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Legislation to reduce open field burning in grass seed fields within the Willamette valley of western Oregon changed established production practices. In the creeping grasses such as Kentucky bluegrass (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra* L.) non-thermal management resulted in reduced yield.

Studies were conducted to examine the effects of three stubble height treatments in comparison to open field burning in creeping red fescue seed production. The effects of light quality on characteristics of plant development were investigated in field and controlled environments. Exogenous applications of plant growth regulators (PGR's) were made to elucidate the causes of low seed yields observed without burning.

Field plots were prepared in fall of 1994, and 1995 in creeping red fescue commercial production fields as well as at Hyslop research farm in 1995. Three cultivars were included in the trial; Shademaster and Hector, which produce many rhizomes, and Seabreeze which produces few rhizomes. The effects of stubble height, PGRs, and field burning were measured during fall regrowth and flowering. Non-structural carbohydrates available for early regrowth were reduced when stubble was removed below 5.0 cm, particularly in first-year stands. Fall tiller height was increased by stubble remaining and was negatively correlated with flowering. Rhizome development was reduced when stubble was removed mechanically or burned to the crown, whereas yield potential was increased.

Fall ethylene application reduced fall tiller height, fall tiller number, and percent fertile tillers the following spring and was similar to control treatment compared with burn. Other PGRs did not produce consistent results in this study. Excess ethylene produced by decaying stubble may impact floral induction and reduce yield potential in creeping red fescue seed crops.

Light quality as measured by red : far-red ratio (R:FR) was reduced by canopy closure during regrowth but not by the presence of stubble. In controlled environment studies, red light (R) promoted taller tillers, greater stage of development, and greater tiller number than far-red (FR) light. Sunlight enriched with FR completely inhibited rhizome formation. Results suggest that environments with excess reflected FR may negatively impact early development of creeping red fescue seed crops.

Physiological Responses of Creeping Red Fescue to Stubble Management and Plant Growth Regulators

by

Paul D. Meints

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Paul D. Meints, Author

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INTRODUCTION

Production of cool season grass seed crops in Oregon's Willamette Valley has provided the world with high quality grass seed for several decades. The Willamette Valley has an ideal environment for producing grass seed as well as other seed crops including vegetable and forage legume seed. Winter temperature averages range from 3.8-6.2°C and 12-18 cm rainfall during December through February (Youngberg, 1980), which allow perennial seed crops to be vernalized without cold injury. Mild fall and spring temperatures permit early regrowth and tillering after harvest and seed set prior to the summer dry period. The dry summer months permit seed harvest with reduced risk of disease incidence or sprout damage due to excess moisture. Grass seed crops are harvested at storage moisture applicable for each species (Klein and Harmond, 1971) eliminating drying costs incurred in other grass seed producing regions.

Burning post-harvest residue on grass production fields has been an established practice throughout the Willamette valley and greater Pacific Northwest. The benefits of open field burning include reduction in disease pathogens, removal of remaining vegetative stems and dead tissue, destruction of volunteer and weed seed on the surface, and destruction of some tiller buds which serves to thin the stand (Chilcote et al., 1974). High populations in grass seed crops such as Kentucky bluegrass *(Poa pratensis L.)* and creeping red fescue *(Festuca rubra L.)* reduced the number of panicles and thus seed yield

(Meijer, 1984). Post-harvest removal of excess straw by open field burning increased seed yield and lowered disease incidence compared to leaving the straw on the field. Straw residue remaining on the field has been associated with fewer fertile tillers per unit area, fewer seeds per tiller, and later panicle emergence the following spring (Chilcote et al., 1980). Since the fertile tiller is the primary unit of reproduction in most perennial grass species, cultural practices that maximize fertile tiller number are of great interest to both the producer and researcher.

Pressure by private citizens and the state legislature to reduce open field burning has intensified research to identify non-thermal methods for residue removal which do not reduce seed yield. Initial alternatives included large machine burners which destroyed the residue with propane flame. Canode and Law (1977) reported yields slightly better than mechanical straw removal but still lower than open field burning yields and cost prohibitive. Subsequent work showed that many perennial grasses grown as seed crops in Oregon have acceptable yield response to certain non-thermal techniques (Young et al., 1994). Unfortunately, non-thermal alternatives have been less successful in Kentucky bluegrass *(Poa pratensis* L.) (Hickey and Ensign, 1983; Coats et al., 1993) and creeping red fescue *(Festuca rubra* L.) Seed production (Chilcote et al., 1980). Chastain et al., (1997) reported that non-thermal practices which removed the greatest amount of residue and stubble from Kentucky bluegrass fields provided seed yields comparable to those of burned. Treatments which did not remove straw and stubble reduced fertile tiller number and subsequent yields in Kentucky bluegrass. Non-thermal stubble management practices also resulted in decreased fertile tiller production and subsequent yields in creeping red fescue (Chastain et al., 1995a). Post-harvest stubble management techniques which remove the greatest amount of straw and stubble best approximate the response in regrowth and flowering found when creeping red fescue is burned (Chastain et al., 1995b). Non-thermal treatments in which Kentucky bluegrass stubble was clipped after the bulk of the straw residue was removed showed higher fertile tiller number and subsequent yield than treatments where only straw residue was removed (Thompson and Clark, 1989). Hickey and Ensign (1983) found that Kentucky bluegrass seed yields from burned plots were greater than those from plots that were clipped and vacuumed to either 2.5 cm or 7.6 cm. Panicle numbers which were significantly correlated with yield greater in the burned plots than in those treated by mechanical removal at either stubble height.

The purpose of this study was to investigate the physiological causes for yield reductions under non-thermal residue management in creeping grass seed crops. In particular this study investigated response in creeping red fescue with the hope that results would have implications toward production of Kentucky bluegrass as well. This study focused on specific factors which influence tillering and yield response in rhizomatous perennial grasses, particularly creeping red fescue. These factors include: the effects of stubble height on light quality (and light quality on growth and development), and available carbohydrates for fall regrowth; the effect of various stubble heights on tillering, development, and flowering; the effect of specific PGRs, applied exogenously, on rhizome verses tiller production and the floral induction of tillers and the interactions between stubble and exogenous applied PGRs.

LITERATURE REVIEW

Stubble Management

In rhizomatous perennial grasses, propagation may be accomplished either by seed production, by natural rhizome spread, or via physical transportation of rhizomes to new locations. Evolutionarily, it could be argued that seed was the primary method of long distance dispersal, while rhizome formation functioned in localized colonization and starch storage for survival of the plant through dormant periods. In mountain meadows, creeping red fescue (*Festuca rubra*) produced twice as many daughter tillers from extravaginal (rhizome originating) as intravaginal (within the leaf sheath originating) tillers (Herben et al., 1994). Extravaginal tillers had longer life spans, were larger at initiation, and were longer than intravaginal tillers. During initial fall regrowth, stored carbohydrate is largely utilized for tiller production. The quantity of carbohydrate reserves was shown to correlate with the capacity of the crown to produce vegetative regrowth in tall fescue (*F. arundinaceae* Schreb.) (Booysen and Nelson, 1975; Volenec, 1986) and switchgrass (*Panicum virgatum* L.) (Anderson et al., 1989).

Rhizome production is usually inversely related to seed production. However, in open meadow swards, fertile tiller production did not differ in number between those produced on the mother plant verses those produced from rhizomatous tillers (Herben et al., 1994). Ensign and Weiser (1975) found that continuous mowing during floral initiation in Kentucky bluegrass (*Poa pratensis* L.) and in creeping red fescue increased root and rhizome production. Production of rhizomes following destruction of potential floral buds may be an innate survival mechanism in creeping grasses. The ecology of a grass seed production field is different from that of a natural sward and may produce a different phenotypic response.

Although open field burning increased seed yield and reduced total rhizome weight in Kentucky bluegrass (Hickey and Ensign, 1983), the physiological mechanisms involved in these changes remain unknown. One possibility is that removal of field straw permits greater soil temperature fluctuations compared to non-burned fields with a residue cover (Chilcote et al., 1980). Aamlid (1992) and Moser et al. (1968) found that cool temperatures promoted tillering while warm temperatures promoted rhizome formation in Kentucky bluegrass. Soils which lack crop residue cover achieve lower night time temperatures which may promote increased tillering some of which are then induced to flower in late fall. Canode and Law (1979) reported that open field burning reduced thatch build up and increased primary tiller and panicle number and consequently, seed yield. Hickey and Ensign (1983) proposed that open burning of straw residue stimulated a physiological change at the tiller apex which released the plant rhizome system from tiller dominance and increased tiller numbers. Chilcote and Ching (1973) also reported an inverse relationship between rhizome formation and seed yield. Cultivars that produced large long rhizomes produced fewer panicles. This suggested a differential allocation of limited resources under conditions which promoted rhizome formation. Although open burning may alter differentiation from rhizome formation to tillering and floral induction the physiological stimulus which causes this change has not been reported.

The use of open field burning as a stubble management technique provided the standards for greatest yield and seed quality in grass seed production for forty years. Subsequent research showed that certain crops such as perennial ryegrass, tall fescue, and orchard grass could be successfully produced with non-thermal management practice (Chastain et al., 1996). Nevertheless, the creeping grasses such as creeping red fescue and Kentucky bluegrass continue to require management practices which remove the greatest share of straw residue and stubble. Removal of all stubble via open burning resulted in greater yields in Kentucky bluegrass than when stubble was clipped to 2.5 cm or 7.6 cm (Hickey and Ensign, 1983). Complete stubble removal with fire increased fertile tiller numbers and fall tillers greater than 2 mm basal diameter, and reduced rhizome production relative to that which occurred in fields with stubble remaining. Removal of stubble to 2.5 cm after the straw was baled reduced flowering shoot height, and increased fertile tiller numbers and overall yield in Kentucky bluegrass (Thompson and Clark, 1989). In a controlled environment study, Thompson and Clark (1993) found that clipping stubble to 2.5 cm or 7.5 cm had no influence on tiller number or panicle number in Kentucky bluegrass. Ackerson and Chilcote (1978) found that clipping Kentucky bluegrass below 2.5 cm caused the greatest reduction in tillering. Using field-scale equipment, Chastain et al. (1996) found that stubble removal below 1.5 cm generally resulted in reduced fall tiller height, no difference in fertile tiller number, and stable yield compared to open field burned Kentucky bluegrass fields. They also reported that in creeping red fescue field trials, fall tiller height was reduced as was fertile tiller number and yield following mechanical removal compared with open field burning. These results suggest that the manner in which residue and stubble is removed can influence floral induction in subsequent regrowth.

Floral induction is mediated by day length and temperature in creeping red fescue (Meijer, 1984) and Kentucky bluegrass (Canode and Perkins, 1977; Lindsey and Peterson, 1964). A number of studies suggest that light quantity and quality are influenced by stubble management practices in a way that may affect floral induction. Ensign et al., (1983) studied the effect of stubble height and found that reduced light in tall crop stubble caused etiolation, reduced panicle number, and seed yield potential. These results show that the ratio of red : far-red light influenced by shading can have marked effects on plant growth. Etiolated stems typically have smaller basal diameter and are less likely to be induced to flower (Canode and Law, 1979; Chastain et al., 1997). Meijer and Vreeke (1988) reported that fall stubble removal provided better illumination and consequent fertile tiller survival and greater yield in Kentucky bluegrass and creeping red fescue. Cordukes and Fisher (1974) reported that shading the leaf sheath of Kentucky bluegrass produced long aerial rhizomes even though the leaf blade was exposed to normal light. The presence of stubble shifts the light quality reaching the crown towards the far-red spectrum. Regrowth also transmits far-red light and absorbs red light. Leaf sheath exposure to far-red light increased tiller and sheath length in *Lolium, Sporobolus, and Paspalum* species (Casal and Derigibus, 1987a). Casal and Smith (1989), and Davis and Simmons (1994), reported that far-red light reflected from neighboring plants caused stem elongation. Far-red light also reduced tiller number in *Lolium multiflorum* Lam. (Casal et al., 1985, 1990; and Casal, 1987b), and *Triticum aestivum* L. (Casal, 1988, 1993).

Plant Growth Regulators

Plant hormones are naturally-occurring compounds involved in the mediation of growth and developmental processes at very low concentrations (Davies, 1995). Plant growth regulators are natural or synthetic compounds that are functional analogs to plant hormones. These compounds often produce responses similar to those of naturally occurring hormones and aid in the study of hormone action and response. Compounds that function as plant growth regulators (PGR) were discovered during the 1940's and were developed as defoliants during World War II. Some of these compounds were later adapted for use in crop production as weed control agents and growth regulators.

Plant hormones regulate gene expression or other protein mediated responses within the plant (Barendse and Peeters, 1995). Some function ubiquitously throughout the life of the plant while others influence specific stages of growth and development. The singular effects of PGRs are more easily measured than interactions between them in the plant. Consequently, much research has examined PGR response in experiments where other hormonal interference has been controlled. The study of PGR effect, production, and regulation within the plant encompasses exogenous application with observed plant response through study of mutants lacking gene expression or response to a particular plant hormone (Davies, 1995). Due to the volume of literature in each of the PGR families utilized in this research, this review will include only a few representative studies.

Ethylene. Ethylene is the only naturally occurring plant hormone that is functionally active in gaseous form. Synthesis occurs at the plasma membrane or tonoplast and transport is via diffusion (Davies, 1995). The general effects of this hormone include: release from dormancy, shoot and root growth differentiation, leaf abscission, floral induction, flower opening, and fruit ripening. The regulation of ethylene production and signaling occurs via the biosynthesis pathway of the ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC) (Ecker, 1995; Jiao et al., 1987).

