2	Second-year seed yield Trial 1
	cm	kg ha^{-1}		
Wheat	15	623	1077	1804
	30	780	1055	1907
Barley	15	427	1115	1828
	30	678	1043	1897
Oats	15	601	757	1861
	30	708	774	1870
	LSD 0.05	NS	NS	NS
<u>Row spacing means</u>				
	15	550	983	1831
	30	722	958	1892
	LSD 0.05	79	NS	NS
<u>Companion crop means</u>				
Wheat		702	1066	1856
Barley		552	1079	1863
Oats		654	766	1866
Control		1059	1833	1931
<u>Contrast</u>[††]				
Control vs. cereals		**	**	NS
Wheat vs. barley & oats		NS	NS	NS
Barley vs. oats		NS	*	NS

[††] Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table I.7. Linear correlation coefficients among growth characteristics and seed yield of orchardgrass seed crops established with cereal companion crops.

	Correlation coefficients	
	Fertile tillers	First-year seed yield
Fall tillers	0.93**	0.82*
Fall dry matter	0.90**	0.84*
Fertile tillers	----	0.76*
Vegetative tillers	-0.92**	-0.77*

*,** Correlation coefficients significantly different from zero at P = 0.05 and 0.01, respectively.

Table I.8. Economic response of orchardgrass seed crops to establishment with cereal companion crops in Oregon.

	Market condition		Net change in income†					
		Time	15-cm rows			30-cm rows		
Trial	Crop Price	period	Wheat	Barley	Oats	Wheat	Barley	Oats
			dollars ha^{-1}					
1	Average cereal, grass‡	2-yr	118	- 85	- 6	230	80	60
		3-yr	20	-166	- 61	212	56	6
2		2-yr	-264	-299	-465	-329	-400	-603
1	High cereal, low grass§	2-yr	266	174	83	352	293	132
		3-yr	186	109	39	337	272	89
2		2-yr	- 88	- 72	-347	-154	-173	-426
1	Low cereal, high grass¶	2-yr	-380	-303	-158	40	-100	- 77
		3-yr	-493	-395	-221	19	-130	-138
2		2 yr	-474	-484	-741	-526	-579	-793

†Change in net income of cropping system compared to monoculture establishment.

‡Average crop prices for 1983-1986 period: wheat = \$0.12 kg^{-1}, barley = \$0.10 kg^{-1}, oats = \$0.10 kg^{-1}, and orchardgrass = \$0.93 kg^{-1}.

§High cereal and low orchardgrass prices for 1983-1986 period: wheat = \$0.14 kg^{-1}, barley = \$0.13 kg^{-1}, oats = \$0.11 kg^{-1}, and orchardgrass = \$0.77 kg^{-1}.

¶Low cereal and high orchardgrass prices for 1983-86 period: wheat = \$0.09 kg^{-1}, barley = 0.08 kg^{-1}, oats = \$0.09 kg^{-1}, and orchardgrass = \$1.04 kg^{-1}.

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MANUSCRIPT II

SPRING ESTABLISHMENT OF TALL FESCUE SEED CROPS WITH CEREAL COMPANION CROPS

ABSTRACT

Spring plantings of tall fescue (Festuca arundinacea Schreb.) for seed production are common in the Pacific Northwest, but seed yields are negligible in the year of planting. Planting tall fescue seed crops with cereal companion crops would provide income in the seeding year and could, increase seed production profits. This study was concerned with determining the competitive effects of cereal companion crops on establishment, seed yield, and economics of turf-type tall fescue seed crops.

'Bonanza' tall fescue was interplanted with 'Waverly' spring wheat (Triticum aestivum L.), 'Steptoe' spring barley (Hordeum vulgare L.), and 'Cayuse' spring oats (Avena fatua var. sativa (L.) Haussk.) in 15- and 30-cm rows at right angles to fescue rows. The experiments were planted in March 1985 on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil near Corvallis, OR, and repeated in 1986.

Establishment with cereals reduced the photosynthetic photon flux density (PPFD) available for tall fescue seedling growth, which caused transient increases in chlorophyll content and reduced soil temperature by 1.8^{0}C. Soil water content was decreased by competition with cereals, causing greater stomatal resistance and lower transpiration rate. The competitive effects of cereals in reducing PPFD and soil water were responsible for low tall fescue tiller and dry matter production. Regrowth of tall fescue following cereal harvest was largely delayed until spring as a consequence of competition with cereals, resulting in low fertile tiller populations and a 61% reduction in first-year seed yield. Low fertile tiller populations were highly correlated (r = 0.95) with poor tall fescue stands in the preceding fall and with low first-year seed yield (r = 0.99). In general, tall fescue growth and seed yield were similar with all cereal crops, row spacings, and combinations of row spacing and cereal crop. Second-year seed yield was 15% greater established with cereals than when planted alone.

Planting tall fescue with spring cereals was generally unprofitable, due to low first-year seed and grain yields. Dry conditions caused low grain yield and made the competitive effects of cereals more severe, and were partly responsible for the poor economic returns. However, tall fescue planted with spring oats earned \$139 ha^{-1} more than monoculture over a 3-year period because of compensatory increases in second-year seed yield. This promising result suggests that tall fescue establishment with cereals could be more profitable in spring with irrigation, or in fall when water is not limiting.

