AN ABSTRACT OF THE THESIS OF

Krista D. Orthel for the degree of Master of Science in Crop Science presented on October 19, 2004.

Title: Spring Irrigation Management of Tall Fescue (*Festuca arundinacea* Schreb.) Seed Crops.

Abstract approved:

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Thomas G. Chastain

Later maturing cultivars and increased ability to apply irrigation have led to inquiries by producers about proper irrigation management in tall fescue (*Festuca arundinacea* Schreb.) seed crops. The literature reveals little information about irrigation of perennial grass seed crops in general, and none about tall fescue in particular. Willamette Valley producers need research-based information on which to base irrigation management decisions.

A field study was established near Corvallis, Oregon on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll) to study the effect of spring irrigation on six cultivars of tall fescue. Dryland conditions were compared to (1) irrigation to fill the profile to field capacity (238 mm) at anthesis and (2) irrigation to maintain water deficit $\leq$ 50 mm below field capacity until the beginning of seed fill. Soil water was monitored with time domain reflectometry (TDR) at 15-cm increments to a depth of 60 cm. Data from the experiment were used to calculate reproductive efficiency (RE), harvest index (HI) and water use efficiency (WUE).

The 2003 growing season was wet during the first half and dry during the second half, while the 2004 season was characterized by alternating moist and dry periods. Both irrigation treatments received 78 mm of water in 2003. In 2004, treatments received 112 and 172 mm of water for the single application and maintained application, respectively. Responses did not differ between the two irrigated treatments. In both years, an interaction existed between irrigation and cultivar for yield but not for seed number and weight. In 2003, yields were increased by 13 to 39% over non-irrigated yields, depending on cultivar. ‘Barrington’ and ‘Bingo’ showed the strongest response to irrigation. ‘Velocity’ was not responsive to irrigation in 2004, though the remaining cultivars exhibited a positive yield response (14%). Seed weight across cultivars increased with irrigation in 2003 and 2004. Seed number increased with irrigation in 2003 but not 2004.

Potential yield, tiller and panicle characteristics, RE, HI and WUE were not affected by irrigation but were cultivar dependant. Average RE was greater in 2004 (31%) than in 2003 (19%). Harvest indices ranged from 0.05 to 0.19. Water use efficiency ranged from 2.92 to 9.92 kg ha^{-1} mm^{-1}, averaging 6.21 kg ha^{-1} mm^{-1}.

In general, the reduction of water deficit stress during seed fill increases tall fescue yield due to increases in seed weight and number. However, level of response depended on cultivar and climatic conditions during the growing season. Irrigation in the present study would have been profitable for Willamette Valley producers.

Spring Irrigation Management of Tall Fescue (*Festuca arundinacea* Schreb.) Seed Crops

by
Krista D. Orthel

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Krista D. Orthel, Author

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To my friends (near and far): I have come to consider each of you part of my family. I can only hope that I have been as good of friend to each of you, as you have been to me.

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INTRODUCTION

Traditionally, perennial grass seed crops are grown under dryland conditions in the Willamette Valley. Increased ability for growers to supply supplemental water and a shift by plant breeding programs towards later maturing cultivars have led to inquiries about irrigation recommendations for tall fescue (*Festuca arundinacea* Schreb.) seed crops. Local growers have reported seed yield increases of three hundred pounds per acre in comparison to fields not receiving irrigation. Few researchers have explored the effects of irrigation management on perennial grass seed production (Rampton and Jackson, 1969; Hebblethwaite and McGowan, 1977; Mitchell et al., 1997b) and none have investigated irrigation management of tall fescue seed crops. Research is needed to clarify the water needs of tall fescue seed crops in the Willamette Valley and identify irrigation management strategies.

Rampton and Jackson (1969) reported no response to irrigation in orchardgrass (*Dactylis glomerata* L.) grown in the Willamette Valley. Results were based on a single year's data in which substantial precipitation was received during the growing season. Nevertheless, it was hypothesized that supplemental water could be beneficial in fall drought conditions or low soil water levels during heading, pollination or seed development. Irrigation in perennial ryegrass (*Lolium perenne* L.) was studied in England on sandy soil (Hebblethwaite and McGowan, 1977). Irrigated plots yielded 16 to 52% more than non-irrigated plots in years of soil water deficit. In the same study during a year of high precipitation, irrigated plots did not show an increase in yield. Soil water data showed that non-irrigated plots drew water from greater depths to meet the evapotranspiration (ET) needs of the plant.

Research investigating water use in perennial grasses has been focused on turf and forage production systems. Tall fescue did not show a water consumption x cultivar interaction in a turf production study (Asay et. al., 2001). However, tall fescue germplasm has been shown to have differences in carbon isotope discrimination values, a common indicator of water use efficiency (WUE) (Johnson and Bassett, 1991). Water use efficiency is the crop yield per unit of crop water use (Howell, 2001). Studies on perennial grasses grown for forage production have reported varying data regarding water use by cultivars within species. Frank et al. (1985) found that cultivars of western wheatgrass (*Agropyron smithii* Rydb.) differed in water use efficiency but crested wheatgrass [*A. desertorum* (Fisch. ex Link) Schult.], reed canarygrass (*Pharlaris arundinacea* L.) and intermediate wheatgrass [*A. intermedia* (Host) Beauv.] cultivars did not.

Harvest index (HI) and reproductive efficiency (RE) measure how plants are allocating assimilates for seed production. The harvest index measures the proportion of total above-ground biomass utilized in economic yield (Sinclair, 1998). Elgersma (1990b) reported a HI of 0.12 to 0.10 for perennial ryegrass cultivars grown in clayey and sandy soils, respectively. Wheat (*Triticum aestivum* L.) values of HI are higher and range from 0.30 to 0.45 (Johnson and Kanemasu, 1982; Yang et al., 2000). Reproductive efficiency is the ratio of harvested seed number to potential seed number (Elgersma, 1985). Reproductive efficiencies of perennial grasses are low due to seed shattering, seed abortion and poor floret site utilization (Marshall, 1985). Young et al. (1998b) reported RE of tall fescue to range from 37% to 53%.

Seed production literature for Oregon produces conflicting water requirements for tall fescue. Watts et al. (1968) reported that 281 mm of water was required for grass seed production in the Willamette Valley. Water needs were based on a growing season from March to June. It is unclear from the publication how crop water use was estimated. Cuenca et al. (1992) used a year-round growing season and estimated over 762 mm of water was required for seed development.

Thus, our field study was established with the following objectives: (1) measure the effect of supplemental irrigation on seed yield components, (2) determine the response of selected tall fescue varieties to irrigation and evaluate the potential need for variety based irrigation management and (3) develop practical irrigation management solutions for tall fescue seed production. Data from the field study was also used to (1) determine the effect of spring irrigation on RE and HI of tall fescue cultivars (2) measure WUE and develop an understanding of the influence of environment on cultivar performance and (3) evaluate the economic feasibility of adopting irrigation as a new management tool in the Willamette Valley.

REVIEW OF LITERATURE

General Stress from Water Deficit

Water deficit in plants leads to a variety of responses that affect growth and development. An initial plant response to water deficit is to reduce stomatal opening to maintain leaf turgor pressure. This slows transpiration leading to an increase in plant temperature as well as limits CO_2 diffusion into the leaves. A typical defense is to avoid sunlight or radiation through turning and curling of leaves, however this action causes the plant to also avoid light needed for photosynthesis. The result on a whole plant level is a reduction of photosynthesis needed for assimilate production (Chaves et al., 2002). The ability of plants to photosynthesize is directly related to crop yield as this process provides the energy and carbohydrates needed for crop growth and development.

At the molecular level, expression of genes controlling cell structure and osmotic adjustment is altered (Bray, 1993). For example, a turfgrass study indicated that drought stressed tall fescue (*Festuca arundinacea* Schreb.) plants had accumulated dehydrins (Jiang and Huang, 2002). Dehydrins are proteins which have been associated with maintaining the integrity of cells and protecting other proteins from damage (Bray, 1993).

Frank et al. (1985) summarized three factors that control plant water use: (1) atmospheric evaporation potential, (2) available soil water and (3) plant characteristics. While plants have little control over the first two factors, species regularly experiencing low water conditions have developed mechanisms that enable them to survive. Some species escape drought by completing the life cycle prior to the onset of drought, i.e., early maturity. Other species have high dehydration tolerance, which allows them to survive drought with low tissue water status. Finally, species may have developed mechanisms that allow them to postpone dehydration and survive water deficit in a state of high water status (Turner, 1986).

Though plants may survive drought and reproduce, under agronomic production minimal levels of photoassimilate must be available for partitioning to sinks of economic value. Perennial crops not only require sufficient water to partition assimilates to reproduction, but also maintain a stand for subsequent harvest years. Responses to water deficit have been explored in a number of grass species but without significant contributions to the knowledge of irrigation management in perennial grass seed crops.

Annual Grasses

Studies of other grass species have found that the impact of water deficit on seed yield is dependant on the growth stage and intensity of stress. Stress during a period of a plant's life cycle most strongly affects the component in active growth and development. Day and Intalap (1970) found that water deficit incurred prior to anthesis in wheat (*Triticum aestivum* L.) decreased yield by reducing the number of grains. Differentiation of florets and the inflorescence occurs during early stages of reproductive growth prior to the elongation of the culm and flowering. If sources for cell division and growth are limiting then fewer florets will be produced and consequently fewer will be available for pollination and grain fill.

Ehlig and LeMert (1976) reported that drought stressed wheat produced a greater number of spike bearing tillers than irrigated treatments. These results conflict with other studies which report that wheat produces a reduced number of spikes in water limiting conditions (Day and Intalap, 1970; Musick and Dusek, 1980). Wheat plants under water deficit conditions headed 7 to 10 days earlier than plants grown under irrigation (Ehlig and LeMert, 1976). These results are confirmed by other researchers who report earlier heading and anthesis in drought stressed plants (Day and Intalap, 1970; Musick and Dusek, 1980; Yang et al., 2001). In response to the water limited conditions, plants shorten their life cycle to mature earlier during more favorable conditions rather than later during conditions of water deficit (i.e., drought avoidance).

The reduction in growing season length in response to water deficit has been found to be more evident when water stress was imposed during flowering or seed fill (Day and Intalap, 1970; Johnson and Moss, 1976; Yang et al., 2001). Stress during jointing led to reduced yield due to a reduction in seed number while stress in the later growth stages caused yield reduction because of decreased seed weight (Day and Intalap, 1970). This finding is supported by the work of Johnson and Moss (1976), when water deficit stress is imposed after heading, kernel weight is the only yield component affected. Water deficit during anthesis and seed fill reduces the duration of seed fill, one of the primary processes that determines seed weight.

In wheat, assimilates from current photosynthesis and mobilization of both pre- and post-anthesis stored assimilates contribute to grain growth (Kobata et al., 1992). Johnson and Moss (1976) exposed stressed and non-stressed plants to $^{14}CO_2$ after heading and found a higher percentage of fixed ^{14}C in the grain (83%) of stressed plants compared to non-stressed plants (69%). Yang et al. (2001) exposed plants to $^{14}CO_2$ at the boot stage and found that mildly and severely stressed treatments remobilized 50 to 80% more pre-anthesis assimilates to the grain than well-watered treatments. These studies show that under stress conditions a greater percentage of stored and current photoassimilates are used in reproductive growth. Pre-anthesis photoassimilates become more important in yield development as drought stress increases.

A study of multiple cultivars and species in wheat showed that the degree to which seed number or seed weight was decreased by water stress was dependant upon cultivar and species (Khanna-Chopra et al., 1994). A reduction in seed weight contributed more to the decrease in seed yield than seed number in the cultivar which showed the highest stability in stressed field conditions.

Forage and Turf Production

Several studies have been conducted to investigate the impact water deficit has on perennial grasses in forage and turf production systems. Continuous clipping or harvest in these systems maintains swards in continuous vegetative growth and precludes them from reproducing sexually. Water use in such systems is influenced by frequency of harvest, nutritional status and cultivar (Frank et al., 1985).

These systems exclude the critical changes which occur during reproductive development that alter the water needs of the plant during flowering and seed set. Turfgrass maintains a high water requirement throughout the season to support growth of vegetation after mowing. However, in seed production, water needs of the plant declines as the seed matures and reproductive tillers senesce (Mitchell et al., 1997b). Water stress has been widely reported to have less negative impacts on vegetative growth than reproductive development (Lambert, 1967a; Hill, 1980; Thomas and Evans, 1990); however, important information can be gathered from study of the grasses in this production system.

Horst and Nelson (1979) suggest that the plant dormancy associated with tall fescue during drought conserves assimilates for recovery when conditions improve. Plants produced equal amounts of dry matter during the year, regardless of available water. Droughted plants had greater regrowth during the recovery period than non-stressed plants. Horst and Nelson (1979) propose that drought stress preconditions the plant and has residual effects for several months.

Osmotic adjustment differs based on the age of tissue. Younger leaves were able to adjust to 0.49 MPa while mature leaf blades only showed an osmotic adjustment of 0.08 MPa. Even in immature leaves the difference in age can be observed in turgor pressure. A decline of 0.42 MPa was seen in newly emerged leaf blades, but in unemerged blades turgor only declined by 0.12 MPa (West et al., 1990).

West et al. (1990) hypothesize that tall fescue plants undergo this osmotic adjustment in order to maintain the survival of tillers rather than leaves.

Perennial ryegrass (*Lolium perenne* L.) utilized fructans for regrowth to a greater extent than tall fescue after a 10 day drought recovery period (Karsten and MacAdam, 2001). The use of stored fructans may weaken the ability of perennial ryegrass to survive under continued poor growing conditions. Both species used osmotic adjustment to temporarily survive water deficit stress. However, the conservation of fructans by tall fescue under drought conditions may indicate it is more adapted to drier environments.

The endophyte *Neotyphodium coenophialum* has been suggested to impart greater drought tolerance to tall fescue. Though not well understood, multiple mechanisms have been implicated. Belesky and Fedders (1995) suggest that endophyte infected plants have a more extensive root system (11% greater biomass over non-infected plants). Increased root length and decreased root diameter may help the plant to increase water uptake (Malinowski and Belesky, 2000). Alterations to leaf structure (i.e., thicker leaf cuticle and enhanced leaf rolling) reduced transpiration losses in a study by Elmi and West (1995). Osmotic adjustment may be increased in endophyte infected plants due to accumulation of simple sugars, fungal metabolites, amino acids and alkaloids (Hill et al., 1990; Malinowski and Belesky, 2000).

Studies in wheat and perennial grasses grown for forage production have reported varying data regarding water use by cultivars within species. Water use efficiency is the crop yield per unit of crop water use (Howell, 2001). Frank et al.

(1985) found that different cultivars of western wheatgrass (*Agropyron smithii* Rydb.) differed in water use efficiency but crested wheatgrass [*A. desertorum* (Fisch. ex Link) Schult.], reed canarygrass (*Pharlaris arundinacea* L.) and intermediate wheatgrass [*A. intermedium* (Host) Beauv.] cultivars did not. Tall fescue did not show an interaction of water consumption and cultivar in one study (Asay et al., 2001). However, tall fescue germplasm has been shown to have differences in carbon isotope discrimination values, a common indicator of water use efficiency (Johnson and Bassett, 1991). Several studies have indicated a difference among and between species in the effects of water deficit on herbage and seed yield (Johns, 1978; Thomas and Evans, 1990; Khanna-Chopra et al., 1994)

Though vegetative-based production systems can provide limited insight into plant water use and responses to water deficit, management for seed production is distinctly different. Our understanding of forage and turfgrass suggests that tall fescue alters source-sink relationships during water deficit. Plants may use the same mechanisms to help survive the stress; however, an additional sink is present which must be provided with assimilates. A limited number of studies have been conducted that specifically investigate water deficit in perennial grass seed crops and none in tall fescue.

Perennial Grass Seed

Smika and Newell (1965) studied the effects of irrigation and nitrogen on side-oats grama [*Bouteloua curtipendula* (Michx) Torr.]. They found that irrigation in fall did not increase yield over the non-irrigated control. However, three of the irrigation treatments did yield significantly above the control, but were not significantly different from each other: (1) fall and heading, (2) spring and heading and (3) fall, spring, and heading (Smika and Newell, 1965). These results suggest that reducing water stress during heading could be the key in increasing seed yield in perennial grasses.

Rampton and Jackson (1969) reported no response to irrigation in orchardgrass (*Dactylis glomerata* L.) grown in the Willamette Valley. Results were based on a single year's data in which substantial precipitation was received during the growing season. Further investigation was not pursued. Nevertheless, it was hypothesized that supplemental water could be beneficial in fall drought conditions or low soil water levels during heading, pollination or seed development.

Irrigation from inflorescence initiation through mid-seed fill in timothy (*Phleum pretense* L.) did not significantly affect seed set, but increased seed size and reduced the proportion of light seeds (Lambert, 1967b). Irrigated plants were able to support 40% more vegetative tillers than non-irrigated plants. Under the dryland conditions of the study, timothy was not reaching its full yield potential. Supplemental irrigation in multiple grass species leads to increased yield suggesting that water is the most limiting input in many agricultural systems. Maman et al. (2003) studied pearl millet [*Pennisetum glaucum* (L.) R. Br.] and grain sorghum [*Sorghum bicolor* (L.) Moench.] which are considered to be drought hardy plants.

They reported that during a growing season of good rainfall the crops were not achieving the yield that could be produced with irrigation.