Seed production management practices including burning and non-thermal treatments may alter the levels of PGRs within the rhizomatous grasses. Smoke from burning is a natural source of ethylene gas and has been utilized to produce uniform ripening in pineapple. Current research has shown that ethylene in smoke can induce flowering in bulb and corm crops such as tulip and wild hyacinth (Imanishi et al., 1993, Han et al., 1990). Buettner et al. (1976) reported that fall application of ethephon increased tillering in one of two Kentucky bluegrass cultivars. Application of ethylene-releasing compounds to barley plants increased tiller production and shortened internodes which reduced lodging (Dathe, 1992; Foster et al., 1992; and Foy and Witt, 1987). In tomato, ethylene stimulated root growth at low concentrations, but had the opposite effect at high concentrations (Jackson, 1979). Shinozaki and Takimoto (1983) reported suppressed root elongation but not floral induction in *Pharbitis nil* by ethylene releasing compounds. Another study showed that imbibition of wheat seeds in an ethylene-releasing compound accelerated the subsequent development of the apical meristem (Banowetz, 1993).

Abscisic acid. Abscisic acid (ABA) was initially thought to control abscission of cotton bolls and bud dormancy (Salisbury and Ross, 1992). Although subsequent work showed that abscisic acid does not appear to regulate either response, the name has remained. Synthesis of ABA occurs via the mevalonic acid pathway in the roots and mature leaves. Transport occurs via the xylem stream to leaf tissue and via the phloem from older leaves to newer (Davies, 1995). The general effects of ABA include: regulation of stomatal closure by inhibiting potassium ion influx and promoting potassium efflux (Mansfield and McAinsh, 1995), inhibition of shoot growth, reduction of gibberellin promotion of α-amylase in germinating caryopses (Jones and Jacobson, 1991), and drought or wound response.

In submerged species such as rice (*Oryza sativa* L.), multiple hormonal interactions regulate the rapid elongation of internodes to enable the plant to break the surface. Ethylene produced in submerged tissue increases the responsiveness to gibberellin promoting growth of the internode. Hoffmann-Benning and Kende, (1992) found that ABA counteracted the activity of GA in submerged rice. Increased endogenous GA correlated with a reduction in the amount of ABA found within submerged tissue.

Several plant hormones are associated with plant stress response including ABA. Drought stress typically results in stunted plants if dessication continues for prolonged periods. ABA applied exogenously to barley (*Hordeum vulgare* L.) shoots at 10^{-4} mol m^{-2} did not inhibit leaf growth except when under osmotic stress (Dodd and Davies, 1996). Inhibition of plant growth and leaf area by ABA required an interaction with osmotic stress as well. Normal levels of ABA in plant tissues serve a regulatory function but when coupled with osmotic stress produce the stunting associated with drought conditions.

Cytokinins. One of the major functions of cytokinins in the plant is regulating cell division. Early research utilized then unknown compounds concentrated in certain tissues, such as young coconut endosperm, which stimulated cytokinesis. Cytokinins are found in the plant in the free base form, which is thought to be physiologically active, and as nucleosides and nucleotides (Salisbury and Ross, 1992). Synthesis occurs in roots and developing seeds and cytokinins are transported via the xylem (Davies, 1995).

Along with promotion of cell division, cytokinins are also implicated in shoot initiation, release of lateral buds from apical dominance, and chloroplast development. Wang and Below (1996) reported that exogenous application of cytokinin mimicked the effect of mixed forms of nitrogen fertilizer in promotion of tillering in wheat. They also reported increased tillering response to nitrogen application resulted from increased synthesis of cytokinin.

Floral induction in plants has been theorized to be under the control of an unidentified plant hormone called florigen. Although this substance has never been isolated, other plant hormones have been linked to the floral initiation process including cytokinins. Kinet et al. (1993) reported that reduction of root initiation or growth promoted floral initiation and that a reduction in roots was correlated with reduced endogenous cytokinin levels. Exogenous cytokinin application had a negative effect on flowering in *Anagallis arvensis* L. (Bismuth and Miginiac, 1984) and promoted flowering in *Sinapis alba* (Bernier et al., 1977). Krekule and Seidlova (1976) reported that the influence of cytokinin on flower initiation was concentration dependent with higher concentrations inhibiting and lower concentrations having a promotional effect. Although the influence of cytokinin is correlative and not direct on floral initiation, conditions that promote root growth may also have a deleterious effect on flowering due to excessive cytokinin synthesis.

Auxin. The role of auxin in the plant was first characterized by Went's classic experiments with oat coleoptile curvature. Since those early experiments, much has been learned about auxin induced responses. The most common form of auxin in the plant is indoleacetic acid (IAA). Synthesis of IAA occurs primarily in apices, leaf primordia, young leaves, and in developing seeds from tryptophan (Davies, 1995). Transport of IAA is via polar diffusion from cell to cell and proceeds slowly at about 1 cm h^{-1} (Salisbury and Ross, 1992). General effects of auxin include: cell enlargement, stimulation of cambium cell division, root initiation, tropic responses, apical dominance, flowering in pineapple, and assimilate partitioning.

Leopold (1949) tested the hypothesis that auxin was responsible for regulating tillering in barley and teosinte as it does in regulating axillary bud break in dicotyledons. Applications of auxin via injection when the apical bud had been destroyed continued to inhibit tillering. The number of tillers produced in barley were also found to be auxin concentration dependent. Ackerson and Chilcote (1978) reported that application of the auxin antagonist triiodobenzoic acid (TIBA) in Kentucky bluegrass increased tillering and decreased carbohydrate reserves in the lower stem.

Auxins are also known to promote formation of adventitious roots. At least four distinct phases of root initiation have been identified and include: differentiation of cells to form new meristem, early cell division localized at this locus, formation of root meristem, and extension of meristematic cells to produce a new root. Blakesley et al. (1991) reported that concentration of indole-3-acetic acid (IAA) peaked during the first two phases of root initiation and then dropped during the third phase. The peaks in IAA have not been proven to be required for phase 1 or 2, but the data suggested that the rise is congruent with root formation.

Differentiation of the meristem from vegetative to floral remains under unknown control or regulation. While GA has been implicated as a possible component of floral initiation auxins generally decline during this phase (Gaspar et al., 1985; Jacobs, 1985). Because auxins function in apical dominance, a reduction in auxin levels during floral initiation may also release genetic inhibition of floral differentiation as the normal meristematic expression. Clifford (1974) suggested that auxins produced from elongating stem internodes during flowering were sufficient to suppress late tiller bud release and conserve energy for floral development.

Gibberellic Acid. The discovery of gibberellic acid (GA) was brought about by study of a fungal disease in rice caused by *Gibberella fujikuroi* which caused tall weak stems and susceptibility to other disease (Salisbury and Ross, 1992). Currently, over one hundred different gibberellic acids have been isolated, but all are variants from the same *ent*-gibberellane ring (Sponsel, 1995). Synthesis of GA occurs in young tissues, developing fruits, and seeds via the mevalonic pathway and transport is via both the xylem and phloem.

In germinated cereal grains, GA is released from the scutellum to the aleurone layer of the seed. Production of the enzyme α-amylase is stimulated by GA and starch stored in the seed is degraded to be utilized by the emerging seeding. Inhibition of GA biosynthesis in germinating seeds does not reduce the α-amylase response suggesting that GA originates from an existing pool during germination rather than ongoing synthesis (Jacobson et al. 1995). Foster et al. (1994) compared GA levels in homozygous and heterozygous offspring of sorghum mutants lacking a 123-kD phytochrome with that in wild-type sorghum. Homozygous 123-kD phytochrome lacking lines had characteristic phenotypes and elevated GA levels. These lines were taller, had longer sheath length, and flowered sooner than lines homozygous for normal 123-kD phytochrome. Phytochrome B appeared to control the sensitivity of tissues to GA as well as participate in the control of endogenous GA levels. Plants which produced high levels of GA exhibited traits similar to these sorghum mutants.

The large number of physiologically active GAs indicates that changes in chemical structure and conformation alter the ability of GA to initiate a plant response. Evans et al. (1994) reported that 3β-hydroxylation in the A ring of several GAs promoted stem elongation in *Lolium temulentum* and reduced floral initiation. During development of the inflorescence 3β-hydroxylated GAs were present and essential for development to continue. Pharis (1972) reported that flowering in *Chrysanthemum* was most effectively promoted by the lowest doses (2 µg rate) of GA_3 and GA_5. Both GA_3 and GA_5 are precursors to other forms of GA in the biosynthesis pathway. Hampton and Hebblethwaite (1985) reported that gibberellin inhibitors increased yield in perennial ryegrass *(Lolium perenne L.)* because of reduced floret abortion caused by competition for assimilate with vegetative tillers. They did not report any effect on fertile tiller numbers.

Light Quality

Phytochrome mediation of growth and development in plants begins with early perception by seedlings for shade avoidance and influences tillering, stand density (Casal and Smith, 1989), and floral induction (Casal et al., 1985). The phytochrome mediation of growth and development is strongly influenced by light quality and red : far-red ratio. It is likely that residue management effects on subsequent plant development are mediated, in part, through mechanisms involving phytochrome. For example, the effect of stubble height in open and shaded burn plots suggested that reduced light in tall crop stubble caused etiolation, reduced panicle number, and seed yield potential (Ensign et al., (1983). Meijer and Vreeke (1988) reported that fall stubble removal increased illumination, consequent fertile tiller survival, and yield in Kentucky bluegrass and creeping red fescue. Cordukes and Fisher (1974) observed long aerial rhizome production following shading of Kentucky bluegrass leaf sheathes suggesting phytochrome involvement.

Light reflected from plant residue has a low red : far-red ratio and this ratio determines the relative abundance of phytochrome species (Kasperbauer and Hunt, 1987). Leaf sheath exposure to far-red light increased tiller and sheath length in *Lolium, Sporobolus, and Paspalum* species (Casal et al., 1987a). Casal and Smith (1989), and Davis and Simmons (1994a; 1994b), reported that reflected far-red light caused stem elongation. Far-red light also reduced tiller number in *Lolium multiflorum* Lam. (Casal et al., 1985, 1988, 1990), and *Triticum aestivum* L. (Casal, 1987b, 1993).

MANUSCRIPT I: STUBBLE MANAGEMENT EFFECTS ON REGROWTH, DEVELOPMENT, AND FLOWERING IN THREE CULTIVARS OF CREEPING RED FESCUE.

ABSTRACT

Non-thermal residue management in creeping red fescue (*Festuca rubra* L.) has been associated with yield loss compared with seed production under open field burn management. This study was conducted during 1995, 1996, and 1997 on three creeping red fescue cultivars to determine what effect stubble remaining on the field had on fall regrowth and development above and below the crown, and on flowering. The effects of two stubble heights, complete mechanical removal, and burning were measured on creeping red fescue seed crops of various aged stands at Corvallis and Sublimity, OR.

Non-structural carbohydrates were reduced when stubble was removed below 5.0 cm in all cultivars. Light quality (red:far-red ratio) was not altered by the presence or absence of stubble and did not influence regrowth or flowering. Regrowth varied by year but was a function of available moisture and not light quality. Fall tillers were etiolated in stubble taller than 2.5 cm but varied in stage of development over stubble treatments. Fall tiller height was shown to be negatively correlated with fertile tiller development in the following spring. Root systems were not affected by presence of stubble or open burn. Rhizome development was consistently reduced when stubble was removed by burn or complete mechanical removal and was negatively correlated with fertile tiller production in Shademaster and Hector, which produce many rhizomes. Fertile tiller production and thus yield potential were greatest when stubble was completely removed.

INTRODUCTION

Open field burning has been a successful management tool for removing residue from production fields, reducing rhizome formation, and maintaining yield and seed quality in creeping red fescue (*Festuca rubra* L.) seed production. Legislated reductions in field burning in Oregon's Willamette valley initiated investigations into non-thermal management alternatives to remove residue without changing crop yield potential.

During initial fall regrowth, stored carbohydrate is utilized for tiller production. Carbohydrate reserves were shown to measure the ability of the crown to produce vegetative regrowth in tall fescue (*F. arundinaceae* Schreb.) (Booysen and Nelson, 1975; Volenec, 1986) and switchgrass (*Panicum virgatum* L.) (Anderson et al., 1989). Stored carbohydrate is necessary to initiate early fall tillers in perennial grass crops. Some of these fall tillers are receptive to floral induction stimuli and may realize yield potential the following spring.

Open burn plots were compared to shaded plots and various residue heights by Ensign et al., (1983) and results suggested that reduced light in tall crop stubble could cause etiolation, reduce panicle number, and seed yield potential. Etiolated stems typically have smaller basal diameter and are less likely to be induced to flower (Canode and Law, 1979; Chastain et al., 1997). Meijer and Vreeke (1988) reported that fall removal of stubble permitted better illumination and consequent fertile tiller survival and greater yield in Kentucky bluegrass (*Poa pratensis* L.) and creeping red fescue. The presence of stubble or plant canopy shifts the light reaching the crown towards the far-red spectrum.

Far-red light reduced tillering in *Lolium multiflorum* Lam. (Casal et al., 1985, 1990; and Casal, 1987b), and *Triticum aestivum* L. (Casal, 1988, 1993).