Additional index words: Grass seed production, Cropping system, *Festuca arundinacea* Schreb., Physiological responses, Growth analyses, Water stress, Wheat, Barley, Oats, Net income

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Spring Establishment of Tall Fescue Seed Crops with Cereal Companion Crops

INTRODUCTION

Traditionally, most tall fescue (Festuca arundinacea Schreb.) seed in the United States has been produced as a by-product of forage production (Youngberg and Wheaton, 1979). In Oregon, however, specialized management practices have been developed for tall fescue seed production. Van Keuren and Canode (1963) reported that spring plantings of tall fescue were best for seed production in the Pacific Northwest. However, exposure to low winter temperatures is needed to promote flowering in tall fescue (Templeton et al., 1961), and such temperatures are not present during spring. Thus, tall fescue seed yields are negligible in the year of planting, resulting in the loss of one season's income. Chastain and Grabe (1988b) showed that planting red fescue (Festuca rubra L.) in the fall with winter wheat (Triticum aestivum L.) increased net income by \$508 ha^{-1} over a 3-year period. These results suggested the need to evaluate companion cropping for tall fescue seed production.

Only the study of Griffiths et al. (1978) in Wales, has sought to determine the feasibility of establishing tall fescue with cereal companion crops. Tall fescue seed yield was reduced 1% by spring barley (Hordeum vulgare L.) over a 2-year period, but income from the cereal more than compensated for this loss.

The recent introduction of turf-type tall fescue cultivars requires that seed production practices, including stand establishment, be reevaluated. Companion crops create a microenvironment that could have a significant effect on tall fescue stand establishment and subsequent seed yield. The objectives of this study were to determine the feasibility of spring establishment of 'Bonanza', a turf-type tall fescue, with cereal companion crops in Oregon's Willamette Valley, and to investigate the effect of cereals on tall fescue growth, seed yield, and economic return.

MATERIALS AND METHODS

'Bonanza' tall fescue was interplanted with 'Waverly' spring wheat, 'Steptoe' spring barley, and 'Cayuse' spring oats on 14 March 1985 (Trial 1) and 27 March 1986 (Trial 2). The experiment was conducted at the Oregon State University Hyslop Crop Science Field Laboratory near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) soil. Cereals were drilled in 15- and 30-cm rows at right angles to fescue rows. Seeding rates were 117 kg ha^{-1} for wheat and barley, and 134 kg ha^{-1} for oats. Tall fescue was planted in 45-cm rows at a 11.2 kg ha^{-1} seeding rate. The experimental design was a split-plot replicated in four randomized blocks. Main plots consisted of cereal row spacings, and subplots were cereal species and tall fescue monoculture (Control). Each subplot was 1.8 m by 6.7 m.

Before seedbed preparation, 0.45 kg ha^{-1} paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was sprayed on the experiment site. Broadleaved weeds were controlled with bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.45 kg ha^{-1}, 22 to 24 days after planting. Late germinating broadleaved weeds were controlled with 0.56 kg ha^{-1} MCPA [(4-chloro-2-methylphenoxy) acetic acid] on 9 May 1986. In late October, 1.12 kg ha^{-1} MCPA was applied to control broadleaved weeds. Annual bluegrass (Poa annua L.) was controlled with 2.24 kg ha^{-1} simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine) applied on 5 November 1985 and 28 October 1986 for Trial 1 and 2, respectively. Volunteer cereals control was achieved by an application of ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methylsulfonate] at 1.12 kg ha^{-1} on 20 November 1985 and 24 October 1986. Spring broadleaved weeds were controlled with 0.56 kg ha^{-1} MCPA and 0.28 kg ha^{-1} dicamba (3,6-dichloro-2-methoxybenzoic acid) in mid-March 1986 and 1987.

Before planting, 56 kg ha^{-1} N and 27 kg ha^{-1} P were incorporated into the seedbed. In mid-April, N and S were applied at 28 and 4 kg ha^{-1}, respectively. Fall N was applied in early October at 73 kg ha^{-1}. Spring fertilizer applications, were made in March of the harvest year at 112 kg ha^{-1} N and 15 kg ha^{-1} S.

Cereal tiller number, tiller height, and leaf area index (LAI) were measured at peak cereal leaf area. Tall fescue tiller number, tiller height, dry matter, and LAI were measured during the growing season and in November (Chastain and Grabe, 1988a).

Stomatal resistance (L_r), leaf temperature (L_t), and transpiration rate (TR) of tall fescue seedlings were determined with a Li-Cor Model 1600 steady state porometer. Porometer measurements were made between 1200 and 1400 h on abaxial and adaxial leaf surfaces, and L_r values were calculated assuming the two leaf surfaces acted in parallel. Chlorophyll was extracted from 1 g samples of fresh tall fescue leaves taken between 1100 and 1200 h. Leaf samples were homogenized in 80% (v/v) acetone at 4°C in darkness. The homogenate was placed in a refrigerated centrifuge for 10 min at 10000 X g. Chlorophyll content in the supernatant was determined with a spectrophotometer (Bruinsma, 1963).