Under irrigated production of Kentucky bluegrass (*Poa pratensis* L.), Mitchell et al. (1997a) found that a late irrigation just prior to harvest produced a slight trend of increased yield, but not a significant increase. Crop water use patterns showed that a decrease in water use corresponded with anthesis (Mitchell et al., 1997b). Available water during anthesis and early seed fill was more important than late season water. Water needs of the plant declined as the seed matured but increased again during fall regrowth.

Irrigation in perennial ryegrass grown in sandy soil showed variable results (Hebblethwaite, 1977). Irrigated plots yielded 16 to 52% more than non-irrigated plots in years of soil water deficit. In the same study during a year of high precipitation, irrigated plots did not show increased yield. Soil water data indicated that non-irrigated plots drew water from greater depths to meet the evapotranspiration needs of the plant. Hebblethwaite and McGowan (1977) report that water deficits of 50 mm can impact transpiration and growth of perennial ryegrass.

Rowarth et al. (1997) found that thousand seed weight, florets per spikelet and spikelets per spike were unaffected by water deficit in perennial ryegrass grown in the greenhouse. Water deficit impact on growth and seed production was dependant on extent of the deficit and growth stage in which the deficit occurred. During stem elongation, plants were most sensitive to water deficit and showed a decrease in seed yield at 50% field capacity. Seed yield was decreased when deficits of 40% field capacity were imposed at anthesis. Interestingly, greater water deficits during seed fill caused an increase in yield when compared to the 70% field capacity treatment.

It is important to note that water deficit stress accumulates more rapidly under greenhouse conditions and simulated swards than in field conditions. In a study which compared field conditions and simulated swards, Jones et al. (1980) found that simulated swards began showing stress under at leaf water potential of -12 bars while field swards did not have visible signs of wilting until -16 bars. Jones et al. (1980) concluded that under natural conditions, leaves adjust to water deficit as water becomes more limiting thereby allowing them to maintain photosynthesis and growth. Caution should be exercised in extrapolating results of a controlled environment study to a field production setting.

Development of Seed Yield

Rowarth et al. (1997) suggested that seed yield loss, resulting from water deficit, during anthesis is a result of the sensitivity of the pollen tube and developing ovule to stress. Hill (1980) reports that low or high temperature stress results in injury to the stamen and pistil. The range of temperatures that are conducive to pollination vary based on species. Dry conditions during anthesis in the Willamette Valley are generally associated with high temperatures. Damage to the reproductive organs due to environmental conditions would reduce seed set. After fertilization, sufficient source materials must be available to maintain growth and prevent early abortion of the developing ovule.

Potential seed weight is determined at anthesis by ovule size. The younger ovules have smaller dry weights at anthesis as well as shorter durations of seed fill as a result of the developmental pattern. Harvested seed weight is a function of duration of growth and growth rate. Under ideal conditions, differences in perennial ryegrass seed weight were more a function of growth rate (60%) rather than duration of growth (30%) (Warringa et al., 1998b).

Research suggests that assimilates are not limiting during reproductive development (Brooks et al., 1982). Assimilates required for seed development in herbage grasses come primarily from the inflorescence (Marshall, 1985). These results are supported by Ong et al. (1978) who reported that the *Poa annua* L. inflorescence was a more important assimilatory organ than leaves during grain filling. During mid-seed filling in perennial ryegrass, the inflorescence accounted for 50% of the assimilation in tillers and approximately 70% of the assimilation in tillers of *P. annua*. Assimilates contributing to the end of seed development were provided by inflorescence photosynthesis (Clemence and Hebblethwaite, 1984).

Decreasing the number of ovules per plant by 50% led to an increase in seed weight of 15%, indicating competition for assimilate supply (Warringa et al., 1998a). Assimilates were mobilized to support seed growth in lodged tall fescue, but this mobilization was not sufficient to maintain seed yield (Griffith, 2000). Though lodged plants had 30 to 60% less water soluble carbohydrates in the stem than upright plants, yield loss was associated with reduced seed weight.

Colvill and Marshall (1984) followed post-anthesis assimilate distribution and found that a greater percentage of assimilate was exported from leaves to the stem than to the inflorescence from the leaves. This is in contrast to our understanding of assimilate partitioning in annual cereal crops that export the majority of assimilates to the inflorescence rather than the stem. Sharing of carbon resources between seeds and stems permits the plant to maintain energy reserves needed for post-reproductive regrowth.

Fall Regrowth

The most important stages of a perennial grass seed crop's growth and development include establishment, seedling development and regrowth following seed harvest (Griffith and Chastain, 1997). Maximizing the number of tillers receptive to floral induction is critical in determining the subsequent season's seed yield. Following seed shedding, assimilates produced by the plant are utilized in tiller growth and development (Clemence and Hebblethwaite, 1984). Chastain and Young (1998) report that greater tiller population density and high leaf area index following fall regrowth are correlated to higher fertile tiller number and increased yield of tall fescue seed crops. The amount of assimilates available to younger plant organs is limited during low water conditions and impacts the ability of the plant to replace aging tillers (Griffith and Chastain, 1997).

Enhancing fall regrowth through additional water could be significant in increasing perennial grass seed yield. Jones et al. (1980) found that water deficit stress in perennial ryegrass reduced the rate of leaf appearance and was potentially compromising the perenniality of the crop. Total dry matter produced was decreased due to a decline in photosynthetic area (i.e., tiller and leaf number). Regrowth after seed harvest in perennial ryegrass was increased by fall irrigation, but did not increase the seed yield the following spring (Velloza, 1997). However, the application of fall irrigation helped to prevent stand die out, a natural process that has been implicated as a reason for yield loss over the age of the stand.

Though total water soluble carbohydrates (WSC) were greater in irrigated tall fescue plants, non-irrigated forage plants had higher WSC in the stem bases than irrigated plants (Horst and Nelson, 1979). Karsten and MacAdam (2001) also report that drought-affected plants conserve stem base dry matter. These plants are not producing tillers necessary to be available for floral induction, but are adapting to enable them to survive the drought conditions. Unfortunately, the authors did not study the effect of irrigation on tiller number.

Thomas and Evans (1990) compared the regrowth of flowering and vegetative perennial ryegrass following an extended period of drought. After irrigation, vegetative plants increased regrowth by 51% over the control while flowering plants decreased the regrowth by 55%. Flowering plants had fewer tillers per plant and greater mortality rates than vegetative plants. After the period of summer drought, perennial grass plants that flowered were less likely to survive and produce new tillers for the subsequent year's harvest.

Fertile tiller number entering the induction period is more critical for tall fescue than perennial ryegrass because of the more stringent requirements for floral induction. Though, Velloza (1997) did not find an increase in seed yield of perennial ryegrass to be associated with increased fall regrowth, increased fall regrowth of tall fescue may correspond with an increase in seed yield.

Current Knowledge and Management

Present irrigation requirements for grass seed crops in the Willamette Valley do not agree and are not based on crops managed for seed production. Watts et al. (1968) reported that 281 mm of water was required for grass seed production. Water needs were based on a growing season from March to June. It is unclear from the publication how crop water use was estimated. Cuenca et al. (1992) used a year-round growing season and estimated over 762 mm of water was required for seed development. Consumptive use values were determined using a reference evapotranspiration, which is affected by multiple variables (i.e., temperature, relative humidity, solar radiation and wind). To determine crop water use, this value is multiplied by the crop coefficient (K_c). The crop coefficient is a value that has been determined based on experiment and is the ratio of actual crop evapotranspiration to reference evapotranspiration. Estimates of K_c were calculated for this publication using standard United Nations Food and Agriculture Organization (FAO) procedures as well as information collected from Oregon State Extension specialists.

MANUSCRIPT I: SPRING IRRIGATION MANAGEMENT OF TALL FESCUE (*Festuca arundinacea* Schreb.) SEED CROPS: SEED YIELD AND SEED YIELD COMPONENTS

ABSTRACT

The literature reveals little information about irrigation of perennial grass seed crops, and none about tall fescue (*Festuca arundinacea* Schreb.). A field study was established near Corvallis, Oregon on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll) to study the effect of spring irrigation on six cultivars of tall fescue. Dryland conditions were compared to (1) irrigation to fill the profile to field capacity (238 mm) at anthesis and (2) irrigation to maintain water deficit ≤ 50 mm below field capacity until the beginning of seed fill. Soil water was monitored with time domain reflectometry (TDR) at 15-cm increments to a depth of 60 cm.

Due to weather conditions in 2003, both irrigation treatments received 78 mm of water. In 2004, treatments received 112 and 172 mm of water for the single application and maintained application, respectively. Responses did not differ between the two irrigated treatments. Potential yield, tiller and panicle characteristics were not affected by irrigation but were cultivar dependant. In both years, an interaction existed between irrigation and cultivar for yield but not for seed number and weight. In 2003, yields were increased by 13 to 39% over non-irrigated yields (1485 kg ha^{-1}), dependant on cultivar. 'Velocity' was not responsive to irrigation in 2004, though the remaining cultivars saw a positive yield response (14%) above non-irrigated yields (2020 kg ha^{-1}). Thousand seed weight increased, regardless of cultivar, with irrigation from 2.52 g to 2.63 g in 2003 and from 2.44 g to 2.50 g in 2004. Seed number increased with irrigation in 2003 but not 2004.

Results show that available water during seed fill is critical to achieving higher seed yields of tall fescue. However, level of response depends on cultivar and climatic conditions during the growing season.

Keywords: Irrigation, *Festuca arundinacea* Schreb., yield components

INTRODUCTION

Oregon is recognized internationally for high quality grass seed production. In 2003, over 140,000 acres of tall fescue (*Festuca arundinacea* Schreb.) were grown and valued at $76 million (Young, 2003). More than 200 tall fescue cultivars are eligible for certification in Oregon (OSCS, 2003). Traditionally, tall fescue has been grown under dryland conditions in the Willamette Valley. However, increased ability for growers to apply irrigation and the genetic diversity of current cultivars have led to inquiries about irrigation recommendations for tall fescue seed crops.

Few researchers have explored the effects of irrigation management on perennial grass seed production (Rampton and Jackson, 1969; Hebblethwaite and McGowan, 1977; Mitchell et. al., 1997) and none have investigated irrigation management of tall fescue in a seed production system. Irrigation in perennial ryegrass (*Lolium perenne* L.) was studied in England on sandy soil (Hebblethwaite and McGowan, 1977). Irrigated plots yielded 16 to 52% more than non-irrigated plots in years of soil water deficit. Rampton and Jackson (1969) reported no response to irrigation in orchardgrass (*Dactylis glomerata* L.) grown in the Willamette Valley. Nevertheless, it was hypothesized that supplemental water could be beneficial in fall drought conditions or low soil water levels during heading, pollination or seed development.

Seed production literature for Oregon produces conflicting water requirements for perennial grasses. Watts et al. (1968) reported that 281 mm of water was required for grass seed production in the Willamette Valley. Water needs were based on a growing season from March to June. Cuenca et al. (1992) used a year-round growing season and estimated over 762 mm of water was required for seed development.

Water deficit stress has been extensively studied in wheat (*Triticum aestivum* L.). Timing of water deficit determines which yield components and to what extent they are influenced by the stress. Water deficit stress prior to heading causes a decrease in seed number (Day and Intalap, 1970; Moustafa et al., 1996), while stress after heading causes a decrease in seed weight (Day and Intalap, 1970; Johnson and Moss, 1976). In response to water limited conditions, wheat shortens its life cycle (Ehlig and LeMert, 1976; Yang et al., 2001) to mature during more favorable conditions (i.e., drought avoidance). However, Keim and Kronstad (1981) did not observe a difference in maturity dates of cultivars with varying drought tolerances suggesting that drought avoidance is not an important survival mechanism. Jointing, flowering, and seed fill are the most sensitive stages of wheat's life cycle (Day and Intalap, 1970; Johnson and Moss, 1976; Yang et al., 2001).

This study was put forth to elucidate the effects of spring irrigation on multiple cultivars of tall fescue grown for seed. Tall fescue is hypothesized to respond to spring irrigation similarly to other grass species (i.e., wheat). The added complexity of the perennial nature of tall fescue may result in residual effects that have not been observed in annual species. The objectives of this study were to (1) measure the effect of supplemental irrigation on seed yield components, (2) evaluate the potential need for cultivar based management and (3) develop practical management solutions for tall fescue seed production.

MATERIALS and METHODS

A field experiment was established at Hyslop Research Farm near Corvallis, Oregon to elucidate the effects of spring irrigation on tall fescue. The soil at the site is a Woodburn silt loam (fine-silty, mixed, mesic, Aquultic Argixeroll). Plots were arranged in a strip-plot experimental design. Six tall fescue cultivars and three irrigation treatments were randomly stripped over four replications. Plots were 15.2 meters long and 3 meters wide. Three meter wide borders were used to separate irrigation treatments and replications. Data were collected in 2003 and 2004 on first- and second-year seed crops, respectively.

Cultivars

Five turf-type tall fescue cultivars ('Arid 3', 'Barrington', 'Bingo', 'SR8600' and 'Velocity') and a single forage cultivar ('Fawn') were selected for use in this study. Cultivars represent a range of genotypes, plant morphological characteristics and crop maturity based on date of anthesis. As the only forage cultivar, 'Fawn' is also one of the longest established public cultivars, released in 1964. Crop maturity among cultivars ranged over a two-week period and ordered from earliest to latest are 'Fawn', 'Arid 3', 'SR8600', 'Bingo', 'Barrington, and 'Velocity'.

Irrigation Treatments

Two spring irrigation regimes were compared to traditional dryland production. A single concentrated treatment was used to fill the soil profile to field capacity prior to seed fill. This treatment simulates current recommendations for tall fescue. Field capacity of the soil at this site has been determined to be 238 mm in the top 60 cm of the profile (Cox, 1982; Velloza, 1997). The last treatment maintained the soil water to a deficit ≤ 50 mm below field capacity (188 mm). This deficit was determined based on reports that deficits at this level begin to impact transpiration and growth of perennial ryegrass (Hebblethwaite and McGowan, 1977). Irrigation ceased after peak anthesis for both treatments. Average growth stage across turf-type cultivars, as determined by visual evaluation of plots, and soil water content were used to schedule irrigation.

Volumetric water content was measured by time domain reflectometry (TDR) (SoilMoisture Equipment Corp., Santa Barbara, CA) (Musters and Bouten, 2000). TDR probes were installed horizontally at 15-, 30-, 45- and 60- cm depths in three replications of 'Arid 3' and 'Velocity'. These cultivars were selected based on relative maturity date (Arid 3—early maturity, Velocity—late maturity). Regular measurements were taken throughout the growing season to monitor changes in soil water.

Irrigation treatments were applied with a Pierce Corporation Acremaster MicroLinear (Eugene, Oregon). The MicroLinear had three spans and valves on each sprinkler allowed control over which spans were operating. The sprinkler package (Nelson Corporation, Walla Walla, Washington) was designed to minimize drift. The system was not run in windy conditions to prevent inaccurate application of treatments. A single span in the MicroLinear had six D3000 sprayheads; two were half circle to control water application between treatments. Pressure regulators (6.90 x 10^4 Pa) and nozzles limited water output. A red nozzle (#24) was used for a portion of 2003 and put out 11.94 liters per minute. To increase application, green nozzles (#34) were installed which increased output to 24.08 liters per minute. Application rates were further controlled by altering MicroLinear speed.

Irrigation applications for 2003 and 2004 are reported in Table 1-1. Expected application rates were determined by using engineering specifications for sprinkler output and rate of linear movement. In addition, field measurements were collected by randomly placing containers along the span of the linear and measuring collected water. Both values are reported.

Crop Management

Crop was managed using common production practices for the Willamette Valley. All chemicals were applied according to label and at recommended rates. A bale and flail strategy was used to manage post-harvest residues in the experiment.

Plots were planted with a double-disk drill on 7 May 2002 (doy 127) on 30 cm row spacing following an application of 36 kg N per hectare. Irrigation was applied to establish a consistent stand. Bronate (bromoxynil + MCPA) and 2,4-D amine were applied to control weeds during establishment on 14 June (doy 165) and 27 June (doy 178), respectively.

A fall application of 45 kg N per hectare was applied on 21 October 2002 (doy 294). Split spring applications were applied on 19 March (doy 78) and 31 March 2003

Table 1-1. Irrigation applications for 2003 and 2004. Applied water is presented as calculated from sprinkler specifications. Applied water as determined by collection cans is reported in parenthesis.

	Single		Moisture Maintained	
	------ mm ------		------ mm ------	
2003				
04 Jun	10	(13)	10	(13)
05 Jun	20	(25)	20	(25)
06 Jun	20	(25)	20	(25)
09 Jun	28	(22)	28	(22)
total	78	(85)	78	(85)
2004				
28 Apr	--	(--)	11	(15)
30 Apr	--	(--)	21	(24)
03 May	--	(--)	28	(32)
06 May	--	(--)	28	(32)
17 May	--	(--)	28	(32)
24 May	28	(30)	28	(30)
25 May	28	(32)	--	(--)
27 May	28	(30)	--	(--)
31 May	28	(32)	28	(32)
total	112	(124)	172	(197)

(doy 90) at 90 kg N and 62 kg N per hectare, respectively. In 2003, a fall application of 47 kg N per hectare was made on 15 October (doy 288). Spring applications were made on 8 March (doy 68) and 24 March (doy 84) in 2004 at 90 and 45 kg N per hectare, respectively.