Rhizome production creates good turf strength, but is inversely related to seed production in Kentucky bluegrass (Chilcote and Ching, 1973). Ensign and Weiser (1975) found that continuous mowing during floral initiation in Kentucky bluegrass and creeping red fescue resulted in increased root and rhizome production.

Removal of all stubble via open burning increased fertile tiller number, large tillers (> 2 mm basal diameter), and yield, but reduced rhizome production compared with stubble clipped to 2.5 cm or 7.6 cm (Hickey and Ensign, 1983). Removal of stubble to 2.5 cm after straw was baled from the field reduced flower shoot height and increased fertile tiller number and overall yield in Kentucky bluegrass (Thompson and Clark, 1989). Using field scale equipment, Chastain et al. (1996) found that stubble removal below 1.5 cm generally resulted in reduced fall tiller height, no difference in fertile tiller number, and seed yield comparable to that achieved with open field burning in Kentucky bluegrass. Similar residue management in creeping red fescue seed fields reduced fall tiller height, fertile tiller number, and yield. Aamlid (1992) and Moser et al. (1968) reported that cool temperatures promoted tillering whereas warm temperatures promoted rhizome formation in Kentucky bluegrass. Soils which lack crop residue cover achieve lower night time temperatures which may promote increased tillering.

The purpose of this study was to investigate the physiological causes for yield reduction under non-thermal residue management in creeping red fescue seed crops. The objectives of this study were to observe the effects of stubble height on; light quality, available carbohydrates for fall regrowth; and on tillering, development, and flowering.

MATERIALS AND METHODS

Stubble Height Treatments. This investigation was conducted in the Willamette Valley of western Oregon during 1994-1997. Trials were conducted in a commercial production field of 'Shademaster' creeping red fescue (IOKA farm), a commercial production field of 'Hector' creeping red fescue (Taylor farm) near Sublimity, Oregon, and in Shademaster and 'Seabreeze' creeping red fescue planted at Hyslop farm research station near Corvallis, Oregon. Plots were 1 m^2, and were established 13 September, 1994 (IOKA) and on 20 September, 1995 (Taylor and Hyslop). Data were taken at IOKA during the second seed production year and at Taylor during the second and third seed production years. Plots at Hyslop research farm were planted using carbon banding in the fall of 1994. Diuron {3-(3,4-dichlorophenyl)-1,1-dimethylurea} was applied pre-emergence to control weeds. Data were taken at Hyslop research farm during the first and second production years.

The experimental design was a randomized complete block. Each location contained three replications. Analysis of variance was conducted to determine if significant differences existed between treatments and mean separations were conducted using Fisher's Least Significant Difference (LSD). Linear regression was conducted to investigate possible relationships between data. Main treatments were three stubble heights imposed after harvest; 0 cm, 2.5 cm, and 5.0 cm and open burn plots.

Zero cm cutting heights were imposed using a gasoline-powered brush cutter with a metal, three-edged blade to remove all vegetative material to the crown. A sickle-bar mower with a 1 meter cutting edge was used for the 2.5 cm and 5.0 cm cutting heights. The cutting height of the sickle-bar was 2.5 cm without modification and the 5.0 cm height was achieved with skids attached to the sickle bar to raise the cutting height. Residue was removed from plots following the stubble cutting treatment with a hand rake. Open burn plots were prepared at Taylor and IOKA by burning straw after harvest in the production fields as in a normal open field burn. At Hyslop research farm, burn plots were clipped prior to seed set to prevent viable seed formation and re-clipped several days prior to burning. Open burns were conducted as close as possible to other stubble treatments.

Stubble Influence on Light Quality at the Crown. Light quality (red : far-red ratio, 660 : 730 nm) was measured during the fall regrowth period at the plant crown. Light quality was measured using a Skye-Probetech (SKR 100, remote probe SKR 110, Skye Instruments. Llandrindod Wells, Powys, UK) red : far-red meter. Readings were taken weekly at mid-day to determine whether the red : far-red ratio showed variation due to reflectance from the canopy. A section of the row in each zero treatment plot and in the open burn was removed to allow the insertion of a light sensor probe at the crown level.

Carbohydrate Reserves for Regrowth. Carbohydrate reserves were measured by using techniques described by Burton et al. (1962) and Burton (1995). Light restricting tubes constructed of PVC pipe with a black interior were placed over plants within the row.

Tubes were sealed with the exception of a light restricting breather hole near the top to prevent heat build-up within the tube. Prior to placement, root and rhizome connections were severed by using a soil core the diameter of the light restriction tube to prevent translocation of water or photosynthate from adjacent plant material. Etiolated tissue was harvested every thirty days following stubble treatments until no further etiolated regrowth was produced. Carbohydrate reserves were estimated from cumulative dry weight of the etiolated regrowth from each light restriction tube.

Sampling Practices. In field experiments sod cores 15 cm x 15 cm were taken between January and March each year following regrowth from imposed stubble height treatments. Samples were brought into the laboratory and tillers were measured for height and growth stage. Tiller height was measured in centimeters (cm) from the crown to the tip of the longest leaf. Growth stages were estimated using a modified Haun stage (Klepper et al., 1982). Tillers were separated by size in 1 mm increments according to basal diameter taken at the base of the tiller just above the point of attachment to the crown or axil. Total tiller number and bulk dry weight were determined on each sample.

Root-rhizome separations were made to determine the dry weight of each in grams (g) $core^{-1}$ and calculate rhizome : root weight ratios. Root zone cores were taken in late winter by using a standard golf course cup cutter with a core volume of 8.83×10^{-3} m^{-3}.

Tiller samples were also taken in spring immediately after anthesis. Vegetative and fertile tillers were counted, dry weights were determined, and the percent fertile tillers were calculated. Percent fertile tillers was used to estimate yield potential in this study.

RESULTS AND DISCUSSION

Non-structural carbohydrates. In 1996 and 1997, non-structural carbohydrate reserves of fall tillers were reduced when stubble was removed to 0.0 cm and 2.5 cm and when burned, but not when stubble was removed to 5.0 cm (Figure I-1). Carbohydrates may be re-mobilized from stubble or rhizomes during early fall regrowth. Volenec (1986) also reported reductions in total non-structural carbohydrates in stem base components after tall fescue was clipped to 7.5 cm compared with un-clipped tillers. Ackerson and Chilcote (1978) found that clipping Kentucky bluegrass below 2.5 cm caused the greatest reduction in water soluble carbohydrate concentration in stem bases compared with 5.0 cm stubble or un-clipped control.

Carbohydrate reserves also depended on cultivar and age of stand (Table I-1). Ackerson and Chilcote (1978) also reported differences in water soluble carbohydrate between cultivars. Seabreeze had the lowest carbohydrate reserves over the two year period followed by Shademaster and Hector, respectively. Seabreeze produces few rhizomes and reductions in stubble height below 5.0 cm greatly reduced etiolated regrowth. Shademaster and Hector produce considerably more rhizomes and had greater reserves for regrowth than Seabreeze. Shademaster and Hector carbohydrate reserves also were slightly reduced when stubble was removed below 5.0 cm. First-year stands contained lower carbohydrate reserves than second-year and third-year stands particularly when stubble was removed below 5.0 cm (Table I-2). Nyahoza et al. (1973) reported that rhizomes appeared to supply carbohydrates for regrowth after defoliation. Older

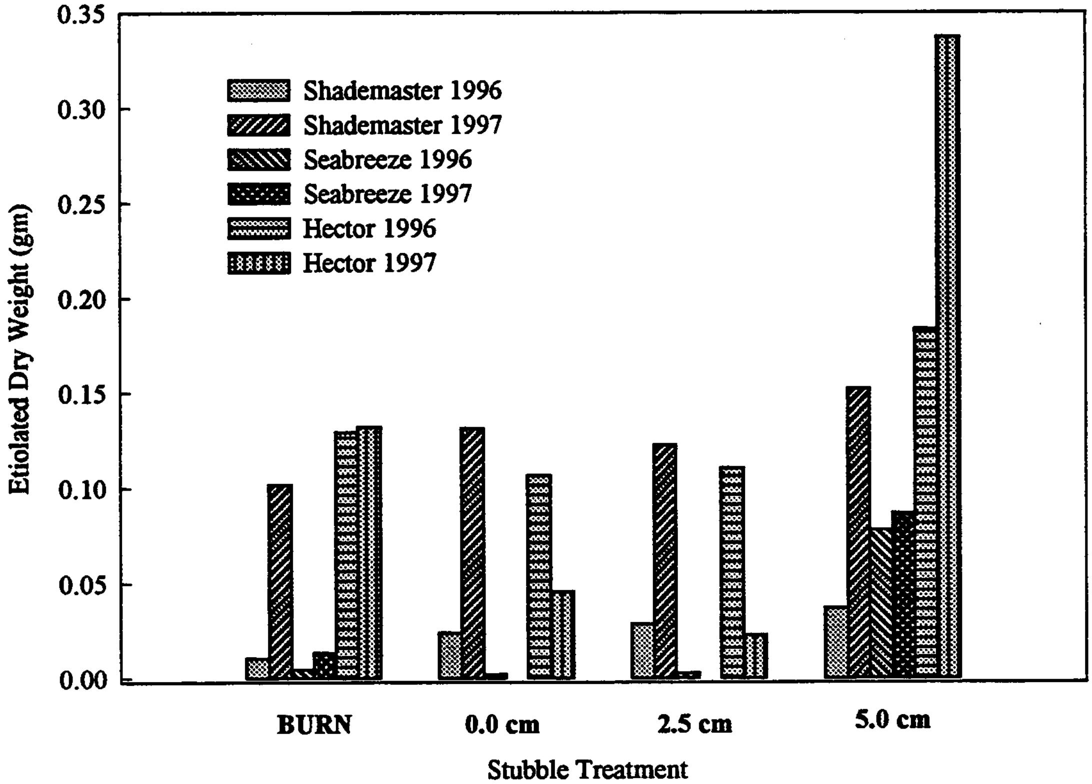

Figure I-1. Carbohydrate reserves measured by etiolated regrowth in three cultivars of creeping red fescue during 1996 and 1997. Shademaster and Seabreeze were first-year stands in 1996 and second-year stands in 1997. Hector was a second-year stand in 1996 and a third-year stand in 1997.

Table I-1. Non-structural carbohydrates measured by etiolated regrowth (g) in different aged stands of three cultivars of creeping red fescue.

Cultivar	Etiolated regrowth	Stand age	Etiolated regrowth
	--- g ---		--- g ---
Shademaster	0.0860 b †	First year	0.0232 a
Seabreeze	0.0166 a	Second year	0.0990 b
Hector	0.1153 c	Third Year	0.1039 b

† Means within a column followed by the same letters were not significantly different (LSD 0.05).

Table I-2. Impact of stubble height treatment (SHT) by mechanical removal or open burning on post-harvest carbohydrate reserves in various aged stands of three cultivars of creeping red fescue.

	Shademaster		Hector		Seabreeze	
SHT	1st year †	2nd year	2nd year	3rd year	1st year	2nd year
	(g)					
Burn	0.0102 a ††	0.2038 b	0.0885 a	0.1319 b	0.0048 a	0.0035 a
0.0 cm	0.0249 b	0.1313 a	0.1067 a	0.0456 a	0.0019 a	0.0000 a
2.5 cm	0.0241 b	0.1226 a	0.1107 a	0.0229 a	0.0027 a	0.0000 a
5.0 cm	0.0401 c	0.1520 ab	0.1835 b	0.2277 c	0.0885 a	0.0617 b

† Production years for Shademaster and Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.
†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

stands with more developed rhizome systems and cultivar differences may account for changes in available non-structural carbohydrate as well as re-mobilization from stubble.

Light Quality. The red:far-red ratio measured at the crown after burn and stubble clipping did not differ for any of the treatments (*P* value = 0.32). Changes in light quality during the regrowth period were not affected by stubble treatment but were influenced by the expanding plant canopy (Figure I-2). In 1996, early rainfall after harvest promoted initiation of tillers more quickly than in 1997 for all three cultivars. The red : far-red ratio at the crown decreased as the canopy expanded (Figure I-3). The inverted spike in red : far-red ratio during week eight in 1996 is due to wilted, chlorotic plants resulting from herbicide injury caused by an application of diuron. As the plants became turgid and green, light quality at the crown returned to levels expected under a healthy canopy. In 1997, regrowth was delayed by lack of adequate soil moisture; thus the canopy did not develop as quickly and light quality did not change substantively over the first ten weeks (Figure I-3). Changes in light quality over the season in 1997 were attributed to expansion of the plant canopy as in 1996 and were not related to stubble treatment.