The percentage of photosynthetic photon flux density (PPFD) incident on tall fescue seedlings was measured with a Li-Cor Model Li-1776 Solar monitor and line quantum sensor (Chastain and Grabe, 1988a). Soil water content was determined gravimetrically from samples taken in the top 15 cm of the soil profile. Soil temperatures were measured at a 5-cm depth between 1200 and 1400 h on 25 June 1986.

Oat and barley companion crops were harvested with a Hege plot combine on 23 July 1985 and 24 July 1986, while wheat was harvested on 5 August 1985 and 1 August 1986. Cereal stubble was flail-chopped and removed in mid-August.

Fertile tiller number, vegetative tiller number, spikelets tiller^{-1}, and florets spikelet^{-1} were measured on two 30-cm sections of fescue row from each subplot at peak anthesis on 2 June 1986 and 23 May 1987. First-year seed crops were harvested with a plot harvester and bagged for drying on 30 June 1986 and 23 June 1987. The second-year seed crop was harvested on 23 June 1987. The dried grass crop was threshed and seed was cleaned with a Clipper M2-B air-screen cleaner before weighing. Plots were burned in August after the first seed harvest.

The effect of cereals on net income from tall fescue seed production was evaluated by the partial budgeting technique described by Chastain and Grabe (1988b).

Analysis of variance (ANOVA) was used to test the effect of row spacing, companion crops, and possible interactions of these factors. Orthogonal contrasts were used to compare planting tall fescue with cereals against monoculture (Control) and to detect possible differential effects among cereal crops. Treatment means were separated by using Fisher's protected least significant difference (FLSD) values.

RESULTS AND DISCUSSION

Intercrop competition

Competition between cereal companion crops and tall fescue seedlings began shortly after emergence in early April and continued until grain harvest in mid-summer. During the period of intercrop competition, the crops received 10 and 16% less precipitation than normal in Trials 1 and 2, respectively. In addition, precipitation was distributed irregularly during this period and was considered poor for establishment of tall fescue seedlings.

No tiller height differences were noted among cereals in Trial 1, whereas oat tillers were tallest in Trial 2 (Table II.1). Row spacing had no effect on cereal tiller height. More tillers were produced by oat companion crops in Trial 1, but similar numbers of tillers were produced among cereals in Trial 2. Fewer tillers were present in 30-cm rows in Trial 2, but not in Trial 1. Oats exhibited greater LAI in Trial 1; however, no differences in LAI were observed among cereals in Trial 2. Row spacing did not affect LAI in Trial 1, whereas cereals planted in 15-cm rows attained greater LAI in Trial 2. There were no row spacing X cereal interactions for cereal growth characteristics.

Wheat, barley, and oat grain yields were similar in Trial 1; however, oats yielded slightly more than wheat, and much more than barley in Trial 2 (Table II.1). Grain yield was not influenced by row spacing in Trial 1. In Trial 2, more grain was produced by cereals planted in 15-cm rows. No interaction effects on grain yield were detected.

Cereal companion crops significantly affected the growth environment of tall fescue seedlings (Table II.2). Less PPFD was available for tall fescue seedlings under oats due to the greater LAI exhibited by oats (Table II.1). Row spacing did not influence PPFD transmission in Trial 1. In contrast, more PPFD was transmitted during Trial 2 under 30-cm rows on 13 July as a result of lower cereal LAI. Soil water content was uniformly reduced by spring cereal crops (Table II.2). In contrast, winter cereals, did not compete with red fescue for soil water (Chastain and Grabe, 1988a). Cereal row spacing had no effect on soil water content. Soil temperatures were 1.8°C lower under cereals due to the interception of solar radiation by cereal leaves. Lower soil temperature under 15-cm rows was attributed to greater LAI of cereals in 15-cm rows. The growth environment was not affected by combinations of row spacing and cereal crop.

Tall fescue seedling growth and development was severely impaired by establishment with spring cereals (Table II.3), and was attributed to competition for light and water. Tiller populations and dry matter production were markedly reduced in spring and fall by cereals. Norris (1982) observed that tall fescue growth rate and tiller numbers were reduced by soil moisture deficit. The reductions in tiller number and dry matter were not different among cereals. In Trial 2, more tillers and dry matter were produced by tall fescue under 30-cm cereal rows because of lower cereal LAI and the resulting increase in PPFD. Tall fescue plants grown in full sunlight had higher photosynthetic and respiration rates than plants grown in 23% sun (Woledge, 1971). Thus, the reduction in dry matter production was probably due in part, to low photosynthetic rates under the shade of cereals.

Companion crop canopies increase the far-red radiation component of the tall fescue growth environment. Deregibus et al. (1983) reported that ryegrass (Lolium spp. L.) tillering was reduced by increased exposure to far-red as under a plant canopy. This effect was counteracted by an exposure to red radiation, suggesting that the tillering response in grasses to light may be mediated by phytochrome and that light quality, as well as quantity, may be important in determining tiller number.