In 2002, Prowl (pendimethalin) was applied on 14 November (doy 318). The following applications were made in 2003: Banvel (dicamba) and MCPA on 9 January (doy 9), 2,4-D amine on 12 February (doy 43), Prowl (pendimethalin) and Axiom (flufenacet + metribuzin) on 21 October (doy 295) and Goal (oxyfluorfen) and diuron on 23 December (doy 358). Tilt (propiconazole) was applied to control rust (*Puccinia graminis*) once in 2003 and twice in 2004.

Seed Harvest

To accommodate swathing equipment and prevent contamination between plots, the outside row on either side of the plot was removed by mowing during April and May. In 2003, the center six rows of crop were harvested. Due to problems encountered during the 2003 harvest, an additional row was removed in 2004.

Time of swathing was determined based on seed moisture. Seed samples were collected from plots of each cultivar and irrigation treatment, weighed fresh then oven dried for 2 hours at 130 °C until constant weight was achieved. Percent seed moisture was calculated from fresh and dried biomass difference. Plots were swathed when seed moisture reached approximately 40 percent. When differences existed between irrigation treatments, swathing decisions were based on the lowest moisture to minimize loss from seed shattering. A John Deere swather (Moline, Illinois), modified for small plots, was used to windrow plots. Two dates were used in both years to accommodate the difference between the earlier maturing 'Fawn' and the other cultivars, 24 June (doy 175) and 1 July (doy 182) in 2003 and 18 June (doy 170) and 26 June in 2004 (doy 178).

A Hege plot combine (Waldenburg, Germany) was used to thresh seed when seed moisture in the swath had decreased to 12 percent. Harvested yield was measured directly in the field with a sub-sample being collected for further analysis in the laboratory. Sub-samples were cleaned to marketable yield using a laboratory size Clipper M-2B (A.T. Farrell, Saginaw, MI). Cleanout from the conditioning process was used to calculate clean yield. Samples to determine seed weight were hand cleaned using screens and a blower prior to counting. Two 1000 seed samples were counted by an electric seed counter (The Old Mill Company, Savage, MD) and weighed.

Plant Samples

Fertile Tillers

Tiller samples were collected just prior to anthesis to determine fertile tiller number and biomass. All cultivars were sampled on 2 June 2003 (doy 153). Greater variation in growth stages among cultivars resulted in two sampling dates in 2004, 5 May (doy 126) and 29 May (doy 150) for 'Fawn' and turf-type cultivars, respectively. Thirty centimeters of two crop rows were hand harvested and oven-dried at 38 °C for two days prior to evaluation. Total above-ground biomass was determined. Fertile tillers were separated from vegetative tillers, counted and weighed.

Panicle Characteristics

Panicle samples were collected on 31 May 2003 (doy 151) to determine panicle length and floret and spikelet number. These samples were collected on 5 May (doy 126) and 25 May 2004 (doy 146) for 'Fawn' and turf-type cultivars, respectively. Approximately 15 panicles were selected at random from within the plot. Panicles were frozen until analysis. Ten panicles were used to count number of spikelets and measure panicle length. Two spikelets were selected at the top, middle and bottom of four panicles to determine floret number.

Fall Regrowth

Thirty centimeters of row were hand harvested on two adjacent crop rows in three replications on 6 November (doy 310) and 1 December 2003 (doy 335). Samples were cleaned to remove soil and dead plant tissue prior to drying at 65 °C for two days prior to weighing. On the December sampling date, tiller number was collected in addition to biomass. The quotient of biomass and tiller number is reported as average tiller weight. A wheel marked at 30 cm increments was rolled the full length of two crop rows on 6 November 2003 (doy 310), intersects with plants were used to calculate stand cover.

Statistical Analysis

Data were tested using PROC GLM in a strip-plot design in the SAS Statistical Package (2001). Contrasts were used to evaluate significant interactions. Appropriate differences between irrigation treatments and cultivars were determined by a Fisher's t-test. A Bartlett's Chi Square was used to determine if it was appropriate to pool years for data analysis. Reported differences are significant at $P = 0.05$ unless otherwise noted.

RESULTS and DISCUSSION

Results of Bartlett's test indicated that data could not be pooled across years. Therefore, the individual results are presented for each production year. In both 2003 and 2004, a cultivar x irrigation interaction was found for seed yield but not for other measured parameters.

Climatic Conditions

Growing seasons in the two years contrasted sharply in weather conditions leading up to seed harvest. In 2003, cool wet weather during early spring led to above normal precipitation (April rainfall was 216% of normal). This was followed by a shift to hot, dry weather near the beginning of May. May and June rainfall were 54 and 21% of normal, respectively. This corresponded with reduced soil water beginning near the onset of anthesis. In 2004, a warm, dry spring caused soil drying earlier in the season. Rainfall in March and May was low, averaging 45 and 68% of normal, respectively. Precipitation in April was normal (94%) while June precipitation was above normal (122%). Soil water declined earlier in 2004 and was being drawn down during culm elongation through seed fill in non-irrigated plots (Figure 1-1). Table 1-2 provides climatic data from the years of the study. In summary, the 2003 season was wet during the first half and dry during the second half, while the 2004 season was characterized by alternating moist and dry periods.

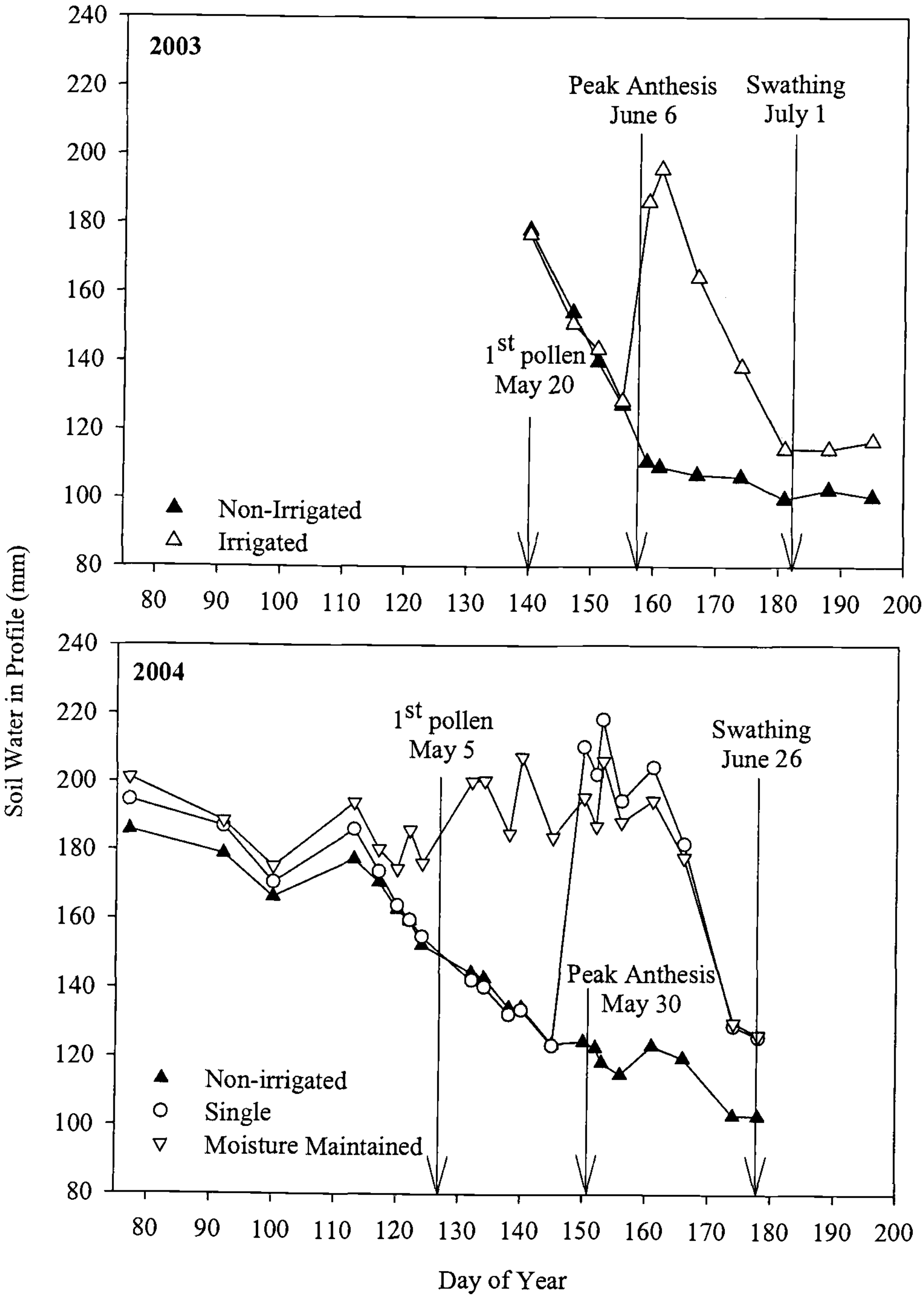

Figure 1-1. Soil water in profile (mm) for 2003 and 2004. Values are averaged across cultivars 'Velocity' and 'Arid 3'. In 2003, irrigated treatments were pooled for presentation (see explanation in text).

Table 1-2. Weekly summary of mean maximum temperature, precipitation and evapotranspiration data measured daily at Hyslop Farm, Corvallis, Oregon. Long-term average as well as both experimental years are included.

Month	Week	Day of Year	Mean Max Temperature			Daily Precipitation			Evapotranspiration		
			Avg	2003	2004	Avg	2003	2004	Avg	2003	2004
			------	°C	------	------	mm	------	------	mm	------
March	1	60	12	11	11	3.56	8.64	3.56	1.52	1.02	1.27
	2	67	13	16	18	3.81	3.56	0.00	1.52	1.52	2.54
	3	74	13	13	17	3.30	9.40	0.00	1.78	1.52	2.79
	4	81	13	13	16	3.56	4.06	3.30	2.54	1.52	2.54
April	1	88	14	15	17	2.79	4.57	0.51	2.54	2.03	3.56
	2	95	16	16	18	2.54	4.83	0.00	2.29	2.03	3.56
	3	102	16	14	18	2.29	6.60	3.56	2.79	2.54	3.05
	4	109	17	14	14	1.78	8.13	4.83	3.05	2.54	2.54
	5	116	18	18	23	2.03	0.76	0.00	3.56	2.03	5.59
May	1	123	19	14	22	1.78	1.27	1.78	3.81	3.56	4.32
	2	130	19	18	19	1.52	2.03	0.51	4.06	3.05	3.56
	3	137	20	22	19	1.27	1.52	1.02	4.83	4.06	4.06
	4	144	21	23	21	1.27	0.51	1.27	4.83	4.83	4.32
June	1	151	22	28	23	1.02	0.00	0.25	5.33	4.83	5.33
	2	158	22	24	18	1.02	0.51	5.08	5.33	8.13	3.56
	3	165	23	24	26	1.02	0.00	0.25	5.33	4.57	9.14
	4	172	24	24	26	1.02	0.76	0.00	5.84	5.08	5.33
	5	179	25	32	28	0.76	0.00	0.00	6.10	7.11	7.40

Fertile Tiller Characteristics

In neither year were fertile tiller characteristics affected by irrigation treatment as panicle, spikelet and floret number were established prior to irrigation. Irrigation treatments were applied after panicle emergence in 2003, and in 2004, began during the early boot stage prior to panicle emergence. Practices such as nutrient management, post-harvest residue management and application of plant growth regulators have been shown to influence seed yield components of perennial grasses (Meints et al., 2001; Young et al., 2003; Zapiola et al., 2003). However, in these studies treatments were applied prior to the completion of the corresponding yield component's development.

Cultivars differed in tiller number and panicle characteristics; variability in reproductive characters among tall fescue genotypes has been previously documented (Nguyen and Sleper, 1983; Ibrahim and Frakes, 1984). Spikelets per panicle and panicle length differed among cultivars in both years. While turf-type cultivars declined in tiller population from 2003 to 2004 (Table 1-3), 'Fawn' maintained a similar tiller population across years. This resulted in lower potential seed number ($P = 0.0625$) for 'Fawn' than the five turf-type cultivars in 2003 but not in 2004. Potential seed number decreased between production years with the exception of 'Fawn' which remained stable.

Table 1-3. Influence of cultivar and year on seed yield components and panicle characteristics in tall fescue. Data is presented as the average of all treatments. Potential seed number was calculated from seed weight at harvest.

Cultivar	Total Biomass	Fertile Tiller Biomass	Fertile Tiller Number	Panicle Length	Spikelets per Panicle	Florets per Spikelet	Potential Seed Number
	------- g m^{-2} -------		no. m^{-2}	--- cm ---	-------- no. --------		no. m^{-2} x 10^5
2003							
Arid 3	1538 c	968 b	702	27.1 d	75 cd	7.3	3.84
Barrington	1610 bc	974 b	747	27.6 cd	81 bc	7.1	4.25
Bingo	1715 abc	1099 ab	690	28.6 bc	78 c	7.8	4.17
Fawn	1919 a	1240 a	525	30.4 a	71 d	7.1	2.64
SR8600	1801 ab	1118 ab	700	29.1 b	87 a	7.1	4.18
Velocity	1784 ab	1128 ab	678	31.2 a	85 ab	7.2	4.32
mean	1729	1089	674	29.0	80	7.3	3.90
LSD 0.05	212	180		0.9	6		
2004							
Arid 3	1571 bc	758 bc	565	24.4 c	84 c	6.4	2.66
Barrington	1496 cd	636 c	470	24.8 c	89 abc	6.3	2.60
Bingo	1961 a	1089 a	652	25.9 b	88 abc	6.3	3.65
Fawn	1276 d	758 bc	547	29.1 a	87 bc	6.1	2.91
SR8600	1778 ab	948 ab	587	26.0 b	94 a	5.7	3.15
Velocity	1735 abc	932 ab	507	26.4 b	92 ab	6.2	2.91
mean	1637	853	555	26.1	89	6.2	2.98
LSD 0.05	246	224		0.8	6		

Fall Regrowth

Tiller populations of tall fescue entering the vernalization period are a strong predictor of seed yield potential in the following year (Chastain and Young, 1998). Fall regrowth was not different between irrigation treatments in 2003 at the October or December sampling date (Table 1-4). Tiller number and average tiller weight obtained from December samples were not different between irrigation treatments. As was noted with spring samples, differences among cultivars were observed on both dates. In this study, fall samples were not a good predictor of seed yield, though December samples were more closely correlated to seed yield than October samples.

Spring irrigation had been hypothesized to potentially influence fall regrowth and prevent stand die-out. Soil water measurements following the 2003 harvest were similar between all treatments (Figure 1-1). As residual water was unavailable for regrowth, a change in carbohydrate storage, as has been reported by Horst and Nelson (1979) and Karsten and MacAdam (2001), would have had to occur to support increased growth of any treatment. Flailing removes the majority of carbohydrates that have been stored in leaf tissue. However, assimilates stored in stem bases or roots could be utilized for regrowth. A significant change in growth and development did not result from potential changes in carbohydrate partitioning.

Velloza (1997) reported that fall irrigation prevented stand die-out in perennial ryegrass fields. Stand density measurements taken in the fall of 2003 do not provide support that spring irrigation will prevent stand die-out in tall fescue. All stands in the experimental area were above 95% stand cover (data not shown). In conditions that

Table 1-4. Fall tiller characteristics of tall fescue cultivars sampled on 27 Oct 2003 and 01 Dec 2003. Averages across irrigation treatments are presented as no irrigation effects were found.

	Tiller Biomass		Tiller No.	Individual Tiller Weight
Cultivar	-- 27 Oct --	-- 01 Dec --	--------------- 01 Dec	---------------
	--------- g m^{-2}	---------	--- no. m^{-2} ---	--- g ---
Arid 3	178.9 c	179.9 bc	2,401 b	0.08 c
Barrington	137.5 bc	128.9 c	1,944 b	0.07 c
Bingo	130.2 a	135.5 a	1,940 a	0.07 bc
Fawn	126.0 ab	130.6 b	1,533 c	0.09 a
SR8600	136.8 bc	184.5 a	2,480 a	0.07 c
Velocity	157.5 c	149.6 bc	1,362 c	0.11 b
mean	144.4	151.6	1,944	0.08
LSD 0.05	7.6	6.3	95	0.01

cause greater stand reduction, spring irrigation may be seen to have a positive influence on stand density over time.

Seed Yield

The forage cultivar, ‘Fawn’, matured earlier than turf-type cultivars. Turf-type cultivars differed in maturity by a few days but not by a large enough margin to require multiple harvest dates. ‘Fawn’ reached peak anthesis on 27 May 2003 (doy 147), while the turf-type cultivars reached peak anthesis on 6 June 2003 (doy 157). Peak anthesis was attained on 10 May (doy 131) and 30 May (doy 151) in 2004 for ‘Fawn’ and the turf-type cultivars, respectively. The difference in maturity and limitations of the experimental design necessitated that irrigation application timing for ‘Fawn’ differ somewhat from the defined treatments. Nevertheless, ‘Fawn’, did not respond differently to irrigation than turf-type cultivars (Table 1-5). Young et al. (1998a) found similar relationships between ‘Fawn’ and turf-type cultivars in response to residue and nutrient management and row spacing. In 2003, ‘Fawn’ did respond differently between the single irrigation and maintained irrigation treatments. However, since irrigated treatments received equivalent amounts of water during the same period in 2003, the variable response of ‘Fawn’ is explained by heterogeneity in the field. At the time of spring tiller sampling in 2003, ‘Fawn’ fertile tiller number varied from 312 tillers m^{-2} to 840 tillers m^{-2} in irrigated plots. This same variation was not observed in other cultivars. Among turf-type cultivars in 2003, and among all

Table 1-5. ANOVA table for seed yield of tall fescue cultivars under irrigation in 2003 and 2004. "None vs. Some" compares no irrigation to any irrigation (single or maintained). "Turf" includes all cultivars with the exception of 'Fawn'.