Fall Regrowth and Development. The height of fall tillers has been shown to be correlated flowering and yield potential in Kentucky bluegrass (Chastain et al., 1997). The height of regrowth is directly related to the height of the stubble remaining following post-harvest management. Fall tillers were significantly shorter when stubble was mechanically removed to 0.0 cm for all three cultivars regardless of age of stand (Table I-3). Tillers in

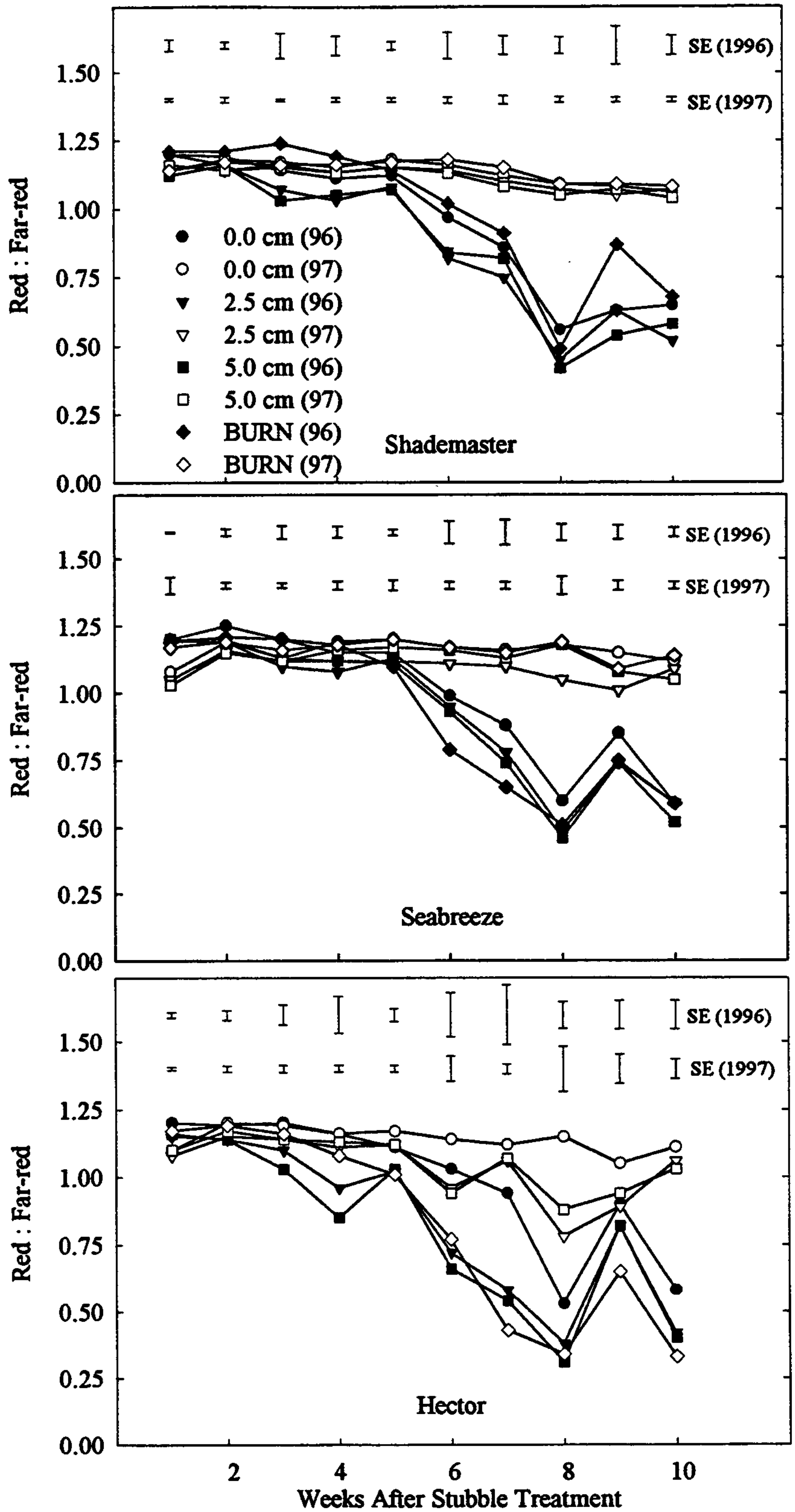

Figure I-2. Fall tiller height during the first ten weeks following stubble treatment in three cultivars of creeping red fescue during 1996 and 1997.

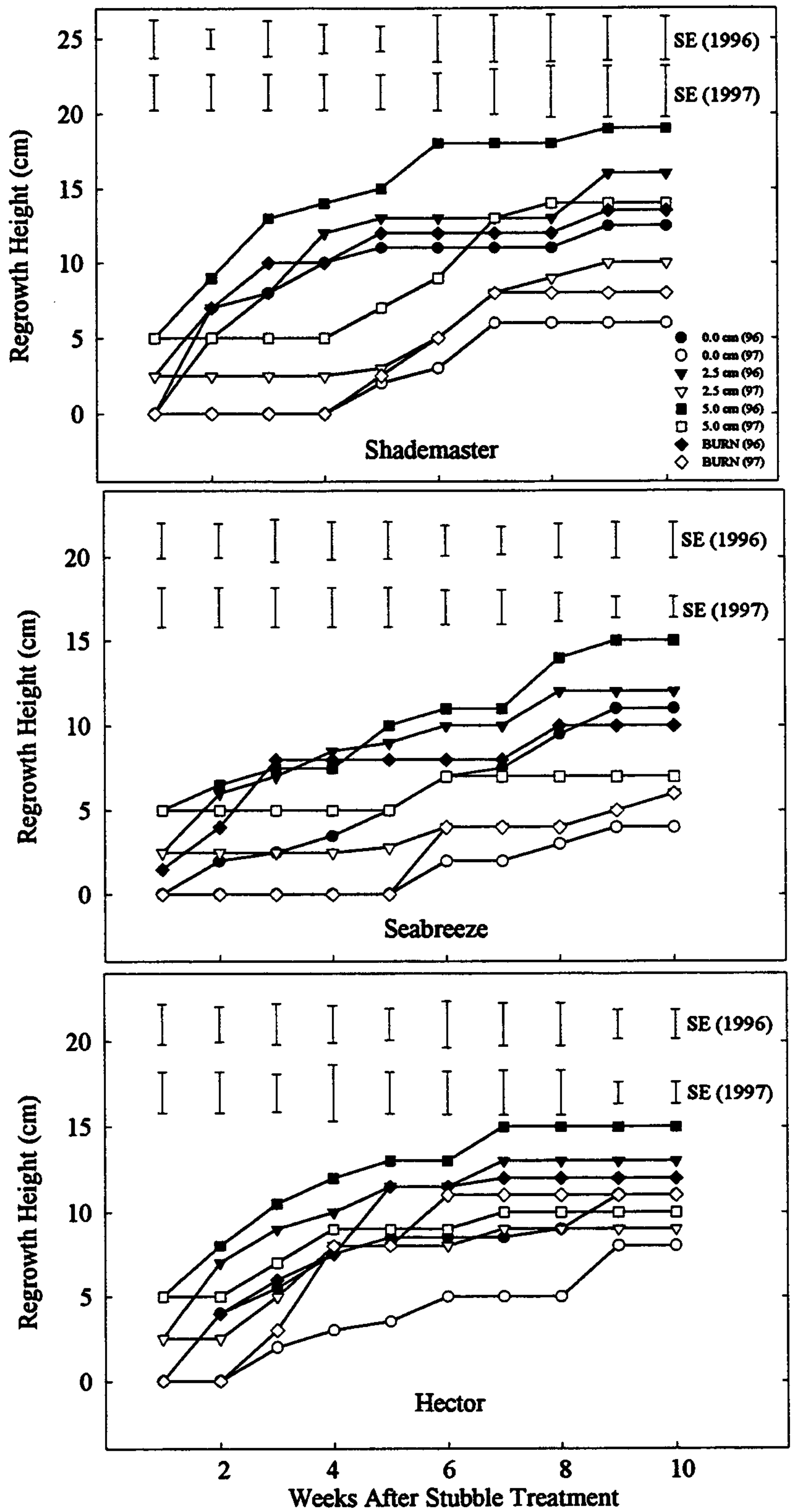

Figure I-3. Change in light quality (red : far-red ratio) during the first ten weeks following stubble treatment in three cultivars of creeping red fescue during 1996 and 1997.

Table I-3. Impact of stubble height treatment (SHT) by mechanical removal or open burn on regrowth height of fall tillers and mean stage by count in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
SHT	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	regrowth height (cm)							
Burn	14.7 b ††	8.4 a	2.8 b	11.2 a	7.2 b	9.7 b	7.3 bc	8.8 b
0.0 cm	12.7 a	9.0 a	2.1 a	9.9 a	6.2 a	8.5 a	6.3 a	7.6 a
2.5 cm	15.3 b	9.0 a	2.9 b	11.7 b	8.0 c	11.4 c	7.1 b	9.5 bc
5.0 cm	14.8 b	10.2 b	3.1 b	11.7 b	8.4 c	11.4 c	7.6 c	9.8 c
	Mean stage by count							
Burn	2.8 b	2.8 b	2.7 ab	2.7	2.0 a	2.5 a	2.9 b	2.7
0.0 cm	2.5 a	2.5 a	2.5 a	2.8	2.1 b	2.6 b	2.8 ab	2.5
2.5 cm	2.6 a	2.6 a	2.6 ab	2.5	1.3 c	2.5 a	2.8 ab	2.6
5.0 cm	2.5 a	2.6 a	2.7 b	2.5	2.4 c	2.5 a	2.7 a	2.6

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

the burn treatment tended to be shorter than when stubble was present. Stubble taller than 2.5 cm caused etiolation of tillers with the exception of Shademaster in 1997. Chilcote et al., (1974) also found that fall tillers of creeping red fescue were shorter when straw and stubble was burned than when the crop was not burned. Hickey and Ensign (1983) found leaf sheath length in Kentucky bluegrass was shortest where residue and stubble was removed below 2.5 cm by either burning or mechanical means. Ensign et al., (1983) reported that residue reduced light penetration into the canopy of Kentucky bluegrass by more than 30%, but a 67% shade treatment did not cause significant differences in tiller height relative to a burn treatment. Their trials also showed that tiller height of fall regrowth was shorter after stubble was clipped to 2.5 cm.

Developmental stage of tillers was variable for treatments and cultivars (Table I-3). The developmental stage of Kentucky bluegrass during fall regrowth was not consistently affected by the presence or absence of burning (Chastain et al., 1997) or when stubble was cut to 2.5 cm or 7.6 cm (Thompson and Clark, 1993). Gamroth et al. (1995) reported that the developmental stage of perennial grasses is dependent on accumulated heat units, formation of new intravaginal tillers, and senescence of older mature leaves lower in the canopy. It is likely that the development of creeping red fescue would be influenced by these same factors although this was not measured in this study.

Chastain et al. (1997) reported increased tiller number with stand age under non-thermal stubble treatments. Tiller number tended to be greater in second-year stands than in first-year stands in Shademaster and Seabreeze, but was reduced in third-year stands compared with second-year stands of Hector (Table I-4). Stubble removal treatment

Table I-4. Impact of stubble height treatment (SHT) by mechanical removal or open burn on fall tiller number, small tiller number (< 2 mm), and large tiller number (> 2 mm) in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
SHT	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
				Fall tiller number				
Burn	331 c ††	567 c	541 ab	438	367	419	702 b	481
0.0 cm	183 a	502 b	578 b	410	391	323	781 c	453
2.5 cm	246 b	477 b	520 a	407	367	370	859 d	464
5.0 cm	232 b	363 a	514 a	410	385	354	623 a	412
				large tillers (< 2 mm)				
Burn	9 a	10 a	48 ab	23	32 a	15 a	23 a	23 a
0.0 cm	11 a	24 b	59 b	29	39 b	18 ab	35 b	31 b
2.5 cm	17 b	29 b	54 ab	25	36 ab	23 c	35 b	31 b
5.0 cm	17 b	32 b	47 a	26	33 ab	22 bc	43 c	31 b
				small tillers (> 2 mm)				
Burn	66 b	65 c	27 b	52	43 b	60	52 c	52
0.0 cm	64 b	51 ab	16 a	46	36 a	57	40 b	44
2.5 cm	58 a	46 ab	21 ab	50	39 ab	52	40 b	43
5.0 cm	58 a	43 a	28 b	49	42 ab	53	32 a	44

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

significantly affected tiller number, although the effects differed between cultivars and age of the stand. Clipping stubble either had no influence on tiller number in Kentucky bluegrass (Thompson and Clark, 1993) or produced inconsistent effects (Ensign et al., 1983; Meijer and Vreeke, 1988). Burned plots produced larger tillers compared with clipping to either 2.5 cm or 7.6 cm in Kentucky bluegrass (Hickey and Ensign, 1983). The results were not as consistent with creeping red fescue plots in this study. Burned plots produced a greater number of large tillers (< 2 mm basal diameter) than mechanical stubble height treatments (Table I-4). Canode and Law (1979) reported that fall tillers must attain a minimum size in order for floral induction to occur. In their studies, burned plots produced more large tillers. Basal diameter was not consistently influenced by mechanical stubble treatments or age of the stand (Table I-4). These results were similar to those reported by Thompson and Clark (1993) but differed from those of Chastain et al. (1997) who reported that the number of large tillers was influenced by the thoroughness of stubble removal. In this study complete stubble removal generally was not equal to the burn treatment in production of large tillers or total tiller number.