Reduction in PPFD transmission by cereals resulted in etiolation of tall fescue tillers (Table II.3). Greater PPFD availability under 30-cm rows was responsible for lower tiller etiolation in 30-cm row treatments. Tall fescue LAI was reduced by cereals, but wider row spacings did not increase LAI. Tall fescue genotypes that have high leaf area expansion rates may be among the most suitable candidates for companion cropping due to superior competitive ability (Forcella, 1987). There were no row spacing X cereal crop interactions for tall fescue growth characteristics.

Cereal companion crops adversely affected physiological functions of tall fescue seedlings (Table II.4). Cereals competed for soil water and caused increased tall fescue stomatal resistance (L_r). Consequently, water stress induced by cereals caused stomatal closure in tall fescue leaves and was responsible for reduced transpiration rates (TR). Reduced tall fescue dry matter production under cereals may be partly attributed to stomatal closure and restricted CO_2 flux as a result of high L_r. Woledge (1971) showed that tall fescue leaves have more stomata in full sun than under 23% sunlight. Fewer stomata due to shading under cereals could be partly responsible for greater L_r.

Greater L_r and reduced TR values were observed under 30-cm wheat and oat rows, but not under 30-cm barley treatments. Seedling leaf temperatures (L_t) were not significantly different (P = 0.05) under cereals, but L_t were probably greater than for unstressed plants in shade.

Chlorophyll content of tall fescue leaves was greater under cereals on 19 and 27 June, whereas less chlorophyll was measured under cereals on 11 July (Table II.4). Chlorophyll content initially was greater in response to cereal shading and, later, as water stress became more severe, chlorophyll content was reduced in the presence of cereals. Tall fescue plants grown in 23% sunlight had 6% more chlorophyll than plants grown in full sun (Woledge, 1971). Inconsistent interaction and row spacing effects were noted and considered unimportant in determining tall fescue chlorophyll content.

Seed Production

Establishment with spring cereals greatly reduced tall fescue fertile tiller populations at peak anthesis (Table II.5). The reduction in fertile tiller numbers by cereals was attributed to poor tall fescue stands in the preceding fall (Tables II.3 and II.6). Fall tillering of tall fescue plants was reduced as a result of competition with cereals, so, fewer tillers were subjected to low winter temperatures that induce floral development (Templeton et al. 1961). Greater numbers of vegetative tillers were produced by tall fescue planted with cereals which indicates that regrowth was largely delayed until spring. Tall fescue planted in monoculture and with cereals did not differ significantly in total tiller numbers. This suggests that the primary effect of cereals on tall fescue tillers was to reduce the proportion of fertile tillers and not affect the overall tiller population. Tiller populations at peak anthesis were not influenced by cereal row spacing or interactions of row spacing and cereal.

Planting tall fescue with cereals did not influence the number of spikelets tiller^{-1} (Table II.5). However, the reduced fertile tiller population of tall fescue established with cereals was somewhat compensated for by an increased number of florets spikelet^{-1}. Averaged over cereal crops, first-year seed yield was reduced 61% by establishment with spring cereals as a result of low fertile tiller populations. Among cereal crops, first-year seed yield was greater when planted with oats rather than barley in Trial 1, whereas the reverse was true in Trial 2. Establishment with wheat resulted in first-year seed yields that were equivalent to planting with barley or oats. First-year seed yield was closely associated with fertile ($r = 0.99$) and fall ($r = 0.95$) tiller populations, inversely related with the number of florets spikelet^{-1} ($r = -0.93$), and not correlated with vegetative tillers or spikelets tiller^{-1} (Table II.6). Very dry conditions contributed to low first-year seed yields of tall fescue planted with cereals. Interactions and row spacings were not significant for first-year seed yield and yield components.

Tall fescue planted with cereals produced 15% greater second-year seed yield than the monoculture (Control) method of planting (Table II.5). Similar compensatory increases in second-year seed yield for tall fescue established with barley were reported by Griffiths et al. (1978). Greater second-year seed yield was obtained from tall fescue planted under 30-cm cereal rows.

Economic Return

The economic effects of companion cropping on tall fescue seed production were evaluated by partial budget analysis (Table II.7). Planting tall fescue with spring cereals was unprofitable under average crop market conditions over a 2-year (seeding and first harvest years) period. However, tall fescue planted with oats in 30-cm rows earned \$139 ha^{-1} more than monoculture over a 3-year period due to compensatory increases in second-year seed yield. Companion cropping tall fescue in spring was also mostly unprofitable when cereal prices were high and tall fescue prices were low. High cereal prices and low fescue prices are the most favorable combination for companion cropping because cereal income would be better able to compensate for losses in seed yield. By comparison, planting tall fescue with spring cereals was never an economically viable alternative when cereal prices were low and tall fescue prices were high.

Dry conditions caused low grain yield and made the competitive effects of cereals more severe on tall fescue seedlings. Income generated from the sale of cereal grain was insufficient to cover the subsequent loss of seed yield and accompanying income due to poor stands under cereals.