		2003		2004	
Source	df	F-ratio	*P*-value	F-ratio	*P*-value
Irrigation	6	54.92	< 0.0001	0.84	0.4757
Cultivar	15	49.54	< 0.0001	98.75	< 0.0001
Irrigation X Cultivar	30	2.60	0.0211	2.28	0.0397
None vs. Some					
Fawn vs. Turf	1	3.26	0.0812	0.16	0.6925
Velocity vs. Arid 3	1	1.51	0.2294	4.21	0.0491
Velocity vs. Barrington	1	5.95	0.0208	12.92	0.0011
Velocity vs. Bingo	1	10.97	0.0024	8.78	0.0059
Velocity vs. SR8600	1	3.36	0.0768	13.42	0.0010
Single vs. Maintained					
Fawn vs. Turf	1	5.95	0.0209	0.36	0.5503
Velocity vs. Arid 3	1	0.00	0.9906	1.12	0.2992
Velocity vs. Barrington	1	2.77	0.1063	3.66	0.0654
Velocity vs. Bingo	1	0.02	0.8836	0.46	0.5023
Velocity vs. SR8600	1	0.00	0.9887	1.19	0.2849

cultivars in 2004, there were no differences in seed yield between single and maintained irrigation treatments.

Seed yield increases above the non-irrigated treatments were evident in both years (Table 1-6). All cultivars in 2003 had a variable, but positive response (13 to 39% over non-irrigated) to irrigation (single and maintained). Contrasts for 'Velocity' vs. 'Barrington' and 'Velocity' vs. 'Bingo' in 2003 indicate that these cultivars had a stronger response (37 to 39%) to irrigation than Velocity (13%). In 2004, 'Velocity' was unresponsive to irrigation, while yield in other cultivars was affected by irrigation. In 2004, irrigated (single and maintained) yields ranged from a loss of -6 to an increase of 28% in comparison with non-irrigated yields. 'Arid 3' was one of the least responsive cultivars in both years; this cultivar did not differ from 'Velocity' in 2003 and had somewhat lower magnitude in yield differences ($P = 0.049$) than other cultivars in 2004. This study corroborates other studies that indicate responses to water are cultivar dependant in tall fescue (Huang and Gao, 2000), four wheatgrass species (*Agropyron* sp.) (Frank et al., 1985) and wheat (Dubetz and Bole, 1973).

Irrigation treatments in 'Fawn' corresponded with late anthesis and continued into the seed fill period for 10 days in 2003 and 20 days in 2004. Irrigation applied during mid- to late- seed fill still provided a beneficial increase to seed yield. Late season irrigation did not increase yield of Kentucky bluegrass (*Poa pratensis* L.) in central Oregon (Mitchell et al., 1997).

Hebblethwaite (1977) found differences in response to irrigation between years based on growing season precipitation. Temperature, amount and timing of

Table 1-6. Influence of irrigation treatment, cultivar and year on seed yield, seed weight and seed number. Percent increase over non-irrigated plots is reported for each irrigation treatment and cultivar.

	Yield					Seed Weight					Seed Number per m^2				
Cultivar	None	Single		Moisture Maintained		None	Single		Moisture Maintained		None	Single		Moisture Maintained	
	kg ha^{-1}	kg ha^{-1}	%	kg ha^{-1}	%	g 1000^{-1}	g 1000^{-1}	%	g 1000^{-1}	%	no x 10^4	no x 10^4	%	no x 10^4	%
2003															
Arid 3	1477	1881	27	1817	23	2.456	2.566	5	2.582	5	6.02	7.33	22	7.05	17
Barrington	1485	1924	30	2121	43	2.355	2.492	6	2.492	6	6.31	7.73	23	8.53	35
Bingo	1711	2388	40	2346	37	2.323	2.379	2	2.446	5	7.37	10.09	37	9.61	30
Fawn	868	1275	47	970	12	3.115	3.264	5	3.306	6	2.79	3.91	40	2.71	-3
SR8600	1807	2293	27	2230	23	2.368	2.458	4	2.439	3	7.64	9.34	22	9.16	20
Velocity	1561	1798	15	1733	11	2.520	2.586	3	2.565	2	6.20	6.96	12	6.76	9
mean	1485	1927	30	1869	26	2.523	2.624	4	2.638	5	6.05	7.56	25	7.30	21
2004															
Arid 3	1810	1950	8	1988	10	2.352	2.451	4	2.414	3	7.70	7.96	3	8.40	9
Barrington	1382	1670	21	1848	34	2.243	2.296	2	2.323	4	6.17	7.28	18	7.99	29
Bingo	2277	2577	13	2553	12	2.262	2.311	2	2.334	3	10.06	11.19	11	10.96	9
Fawn	2069	2357	14	2300	11	3.228	3.247	1	3.162	-2	6.42	7.27	13	6.95	8
SR8600	2446	2811	15	2854	17	2.237	2.290	2	2.262	1	10.95	12.27	12	12.62	15
Velocity	2136	2071	-3	1936	-8	2.344	2.449	4	2.405	3	9.12	8.45	-7	8.05	-12
mean	2020	2239	11	2247	11	2.444	2.507	3	2.483	2	8.40	9.07	8	9.16	9

precipitation and variable disease pressures between years can impact the beginning of spring growth, yield component development and pollination. The weaker response to a greater amount of irrigation in 2004 with comparison to 2003 suggests that influence of irrigation on seed yield can not be easily quantified as the surrounding environment determines stress conditions.

Higher total precipitation was received in 2003 (Figure 1-2). However, above average precipitation in the second week of June 2004 provided sufficient moisture to relieve stress during a critical period (Table 1-2) and reduce the difference between irrigated and non-irrigated plots.

Components of Seed Yield

Timing of water deficit stress in grass species determines the effect on yield components (Day and Intalap, 1970; Johnson and Moss, 1976; Hebblethwaite, 1977; Rowarth et al., 1997). Hebblethwaite (1977) found that stress at multiple times were additive in decreasing yield but certain growth stages were more sensitive. Irrigation coincided with anthesis and the beginning of seed fill, reducing water deficit (Figure 1-1) in the seed fill process.

An increase in yield must be explained by an increase in seed number or seed weight or by a combination of the two (Ibrahim and Frakes, 1984; Fairey and Lefkovitch, 1999). Though interactions were evident in both years for yield response to irrigation, the two main components of seed yield, seed weight and seed number, did not exhibit a cultivar x irrigation interaction (Table 1-7). Results indicate that the

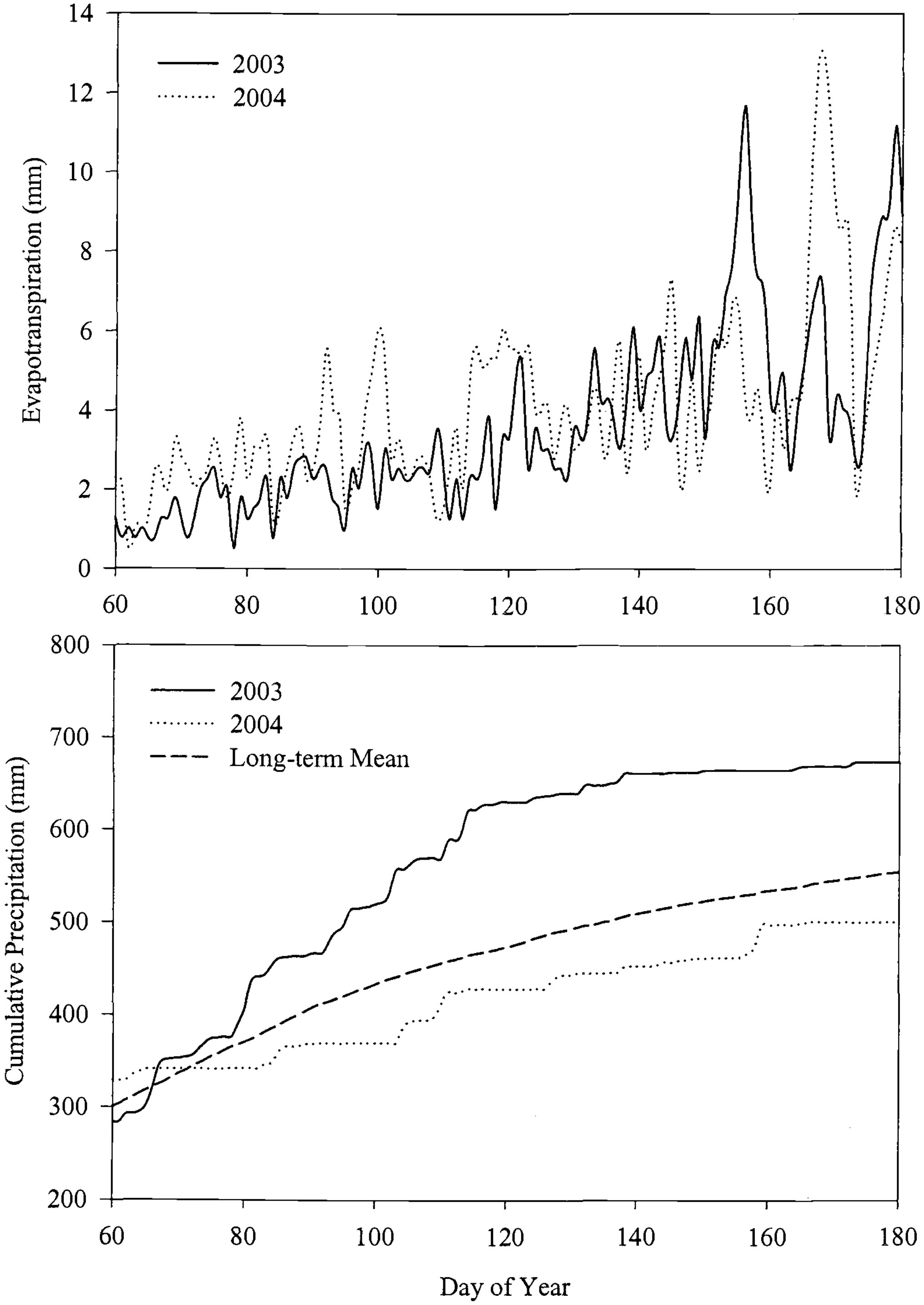

Figure 1-2. Evapotranspiration (ET) and cumulative precipitation for 2003 and 2004.

Table 1-7. ANOVA tables for seed weight and seed number of tall fescue cultivars under irrigation in 2003 and 2004.

		2003		2004	
Source	df	F-ratio	p-value	F-ratio	p-value
Seed Weight					
Irrigation	6	21.93	0.0017	9.51	0.0138
Cultivar	15	305.89	< 0.0001	279.16	< 0.0001
Irrigation X Cultivar	30	0.87	0.5704	1.36	0.2475
Seed Number					
Irrigation	6	28.63	0.0009	0.47	0.6437
Cultivar	15	79.43	< 0.0001	145.22	< 0.0001
Irrigation X Cultivar	30	2.07	0.0605	1.87	0.0904

additional water applied in the maintained treatment did not increase seed weight or seed number when compared to the single irrigation treatment. For discussion, irrigation treatments have been pooled and will be collectively referred to as irrigated.

Seed Weight

Seed weight was influenced by cultivar and irrigation in both years (Table 1-6). The increase of seed weight due to irrigation contradicts Rowarth et al. (1997) who did not observe changes in seed weight between stressed and non-stressed perennial ryegrass. Seed weight is a relatively constant character and changes are often small across a wide range of environments (Marshall, 1985; Young et al., 1998b). 'Fawn' had a much higher seed weight than the turf-type cultivars. Ibrahim and Frakes (1984) also found seed weight to be a genotype dependant characteristic.

Increased seed weight has been attributed to longer seed fill periods. Warringa et al. (1998) found that differences in seed weight within a spikelet could be partially attributed to different flowering times but a single ripening period. Species avoid drought by reaching physiological maturity earlier and reducing the amount of time water limited conditions must be survived (Lambert, 1967b; Kobata et al., 1992; Chaves et al., 2002). Typically, this hastens seed fill and results in lower seed weights (Johnson and Moss, 1976; Brooks et al., 1982).

Irrigated plots had slightly higher seed moisture content at swathing in 2003 but differences were more extreme in 2004. Experimental design prevented two swathing dates, however seed moisture differences would have resulted in only a few days between swathing dates. Delayed harvest has been reported in irrigated stands of timothy (*Phleum pretense* L.) (Lambert, 1967a) and perennial ryegrass (Hebblethwaite, 1977). Later senescence of irrigated stand may have led to increased seed weight as a result of a longer seed fill period.

Assimilates are not considered to be limiting in seed fill processes of perennial grasses (Warringa et al., 1998) as the inflorescence is the primary photosynthetic organ during this period (Marshall, 1985). Inflorescence assimilates are supported by mobilization of pre-anthesis photoassimilates and current photoassimilates from leaves and stems during stress (Clemence and Hebblethwaite, 1984). Griffith (2000) suggested that secondary growth may compete with seeds for assimilates, but agreed older tillers were not competing with seeds. Despite increased biomass production in irrigated plots, seed weight also increased. This corroborates Warringa and Kreuzer's (1996) findings that seed development was independent of new tiller growth in perennial ryegrass.

Though 'Velocity' did not show a yield response in 2004, seed weight was increased by irrigation. Seed weight has been associated with vigor (Berdahl and Frank, 1998), and Lewis and Garcia (1979) found that heavier seed produced higher seedling dry matter than lighter seed. The benefits of heavier seed are limited to early stages of seedling growth and development; however, stand establishment is important in the turf and forage industries. Ease of seed conditioning processes may be increased with larger seed size and help to minimize post-harvest expenses.

Seed Number

The influence of irrigation on seed number was inconsistent between years (Table 1-7) but cultivar differences existed in both years. In 2003, irrigation increased seed number but not in 2004. There is a high likelihood (*P* = 0.0605 in 2003 and *P* = 0.0904 in 2004) that seed number increases due to irrigation are cultivar dependant. For example, in 2004, 'Velocity' had a decline in seed number with irrigation, while other cultivars saw an increase.

Young et al. (1998b) and Elgersma (1990b) suggested that management practices needed to influence seed number rather than seed weight of turf-type cultivars to improve yield. Seed number was the most important component that led to increased yield in this study. Larger yield differences were observed in 2003 when irrigation increased seed number more than in 2004. A positive linear relationship ($y = 459.06 + 189.90x$, $r^2 = 0.87$) exists between seed number and seed yield for tall fescue (Figure 1-3). A similar relationship was found by Hebblethwaite et al. (1980) in perennial ryegrass.

Greater water resources may have increased assimilate availability to developing seeds and prevented seed abortion in irrigated plants. Abortion of developing seeds is common in perennial grasses (Marshall, 1985) and has often been attributed to lack of sufficient assimilate (Elgersma, 1990b). Changes in seed number due to seed abortion or shattering prior to harvest are unknown.

The increase in seed weight may have increased the efficiency of mechanical harvest and allowed a greater harvestable number of seeds as was found by Lambert

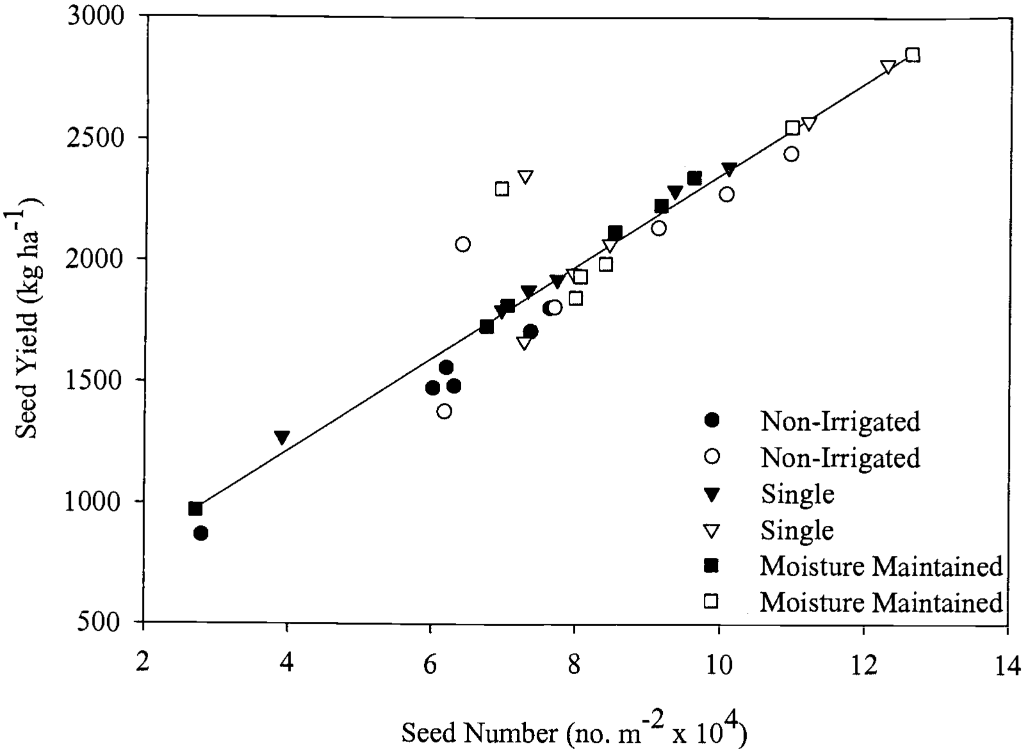

Figure 1-3. Seed yield (kg ha^{-1}) vs. seed number (no. m^{-2} x 10^{4}) for three irrigation treatments in 2003 (solid symbols) and 2004 (hollow symbols). Regression equation: $y = 459.06 + 189.90x$; $r^2 = 0.87$, $P < 0.001$.