Root and Rhizome Development. Development of underground tissues was impacted by stubble treatments (Table I-5). Root dry weight was reduced in first-year stands when stubble was removed to 0.0 cm. Burn treatment did not consistently change root dry weight from year to year and varied between cultivars. Although soil temperatures under open burn might be expected to damage shallow roots, Chilcote et al. (1980) reported greater root dry weight in the soil profile above 2.5 cm in burn plots than in unburned

Table I-5. Impact of stubble height treatment (SHT) by mechanical removal or open burn on root dry weight and rhizome dry weight in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
SHT	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	root dry weight (g core^{-1})							
Burn	2.83 ab ††	21.54 b	3.60 a	4.05 b	3.22	2.94 b	11.42 b	7.08 b
0.0 cm	2.47 a	10.78 a	5.88 b	2.89 a	3.59	1.82 a	7.54 a	4.43 a
2.5 cm	3.90 c	12.26 a	5.35 b	3.07 a	4.15	2.97 b	8.75 a	5.68 ab
5.0 cm	3.54 bc	12.83 a	5.12 b	2.99 a	4.35	2.68 b	7.65 a	5.51 ab
	rhizome dry weight (g core^{-1})							
Burn	0.19 a	0.32	0.81 a	0.57 ab	0.31 a	0.01 a	0.22 b	0.35 a
0.0 cm	0.16 a	0.40	0.81 a	0.47 a	0.37 a	0.01 a	0.04 a	0.32 a
2.5 cm	0.54 b	0.30	1.19 b	0.67 b	0.62 b	0.24 c	0.15 b	0.53 b
5.0 cm	0.45 b	0.41	1.13 b	0.68 b	0.67 b	0.15 b	0.16 b	0.52 b

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

plots and no differences lower in the soil profile. Hickey and Ensign (1983) found no difference in root weight between burned plots or those where 7.6 cm stubble remained.

Rhizome dry weight was reduced in the burn treatment and 0.0 cm stubble treatment (Table I-5). Ensign and Weiser (1975) found a significant correlation between rhizome weight and rhizome number. Plant populations under intensive stubble management (burn or complete removal) produced fewer rhizomes than in those plots where stubble remained. Hickey and Ensign (1983) reported that burning reduced rhizome weight in Kentucky bluegrass compared with clipping stubble to 7.6 cm. Destruction of rhizomes by heat does not necessarily explain the lower rhizome weight in the burn treatment. When stubble remained, rhizome weights were consistently equal to or greater than when stubble was removed either by burn or mechanical means (Table I-5). Rhizome weights differed among cultivars and were characteristic of rhizome formation inherent in each cultivar (Figure I-4). Seabreeze consistently produced fewer rhizomes under all treatments than Shademaster or Hector. Moser et al. (1968) and Hickey and Ensign (1983) also reported variation in rhizome weight due to cultivar differences.

Yield Potential. The percent of the tiller population that flowered was generally reduced when stubble was greater than 2.5 cm in the previous fall (Table I-6). Burn treatment and complete mechanical removal produced greater percent fertile tiller number than when stubble was not removed. Percent fertile tillers generally increased with age of stand for these cultivars of creeping red fescue, in contrast to the trend reported by Canode and Law (1975) for Kentucky bluegrass. The greatest percentage of fertile tillers has generally

Table I-6. Impact of stubble height treatment (SHT) by mechanical removal or open burn on percent fertile tiller number in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
SHT	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
Burn	16 ab ††	44 c	32 b	53 b	64 b	28 b	32	38 b
0.0 cm	17 b	31 b	29 b	52 b	61 b	19 a	32	35 a
2.5 cm	15 a	22 a	22 a	39 a	53 a	21 a	33	27 a
5.0 cm	13 a	19 a	22 a	38 a	58 ab	21 a	30	29 a

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

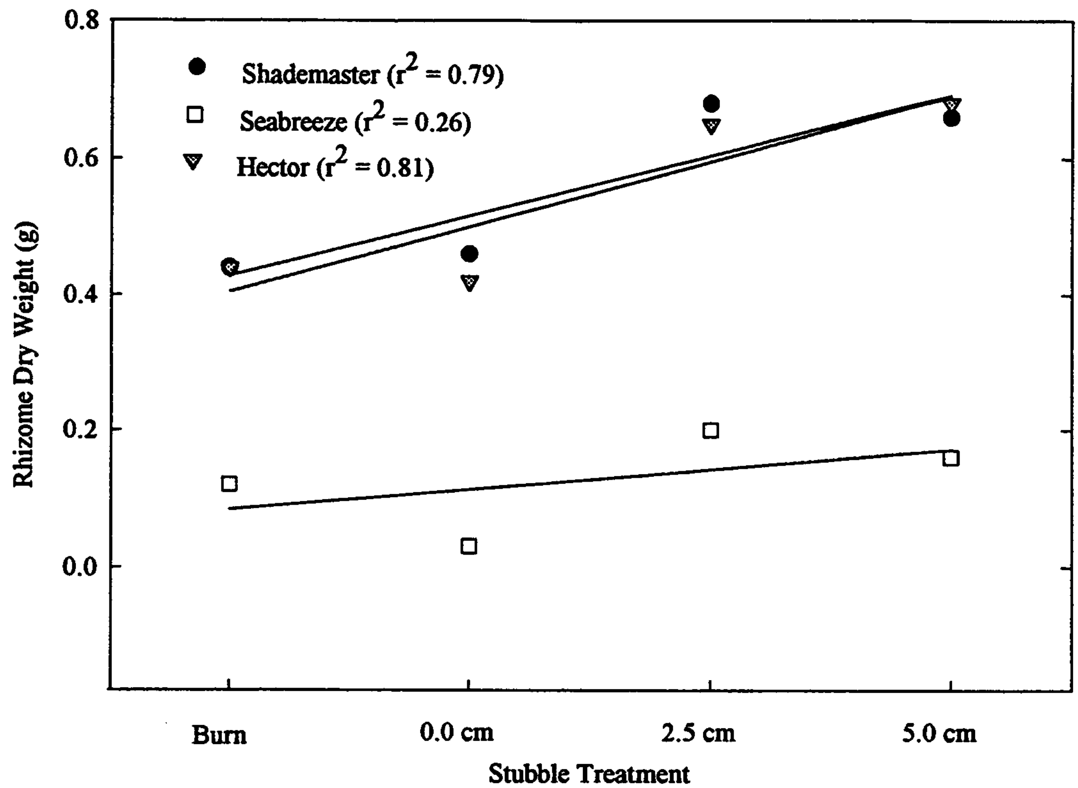

Figure I-4. Relationship of stubble removal treatment to rhizome dry weight in three cultivars of creeping red fescue. Data points are means over years for each cultivar. Regression equation for the fitted line for each cultivar is: Shademaster, $Y = 0.428 + 0.088X$, Seabreeze, $Y = 0.084 + 0.29X$, and Hector, $Y = 0.405 + 0.095X$.

been associated with field burning (Chilcote et al., 1980; Hickey and Ensign, 1983), although Chastain (1997) found Kentucky bluegrass fertile tiller number to be equivalent with burning when stubble was removed shorter than 4.1 cm in trials utilizing field scale practices. Chastain et al. (1995b) also reported greater percent fertile tiller numbers in creeping red fescue under burn than in non-thermal treatments. In seed production fields, complete mechanical stubble removal to the crown provided the same yield potential as burn.

The production of fertile tillers is influenced by factors that occur early during fall regrowth. Meijer (1984) reported that tillers emerging in the early fall were more likely to produce panicles than late emerging tillers. Fall tiller height showed an inverse relationship with percent fertile tiller production (Figure I-5) similar to that reported by Chastain et al. (1997). Other regrowth characteristics that have been associated with fertile tiller production were not consistently associated with yield potential in this study (Table I-7).

Reduced carbohydrate reserves in plots where stubble was removed below five cm was found in all cultivars examined, but was particularly evident in Seabreeze , a cultivar that produces few rhizomes. Hector and Shademaster produce many rhizomes, yet carbohydrate availability was also reduced when stubble was removed. First-year stands not only exhibited less rhizome development than older stands, but also had lower available carbohydrates when stubble was burned or removed. These reductions in carbohydrate reserves may result in loss of yield potential when they occur in combination with other stresses such as drought.

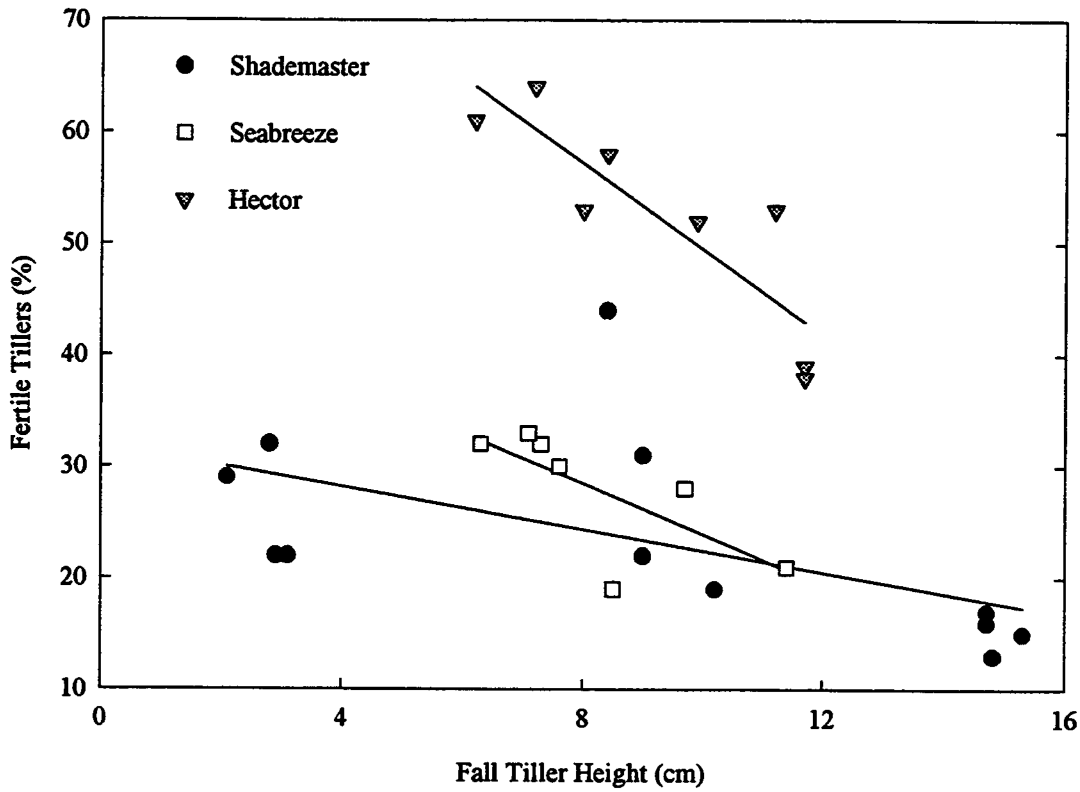

Figure I-5. Relationship of fall tiller height to percent fertile tiller in three cultivars of creeping red fescue (Shademaster r = 0.55, $P < 0.10$; Seabreeze r = 0.78, $P < 0.05$; Hector r = 0.87, $P < 0.01$). Regression equation for the fitted line for each cultivar is: Shademaster, Y = 32.01 - 0.95X, Seabreeze, Y = 46.72 -2.28X, and Hector, Y = 87.84 - 3.83X.

Table I-7. Phenotypic correlation coefficients (r) among seven traits measured on three cultivars of creeping red fescue (means across three locations and three replicates in Shademaster and two locations and three replicates in Seabreeze and Hector).

Shademaster	1	2	3	4	5	6	7
(1) Stubble Treatment	--						
(2) MSC	-0.36**	--					
(3) Fall dry weight (g)	-0.50**	0.61**	--				
(4) Root dry weight (g)	-0.18	0.55**	0.38**	--			
(5) Rhizome dry weight	0.22	0.09	-0.07	0.19	--		
(6) Fall tiller number	-0.29*	0.38**	0.72**	0.27*	-0.15	--	
(7) < 2 mm tillers	-0.35**	0.51**	0.53**	0.14	0.15	0.38**	--
(8) Percent fertile tillers	0.19	-0.20	-0.15	-0.10	0.09	-0.27*	-0.14
Seabreeze	**1**	**2**	**3**	**4**	**5**	**6**	**7**
(1) Stubble Treatment	--						
(2) MSC	-031*	--					
(3) Fall dry weight (g)	-0.00	0.27*	--				
(4) Root dry weight (g)	-0.17	-0.08	0.24	--			
(5) Rhizome dry weight	0.34**	-0.10	0.22	0.18	--		
(6) Fall tiller number	-0.17	0.14	0.56**	0.09	0.10	--	
(7) < 2 mm tillers	-0.32**	0.45**	0.45**	0.03	0.02	0.19	--
(8) Percent fertile tillers	-0.18	0.16	0.33**	0.19	0.00	0.12	0.29
Hector	**1**	**2**	**3**	**4**	**5**	**6**	**7**
(1) Stubble Treatment	--						
(2) MSC	0.03	--					
(3) Fall dry weight (g)	0.39**	0.14	--				
(4) Root dry weight (g)	0.07	-0.00	0.12	--			
(5) Rhizome dry weight	0.43**	-0.15	0.23	0.10	--		
(6) Fall tiller number	-0.01	0.26*	0.56**	-0.00	-0.07	--	
(7) < 2 mm tillers	0.08	0.01	0.50**	0.02	-0.04	0.17	--
(8) Percent fertile tillers	-0.42**	0.04	-0.15	-0.07	-0.05	0.01	0.15

*, ** Significant at the $P < 0.05$ and $P < 0.01$ levels respectively.

Reduction in stubble height caused fall tillers to be shorter. Reduced fall tiller height was a strong indicator of yield potential the following spring. Reduction in stubble height also reduced rhizome formation. Although other growth and development indicators were not consistently affected by stubble treatments, short fall tiller height and reduction in rhizomes were nearly always predictors of yield potential across cultivars and locations. Management practices that removed stubble to the crown might provide yield potentials similar to that observed in this study however, open burning currently provides the only alternative to maintaining yield in Oregon's creeping red fescue seed crops.