The economically successful establishment of red fescue with winter cereals (Chastain and Grabe, 1988b) and good tall fescue stands after planting with winter wheat (Chastain and Grabe, unpublished), suggest that profitable tall fescue establishment is possible with winter cereals. Fall-planted tall fescue may be more competitive with cereals in the following spring. This study showed minor success with spring oats in 30-cm rows and indicates that irrigation may be the key to consistent profitable spring establishment of tall fescue with cereals. Since fall tiller populations were closely associated with first-year seed yield, additional management inputs such as N fertilizer and irrigation are needed to facilitate regrowth after cereal harvest to maximize fall tiller numbers and increase seed yield. Finally, reducing cereal seeding rates may have improved stand establishment of tall fescue seed crops and subsequent economic returns.

Table II.1. Growth characteristics and grain yield of cereal companion crops used to establish tall fescue seed crops.

Companion crop	Cereal row spacing	Tiller Height		Tiller number		LAI		Grain Yield	
		Trial 1†	Trial 2‡	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
	cm	— cm —		– tillers m^{-2} –				— kg ha^{-1} —	
Wheat	15	31.6	66.6	431	544	1.24	3.25	4712	3230
	30	32.5	66.8	315	396	0.98	2.13	5179	2641
Barley	15	35.4	61.8	447	490	1.79	3.89	5320	2164
	30	36.4	61.0	358	390	1.45	2.69	5221	2013
Oats	15	33.1	74.5	614	592	2.29	3.89	5132	4338
	30	33.1	70.0	425	417	1.72	2.42	4706	3550
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing means									
	15	33.4	67.6	497	542	1.77	3.67	5055	3244
	30	34.0	65.9	366	401	1.38	2.41	5035	2735
	LSD 0.05	NS	NS	NS	49	NS	0.61	NS	420
Cereal crop means									
Wheat		32.0	66.7	373	470	1.11	2.69	4946	2935
Barley		35.9	61.4	402	440	1.62	3.29	5270	2089
Oats		33.1	72.3	519	505	2.01	3.16	4919	3944
Contrast§									
Wheat vs. barley & oats		NS	NS	*	NS	**	NS	NS	NS
Barley vs. oats		NS	**	**	NS	NS	NS	NS	**

†Trial 1 was planted in 1985. Growth characteristics were measured on 20 May 1985.
‡Trial 2 was planted in 1986. Growth characteristics were measured on 12 June 1986.
§Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table II.2. Effect of cereal companion crops on tall fescue growth environment.

Companion crop	Cereal row spacing	PPFD transmission			Soil Water content§		Soil temperature
		Trial 1†	Trial 2‡				
		13 June	10 June	13 July	Trial 1	Trial 2	Trial 2
	cm	% PPFD			$mg\ kg^{-1}$		°C
Wheat	15	39	43	41	94	73	23.6
	30	49	40	51	94	80	24.6
Barley	15	42	35	39	91	73	23.8
	30	46	39	58	89	72	24.7
Oats	15	23	23	32	90	77	23.1
	30	30	31	42	96	78	23.6
	LSD 0.05	NS	NS	NS	NS	NS	NS
Row spacing means							
	15	35	34	38	92	75	23.5
	30	42	37	50	93	77	24.3
	LSD 0.05	NS	NS	9	NS	NS	0.7
Cereal crop means							
Wheat		44	41	46	94	77	24.1
Barley		44	37	49	90	73	24.3
Oats		27	27	37	93	78	23.4
Control		--	--	--	140	126	26.3
Contrast#							
Control vs. cereals		--	--	--	**	**	**
Wheat vs. barley & oats		NS	*	NS	NS	NS	NS
Barley vs. oats		**	*	**	NS	NS	NS

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†Trial 1 was planted in 1985.

‡Trial 2 was planted in 1986.

§Soil water content was 278 and 128 $mg\ kg^{-1}$ at soil water potentials of -0.01 and -1.5 MPa, respectively.

#Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table II.3. Growth characteristics of tall fescue seed crops established with cereal companion crops.

Companion Crop	Cereal row spacing	Tiller number				Dry matter				Tiller height				LAI	
		Trial 1 †	Trial 2 ‡			Trial 1	Trial 2			Trial 1	Trial 2			Trial 2	
		20 May	12 June	17 July	13 Nov	20 May	12 June	17 July	13 Nov	20 May	12 June	17 July	13 Nov	17 July	13 Nov
	cm	tillers m^{-2}				g m^{-2}				cm					
Wheat	15	441	731	739	910	16.45	18.87	23.02	26.62	10.8	11.5	10.4	9.0	0.20	0.34
	30	530	863	847	827	19.61	21.04	30.12	26.86	9.9	11.1	10.3	10.9	0.23	0.41
Barley	15	416	506	610	969	15.75	10.26	20.51	28.33	10.7	11.6	12.8	10.2	0.20	0.43
	30	444	829	720	956	15.13	22.19	27.86	31.68	10.3	11.2	10.0	9.6	0.19	0.36
Oats	15	364	490	610	789	13.80	9.44	16.08	27.57	10.8	10.4	11.7	10.8	0.21	0.40
	30	443	788	834	861	17.22	19.25	28.04	25.39	10.4	10.2	10.4	10.3	0.24	0.36
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Row spacing means</u>															
	15	407	575	653	889	15.33	12.86	19.87	27.51	10.8	11.2	11.6	10.0	0.20	0.39
	30	472	827	800	881	17.32	20.83	28.67	27.98	10.2	10.8	10.2	10.3	0.22	0.38
	LSD 0.05	NS	184	NS	NS	NS	5.45	NS	NS	NS	NS	0.6	NS	NS	NS
<u>Companion crop means</u>															
Wheat		485	797	793	868	18.03	19.96	26.57	26.74	10.3	11.3	10.4	10.0	0.22	0.38
Barley		430	668	665	962	15.44	16.23	24.18	30.01	10.5	11.4	11.4	9.9	0.20	0.40
Oats		404	639	722	825	15.51	14.34	22.06	26.48	10.6	10.3	11.0	10.6	0.23	0.38
Control §		574	1184	1504	2413	21.08	46.07	108.10	171.80	8.9	8.5	8.9	12.5	0.64	1.83