(1967a). Seed loss during harvest was not measured quantitatively, however visual observations do not provide evidence that different numbers of light seeds were being lost in any treatment. Light seeds contribute little to cleanout percentages, however differences between irrigation treatments during seed conditioning were not observed.

The relative importance of seed number and seed weight is cultivar dependant with a tendency for seed number to be more important (Elgersma, 1990a; Khanna-Chopra et al., 1994). Results highlight these differences (Table 1-6). 'SR8600' had small increases in seed weight but the increase in yield was better explained by seed number. 'Barrington' had the greatest increase in seed weight in both years and also had a large increase in seed number.

Soil Water Depletion

Tall fescue is a deep-rooted plant with a root system that may extend beyond the 60 cm monitored by TDR. Burch and Johns (1978) observed soil water depletion by tall fescue to a depth of 80 cm, Karsten and MacAdam (2001) to a depth of 90 cm and Hebblethwaite and McGowan (1977) to 100 cm. Depletion of soil water was observed down to 60 cm, the bottom of the monitored profile (Figures 1-4 and 1-5). Depletion of soil water continued below this point, though amount and depth is unknown.

After 22 June 2004 (doy 174), 103 mm of water remained in the soil profile of non-irrigated plots, until swathing. In 2003, non-irrigated plots had 111 mm of water in the soil profile on 8 June (doy 159) and plants only drew an additional 10 mm of

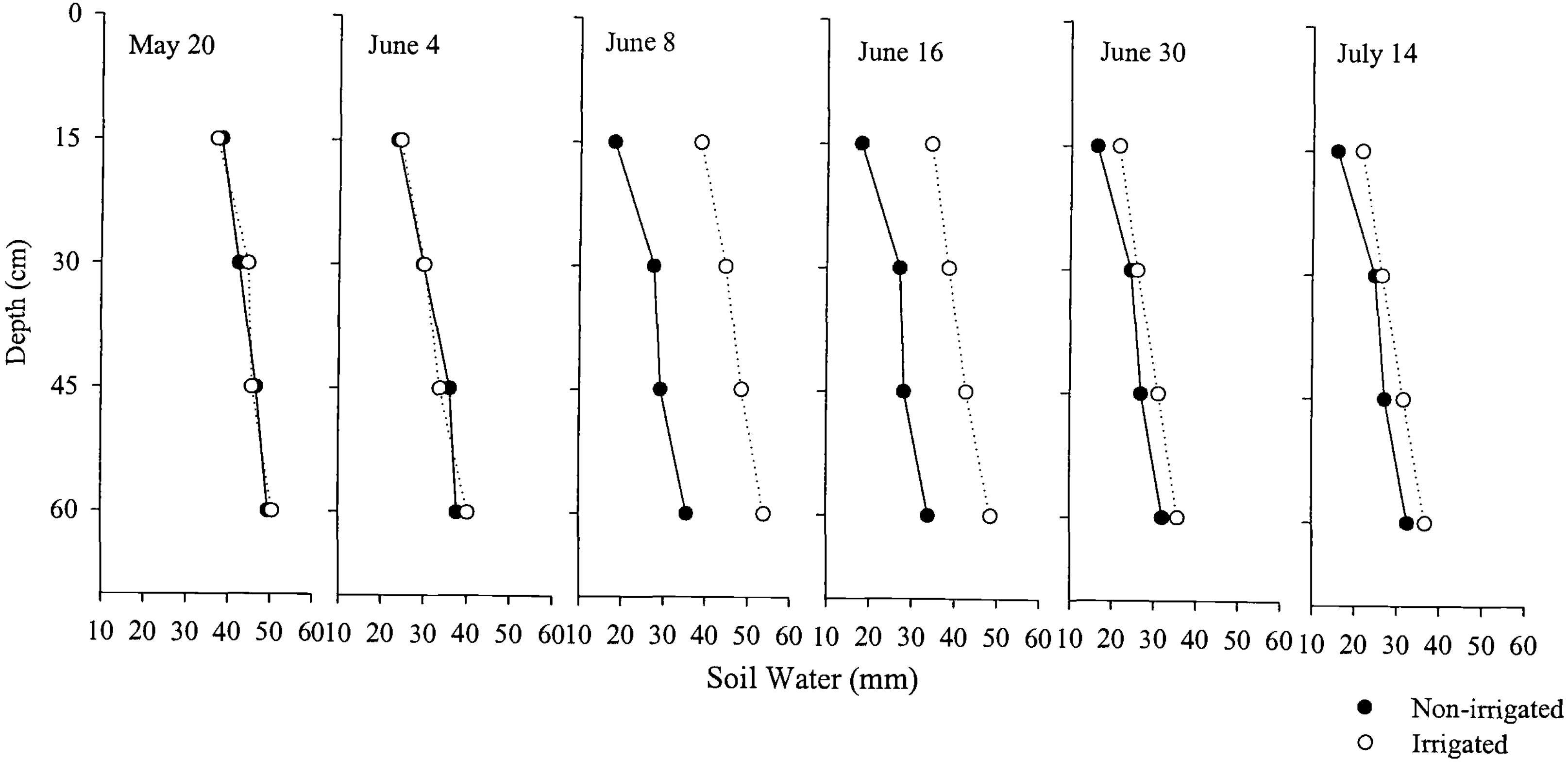

Figure 1-4. Profile soil water content for selected dates in 2003.

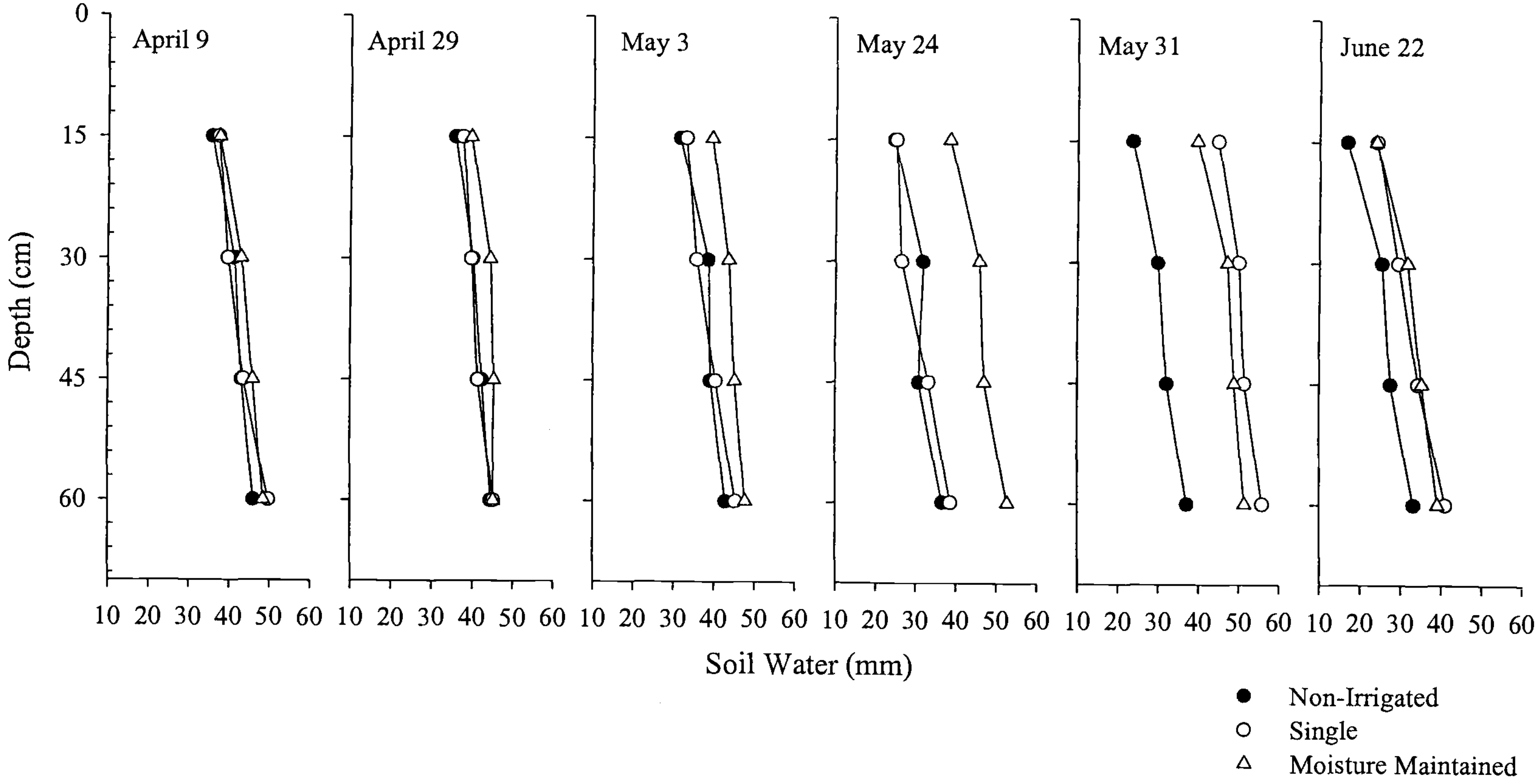

Figure 1-5. Profile soil water content for selected dates in 2004.

water until swathing on 1 July (doy 182) (Figure 1-1). Water tension must prevent further reductions in soil water and water demands must be met with water from lower in the profile. In neither year did plants have visible signs of wilting or stress, though leaf senescence began earlier in non-irrigated plants than in irrigated plants.

Irrigation in the maintained treatment was initiated on 28 April 2004 (doy 119) while it had been delayed until 4 June (doy 155) in 2003. Despite differences in weather between years, soil water had declined to similar levels in the single treatment by the time of the irrigation application 123 mm and 127 mm on 24 May 2004 (doy 145) and 4 June 2003 (doy 155), respectively.

Expected variation in maturity dates between ‘Velocity’ and ‘Arid 3’ was not observed. In addition, ‘Velocity’ did not show a consistent response to irrigation and ‘Arid 3’ was one of the weakest responding cultivars. ‘Arid 3’ and ‘Velocity’ did respond similarly in seed weight and calculated seed number to other cultivars. However, this does pose an interesting research question since these were the only two cultivars monitored. Is the soil water use pattern the same for cultivars responding differently to irrigation?

It is unknown whether processes within the plant (i.e., an ability to survive at low water potential or a difference in preferential partitioning of assimilates to seeds over vegetative components) influence yield responses or if differences in root systems are responsible. Root development of tall fescue cultivars is known to differ (Johnson and Asay, 1993) and could influence the amount of water available to plants.

Crop Management Observations

Within the stand, the crop provided sufficient competition to suppress weeds. Thin stands or fields planted on wider row spacing may be susceptible to weed control problems. Disease was not exacerbated by application of irrigation. Though fungicide was applied in both years, only a single application was necessary to control disease. Irrigation alters the canopy structure by increasing vegetative matter and reducing air movement through the stand. Problems could arise in years with high disease pressure. In 2003, irrigation did not increase lodging but when greater amounts of water were applied in 2004 lodging was slightly increased in irrigated plots.

In tall fescue cultivars the endophyte, *Neotyphodium coenophialum*, is considered to impart drought tolerance through multiple mechanisms (Malinowski and Belesky, 2000). Endophyte levels ranged from 0 to 95% for cultivars in the study (Gingrich et al., 2003). Endophyte level does not appear to be a predictor of response to irrigation with respect to seed yield of tall fescue.

CONCLUSIONS

This study demonstrates for the first time that spring irrigation increases seed yield of tall fescue. Response to irrigation was found to be cultivar dependant, but response could not be predicted by cultivar maturity date. As expected, yield increases in the Willamette Valley were dependant on growing season precipitation, specifically precipitation near anthesis and early seed fill. Available water during these growth stages increased yield and indicates the sensitivity of these periods to water deficits. Both seed number and weight were influenced by irrigation; however, greater yield increases were observed when seed numbers were increased. Irrigation and other management practices should aim to increase harvestable seed number.

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MANUSCRIPT II: SPRING IRRIGATION MANAGEMENT OF TALL FESCUE (*Festuca arundinacea* Schreb.) SEED CROPS: MEASURES OF BIOLOGICAL AND ECONOMIC EFFICIENCIES

ABSTRACT

Seed yield of tall fescue (*Festuca arundinacea* Schreb.) is increased with irrigation when water is limiting during seed fill in the Willamette Valley. This study reports biological (reproductive efficiency, harvest index and water use efficiency) and economic efficiencies of irrigation using data from a field study near Corvallis, Oregon. Six tall fescue cultivars were grown under three irrigation regimes: (1) dryland production, (2) irrigation just prior to anthesis to fill the soil profile to field capacity and (3) irrigation to maintain soil water deficit ≤ 50 mm below field capacity.

Irrigation did not increase reproductive efficiency in either year. Reproductive efficiencies differed for cultivars in 2003 but not in 2004. A slight trend of increased harvest index was observed with irrigation. Water use efficiencies ranged from 2.94 to 9.92 kg ha^{-1} mm^{-1} and response was dependent on year. Some cultivars showed a greater response to irrigation than other cultivars indicating greater sensitivity to environmental conditions. An economic analysis indicates that over the life of the stand, net income would increase with irrigation in responsive cultivars.

Keywords: Irrigation, *Festuca arundinacea* Schreb., Water Use Efficiency, Harvest Index, Reproductive Efficiency, Economic Analysis

INTRODUCTION

The Willamette Valley has traditionally produced high quality tall fescue grass seed without the aid of irrigation. However, the region receives 90 percent of its annual precipitation (1015 mm) between October and April, with little precipitation during late spring and summer. The summer drought limits crop production but our companion study found that spring irrigation increased seed yield of tall fescue (*Festuca arundinacea* Schreb.) (Orthel and Chastain, 2004). This study examines the biological and economic efficiencies of irrigating tall fescue seed crops.

Understanding changes in biological efficiencies provide insight into how a plant is utilizing resources and which components are most affected by inputs. Allocation of assimilates can be measured using harvest indices. Harvest index (HI) measures the proportion of total above-ground biomass utilized in economic yield (Sinclair, 1998). Traditionally, HI has been used to measure improvements in breeding programs over time. Reported HI values for wheat (*Triticum aestivum* L.) range from 0.30 to 0.45 (Johnson and Kanemasu, 1982; Yang et al., 2000). Elgersma (1990b) reported a HI of 0.12 and 0.10 for perennial ryegrass (*Lolium perenne* L.) cultivars grown in clayey and sandy soils, respectively.

Reproductive efficiency (RE) is the ratio of seeds recovered during harvest to the total amount of developed florets (Elgersma, 1985). Reproductive efficiencies of perennial grasses are low due to seed shattering, abortion and poor floret site utilization (Marshall, 1985). Young et al. (1998) reported RE of tall fescue to be from 37% to 53%.

Water use efficiency (WUE) is the crop yield per unit of water use (Howell, 2001). A wide range of WUE exist for crops and are influenced by management practices, soil characteristics and climatic conditions (Hatfield et al., 2001). Chen et al. (2003) did not find WUE differences among eight wheat cultivars in northeastern Oregon. WUE ranged from 13.7 kg ha^{-1} mm^{-1} to 15.5 kg ha^{-1} mm^{-1} under different irrigation treatments in the same cultivar (Ehlig and LeMert, 1976). In a review, Hatfield et al. (2001) cited wheat WUE ranged from 2.5 kg ha^{-1} mm^{-1} to 18.3 kg ha^{-1} mm^{-1}. No study was found that reported WUE for tall fescue seed.

WUE is calculated based on an estimate of crop water use (CWU). Hillel (1998) defines water use as:

[Eq 1] $CWU = R + D + E_d + E_s + T_w + T_c$

Where, R is runoff, D is deep percolation, E_d is water lost to evaporation during delivery to the field, E_s is evaporation from the soil, T_w is amount of water used by weeds and T_c is the volume transpired by the crop. A modified version Equation 1 is used for calculations in this study.

In productive cropping systems, producers need to make the most effective use of available water, labor and capital. Regardless of the increase in yield from irrigation, to implement a change in management practice in a production setting, a return must be seen beyond increased yield (i.e., improved soil conservation, improved weed control or a positive return to net profit). Water resources for irrigation are not limited and are relatively inexpensive within the Willamette Valley as is not the case in other areas of Oregon and the United States. However, irrigation can be a large expense of crop production and economics should be a major consideration in adopting alternative crop production practices.