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MANUSCRIPT II: POST-HARVEST APPLICATION OF ETHYLENE REDUCED TILLER PRODUCTION AND FLOWERING IN THREE CULTIVARS OF CREEPING RED FESCUE.

ABSTRACT

Plant growth regulators mediate multiple aspects of regrowth and development at very low concentrations in plants. Non-thermal residue management in creeping red fescue (*Festuca rubra* L.) has been associated with yield reduction compared with open field burning. Crown bud differentiation to tillers or rhizomes during the fall regrowth period may be affected by the hormone balance within the crown during this period. The effect of exogenous application of five plant regulators and open field burning were measured on creeping red fescue seed crops at Corvallis and Sublimity, OR.

Fall tiller height was reduced by early fall application of ethylene over locations and cultivars. Fall tiller number and subsequent vegetative dry weight were equal to control treatment (IE. no burn, no PGRs) when ethylene was applied and both were reduced compared with burning. Open burn consistently resulted in greater large tiller number than other PGR treatments examined. Ethylene application reduced tiller mortality in second-year and third-year stands compared to burn and control treatment but was intermediate in first-year stands. Root production was reduced by all PGRs whereas rhizome production was not consistently affected by PGRs but was greater than when burned. Increased rhizome weight caused reduction in fertile tiller production. Fertile tiller number was reduced with ethylene and the control treatment compared with open

burn. Presence of natural ethylene in increased quantity under non-thermal management may alter floral induction and reduce yield potential compared with field burning.

INTRODUCTION

Plant hormones regulate gene expression and other protein mediated responses within the plant (Barendse and Peeters, 1995). Some function throughout the life of the plant while others influence very specific stages of growth and development. Plant growth regulators are natural or synthetic compounds that are functional analogs to plant hormones. The singular effects of PGRs are more easily measured than interactions between them in the plant. It is possible that management practices used in grass seed production alter the levels of different PGRs within the rhizomatous grasses. These alterations may determine, in part, the efficacy of those practices.

Ethylene is the only naturally occurring plant hormone that is functionally active in gaseous form. Buettner et al. (1976) reported that fall application of ethephon increased tillering in one Kentucky bluegrass cultivar, but not in another. Exogenous application of ethylene releasing compounds to barley seedlings increased tiller production, shortened internodes, and reduced lodging (Dathe, 1992; Foster et al., 1992; and Foy and Witt, 1987). Ethylene stimulated root growth of tomato plants at low concentrations, but had the opposite effect at high concentrations (Jackson, 1979). Shinozaki and Takimoto (1983) reported that root elongation but not floral induction was suppressed in *Pharbitis nil* by ethylene releasing compounds.

Abscisic acid is involved in regulation of stomatal closure (Mansfield and McAinsh, 1995), inhibition of shoot growth, reduction of gibberellin promotion of α-amylase in germinating caryopses (Jones and Jacobson, 1991), and drought or wound response. Drought stress typically results in stunted plants if the dessication persists for prolonged periods. ABA application to barley (*Hordeum vulgare* L.) shoots at 10^{-4} mol m^{-3} did not inhibit leaf growth except when plants were subjected to osmotic stress (Dodd and Davies, 1996). Inhibition of plant growth and leaf area by ABA required some specific interaction with osmotic stress as well.

Along with promotion of cell division, cytokinins are implicated in shoot initiation, release of lateral buds from apical dominance, and chloroplast development. Kinet et al. (1993) reported that reduced root initiation or growth promoted floral initiation and that a reduction in roots correlated with reduced endogenous cytokinin levels. Krekule and Seidlova (1976) reported a concentration-dependent influence of cytokinin on flower initiation. Concentrations above a certain threshold inhibited floral initiation while lower concentrations had a promotional effect.

Auxin activity on plant tissue was first demonstrated by Went's classic experiments with oat coleoptile curvature. Leopold (1949) tested the hypothesis that auxin regulated tillering in barley and teosinte in a manner similar to its regulation of axillary bud break in dicotyledons. Ackerson and Chilcote (1978) reported that application of the auxin antagonist triiodobenzoic acid (TIBA) to Kentucky bluegrass increased tillering and decreased carbohydrate reserves in the lower stem. Clifford (1974) suggested that auxins produced from elongating stem internodes during flowering were sufficient to suppress late tiller bud release, conserving energy for floral development.

The large number of physiologically active GAs indicates that changes in chemical structure and conformation alter the ability of GA to initiate a plant response. Evans et al. (1994) reported that 3β-hydroxylation in the *A* ring of several GAs promoted stem elongation in *Lolium temulentum* and reduced floral initiation.

The purpose of this study was to determine if application of ethylene or representatives of other plant growth regulator groups would mimic creeping red fescue growth or flowering responses that occur following thermal and non-thermal residue management practices.

MATERIALS AND METHODS

Plant Growth Regulator Treatments. This investigation was conducted in the Willamette Valley of western Oregon during 1994-1997. Trials were conducted in a commercial production field of 'Shademaster' creeping red fescue (IOKA farm), commercial production field of 'Hector' creeping red fescue (Taylor farm) near Sublimity, Oregon, and in Shademaster and 'Seabreeze' creeping red fescue planted at Hyslop farm research station near Corvallis, Oregon. Plots were 1 m^2, and were established 13 September, 1994 (IOKA) and on 20 September, 1995 (Taylor and Hyslop). Data were taken on a second-year production field at IOKA and at Taylor on second-year and third-year production fields. Plots at Hyslop research farm were planted using carbon banding in the fall of

1994. Diuron {3-(3,4-dichlorophenyl)-1,1-dimethylurea} was applied pre-emergence to control weeds. Data taken at Hyslop farm were on first-year and second-year plots.

The experimental design was a randomized complete block with split plot restrictions of PGR application. Each location contained three replications. Statistical Analysis System (SAS) was used to conduct an analysis of variance. Mean separation was conducted using Fisher's protected least significant difference (LSD).

Open burn plots were not treated with any PGRs and were prepared by burning straw and stubble in the production fields. At Hyslop research farm, burn plots were clipped prior to seed set to prevent viable seed formation and re-clipped prior to burning to simulate swathing prior to harvest.

Five growth regulators cytokinin (benzyl adenine; CYT), indole-acetic acid (IAA), abscisic acid (ABA), gibberellic acid (GA), Ethrel (ethephon; ETH), and water as a control were applied at lx and 10x rates to three different cutting heights. The lx rate of application was 10^{-6} *M* solution and the 10x rate of application was 10^{-5} *M* solution for each of the PGRs (Appendix I). PGR solutions were applied with a backpack sprayer equipped with a flooding fan spray tip at 0.1 MPa line pressure, and an equivalent quantity of water was applied on the control plots. The sprayer was calibrated for liters minute^{-1} and each plot was sprayed for the time required to deliver 0.313 liters volume of PGR solution (Appendix I). The cutting height and PGR treatments were conducted post-harvest in the fall prior to any regrowth.

Sampling Practices. In field experiments, sod cores 15 cm x 15 cm were taken between January and March each year following regrowth from imposed stubble height treatments. Samples were brought into the laboratory and tiller height, growth stage, total tiller number, and bulk dry weight were recorded for each sample. Tiller height was measured in centimeters (cm) from the crown to the tip of the longest leaf. Growth stage was estimated using a modified Haun stage (Klepper et al., 1982). Tillers were separated by size in 1 mm increments according to basal diameter measured just above the point of attachment to the crown or axil. Root-rhizome separations were made to determine the dry weight of each in grams (g) area^{-1} and rhizome : root weight ratios. Root cores were taken in late winter using a golf course cup cutter with a core volume of 8.83×10^{-3} m^{-3}.

Tiller samples were taken in spring after anthesis. Vegetative and fertile tillers were counted, dry weights noted, and percent fertile tillers was calculated. The percentage of fertile tillers was used to estimate yield potential. Seed yield was not measured in this study.

RESULTS AND DISCUSSION

Rate of Plant Growth Regulator. The rate of PGR application did not significantly influence any measurements taken in this study with the exception of spring vegetative dry weight in 1995 (Appendix II). Consequently, the analysis was conducted with combined means over rate of application.

Fall Regrowth and Development. Fall tiller height in plots treated with ethephon tended to be shorter than those measured in burned on control plots, although the reduction was not significant (Table II-1). Tiller height was increased by fall application of GA (Table II-1). Application of GA has been observed to increase stem length in Oryza sativa L. (Hoffmann-Benning and Kende, 1992) and *Lolium temulentum* L. (Evans et al., 1994). Fall regrowth tended to be taller in first-year stands regardless of treatment. Chilcote et al. (1974) reported that fall tiller height was reduced with open field burning compared with non-thermal management. Chastain et al. (1997) found that fall tiller height influenced flowering and yield in Kentucky bluegrass plots.

Developmental stage was not affected by ethylene compared to burn or zero treatment (Table II-2). Tillers produced from crowns that were treated with CYT were more mature than control tillers, but not different from burned or ABA-treated plots.

Total vegetative dry weight was not changed by application of PGRs or water, but was significantly increased by burning (Table II-3). Differences in vegetative dry weight were attributed to greater production of large (> 2 mm) tillers and consequent reduction in small tillers (< 2 mm) in the burn treatment. It is likely that removal of stubble by burning had greater influence on tiller size and vegetative biomass than early PGR application.

Tiller number in the burned plots was greater than those of the ethylene-treated or the control plots (Table II-4). Other PGR-treated plots had fall tiller numbers between ethylene and burned plots. Ethylene-treatment of barley plants increased tillering (Dathe, 1992; Foster et al., 1992; and Foy and Witt, 1987) whereas Kentucky bluegrass cultivars varied (Buettner et al, 1976). In annual grasses such as barley, tiller production increased

Table II-1. Impact of exogenous PGRs, open burn and no treatment on regrowth height of fall tillers in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	tiller height (cm)							
Burn	14.7 b	8.4 a	2.8 †	11.2	7.2	9.7 ab	7.3	8.8 ab
ETH †††	15.0 b	9.2 ab	2.7	10.3	7.2	8.8 a	6.8	8.6 a
ABA	14.5 b	9.7 b	2.7	11.0	7.3	10.0 ab	7.6	8.9 ab
CYT	14.9 b	9.1 ab	2.9	11.2	7.5	10.4	6.9	9.1 bc
IAA	14.3 ab	9.9 b	2.7	11.0	7.6	11.2	6.8	9.1 bc
GA	14.3 ab	9.7 ab	2.6	11.5	8.0	11.8 c	6.9	9.3 c
Control	12.7 a	8.8 ab	2.7	11.7	7.7	10.4	7.1	8.7 ab

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.
†† Means within a column followed by the same letters were not significantly different (LSD 0.05).
††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

Table II-2. Impact of exogenous PGRs, open burn and no treatment on mean stage by count in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
Burn †††	2.8 b ††	2.8 c	2.6	2.7 ab	2.0 a	2.5 ab	2.9	2.6 ab
ETH	2.7 b	2.5 ab	2.4	2.4 a	2.2 abc	2.6 ab	2.7	2.5 a
ABA	2.6 ab	2.8 c	2.7	2.4 a	2.4 c	2.5 ab	2.8	2.6 ab
CYT	2.6 ab	2.5 ab	2.5	3.4 b	2.4 c	2.6 ab	2.8	2.7 b
IAA	2.6 ab	2.6 abc	2.7	2.5 ab	2.2 abc	2.4 a	2.7	2.5 a
GA	2.4 a	2.5 ab	2.4	2.4 a	2.3 Bc	2.7 b	2.9	2.5 a
Control	2.4 a	2.4 a	2.6	2.5 ab	2.1 ab	2.5 ab	2.7	2.5 a

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.
†† Means within a column followed by the same letters were not significantly different (LSD 0.05).
††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

Table II-3. Impact of exogenous PGRs, open burn and no treatment on dry weight, small tiller number (< 2 mm), and large tiller number (> 2 mm) in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	dry weight (g)							
Burn	6.68 c	5.93 b	5.56 b	4.97 b	2.43 ab	4.45 Bc	4.93 b	4.99
ETH †††	4.93 b	4.31 a	3.24 a	3.59 a	2.20 a	2.71 a	7.29 a	4.04
ABA	4.49 b	4.52 a	4.01 a	5.23 b	2.51 ab	3.48 abc	7.71 a	4.56
CYT	4.09 ab	4.60 a	3.66 a	5.01 b	2.96 b	3.60 abc	7.45 a	4.48
IAA	4.66 b	5.09 ab	3.32 a	4.65 ab	2.44 ab	4.59 c	8.93 ab	4.81
GA	3.70 ab	5.10 ab	3.57 a	5.41 b	2.53 ab	4.97 c	7.80 a	4.72
Control	2.94 a	4.37 a	3.68 a	4.52 ab	2.61 ab	2.89 ab	8.72 ab	4.25
	small tillers (< 2 mm)							
Burn	9 a	10 a	60	23 ab	32	15 a	23 a	25 a
ETH	13 ab	20 ab	63	37 c	35	16 a	35 b	31 b
ABA	13 ab	28 Bc	72	26 ab	34	23 b	35 b	33 b
CYT	11 a	33 c	67	26 ab	33	22 b	38 b	33 b
IAA	22 c	31 Bc	67	24 ab	38	23 b	38 b	35 b
GA	18 Bc	27 Bc	62	27 b	37	21 ab	41 b	33 b
Control	14 ab	32 Bc	61	20 a	38	20 ab	40 b	32
	large tillers (> 2 mm)							
Burn	66 c	65 c	40	52 b	43	60	52 b	50 b
ETH	65 Bc	55 Bc	37	38 a	40	59	40 a	44 a
ABA	65 Bc	47 ab	28	49 b	41	52	40 a	42 a
CYT	64 Bc	42 a	33	49 b	42	53	37 a	42 a
IAA	53 a	44 ab	33	54 b	37	52	37 a	40 a
GA	57 ab	48 ab	38	48 b	38	54	34 a	42 a
Control	61 b	43 ab	39	55 b	37	55	35 a	43 a

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively; for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively; and for Hector second-year and third-year stands were 1996 and 1997, respectively.
†† Means within a column followed by the same letters were not significantly different (LSD 0.05).
††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

Table II-4. Impact of exogenous PGRs, open burn and no treatment on fall tiller number in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
Burn	331 c ††	567 b	541	331 c	363 a	419 ab	702	464 b
ETH †††	248 b	428 a	501	248 b	371 a	257 a	699	393 a
ABA	236 ab	443 a	593	236 ab	355 a	303 ab	790	422 ab
CYT	208 ab	404 a	552	208 ab	437 b	460 b	786	436 ab
IAA	247 b	447 a	211	247 b	380 ab	391 ab	765	384 ab
GA	197 ab	477 ab	272	197 ab	368 a	388 ab	754	379 ab
Control	186 a	485 ab	554	186 a	376 ab	293 ab	731	401 a

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.
†† Means within a column followed by the same letters were not significantly different (LSD 0.05).
††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

panicle production whereas perennial grass tillers are not always induced to flower. Many tillers survive to the next season before producing a panicle. Fall tillers in control first-year stands were more likely to survive until spring than those in burned or ethylene-treated plots (Figure II-1). Reduced tiller mortality resulted in greater tiller numbers in spring than observed in the previous fall. In young stands, tillers were small and less likely to be induced to flower. Canode and Law (1979) reported that fall tillers of Kentucky bluegrass needed to reach a minimum size to be induced to flower.