Table II.3. (cont'd.)

Companion Crop	Cereal row spacing	Tiller number				Dry matter				Tiller height				LAI	
		Trial 1	Trial 2			Trial 1	Trial 2			Trial 1	Trial 2			Trial 2	
		20 May	12 June	17 July	13 Nov	20 May	12 June	17 July	13 Nov	20 May	12 June	17 July	13 Nov	17 July	13 Nov
	cm	tillers m^{-2}				g m^{-2}				cm					
Contrast¶															
Control vs. cereals		**	**	**	**	NS	**	**	**	**	**	**	**	**	**
Wheat vs. barley & oats		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Barley vs. oats		NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS

†Trial 1 was planted in 1985.

‡Trial 2 was planted in 1986.

§Control indicates tall fescue planted without cereals.

¶Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table II.4. Physiological responses of tall fescue seed crops to establishment with cereal companion crops in 1986.

Companion crop	Cereal row spacing	Stomatal resistance (L_r)	Transpiration rate (TR)	Leaf temperature (L_t)	Leaf chlorophyll (a+b)[†]		
					19 June	27 June	11 July
	cm	$s\ cm^{-1}$	$\mu g\ cm^{-2}\ s^{-1}$	^{o}C	$g\ kg^{-1}FW$		
Wheat	15	5.5	3.6	28.7	3.9	3.2	1.8
	30	10.5	1.9	28.6	2.5	5.2	1.5
Barley	15	11.9	1.6	29.0	3.7	4.4	2.6
	30	6.3	3.2	28.3	3.5	3.0	2.6
Oats	15	5.3	3.2	28.9	2.6	3.6	2.6
	30	8.1	2.0	27.4	2.6	3.9	2.1
	LSD 0.05	3.8	1.2	NS	NS	0.5	NS
<u>Row spacing means</u>							
	15	7.6	2.8	28.9	3.4	3.7	2.3
	30	8.3	2.4	28.1	2.9	4.0	2.1
	LSD 0.05	NS	NS	NS	0.6	NS	NS
<u>Companion crop means</u>							
Wheat		8.0	2.8	28.7	3.2	4.2	1.7
Barley		9.1	2.4	28.7	3.6	3.7	2.6
Oats		6.7	2.6	28.2	2.6	3.7	2.4
Control[‡]		4.2	4.3	29.0	2.7	3.1	2.8
<u>Contrast</u>[§]							
Control vs. cereals		**	**	NS	**	**	**
Wheat vs. barley & oats		NS	NS	NS	NS	**	**
Barley vs. oats		NS	NS	NS	**	NS	NS

[†] Mean of three 1 g leaf samples per subplot

[‡] Control indicates tall fescue planted without cereals.

[§] Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table II.5. Seed yield and yield components of tall fescue established with cereal companion crops.

Companion crop	Cereal row spacing	Fertile tillers		Vegetative tillers		Total tillers		Spikelets tiller^{-1}		Florets spikelet^{-1}		Seed yield First-year		Seed yield Second-year
		Trial 1†	Trial 2‡	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1
	cm	tillers m^{-2}						No.				kg ha^{-1}		
Wheat	15	93	232	1839	1873	1932	2105	117	93	6.9	5.9	758	794	2350
	30	174	192	1688	2203	1862	2395	101	90	6.5	6.1	526	757	2545
Barley	15	93	156	1539	1776	1633	1932	99	84	7.2	6.1	875	653	2397
	30	101	178	1661	2409	1762	2587	120	93	7.6	6.2	925	833	2297
Oats	15	99	67	1638	1287	1737	1353	97	109	7.1	6.2	745	505	2488
	30	129	60	1706	1645	1835	1705	115	93	6.8	6.7	1002	422	3022
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Row spacing means</u>														
	15	95	151	1672	1645	1767	1796	104	95	7.1	6.1	720	651	2411
	30	135	143	1685	2086	1820	2229	112	92	7.0	6.3	891	671	2621
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	62
<u>Companion crop means</u>														
Wheat		134	212	1764	2038	1897	2250	109	91	6.7	6.0	842	775	2448
Barley		97	167	1600	2093	1697	2260	110	88	7.4	6.1	635	743	2347
Oats		117	63	1672	1466	1786	1529	106	101	6.9	6.5	938	463	2755
Control§		506	598	1383	1950	1889	2548	107	90	5.4	5.2	2085	1705	2191

Table II.5. Seed yield and yield components of tall fescue established with cereal companion crops (cont'd).