The objectives of this study were to (1) determine the effect of spring irrigation on RE and HI of tall fescue cultivars, (2) measure WUE and develop an understanding of the influence of environment on cultivar performance and (3) evaluate the economic feasibility of irrigating tall fescue seed crops in the Willamette Valley.

MATERIALS and METHODS

Data collected from Orthel and Chastain (2004) were used to calculate measures of biological and economic efficiencies of irrigation in tall fescue seed production. The field experiment was conducted with six tall fescue cultivars and three irrigation treatments. Plots were arranged in a strip-plot experimental design. Five turf-type cultivars (‘Arid 3’, ‘Barrington’, ‘Bingo’, ‘SR8600’ and ‘Velocity’) and a single forage cultivar (‘Fawn’) were selected to represent a range of genotypes, plant morphological characteristics and crop maturity based on date of anthesis. Traditional dryland production was compared to (1) a single concentrated treatment that filled the soil profile to field capacity prior to seed fill and (2) a treatment that maintained the soil moisture to a deficit ≤ 50 mm below field capacity until peak anthesis. Regular soil moisture measurements were taken with time domain reflectometry (TDR) (SoilMoisture Equipment Corp., Santa Barbara, CA) (Musters and Bouten, 2000) throughout the growing season to monitor changes in soil water. Irrigation was applied with a Pierce Corporation Acremaster MicroLinear (Eugene, Oregon) equipped with D3000 sprayheads (Nelson Corporation, Walla Walla, Washington).

Plots were harvested with plot equipment. Harvested yield was measured directly in the field with a sub-sample being collected. Sub-samples were cleaned to marketable yield using a laboratory size Clipper M-2B (A.T. Farrell, Saginaw, MI). Samples to determine seed weight were hand cleaned using screens and a blower prior to counting. Two 1000 seed samples were counted by an electric seed counter (The Old Mill Company, Savage, MD) and weighed.

Measures of Biological Efficiency

Potential seed number (Y) was calculated using Equation 2 and is reported as potential seed number m^{-2}.

[Eq 2] Y = fertile tillers m^{-2} x spikelets $panicle^{-1}$ x florets $spikelet^{-1}$

Actual seed number was estimated by dividing total yield by seed weight. Reproductive efficiency (RE) is the ratio of actual seed number to potential seed number (Equation 3).

[Eq 3] RE = actual seed number / potential seed number

Harvest index (HI) was calculated using Equation 4.

[Eq 4] HI = clean seed yield $plot^{-1}$ / total above-ground plant biomass $plot^{-1}$

Two 30-cm sections of crop row were hand harvested in the spring just prior to anthesis to determine total above-ground plant biomass. Samples were oven-dried at 38 °C for two days prior to weighing.

The crop growing season was defined to start on 15 March (doy 75) and end on the day of swathing. Growing season crop water use (CWU) was calculated using Equation 5.

[Eq 5] $CWU = \Delta \text{Soil Water} + P + I - D - R$

Where, Δ soil water is the difference between beginning and ending soil water measurements, P is precipitation, I is irrigation, D is drainage and R is runoff. Drainage and runoff are considered negligible for the soil type. This equation does not account for water used prior to TDR measurements when the soil was saturated. Evapotranspiration (ET) reported by Agrimet (2004) has been used to estimate this water use. ET was summed from 15 March (doy 75) until the first TDR measurement and added to CWU.

Water use efficiency (WUE) was defined as

[Eq 6] WUE = Seed Yield / CWU

(Howell, 2001) and is expressed in kg ha^{-1} mm^{-1}. CWU is only known for two of the six cultivars. An average CWU from data was used to calculate WUE for all cultivars.

To estimate cultivar response to different environments, observed seed yields were regressed on means of the environment (year and irrigation treatment) (Elgersma, 1990a).

Economic Analysis

A partial budget was outlined to evaluate the economic feasibility of irrigation in tall fescue. Irrigation system expenses were determined using the Mississippi Budget Generator (Laughlin and Spurlock, 2004) and information from area producers. Early 2004 costs were used in this analysis. Fixed expenses represent the cost of owning equipment, including depreciation and interest. Direct costs include repair and maintenance, labor and fuel expense.

Irrigation system assumptions and costs are outlined in Table 2-1. Expected life, repair and maintenance, labor hours and application efficiencies were reported by Burt et al. (1999). This analysis assumes producers already own equipment and have the ability to irrigate. Custom conditioning costs (\$ 0.13 kg^{-1}) were used to measure changes in post-harvest conditioning expense. Changes in harvest expenses represent

Table 2-1. Assumptions used to calculate irrigation system fixed and direct costs.

Irrigation System		Purchase Price	Salvage Value	Annual Use	Useful Life	Performance Rate	Labor	R & M
	ha	------- $	-------	hrs	yrs	hrs ha-mm^{-1}	hrs ha-mm^{-1}	%*
Wheel-line	16	9,000	2,700	1600	15	2.6	0.012	2
Big Gun	28	40,000	8,000	700	15	10.3	0.007	6
Linear	24	80,000	24,000	1000	20	6.28	0.002	6

*Repair and maintenance: percent of capital cost hauling costs. Commodity price was assumed to be \$ 0.99 kg^{-1}. Average across all cultivars was used as the non-irrigated yield for each respective year.

Statistical Analysis

Data were tested using PROC GLM in a strip-plot design in the SAS Statistical Package (2001). Appropriate differences between irrigation treatments and cultivars were determined by a Fisher's t-test. Reported differences are significant at $P = 0.05$ unless otherwise noted.

RESULTS and DISCUSSION

Tables 2-2 reports yield data from the field experiment. Discussion of seed yield and seed yield components is presented in (Orthel and Chastain, 2004). Spring irrigation increased seed yield of most tall fescue cultivars. Magnitude of response was dependant on growing season precipitation, specifically near anthesis and early seed fill. Both seed weight and number were influenced positively by irrigation; however, greatest yield increases were seen when seed number was increased.

Reproductive Efficiency

Reproductive efficiency of perennial grasses is low (Marshall, 1985; Elgersma 1990b; Griffith and Chastain, 1997) and management practices that improve upon base values could be beneficial to the production system. Increases in RE could stem from a reduction in seed abortions or an increase in seed set at anthesis or both. Spring irrigation of tall fescue did not improve RE ($P = 0.54$, $P = 0.12$ for 2003 and 2004, respectively). In 2003, cultivars had different RE's as some cultivars were able to achieve a greater portion of potential yield (Table 2-3). Cultivar differences were not evident in 2004. Reported RE's are lower than those previously reported for tall fescue (Young et al., 1998).

Seed number was increased by irrigation in 2003 but not in 2004 (Table 2-2). A reduction in seed abortion may have occurred in 2003 because a larger supply of assimilates were available to support seed fill in irrigated plants. Whereas in 2004, the

Table 2-2. Influence of irrigation treatment, cultivar and year on seed yield, seed weight and seed number.

	Yield			Seed Weight			Seed Number per m^2		
Cultivar	None	Single	Moisture Maintained	None	Single	Moisture Maintained	None	Single	Moisture Maintained
	------ kg ha^{-1} ------			------ g 1000^{-1} ------			------ no x 10^4 ------		
2003									
Arid 3	1477	1881	1817	2.456	2.566	2.582	6.02	7.33	7.05
Barrington	1485	1924	2121	2.355	2.492	2.492	6.31	7.73	8.53
Bingo	1711	2388	2346	2.323	2.379	2.446	7.37	10.09	9.61
Fawn	868	1275	970	3.115	3.264	3.306	2.79	3.91	2.71
SR8600	1807	2293	2230	2.368	2.458	2.439	7.64	9.34	9.16
Velocity	1561	1798	1733	2.520	2.586	2.565	6.20	6.96	6.76
mean	1485	1927	1869	2.523	2.624	2.638	6.05	7.56	7.30
2004									
Arid 3	1810	1950	1988	2.352	2.451	2.414	7.70	7.96	8.40
Barrington	1382	1670	1848	2.243	2.296	2.323	6.17	7.28	7.99
Bingo	2277	2577	2553	2.262	2.311	2.334	10.06	11.19	10.96
Fawn	2069	2357	2300	3.228	3.247	3.162	6.42	7.27	6.95
SR8600	2246	2811	2854	2.237	2.290	2.262	10.95	12.27	12.62
Velocity	2136	2071	1936	2.344	2.449	2.405	9.12	8.45	8.05
mean	2020	2239	2247	2.444	2.507	2.483	8.40	9.07	9.16

Table 2-3. Reproductive efficiency of tall fescue cultivars under different irrigation regimes in 2003 and 2004.

	2003				2004			
Cultivar	Non-irrigated	Single	Moisture Maintained	mean	Non-Irrigated	Single	Moisture Maintained	mean
Arid 3	18	21	19	19 a[1]	24	29	36	29
Barrington	14	20	25	20 a	30	29	30	30
Bingo	21	22	23	22 a	32	30	33	32
Fawn	12	16	10	13 b	24	28	20	24
SR8600	23	20	24	22 a	32	49	43	41
Velocity	16	16	20	17 ab	33	29	33	32
mean	17	19	20	19	29	32	32	31

[1] LSD 0.05 = 5

rain events during the second week of June (36 mm) likely provided sufficient assimilates to reduce seed abortion in non-irrigated plants.

Pollination and fertilization were unlikely to be altered by irrigation. Regardless of irrigation, plants experienced the same fluctuations in temperature and humidity that influence flowering processes. Reproductive efficiency across all treatments between years (0.19 in 2003, 0.31 in 2004) is indicative of a more favorable pollination environment in 2004. Irrigation would have helped to minimize stress of high temperatures that occurred near anthesis in 2003. However, 'Fawn', which reached anthesis earlier, had more favorable conditions than turf-type cultivars during peak anthesis, but still had an increase in seed number with irrigation.

Reproductive efficiency is calculated from many different components. Error in sampling within each of these components may be multiplied through the calculation and strongly influence the final value. Floret site utilization is not known as seed number was based on harvested yield rather than individual bagged panicles. Seed lost during thrashing as well as loss from shedding was not accounted for in the present work.

Harvest Index

An increase in HI indicates that a greater share of assimilates are being partitioned to seed yield rather than vegetative growth. Harvest index was cultivar dependant in both 2003 and 2004 (Table 2-4). A slight trend of increased HI is observed in irrigated plants over non-irrigated plants. Elgersma (1990b) found that

Table 2-4. Harvest index (HI) and water use efficiency (WUE) of tall fescue cultivars in 2003 and 2004. Plant biomass samples taken at anthesis and seed biomass from harvest were used to estimate HI. Water use calculations were made using crop water use estimates based on applied water from sprinkler output specifications. Water use estimates for 2003 were 266, 330 and 330 mm for non-irrigated, single and moisture maintained, respectively. Water use estimates for 2004 were 247, 343 and 409 for non-irrigated, single and moisture maintained, respectively.

	2003				2004			
Cultivar	Non-Irrigated	Single	Moisture Maintained	mean	Non-Irrigated	Single	Moisture Maintained	mean
	---------- Harvest Index ----------							
Arid 3	0.10	0.13	0.12	0.12 a[1]	0.12	0.13	0.13	0.12 b[2]
Barrington	0.09	0.12	0.14	0.12 a	0.10	0.10	0.14	0.11 b
Bingo	0.11	0.14	0.13	0.13 a	0.12	0.13	0.14	0.13 b
Fawn	0.05	0.06	0.05	0.05 c	0.17	0.19	0.17	0.18 a
SR8600	0.10	0.13	0.14	0.12 a	0.13	0.17	0.18	0.16 a
Velocity	0.09	0.10	0.10	0.10 b	0.12	0.12	0.12	0.12 b
mean	0.09	0.11	0.11	0.10	0.12	0.14	0.15	0.10
	---------- Water Use Efficiency (kg ha^{-1} mm^{-1}) ----------							
Arid 3	5.55	5.68	5.52	5.58	7.34	5.68	4.86	5.96
Barrington	5.57	5.81	6.44	5.94	5.60	4.86	4.52	4.99
Bingo	6.42	7.22	7.12	6.92	9.23	7.51	6.24	7.66
Fawn	3.26	3.85	2.94	3.35	8.39	6.86	5.62	6.96
SR8600	6.78	6.93	6.77	6.83	9.92	8.19	6.98	8.36
Velocity	5.86	5.43	5.26	5.52	8.66	6.03	4.73	6.47
mean	5.57	5.82	5.68	5.69	8.19	6.52	5.49	6.73

[1] LSD 0.05 = 0.02

[2] LSD 0.05 = 0.02

perennial ryegrass grown on soils with higher water holding capacity (clay soils) had higher HI than soils with a lower water holding capacity (sandy soils).

Calculations were made based on above-ground plant biomass at anthesis and as irrigated plants had greater biomass at harvest than non-irrigated plants this may not be a true measure of HI. Unlike an annual plant, the perennial nature of tall fescue utilizes current assimilates during seed fill to support growth of vegetative tillers. Greatly increasing the HI may be detrimental to the perenniality of the crop as vegetative growth may not be maintained.

Water Use Efficiency

In 2003, crop water use estimates were 266 and 330 mm for non-irrigated and irrigated (single and maintained) treatments, respectively. Crop water use estimates were 247, 343 and 409 mm for non-irrigated, single and maintained treatments in 2004, respectively. These estimates are based on the assumptions that the effective rooting zone of tall fescue is 60 cm and all cultivars used soil water similarly. Watts et al. (1968) reported a similar value of water (281 mm) needed for the growing season from March to June. Cuenca et al. (1992) reported a much higher value of 762 mm, however this estimate was based on a year-round growing season.

In non-irrigated treatments, WUE was greater in 2004 than in 2003 (Table 2-4). In 2003, WUE of irrigated plants (5.75 kg ha^{-1} mm^{-1}) was greater than that of non-irrigated plots (5.57 kg ha^{-1} mm^{-1}), but not in 2004. These values are within the same range as WUE reported for major grass species [corn (*Zea mays* L.): 4.64 to 12.03 kg ha^{-1} mm^{-1} (Norwood, 2001); wheat: 2.5 to 18.3 kg ha^{-1} mm^{-1} (Hatfield et al., 2001)]. Higher water use efficiencies were achieved when sufficient water (but not excess water as in the maintained treatment) was available to support early seed fill. If crop water use for an individual cultivar differs from these estimates, WUE could be significantly different.

Environmental Response

The relation between environment and individual cultivars are graphed in Figure 2-1. All cultivars, with the exception of 'Barrington' ($r^2 = 0.03$), show a linear relationship to environment ($r^2 = 0.68$ to 0.98). While response to irrigation is seen, the unknown variables that increased yield in 2004 over 2003 did not influence 'Barrington'.

Nguyen and Sleper (1983) reported a cultivar x environment interaction in tall fescue seed production. Tall fescue cultivars are synthetics composed of multiple genotypes. Synthetics are considered to be buffered against environmental changes to a greater extent than a cultivar of a single genotype. 'Arid 3' and 'Velocity', which responded least to irrigation, may have a complement of genotypes that minimize the effect of drought. Large changes in yield with increased water would not be expected in this case, as was observed in this study.

The difference in the magnitude of response to irrigation (28 and 11% yield increase over non-irrigated yields for 2003 and 2004, respectively) between years could be attributed to (1) different responses through the life of the stand, (2) different

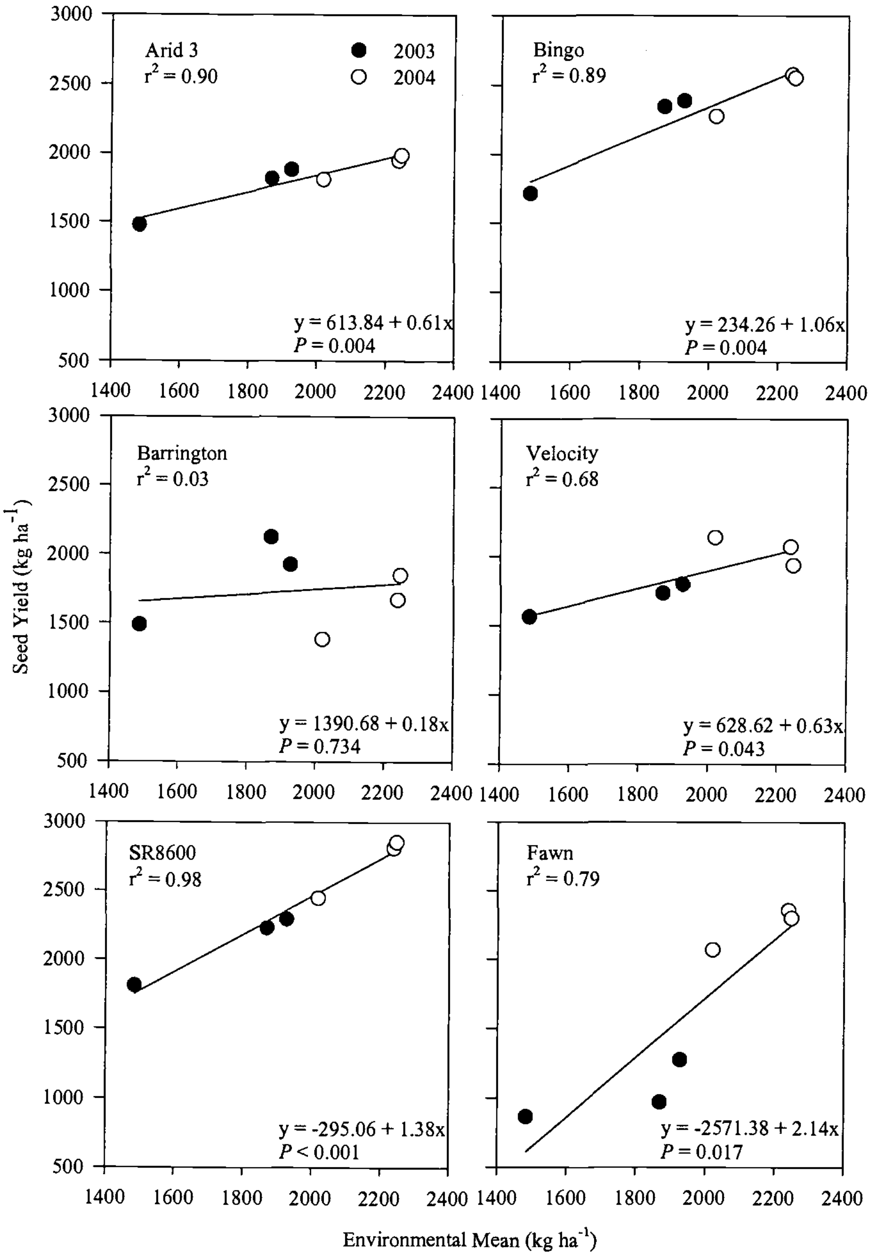

Figure 2-1. Response of tall fescue cultivars to environmental conditions in 2003 and 2004. Environmental mean is the average seed yield across cultivars of each year and treatment.

environmental conditions between years or (3) unmeasured residual effects. Zapiola et al. (2003) has found that response to plant growth regulators is dependent on the age of a fine fescue (*Festuca rubra* L.) stand. Yields of alfalfa (*Medicago sativa* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) seed responded differently to irrigation based on stand age (Steiner et al., 1992; Garcia-Diaz and Steiner, 2000). Seed yield changes over the life of a tall fescue stand and yield is maintained by maximizing number of fertile tillers (Young et al., 1998). Because this study did not replicate stand years and only includes data from a single stand, stand age effects cannot be determined.