Tiller mortality increased as the stands aged so that fewer tillers remained in spring than following fall regrowth. Fall tiller number was reduced by ethylene treatment (Table II-4) but overwinter tiller survival was greater than provided by control or burn treatments, especially in second-year stands (Figure II-1). Plots treated with CYT had tiller production through spring equal to that of the control in first-year stands. The CYT-treated plots had the greatest tiller mortality in third-year stands (Figure II-1). Cytokinin application may promote axillary bud initiation and increased tillering in young stands, but in older stands, density-dependence may contribute to poor tiller development and reduced tiller survival.

Root and rhizome development. Combined location means indicated that root development was suppressed by all non-burn treatments although treatment effects varied with stand age and cultivar (Table II-5). The burn-associated increase in root weight was similar to that reported by Chilcote et al (1980). Ethylene has been reported to suppress root elongation in *Pharbitis nil* (Shinozaki and Takimoto, 1983) and although not statistically significant, produced the lowest root dry weight combined over locations in

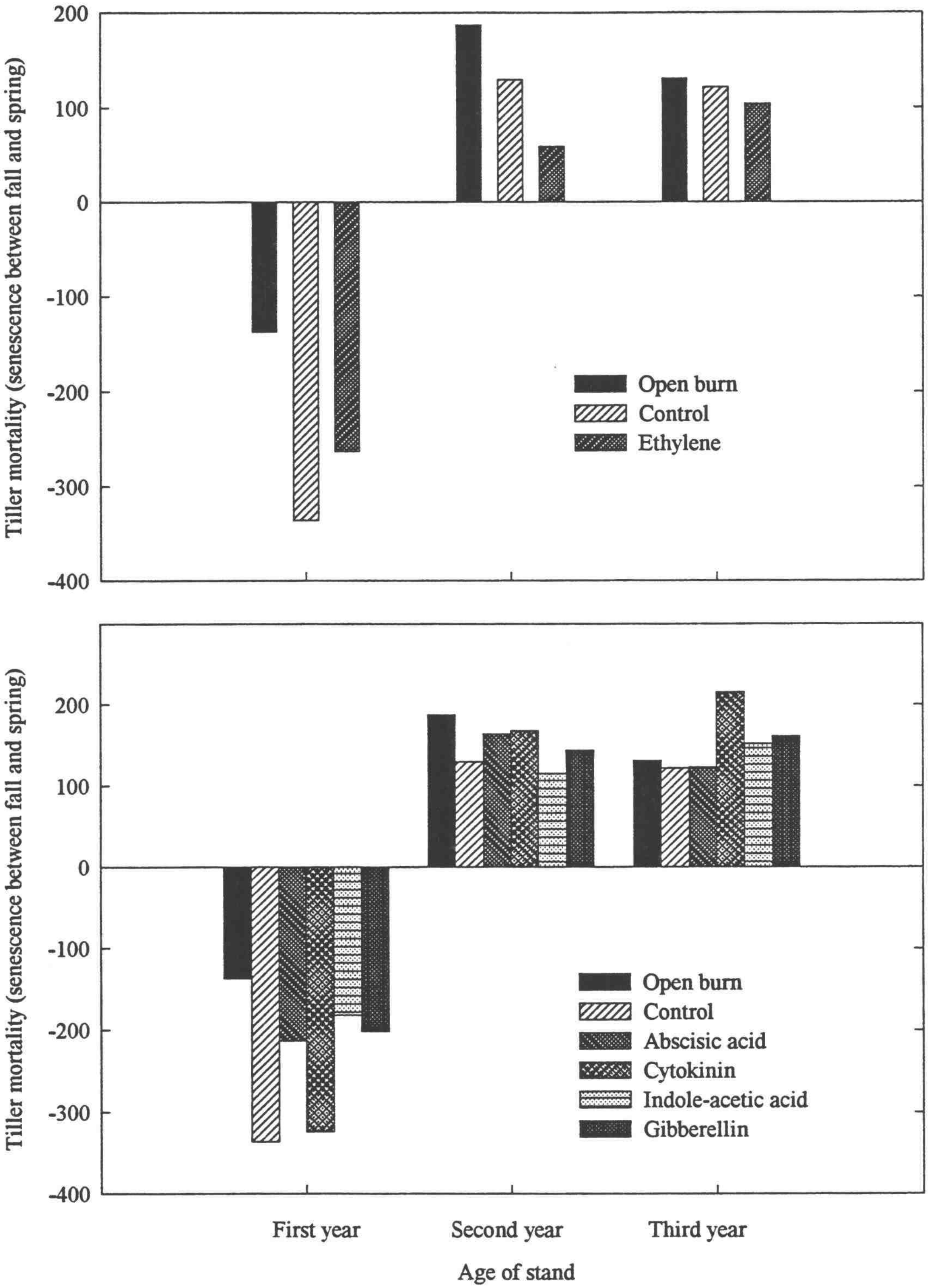

Figure II-1. The effect of stand age on tiller mortality of creeping red fescue from fall through floral initiation. Treatments are open burn, control, ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellin.

Table II-5. Impact of exogenous PGRs, open burn and no treatment on root dry weight and rhizome dry weight in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	root dry weight (g core^{-1})							
Burn	2.82 a ††	21.54 b	5.88 b	4.05 b	3.30	2.94 cd	11.42 b	7.08 b
ETH †††	3.00 a	10.28 a	4.59 a	3.13 ab	4.04	2.04 ab	7.29 a	4.84 a
ABA	2.71 a	10.96 a	5.14 ab	3.20 ab	5.12	2.61 abcd	7.71 a	5.29 a
CYT	4.41 b	11.87 a	4.55 a	2.97 a	3.60	2.75 bcd	7.45 a	5.19 a
IAA	2.83 a	13.18 a	4.95 ab	3.06 ab	3.44	3.14 d	8.93	5.49 a
GA	3.78 ab	13.95 a	4.12 a	2.54 a	3.80	2.41 abc	7.80 a	5.18 a
Control	3.06 a	11.52 a	4.82 ab	2.99 a	4.28	1.98 a	8.72	5.22 a
	rhizome dry weight (g core^{-1})							
Burn	0.19 a	0.32 ab	0.81	0.57	0.30 a	0.01 a	0.22 b	0.35 a
ETH	0.38 ab	0.26 a	1.09	0.60	0.58 ab	0.09 ab	0.11 ab	0.44 bc
ABA	0.38 ab	0.29 ab	1.03	0.67	0.68 b	0.18 b	0.10 ab	0.47 bc
CYT	0.35 ab	0.43 ab	0.99	0.49	0.59 b	0.15 b	0.06 a	0.43 abc
IAA	0.36 ab	0.52 b	1.10	0.72	0.45 ab	0.20 b	0.16 ab	0.50 c
GA	0.38 ab	0.46 ab	1.11	0.65	0.58 ab	0.11 ab	0.16 ab	0.49 c
Control	0.43 b	0.29 ab	0.94	0.50	0.45 ab	0.08 ab	0.11 ab	0.40 ab

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

this study. In general, rhizome dry weight was lowest in burned plots, although differences were not significant when considered over all locations. Hickey and Ensign (1983) reported that burning reduced rhizome dry weight in Kentucky bluegrass plots compared to non-burn treatments.

Spring Reproductive and Vegetative Development. The percent of the tiller population induced to flower was greatest in burned plots and was consistently reduced by ethylene and when no PGR was applied (Table II-6). Shinozaki and Takimoto (1983) suggested that applications of an ethylene releasing compound inhibited flowering in *Pharbitis nil*. All other PGR applications reduced fertile tiller production compared to burning. Vegetative dry weight in spring was consistently lower in PGR-treated plots and control plots than in burned plots (Table II-6).

Fertile tiller percentages were associated with above-ground dry weight observed in the previous fall regardless of treatment (Figure II-2). Other fall regrowth characteristics associated with prediction of yield potential such as tiller height (Chastain et al., 1997) were not correlated with fertile tiller percentage.

Bernier et al. (1977) reported that application of cytokinin (benzyl adenine or zeatin) to *Sinapsis alba* resulted in a mitotic wave similar to naturally induced plants but was unable to mimic floral induction itself. Their work suggested that cytokinins were involved in floral induction, but not sufficient by themselves to cause induction. Jacobs (1985) reviewed auxin effects on floral induction and suggested that auxin was a background inhibitor of flowering. Hampton and Hebblethwaite (1985) applied gibberellin inhibitors to *Lolium perenne* in the spring and found decreased lodging and increased

Table II-6. Impact of exogenous PGRs, open burn and no treatment on percent fertile tiller number and spring vegetative dry weight in three cultivars of creeping red fescue and over combined location means (CLM).

	Shademaster			Hector		Seabreeze		
	1st year †	2nd year	2nd year	2nd year	3rd year	1st year	2nd year	CLM
	fertile tiller number (%)							
Burn	16 ††	44 c	33 b	53 b	64 ab	28 b	32	38 d
ETH †††	16	21 a	22 a	34 a	51 a	20 a	33	27 a
ABA	15	29 b	28 ab	46 b	57 abc	20 a	39	32 c
CYT	13	28 bc	23 ab	46 ab	62 abc	19 a	32	30 abc
IAA	16	23 bc	26 ab	43 ab	56 abc	22 a	29	30 abc
GA	15	22 bc	29 ab	44 ab	65 a	22 a	28	31 bc
Control	13	21 a	27 ab	44 ab	53 bc	18 a	29	29 ab
	spring vegetative dry weight (g)							
Burn	63.97	68.23 a	24.80	46.33	35.07	59.07	51.90 a	49.91 b
ETH	52.22	46.22 b	22.16	39.88	31.19	39.86	39.57 b	38.72 a
ABA	48.98	48.07 b	21.47	40.49	31.34	46.29	47.53 ab	40.59 a
CYT	54.51	47.84 b	20.46	39.00	32.04	51.57	39.68 b	40.76 a
IAA	50.18	44.26 b	21.61	36.42	29.81	51.01	42.5 ab	39.40 a
GA	57.83	53.99 b	21.46	38.71	31.89	43.71	41.91 ab	41.36 a
Control	62.71	47.84 b	22.23	35.73	29.56	42.84	42.47 ab	40.48 a

† Production years for Shademaster first-year stand was 1996 and second-year stands were 1995 and 1997, respectively. Production years for Seabreeze first-year stands and second-year stands were 1996 and 1997, respectively. Production years for Hector second-year and third-year stands were 1996 and 1997, respectively.

†† Means within a column followed by the same letters were not significantly different (LSD 0.05).

††† ETH, ABA, CYT, IAA, and GA are abbreviations for ethylene, abscisic acid, cytokinin, indole-acetic acid, and gibberellic acid, respectively.