Companion crop	Cereal row spacing	Fertile tillers		Vegetative tillers		Total tillers		Spikelets tiller^{-1}		Florets spikelet^{-1}		Seed yield First-year		Seed yield Second-year
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1
	cm	tillers m^{-2}						No.				kg ha^{-1}		
Contrast[¶]														
Control vs. cereals		**	**	*	NS	NS	**	NS	NS	**	**	**	**	**
Wheat vs. barley & oats		NS	**	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
Barley vs. oats		NS	*	NS	**	NS	**	NS	NS	*	NS	**	*	**

[†] Trial 1 was planted in 1985.

[‡] Trial 2 was planted in 1986.

[§] Control indicates tall fescue planted without cereals.

[¶] Orthogonal contrasts significant at the P = 0.05 (*) and P = 0.01 (**) levels.

Table II.6. Linear correlation coefficients among growth characteristics, seed yield components, and seed yield of tall fescue seed crops established with cereal companion crops.

	Correlation coefficients			
	Fertile tillers	Spikelets tillers^{-1}	Florets spikelet^{-1}	First-year seed yield
Fall tillers	0.95**	-0.26	-0.85*	0.95**
Spring vegetative tillers	0.33	-0.56	-0.21	0.37
Fertile tiller	---	-0.35	-0.94**	0.99**
Spikelets tiller^{-1}	---	---	0.21	-0.31
Florets spikelet^{-1}	---	---	---	-0.93**

*, ** Correlation coefficients significantly different from zero at P = 0.05 (*) and P = 0.01 (**).

Table II.7. Economic response of tall fescue seed crops to establishment with cereal companion crops in Oregon.

	Market condition		Net change in income‡					
	Crop	Time	15-cm rows			30-cm rows		
Trial	price	period	Wheat	Barley	Oats	Wheat	Barley	Oats
			dollars ha^{-1}					
1	Average cereal, fescue†	2-yr	-506	-806	-569	-398	-654	-512
		3-yr	-381	-644	-337	-121	-570	139
2		2-yr	-474	-749	-697	-568	-623	-828
1	High cereal, low fescue §	2-yr	-450	-529	-447	-217	-395	-400
		3-yr	-346	-395	-254	13	-326	141
2		2-yr	-299	-554	-509	-398	-452	-635
1	Low cereal, high fescue ¶	2-yr	-1040	-1315	-959	-843	-1107	-862
		3-yr	-884	-1112	-667	-495	-1003	- 46
2		2-yr	-751	-1013	-1001	-833	-845	-1127

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†Change in net income of cropping system compared to monoculture establishment.

‡Average crop prices for 1983-1986 period: wheat = \$0.12 kg^{-1}, barley = \$0.10 kg^{-1}, oats = \$0.10 kg^{-1}, and tall fescue = \$0.93 kg^{-1}.

§High cereal and low tall fescue prices for 1983-1986 period: wheat = \$0.14 kg^{-1}, barley = \$0.13 kg^{-1}, and tall fescue = \$0.79 kg^{-1}.

¶Low cereal and high tall fescue prices for 1983-1986 period: wheat = \$0.09 kg^{-1}, barley = \$0.08 kg^{-1}, oats = \$0.09 kg^{-1}, and tall fescue = \$1.12 kg^{-1}.

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CONCLUSION

Stand establishment of orchardgrass and tall fescue seed crops was adversely affected by spring planting with cereals. Increased economic returns are still possible when spring-planting orchardgrass seed crops with cereals, but are not as promising for tall fescue without irrigation. However, dry weather conditions during this investigation made the competitive effects of cereals more severe than normal, reducing first-year seed yields and economic return from companion cropping.

Spring wheat, barley, and oats reduced orchardgrass and tall fescue growth characteristics to the same extent. Orthogonal comparisons indicated that no advantage in grass seedling growth was conferred by planting early-maturing cereals (barley and oats) rather than wheat and that seedling growth under barley was similar to growth under oats. Cereals caused a transient increase in chlorophyll content of grass leaves and imposed water stress on grass seedlings, causing increased stomatal resistance and reduced transpiration rate. The environment under 30-cm cereal rows was not substantially more conducive to grass seedling growth than that under 15-cm rows. As a result, cereal row spacing essentially had no effect on orchardgrass and tall fescue growth, physiology, or seed yield. By spring of the harvest-year, no detrimental effects of cereal crops on the total tiller population were detected, but fertile tiller numbers were markedly reduced.