Root growth and development in tall fescue are known to be influenced by available water (Huang and Gao, 2000). Irrigation may have limited root growth in 2003 as the plants did not need to explore a greater volume of soil to meet water demands. On the other hand, Huang and Gao (2000) report root mortality in drying soils down to 60 cm. Burch and Johns (1978) found that small changes (0.2 cm cm^{-3}) influenced the rate of water uptake by tall fescue. Jones et al. (1980) suggested that a drought stressed sward had greater root biomass than an irrigated sward. A lack of root mass may precondition the plant for a reduction in drought hardiness.

Using root mass and soil water depletion, Lambert (1967) was able to understand differences in response to irrigation. In plants with similar root mass, plants under higher deficit showed greater response to irrigation than plants under a lower deficit. At a lower root mass, yields were increased with irrigation even when water deficits were not extreme. Experimental design precluded destructive sampling of plots to study effective rooting depth and effect of irrigation on roots.

Economic Analysis

Table 2-5 outlines partial budgets for change in net income of irrigated production over dryland production. For experimental results, irrigation increased per hectare net profits by \$253 and \$216 for wheel-lines and a big gun system, respectively in 2003. In the single application of 112 mm of 2004, an additional \$79 ha^{-1} was earned with a wheel-line system. The profits increased to \$65 ha^{-1} if the 172 mm of water was applied in the maintained treatment. The big gun earned approximately \$42 ha^{-1} for the single application rate and \$28 ha^{-1} for the maintained treatment.

The greatest increase in costs, in irrigated production, is associated with the fixed costs of irrigation equipment. Much greater fixed costs are associated with the newer linear system technology than with more traditional irrigation systems (Table 2-5 and 2-6.) Higher net returns are likely to be observed by growers as older irrigation equipment is used or the fixed costs associated with irrigation equipment are covered by crops more traditionally irrigated.

The effect of market changes can be observed in Table 2-6. Changes in net income are reflective of tall fescue cultivars grown on a silt clay loam soil with good drainage. Production in regions of sandy soil will require irrigation to make a net profit while regions with poor drainage may see detrimental responses to irrigation as a result of anoxia. However, profitability over the life of the stand will most likely be increased with spring irrigation in regions having soils with similar texture and drainage

Table 2-5. Net change in income over non-irrigated production for spring irrigated tall fescue in the Willamette Valley.

	2003			2004					
				Single			Maintained		
	Wheel-line	Big Gun	Linear	Wheel-line	Big Gun	Linear	Wheel-line	Big Gun	Linear
	$\$$ ha^{-1}								
Increased Returns									
Seed Yield*	411.84	411.84	411.84	219.78	219.78	219.78	219.78	219.78	219.78
Reduced Costs	--	--	--	--	--	--	--	--	--
Increased Costs									
Irrigation									
Fixed Annual Costs	86.45	123.50	296.40	86.45	123.50	296.40	86.45	123.50	296.40
Direct Costs	17.16	17.16	17.16	24.64	24.64	24.64	39.16	39.16	39.16
Seed Conditioning	54.08	54.08	54.08	28.86	28.86	28.86	28.86	28.86	28.86
Harvest	0.44	0.44	0.44	0.22	0.22	0.22	0.22	0.22	0.22
Reduced Returns	--	--	--	--	--	--	--	--	--
Net Change in Income	253.71	216.65	43.75	79.61	42.56	-130.34	65.09	28.04	-144.86

*Non-irrigated yields were 1485 and 2020 kg ha^{-1} for 2003 and 2004, respectively. Average percent increase with irrigation in 2003 was 28%. Average percent increase for single and maintained in 2004 were 11 and 11%, respectively.

Table 2-6. Net income for tall fescue at various commodity prices and levels of yield increase resulting from irrigation in 2003 and 2004.

Yield Increase	Wheel-line					Big Gun					Linear				
	Commodity Price ($ kg^{-1})														
	0.77	0.88	0.99	1.10	1.21	0.77	0.88	0.99	1.10	1.21	0.77	0.88	0.99	1.10	1.21
kg ha^{-1}	$ ha^{-1}														
2003															
200	24.17	46.17	68.17	90.17	112.17	-12.88	9.12	31.12	53.12	75.12	-188.78	-164.78	-142.78	-120.78	-98.78
300	88.06	121.06	154.06	187.06	220.06	51.01	84.01	117.01	150.01	183.01	-122.89	-89.89	-56.89	-23.89	9.11
400	151.95	195.95	239.95	283.95	327.95	114.90	158.90	202.90	246.90	290.90	-59.00	-15.00	29.00	73.00	117.00
416	162.19	207.95	253.71	299.47	345.23	125.14	170.90	216.66	262.42	308.18	-48.76	-3.00	42.76	88.52	134.28
500	215.84	270.84	325.84	380.84	435.84	178.79	233.79	288.79	343.79	398.79	4.89	59.89	114.89	169.89	224.89
2004 Single Treatment															
100	-47.20	-36.20	-25.20	-14.20	-3.20	-84.25	-73.25	-62.25	-51.25	-40.25	-257.15	-246.15	-235.15	-224.15	-213.15
200	16.69	38.69	60.69	82.69	104.69	-20.36	1.64	23.64	45.64	67.64	-193.26	-171.26	-149.26	-127.26	-105.26
222	30.77	55.19	79.61	104.03	128.45	-6.28	18.14	42.56	66.98	91.40	-179.18	-154.76	-130.34	-105.92	-81.50
300	80.58	113.58	146.58	179.58	212.58	43.53	76.53	109.53	142.53	175.53	-129.37	-96.37	-63.37	-30.37	2.63
400	144.47	188.47	232.47	276.47	320. 47	107.42	151.42	195.42	239.42	283.42	-65.48	-21.48	22.52	66.52	110.52
2004 Maintained Treatment															
100	-61.72	-50.72	-39.72	-28.72	-17.72	-98.77	-87.77	-76.77	-65.77	-54.77	-271.67	-260.67	-249.67	-238.67	-227.67
200	2.17	24.17	46.17	68.17	90.17	-34.88	-12.88	9.12	31.12	53.12	-207.78	-185.78	-163.78	-141.78	-119.78
222	16.25	40.67	65.09	89.51	113.93	-20.80	3.62	28.04	52.46	76.88	-193.70	-169.28	-144.86	-120.44	-96.02
300	66.06	99.06	132.06	165.06	198.06	29.01	62.01	95.01	128.01	161.01	-143.89	-110.89	-77.89	-44.89	-11.89
400	129.95	173.95	217.95	261.95	305.95	92.90	136.90	180.90	224.90	268.90	-80.00	-36.00	8.00	52.00	96.00

CONCLUSIONS

Irrigation was not found to change RE or HI of tall fescue cultivars. Effects on WUE were different between the two years and reflect the amount of water applied. Crop water use was similar between years for the dryland treatments; however, due to the pattern of precipitation, seed yields were increased in 2004 resulting in an increase of WUE over 2003 dryland yields. Higher WUE will be achieved when plants have available water during the seed fill period.

This study shows that genetic differences exist among cultivars for assimilate utilization during seed production. Cultivar differences were evident for RE in 2003 and for WUE and HI in both years. Water use efficiencies reported here are similar to other grass species; however, HI was lower than in wheat but similar to values observed for perennial ryegrass.

An economic analysis demonstrates that irrigation of tall fescue in the Willamette Valley can increase profitability of seed production over the life of a stand. Irrigation should be applied to provide soil water during early seed fill of tall fescue for the most efficient use of the resource and highest economic return.

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SUMMARY and CONCLUSIONS

Reduced water deficit, at the beginning of seed fill, increased seed yield of tall fescue. Maintaining soil water deficit at a level that prevents stress did not provide any additional benefits to a well-planned irrigation just prior to seed fill. In 2003, the weather was hot and dry from anthesis through seed fill while in 2004, above average precipitation (122%) was received during the beginning of seed fill. In 2004, all cultivars were responsive to irrigation with the exception of 'Velocity'. Greater increases above non-irrigated yields were observed in 2003 for all cultivars when less precipitation was received during anthesis and seed fill. Regardless of seed yield response, irrigation increased seed weight in 2003 and 2004. Seed number was increased by irrigation in 2003 but not in 2004. Increases of seed number are critical to improving yields of tall fescue as greater yield responses were observed when irrigation increased seed number.

Irrigation did not improve HI or RE of tall fescue. These values, in addition to many characteristics of the panicle, were determined by cultivar. Reported values of HI are similar to findings of other authors (Elgersma, 1990b); however, RE in the present experiment was lower than was found by Young et al. (1998). Water use efficiencies were in a similar range as other grass species (Hatfield et al., 2001; Norwood, 2001).

Some cultivars showed greater stability across environments than others. Irrigation will be more beneficial in very responsive cultivars and provide a greater return for investments in irrigation.

Future Research

This research increased our understanding of irrigation in tall fescue. However, as in all research, findings provide further questions to be answered. Root development in tall fescue has been studied in other tall fescue production systems but not in reference to irrigation for seed yield. If seed yield response to tall fescue is influenced by root growth and development, this could provide a potential screening tool in breeding programs to develop cultivar-specific management practices. Use of plant growth regulators (PGR) to control lodging is widespread in the Willamette Valley. Understanding interactions between irrigation and PGR's is necessary to develop best management practices. Fall irrigation has been studied in perennial ryegrass but not in tall fescue. Continued research should address the potential impacts of fall irrigation on stand persistence and seed yield.

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APPENDIX

Appendix-Table 1. Soil water data based on TDR measurements in 2003 for the cultivar 'Arid 3'.

		Volumetric Water Content (θ)				mm of water				
Trt	Date	15 cm	30 cm	45 cm	60 cm	15 cm	30 cm	45 cm	60 cm	profile
None	20 May	25.0	30.2	32.0	33.5	37.55	45.35	47.95	50.20	181.05
	27 May	18.9	25.5	29.2	31.4	28.35	38.30	43.75	47.10	157.50
	31 May	16.1	22.9	26.6	29.9	24.15	34.35	39.90	44.80	143.20
	4 Jun	16.4	19.5	25.2	25.3	24.55	29.25	37.80	37.95	129.55
	8 Jun	11.9	19.3	21.4	24.1	17.85	28.90	32.15	36.20	115.10
	10 Jun	10.4	19.4	21.1	24.0	15.65	29.10	31.65	36.00	112.40
	16 Jun	11.9	19.0	20.3	23.0	17.90	28.50	30.45	34.50	111.35
	23 Jun	12.4	18.8	20.7	22.6	18.60	28.15	31.10	33.85	111.70
	30 Jun	10.7	17.4	18.7	21.7	16.00	26.05	28.00	32.60	102.65
	7 Jul	10.7	16.2	21.6	22.7	16.10	24.30	32.40	34.05	106.85
	14 Jul	10.2	17.4	18.9	22.2	15.35	26.10	28.40	33.30	103.15
Single	20 May	24.2	28.5	32.5	32.5	36.35	42.75	48.80	48.80	176.70
	27 May	20.7	24.4	30.0	30.3	31.10	36.55	45.00	45.50	158.15
	31 May	18.9	22.8	27.5	28.5	28.35	34.15	41.20	42.80	146.50
	4 Jun	17.1	20.0	22.7	28.5	25.60	30.05	34.10	42.70	132.45
	8 Jun	31.0	30.6	33.1	36.2	46.45	45.90	49.60	54.25	196.20
	10 Jun	32.1	31.9	33.3	36.7	48.15	47.90	49.90	55.00	200.95
	16 Jun	25.5	26.0	29.6	32.4	38.20	39.05	44.40	48.60	170.25
	23 Jun	20.2	22.0	25.1	28.4	30.35	32.95	37.65	42.55	143.50
	30 Jun	16.3	18.3	20.8	22.0	24.40	27.45	31.25	33.00	116.10
	7 Jul	15.2	18.0	21.2	24.8	22.85	26.95	31.80	37.20	118.80
	14 Jul	16.3	17.9	20.7	24.7	24.40	26.85	31.05	37.05	119.35
Main.	20 May	26.4	30.3	30.5	32.6	39.55	45.45	45.70	48.95	179.65
	27 May	22.1	26.5	27.4	31.0	33.20	39.70	41.05	46.45	160.40
	31 May	20.9	24.5	24.9	29.1	31.30	36.80	37.40	43.70	149.20
	4 Jun	16.6	23.3	23.9	25.9	24.90	34.95	35.80	38.80	134.45
	8 Jun	27.4	30.4	32.9	33.9	41.05	45.55	49.30	50.90	186.80
	10 Jun	27.3	30.6	33.0	34.8	41.00	45.85	49.50	52.15	188.50
	16 Jun	21.7	27.0	29.7	31.4	32.50	40.45	44.60	47.05	164.60
	23 Jun	17.0	23.4	25.9	27.3	25.55	35.05	38.80	40.90	140.30
	30 Jun	13.2	18.9	22.0	23.5	19.80	28.35	33.00	35.25	116.40
	7 Jul	11.3	20.8	20.4	22.8	17.00	31.15	30.60	34.15	112.90
	14 Jul	12.7	18.5	22.1	23.8	19.10	27.70	33.10	35.70	115.60

Appendix-Table 2. Soil water data based on TDR measurements in 2003 for the cultivar 'Velocity'.

		Volumetric Water Content (θ)				mm of water				
Trt	Date	15 cm	30 cm	45 cm	60 cm	15 cm	30 cm	45 cm	60 cm	profile
None	20 May	24.5	29.4	28.9	34.0	36.80	44.10	43.35	50.95	175.20
	27 May	18.7	25.2	24.5	32.0	28.10	37.75	36.75	48.00	150.60
	31 May	16.3	23.7	22.5	28.6	24.50	35.50	33.70	42.90	136.60
	4 Jun	15.2	20.2	22.9	25.1	22.75	30.35	34.35	37.70	125.15
	8 Jun	12.2	17.6	17.7	23.4	18.30	26.40	26.55	35.10	106.35
	10 Jun	11.7	16.8	18.7	23.4	17.60	25.25	28.05	35.10	106.00
	16 Jun	11.9	17.1	17.2	22.2	17.85	25.60	25.80	33.35	102.60
	23 Jun	11.6	16.8	16.7	22.1	17.45	25.25	25.10	33.15	100.95
	30 Jun	11.0	15.3	17.3	21.2	16.50	22.95	26.00	31.75	97.20
	7 Jul	11.3	16.0	16.0	22.2	16.95	24.05	23.95	33.30	98.25
	14 Jul	10.9	15.7	17.4	21.4	16.30	23.50	26.05	32.05	97.9
Single	20 May	25.0	28.2	30.6	35.0	37.55	42.35	45.85	52.45	178.20
	27 May	13.1	15.9	26.8	32.9	19.60	23.90	40.15	49.40	133.05
	31 May	16.7	19.3	24.7	31.0	25.00	29.00	37.00	46.45	137.45
	4 Jun	17.4	17.6	20.2	26.8	26.10	26.35	30.25	40.25	122.95
	8 Jun	21.9	29.3	32.2	38.1	32.85	43.90	48.25	57.15	182.15
	10 Jun	29.9	33.2	33.3	41.6	44.90	49.85	50.00	62.45	207.20
	16 Jun	23.0	25.0	27.9	35.2	34.45	37.45	41.90	52.85	166.65
	23 Jun	17.6	20.3	23.9	29.3	26.45	30.40	35.90	44.00	136.75
	30 Jun	13.9	14.6	19.5	26.5	20.90	21.85	29.20	39.70	111.65
	7 Jul	12.1	16.1	20.0	25.9	18.10	24.15	30.05	38.85	111.15
	14 Jul	14.1	15.8	20.7	26.3	21.10	23.65	31.05	39.40	115.2
Main.	20 May	26.1	26.2	30.7	32.1	39.20	39.30	46.00	48.20	172.70
	27 May	21.6	21.4	28.3	29.6	32.45	32.05	42.50	44.40	151.40
	31 May	20.3	19.3	26.8	27.6	30.45	28.90	40.20	41.45	141.00
	4 Jun	14.0	19.2	23.0	26.3	21.00	28.85	34.55	39.50	123.90
	8 Jun	23.0	29.1	31.6	35.9	34.45	43.70	47.40	53.80	179.35
	10 Jun	27.4	29.0	31.2	36.6	41.10	43.50	46.85	54.90	186.35
	16 Jun	21.6	24.9	26.8	30.6	32.35	37.35	40.20	45.95	155.85
	23 Jun	17.7	21.4	23.2	26.7	26.55	32.05	34.85	40.00	133.45
	30 Jun	14.0	17.7	20.7	23.4	21.00	26.50	31.05	35.10	113.65
	7 Jul	13.6	17.6	22.5	22.8	20.40	26.40	33.75	34.20	114.75
	14 Jul	14.7	18.7	21.1	23.6	22.10	28.00	31.60	35.40	117.1

Appendix-Table 3. Soil water data based on TDR measurements in 2004 for the cultivar 'Arid 3'.

		Volumetric Water Content (θ)				mm of water				
Trt	Date	15 cm	30 cm	45 cm	60 cm	15 cm	30 cm	45 cm	60 cm	profile
None	17 Mar	26.9	31.9	33.2	34.7	40.43	47.85	49.80	52.05	190.13
	1 Apr	26.3	30.6	30.6	32.3	39.45	45.90	45.90	48.50	179.75
	9 Apr	23.6	28.2	29.3	31.1	35.50	42.35	43.95	46.75	168.55
	22 Apr	29.2	32.6	28.1	31.1	43.88	49.00	42.23	46.75	181.85
	26 Apr	25.7	27.6	28.4	31.1	38.63	41.45	42.60	46.65	169.33
	29 Apr	23.6	26.3	27.7	30.2	35.50	39.50	41.63	45.35	161.98
	1 May	22.8	26.7	28.1	30.1	34.20	40.15	42.23	45.20	161.78
	3 May	21.4	26.3	27.2	29.6	32.10	39.50	40.88	44.40	156.88
	11 May	20.3	24.6	25.9	28.4	30.53	36.90	38.93	42.70	149.05
	13 May	19.6	24.8	26.1	28.1	29.48	37.20	39.23	42.25	148.15
	17 May	17.4	23.4	25.0	27.0	26.10	35.10	37.58	40.55	139.33
	19 May	18.6	23.0	25.1	27.0	27.90	34.50	37.73	40.50	140.63
	24 May	17.0	22.2	20.1	26.6	25.50	33.30	30.15	39.98	128.93
	29 May	16.0	21.7	23.9	23.7	24.08	32.55	35.85	35.63	128.10
	31 May	16.3	20.8	23.5	25.6	24.55	31.20	35.25	38.40	129.40
	1 Jun	15.4	20.6	23.7	24.3	23.15	30.90	35.63	36.50	126.18
	4 Jun	14.8	19.4	22.8	23.6	22.30	29.10	34.20	35.45	121.05
	9 Jun	19.0	20.2	22.5	23.4	28.50	30.30	33.75	35.15	127.70
	14 Jun	17.4	20.1	22.0	23.5	26.10	30.25	33.00	35.35	124.70
	22 Jun	10.7	18.0	20.6	22.3	16.10	27.00	30.98	33.45	107.53
	26 Jun	10.8	17.7	21.1	22.3	16.25	26.55	31.65	33.50	107.95
	16 Jul	9.7	17.4	20.1	22.3	14.60	26.10	30.23	33.50	104.43
Single	17 Mar	30.3	29.3	33.6	35.1	45.45	43.95	50.40	52.65	192.45
	1 Apr	30.8	28.0	31.7	33.2	46.20	42.05	47.55	49.90	185.70
	9 Apr	26.0	26.6	29.6	31.5	39.05	40.00	44.45	47.30	170.80
	22 Apr	33.5	33.0	29.4	29.4	50.30	49.55	44.15	44.15	188.15
	26 Apr	29.1	29.1	29.0	29.5	43.75	43.65	43.50	44.25	175.15
	29 Apr	26.3	26.9	28.1	29.2	39.45	40.40	42.25	43.80	165.90
	1 May	25.0	26.2	27.7	28.7	37.60	39.30	41.60	43.15	161.65
	3 May	23.5	24.7	27.2	29.4	35.30	37.10	40.85	44.10	157.35
	11 May	22.5	22.6	24.7	27.4	33.80	34.00	37.15	41.20	146.15
	13 May	22.0	22.5	24.6	25.7	33.10	33.85	37.00	38.65	142.60
	17 May	19.2	21.4	24.1	26.9	28.90	32.15	36.25	40.40	137.70
	19 May	20.8	20.7	23.6	27.3	31.20	31.15	35.40	41.00	138.75
	24 May	18.6	18.0	21.4	25.2	27.90	27.00	32.10	37.88	124.88
	29 May	32.9	35.2	36.2	36.4	49.35	52.88	54.30	54.68	211.20
	31 May	30.7	33.0	36.1	36.3	46.10	49.50	54.20	54.50	204.30
	1 Jun	32.7	36.2	37.5	37.8	49.10	54.35	56.35	56.70	216.50
	4 Jun	28.6	29.9	35.0	35.6	42.95	44.90	52.60	53.45	193.90
	9 Jun	32.6	35.6	35.1	37.0	49.00	53.40	52.75	55.55	210.70
	14 Jun	28.2	29.8	33.1	34.1	42.30	44.70	49.70	51.25	187.95
	22 Jun	18.1	21.2	24.3	27.5	27.20	31.90	36.50	41.30	136.90
	26 Jun	17.9	19.9	22.9	26.6	26.95	29.90	34.40	40.00	131.25
	16 Jul	17.4	18.3	21.2	26.0	26.15	27.50	31.90	39.10	124.65
Main.	17 Mar	27.4	34.4	35.6	36.3	41.15	51.60	53.50	54.45	200.70
	1 Apr	26.3	32.5	33.0	33.1	39.50	48.75	49.55	49.70	187.50
	9 Apr	24.1	29.5	31.2	32.3	36.20	44.35	46.90	48.55	176.00
	22 Apr	32.0	35.1	30.7	30.8	48.10	52.70	46.15	46.30	193.25
	26 Apr	27.5	32.3	30.4	30.0	41.30	48.50	45.65	45.00	180.45
	29 Apr	25.6	30.6	30.3	30.1	38.50	45.95	45.45	45.20	175.10
	1 May	28.3	32.3	32.2	32.7	42.50	48.50	48.40	49.15	188.55
	3 May	25.6	30.4	30.6	31.9	38.45	45.70	45.90	47.85	177.90
	11 May	29.7	34.5	34.1	35.3	44.55	51.75	51.15	53.00	200.45
	13 May	28.2	34.8	35.0	36.0	42.30	52.20	52.60	54.10	201.20
	17 May	25.3	31.3	32.6	34.2	38.00	47.00	48.90	51.30	185.20
	19 May	31.9	35.5	35.2	36.9	47.95	53.35	52.90	55.35	209.55
	24 May	25.4	32.2	33.3	36.1	38.10	48.38	50.03	54.15	190.65
	29 May	27.7	34.0	34.2	34.7	41.55	51.00	51.30	52.13	195.98
	31 May	24.8	32.9	33.8	34.3	37.30	49.45	50.70	51.45	188.90
	1 Jun	31.1	35.2	35.3	37.5	46.70	52.80	53.05	56.35	208.90
	4 Jun	25.1	32.2	33.2	35.8	37.70	48.40	49.90	53.75	189.75
	9 Jun	31.0	34.5	34.5	35.7	46.55	51.85	51.80	53.60	203.80
	14 Jun	25.5	31.4	32.4	34.1	38.25	47.20	48.65	51.15	185.25
	22 Jun	15.0	22.4	24.0	26.3	22.55	33.70	36.00	39.50	131.75
	26 Jun	15.3	21.1	22.9	25.0	22.95	31.75	34.40	37.50	126.60
	16 Jul	14.8	20.6	22.8	24.9	22.30	31.00	34.25	37.35	124.90

Appendix-Table 4. Soil water data based on measurements by TDR in 2004 for the cultivar 'Velocity'

		Volumetric Water Content (θ)				mm of water				
Trt	Date	15 cm	30 cm	45 cm	60 cm	15 cm	30 cm	45 cm	60 cm	profile
None	17 Mar	27.5	29.8	30.5	33.0	41.25	44.65	45.80	49.55	181.25
	1 Apr	27.0	28.0	32.1	31.6	40.45	42.00	48.08	47.40	177.93
	9 Apr	24.0	26.9	28.2	30.3	36.00	40.35	42.30	45.45	164.10
	22 Apr	29.4	31.8	23.5	30.6	44.10	47.70	35.18	45.85	172.83
	26 Apr	26.6	28.7	30.3	29.0	39.90	43.00	45.45	43.55	171.90
	29 Apr	24.0	27.1	28.7	29.2	36.05	40.70	43.05	43.75	163.55
	1 May	22.8	26.4	26.6	29.0	34.15	39.60	39.90	43.50	157.15
	3 May	20.8	25.2	25.1	27.6	31.25	37.75	37.60	41.40	148.00
	11 May	19.7	22.9	24.7	25.9	29.50	34.30	37.05	38.85	139.70
	13 May	19.3	22.9	23.4	26.1	29.00	34.35	35.15	39.15	137.65
	17 May	17.1	21.6	22.1	25.2	25.70	32.45	33.20	37.80	129.15
	19 May	17.4	21.3	21.1	25.6	26.10	31.95	31.60	38.35	128.00
	24 May	15.9	20.2	21.0	22.2	23.78	30.23	31.43	33.23	118.65
	29 May	15.3	17.5	23.1	24.6	22.88	26.25	34.65	36.83	120.60
	31 May	15.1	18.9	19.4	23.9	22.70	28.40	29.05	35.85	116.00
	1 Jun	14.1	19.1	17.7	22.9	21.10	28.65	26.55	34.30	110.60
	4 Jun	13.8	18.3	17.3	23.1	20.65	27.45	25.90	34.65	108.65
	9 Jun	19.6	18.3	18.1	23.1	29.40	27.50	27.15	34.60	118.65
	14 Jun	16.1	18.5	19.1	22.7	24.10	27.70	28.60	34.00	114.40
	22 Jun	11.8	15.8	16.1	21.9	17.65	23.75	24.15	32.90	98.45
	26 Jun	10.5	16.5	16.3	21.9	15.70	24.75	24.45	32.85	97.75
	16 Jul	9.6	15.3	17.1	21.6	14.45	22.95	25.70	32.45	95.55
Single	17 Mar	28.9	30.5	33.2	38.5	43.30	45.70	49.85	57.75	196.60
	1 Apr	28.6	29.0	31.4	36.4	42.90	43.55	47.05	54.60	188.10
	9 Apr	23.8	26.3	28.5	34.9	35.75	39.45	42.75	52.30	170.25
	22 Apr	32.4	30.7	27.3	32.3	48.55	46.00	41.00	48.40	183.95
	26 Apr	27.7	28.1	27.3	31.8	41.60	42.15	41.00	47.65	172.40
	29 Apr	23.8	26.1	26.9	31.1	35.75	39.10	40.40	46.65	161.90
	1 May	22.5	24.9	26.5	31.2	33.70	37.35	39.80	46.85	157.70
	3 May	20.7	23.0	26.7	31.1	31.10	34.45	40.05	46.65	152.25
	11 May	18.2	20.8	24.2	29.1	27.25	31.15	36.25	43.65	138.30
	13 May	18.5	20.2	23.4	29.9	27.75	30.25	35.15	44.90	138.05
	17 May	16.5	18.3	22.1	27.7	24.80	27.45	33.15	41.55	126.95
	19 May	16.6	18.7	22.2	28.2	24.95	28.10	33.25	42.35	128.65
	24 May	14.8	17.3	22.9	26.3	22.20	25.95	34.28	39.45	121.88
	29 May	32.8	35.8	33.5	37.6	49.13	53.63	50.25	56.40	209.40
	31 May	29.1	33.7	32.4	38.2	43.65	50.50	48.65	57.25	200.05
	1 Jun	32.6	36.6	36.4	41.2	48.95	54.90	54.60	61.75	220.20
	4 Jun	26.8	31.4	33.7	38.1	40.25	47.05	50.55	57.20	195.05
	9 Jun	31.7	31.9	32.8	35.7	47.50	47.85	49.15	53.50	198.00
	14 Jun	25.5	27.6	29.0	35.1	38.25	41.35	43.55	52.70	175.85
	22 Jun	14.2	17.9	21.5	27.2	21.25	26.90	32.20	40.75	121.10
	26 Jun	13.6	18.3	21.6	26.8	20.35	27.40	32.45	40.15	120.35
	16 Jul	14.2	16.1	20.7	26.6	21.35	24.20	31.05	39.95	116.55
Main.	17 Mar	30.0	33.0	34.3	36.9	45.00	49.45	51.45	55.40	201.30
	1 Apr	29.5	31.1	31.6	34.2	44.25	46.65	47.35	51.30	189.55
	9 Apr	26.1	27.9	30.0	32.4	39.08	41.80	44.95	48.60	174.43
	22 Apr	33.4	34.6	31.2	30.5	50.03	51.95	46.75	45.80	194.53
	26 Apr	28.6	30.5	31.0	30.0	42.90	45.70	46.55	44.95	180.10
	29 Apr	27.2	28.6	30.1	30.1	40.73	42.90	45.15	45.10	173.88
	1 May	29.5	30.6	29.7	32.3	44.18	45.95	44.60	48.40	183.13
	3 May	27.1	27.8	29.6	31.8	40.65	41.65	44.40	47.70	174.40
	11 May	31.1	33.8	33.0	35.4	46.58	50.75	49.50	53.05	199.88
	13 May	29.6	34.0	33.3	36.2	44.40	51.05	49.95	54.25	199.65
	17 May	27.5	30.1	30.8	34.7	41.18	45.15	46.20	52.10	184.63
	19 May	33.4	33.4	33.0	36.9	50.10	50.15	49.55	55.35	205.15
	24 May	25.9	28.8	29.3	34.2	38.85	43.13	43.95	51.23	177.15
	29 May	28.6	32.1	33.3	36.0	42.90	48.08	49.95	53.93	194.85
	31 May	28.0	29.8	31.4	34.2	42.00	44.75	47.10	51.35	185.20
	1 Jun	31.3	32.8	33.8	37.7	46.88	49.20	50.75	56.55	203.38
	4 Jun	27.5	29.8	31.6	35.6	41.18	44.75	47.40	53.45	186.78
	9 Jun	31.2	29.0	29.5	33.9	46.80	43.50	44.25	50.90	185.45
	14 Jun	26.7	26.2	28.7	32.2	40.05	39.25	43.05	48.30	170.65
	22 Jun	17.0	19.7	22.9	25.7	25.50	29.60	34.40	38.60	128.10
	26 Jun	17.6	19.5	22.3	24.8	26.40	29.20	33.45	37.20	126.25
	16 Jul	15.8	18.7	21.9	24.2	23.70	28.00	32.85	36.25	120.80

Appendix-Table 5. Percent cleanout based on seed conditioning of tall fescue cultivars under three irrigation treatments in 2003 and 2004.

	2003			2004		
Cultivar	Non-irrigated	Single	Moisture Maintained	Non-irrigated	Single	Moisture Maintained
	----------------------------------			% ------------------------------------		
Arid 3	3	3	3	4	4	4
Barrington	2	2	2	2	2	2
Bingo	2	2	2	1	2	2
Fawn	5	4	6	2	3	3
Velocity	2	2	2	5	7	6
SR8600	2	2	2	2	2	3
mean	3	2	3	3	3	3

Appendix-Table 6: Percent stand cover measured on 28 October 2003 for tall fescue under three spring irrigation regimes.

	Non-irrigated	Single	Moisture Maintained
	------------------	%	------------------
Arid 3	99.8	99.5	99.8
Barrington	99.8	99.5	99.7
Bingo	99.8	99.2	99.5
Fawn	99.5	98.8	99.0
SR8600	99.7	99.3	99.7
Velocity	99.5	98.8	99.7
mean	99.7	99.2	99.6

Appendix-Table 7. Soil characteristics of Woodburn silt loam (fine-silty, mixed, mesic, Aquultic Argixeroll) (Benton County Soil Survey).

Permeability		0.6 – 2 in/hr
Available Water Capacity		0.19 - 0.21 in/in
Effective Rooting Depth		60 in
Water Table		2 - 3 ft (Dec to Apr)
pH		5.6 – 6.5
Organic Matter		3 – 5%
Clay Content	0-19 in	10 – 20%
	19-54 in	20 – 35%
	54-60 in	15 – 30%
Bulk Density	0-19 in	1.2-1.4 g/cm
	19-54 in	1.2-1.4 g/cm
	54-60 in	1.3-1.5 g/cm