It was evident, however, that orchardgrass seed production responded more favorably to establishment with spring cereals than did tall fescue. Fall tiller production of tall fescue crops responded similarily as orchardgrass to cereals (37% vs. 33% of control), but fertile tiller production in the following spring was much lower (24% vs. 49% of control). It is possible that the greater number of orchardgrass fertile tillers relative to tall fescue was a result of late-winter or early-spring vernalization of tillers formed during winter regrowth. Orchardgrass may be more competitive under shade than tall fescue because photosynthetic rates are not appreciably different in shade than in full sun (Singh et al., 1974), whereas tall fescue photosynthetic rates are considerably less in shade (Woledge, 1971). Consequently, more stored carbohydrates may be present in orchardgrass than tall fescue in fall and may provide material for additional regrowth after early November. Thus, orchardgrass fall tiller number alone may not be representative of the potential fertile tiller population in spring, although the importance of fall tillers in contributing to fertile tiller numbers cannot be discounted.

Red fescue was planted in spring 1985 with the same companion cropping treatments, and adjacent to the tall fescue and orchardgrass study site. First-year and second-year seed yields were not reduced by companion crops and consequently, red fescue seed crops established with cereals would have earned at least \$121 ha^{-1} more than monoculture (Chastain and Grabe, unpublished). This indicates that tall fescue and orchardgrass seedlings may not be as competitive as red fescue, and that red fescue may be better adapted for spring companion cropping on drier soils and during periods of drought. Tall fescue planted in monoculture appeared to suffer less from drought conditions than orchardgrass both in terms of growth and seed yield.

In fall plantings of grasses with cereals, extensive root systems and large numbers of tillers are formed before cereals begin to compete for light and water in spring (Chastain and Grabe, 1988a). In contrast, young grass seedlings are much more susceptible to shading and soil water deficit than older plants. Therefore, fall seedings of grasses with companion crops are probably superior to spring plantings because the grass plants have more time to develop over the fall and winter before competition with cereals begins in spring. Fertile tiller populations of red fescue seeded in fall with cereals (Chastain and Grabe, 1988b) were not reduced to the extent that orchardgrass and tall fescue were when spring-seeded with cereals. This implies that greater pre-induction tiller populations may be obtained by fall seedings with cereals than spring seedings as a result of lower tiller mortality from competition in spring.

Prior to this investigation, no studies examined the effect of companion crops on the physiology of grass seed crops and few have been concerned with morphological responses to companion crops. There is a need to elucidate the causes for the differential responses among grass seed crops to establishment with companion crops. In addition, more work is required to better understand the physiological processes involved in the production of a grass seed crop.

Seeding orchardgrass seed crops in spring with wheat in 30-cm rows could allow growers to produce a cash crop and thereby avoid the loss of one year's income. By comparison, income from tall fescue seed production was reduced by spring wheat and barley, but not by oats in 30-cm rows. Market conditions influence the profitability of companion cropping. The highest profits would be earned when cereal prices are relatively high because the greatest income would be generated to compensate for seed yield reductions. Irrigation and further refinement of cultural practices, may improve the profitability of spring companion cropping. Grass seed crop establishment with companion crops may be more profitable in fall when water is not limiting.

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APPENDIX

Appendix Table 1. Experimental procedure for spring-planting 'Hallmark' orchardgrass with wheat, barley, and oats in Oregon. Cultural practices appear in chronological order.

Year	Month	Cultural practice	Rate
			kg ha-1
Establishment			
	March	Sprayed paraquat	0.45
		Incorporated 16-20-0 into seedbed	56 N, 27 P
		Planted cereals	
		Wheat	117
		Barley	117
		Oats	134
		Planted orchardgrass	9
	April	Sprayed bromoxynil	0.45
		Applied 40-0-0-6	28 N, 4 S
	May	Sprayed MCPA	0.56
	July/ August	Harvested cereal crop	
		Flail-chopped and removed cereal residue	
	October	Applied 33-0-0	50 N
		Sprayed MCPA	1.12
		Sprayed simazine	2.24
	November	Sprayed ethofumesate	1.12
First-year			
	March	Applied 40-0-0-6	112 N, 15 S
		Sprayed MCPA	0.56
		Sprayed dicamba	0.28
	June	Harvested first seed crop	
	July	Field burning	
	October	Applied 33-0-0	50 N
		Sprayed simazine	2.24
Second-year			
	Repeated first-year procedure		

Appendix Table 2. Experimental procedure for spring-planting 'Bonanza' tall fescue with wheat, barley, and oats in Oregon. Cultural practices appear in chronological order.

Year	Month	Cultural practice	Rate
			kg ha-1
Establishment			
	March	Sprayed paraquat	0.45
		Incorporated 16-20-0 into seedbed	56 N, 27 P
		Planted cereals	
		Wheat	117
		Barley	117
		Oats	134
		Planted tall fescue	11.2
	April	Sprayed bromoxynil	0.45
		Applied 40-0-0-6	28 N, 4 S
	May	Sprayed MCPA	0.56
	July/ August	Harvested cereal crop	
		Flail-chopped and removed cereal residue	
	October	Applied 33-0-0	73
		Sprayed MCPA	1.12
		Sprayed simazine	2.24
	November	Sprayed ethofumesate	1.12
First-year			
	March	Applied 40-0-0-6	112 N, 15 S
		Sprayed MCPA	0.56
		Sprayed dicamba	0.28
	June	Harvested first seed crop	
	July	Field burning	
	October	Applied 33-0-0	73 N
		Sprayed simazine	2.24
Second-year			
	Repeated first-year procedure		