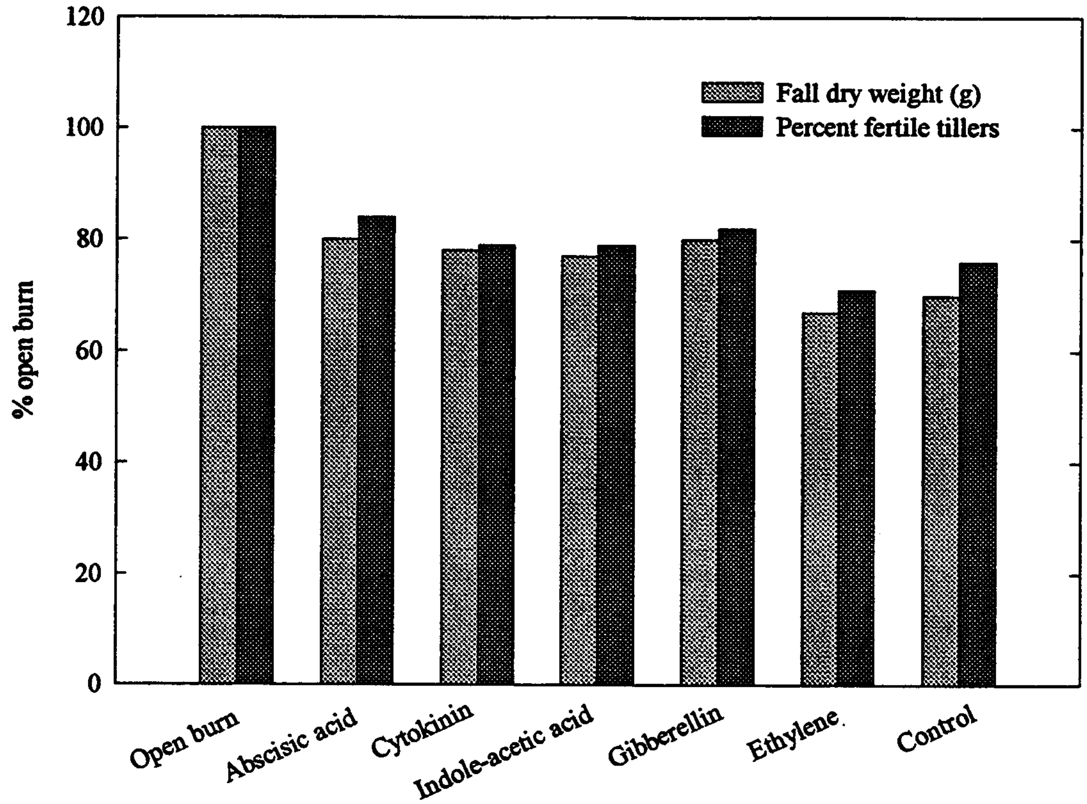

Figure II-2. Fall dry weight and percent fertile tillers expressed as a percent of the open burn for abscisic acid, cytokinin, indole-acetic acid, gibberellin, ethylene, and control in creeping red fescue.

yield due to increased fertile tiller number and number of seeds per spikelet. Application of cytokinin, auxin, or gibberellin to creeping red fescue did not stimulate fertile tiller production equivalent to that of burning in this study, although it is possible that different timing or rates of application may influence tillering. PGRs were applied only once in autumn prior to regrowth.

Ethylene produced the most consistent response by reducing fall tiller height and fall tiller number, increasing rhizome number, and reducing percent fertile tillers compared with open burn. Although ethylene treatment tended to decrease tiller mortality in stands older than the second year, these tillers were not induced to flower the following spring. The presence of higher concentrations of ethylene during early fall regrowth may adversely affect fall regrowth characteristics that influence subsequent capacity to respond to floral induction signals. The effect of ethylene treatment on plant development was similar to that of the control, suggesting that the natural decay of stubble and residue not removed by open field burning might lead to the release of ethylene. It is possible that increased ethylene exposure during the critical early fall regrowth period reduces yield potential. Further study is necessary to determine whether the removal of stubble-generated ethylene is responsible for the beneficial effects of burning on yield potential in creeping red fescue seed production.

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MANUSCRIPT III: LIGHT QUALITY INFLUENCES GROWTH AND DEVELOPMENT OF CREEPING RED FESCUE SEED CROPS.

ABSTRACT

Establishment of seedling grass stands and regrowth of established stands following harvest is important to stand health and achievement of maximum yield potential in perennial grass seed crops. Light quality can impact developmental processes from early tillering and growth through floral induction and can be altered by the presence of stubble, neighboring plants, and plant canopy architecture and coverage.

Experiments were conducted in plant trials and in controlled environments to examine the influence of light quality on plant growth and early development of creeping red fescue. Presence of stubble did not alter light quality in the field, but did impact canopy development and crown shading. The red : far-red ratio at the crown was reduced as the plant canopy expanded during fall regrowth under field conditions. Poor yields in creeping red fescue seed fields managed without burning are not attributable to a change in light quality when stubble is present in the field.

In a controlled environment, seedlings were taller, more mature, and produced more tillers under high red (R) than high far-red (FR) irradiation. Seedlings grown in R or FR enriched sunlight were not different in height or maturity but showed increased root biomass and reduced tillering. Rhizome formation was greatly inhibited by FR enriched sunlight. Impaired light quality (reflected FR) may adversely impact seedling development and reduce stand establishment in creeping red fescue seed crops.

INTRODUCTION

Plant growth and development processes including shade avoidance, tillering, floral induction, and population density are mediated by phytochrome (Casal et al., 1985; Casal and Smith, 1989). Floral induction is also mediated by day length and temperature in creeping red fescue (Meijer, 1984) and in Kentucky bluegrass (Canode and Perkins, 1977; Lindsey and Peterson, 1964). Phytochrome-mediated growth processes are influenced by light quality (i.e. red : far-red ratio). It is likely that phytochrome-mediated processes are crucial to stand establishment and post-harvest regrowth in grass seed production. In grass seed production, post-harvest residue management practices can affect the quality of light which reaches the plant crown and newly-developed tillers.

Ensign et al. (1983) compared thermal and non-thermal residue management practices in Kentucky bluegrass seed production. Their results suggested that reduced light quality by tall crop stubble caused etiolation of young regrowth, reduced panicle number, and seed yield potential. They did not measure the effects of stubble on light quality. Etiolated stems typically have a smaller basal diameter and are less likely to be induced to flower (Canode and Law, 1979; Chastain et al., 1997). Meijer and Vreeke (1988) reported that fall removal of stubble provided better illumination, fertile tiller survival, and greater seed yield in Kentucky bluegrass and creeping red fescue. Cordukes and Fisher (1974) found that when Kentucky bluegrass leaf sheathes were shaded, the plants produced long aerial rhizomes even though the leaf blade was exposed to normal light. All of these observations suggest that phytochrome mediation plays a large role in physiological processes that affect grass seed production.

Crop residues have been shown to reflect light with a decreased red : far-red ratio compared to normal sunlight (Kasperbauer and Hunt, 1987). Leaf sheath exposure to far-red light increased tiller and sheath length in *Lolium, Sporobolus, and Paspalum* species (Casal et al., 1987a). Casal and Smith (1989), and Davis and Simmons (1994a; 1994b), reported that far-red light reflected from neighboring plants caused stem elongation. Far-red light also caused a reduction in tiller number in Italian ryegrass (*Lolium multiflorum* Lam.) (Casal et al., 1985, 1988, 1990), and in wheat (*Triticum aestivum* L.) (Casal, 1987b, 1993).

Residue management practices used in grass seed production influence phytochrome-mediated growth processes that are critical to subsequent seed production including tillering and floral induction (Chastain et al., 1997). Little is known about the effects of these management practices on light quality. This study had two objectives: 1. To determine the effect of crop stubble on light quality at the crown level of creeping red fescue plants; 2. To measure the effects of light quality on seedling growth and development of creeping red fescue.

MATERIALS AND METHODS

Field Experiment. Field investigations were conducted in the Willamette Valley of western Oregon during 1994-1997. Trials were conducted in a commercial seed production field of 'Hector' creeping red fescue (Taylor farm) near Sublimity, Oregon and in Shademaster and 'Seabreeze' creeping red fescue planted at Hyslop farm research station near Corvallis, Oregon. Data taken at Taylor were on a second-year and third-year production field. Data taken at Hyslop research farm were on first-year and second-year stands.

Light quality (red : far-red ratio) was measured each week to detect changes due to stubble and new vegetative material. Measurements were made at the plant crown using a Skye-Probetech (SKR 100, remote probe SKR 110, Skye Instruments. Llandrindod Wells, Powys, UK) red : far-red meter. A section of the row in each plot was removed to allow the insertion of a light sensor probe at crown level. Measurements were taken at mid-day, beginning seven days after stubble was removed by burning or by cutting stubble to 0.0, 2.5, or 5.0 cm., and were continued until 10 weeks after the stubble treatments.

The experimental design was a randomized complete block. Each location contained three replications. Analysis of variance was conducted to determine if significant differences existed between treatments and mean separations were conducted using Fisher's Least Significant Difference (LSD). Linear regression was used to examine possible relationships between data.

Growth Chamber Experiment. Shademaster, Seabreeze, and an experimental line 4DR were planted in nursery cones with a volume of 656 mL cone^{-1} in the greenhouse. A standard soil media composed of loam, sand, and peat was used. Seedlings were thinned to one cone^{-1} at the two-leaf stage and placed in two separate growth chambers. Seedlings were exposed to a red : far-red ratio of 1.65 by using incandescent lamps (4; GE 25W) in combination with fluorescent lamps (8; GE 60W) filtered through Rohm and Haus number 2425 plexiglas. In a second chamber, seedlings were exposed to a red : far-red ratio of 0.75 by using incandescent lamps (2; 25 W and 2; 40 W). Each chamber had photosynthetically active radiation (PAR) levels at 114±4 μmol m^{-2} s^{-1} with a 14 hour photoperiod. Lighted period temperature was 28±2 °C and dark period temperature was 14±2 °C. Seedlings were fertilized each week using 20-20-20 (NPK) water soluble fertilizer and harvested after 67 days. Seedlings were measured for tiller number, height, growth stage (measured by a modified Haun scale (Klepper et al., 1982), vegetative dry weight, and rhizome dry weight.

A completely randomized design was used and analysis of variance was conducted to identify treatment effects. Mean separation was conducted using Fisher's protected least significant difference (LSD). An outside perimeter of seedlings was not measured to reduce border effect within each chamber.

Greenhouse Experiment. Seed of Shademaster were planted in the greenhouse in 3.78 liter pots containing using a standard soil media composed of loam, sand, and peat. Plants were thinned to one pot^{-1} at two-leaf stage. Ambient light in the greenhouse was enriched for red and far-red light using techniques similar to those described by Casal et al. (1987a). Red light was enriched by placing sodium high pressure lamps over the pots and

R:FR was 1.39 measured at mid-day. In a separate location, ambient light was enriched for far-red light by placing incandescent lamps (6; GE 150W soft white) over pots and R:FR was 0.86 measured at mid-day. To equilibrate PAR, lamps were placed at different heights over the bench to equilibrate to 520±5 μmol m^{-2} s^{-1}. The duration of exposure for each set of lamps was adjusted weekly to correct for changes in day length and were turned on and off at 15±5 minutes prior to and following official sunrise and sunset each day.

Thirty six pots were placed under each enriched light regime. Pots were fertilized weekly with 20-20-20 (NPK) water soluble fertilizer. Three plants were measured weekly from each light regime. Seedlings were measured for tiller number, height, growth stage, vegetative dry weight, rhizome dry weight, and number of ramets produced per plant. For the purpose of this study, ramets were defined as tillers initiated from rhizomes and did not include axillary tillers produced on the mother plant.

A completely randomized resign was used and analysis of variance was conducted to identify treatment effects. Mean separation was conducted using Fisher's protected least significant difference (LSD). Pots were re-randomized each week to reduce border effects at the perimeter of the greenhouse bench.

RESULTS AND DISCUSSION

Field Experiment. Light quality was not affected by the presence or absence of stubble during early regrowth in three cultivars of creeping red fescue. The R:FR measured at the plant crown was not correlated with stubble height but was negatively correlated with height of the regrowth canopy in Shademaster and Hector (Table III-1). No effect of R:FR on the regrowth canopy was observed in Seabreeze. The absence of an R:FR effect in Seabreeze likely resulted from low carbohydrate reserves caused by stubble removal. This effect was not noted in Shademaster (Meints et al, 1997). In other research, neighboring plant tissue has been shown to reduce R:FR via reflection of far-red radiation (Casal et al., 1990; Davis and Simmons, 1994 a, 1994 b; Kasperbauer and Karlen, 1994). Regrowth height was positively correlated with initial stubble treatment whereas taller stubble resulted in taller etiolated regrowth.

The presence of stubble did not directly impact light quality measured at mid-day. Nevertheless, the presence of stubble was associated with etiolated regrowth. The correlation of etiolation and tiller elongation with stubble presence suggests that quantitative differences in R:FR occurred (Figure III-1). It is possible that measurements taken at other points during the day would have demonstrated reduced R:FR ratios in plots which contained stubble. Meijer and Vreeke (1988) reported reduced yield in Kentucky bluegrass (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra*) due to reduced light penetration from stubble presence. Ensign et al. (1983) also reported reduced seed yield in Kentucky bluegrass under artificial shading compared to mechanical removal of stubble. Since light quality was equivalent with or without stubble prior to the expansion of the regrowth canopy, it is not likely that shading by stubble reduces seed yield. Reduction in light quality in plots retaining stubble was caused by the differential expansion of plant canopies.

Table III-1. Correlation coefficients and statistical significance for red : far-red ratio vs. stubble height treatment and vegetative regrowth height over ten weeks following stubble treatment in three cultivars of creeping red fescue 1996 and 1997.

	Shademaster		Hector		Seabreeze	
	SHT †	VRH	SHT	VRH	SHT	VRH
R:FR	-0.15 NS	-0.69***	-0.03 NS	-0.65***	0.05 NS	-0.01 NS
SHT		0.35*		0.27*		0.36*

† R:FR, SHT, VRH are abbreviations for red : far-red ratio, stubble height treatment, and vegetative regrowth height, respectively.
*,*** Significant at the P < 0.01 or 0.001 levels respectively; NS not significant at P <0.05.

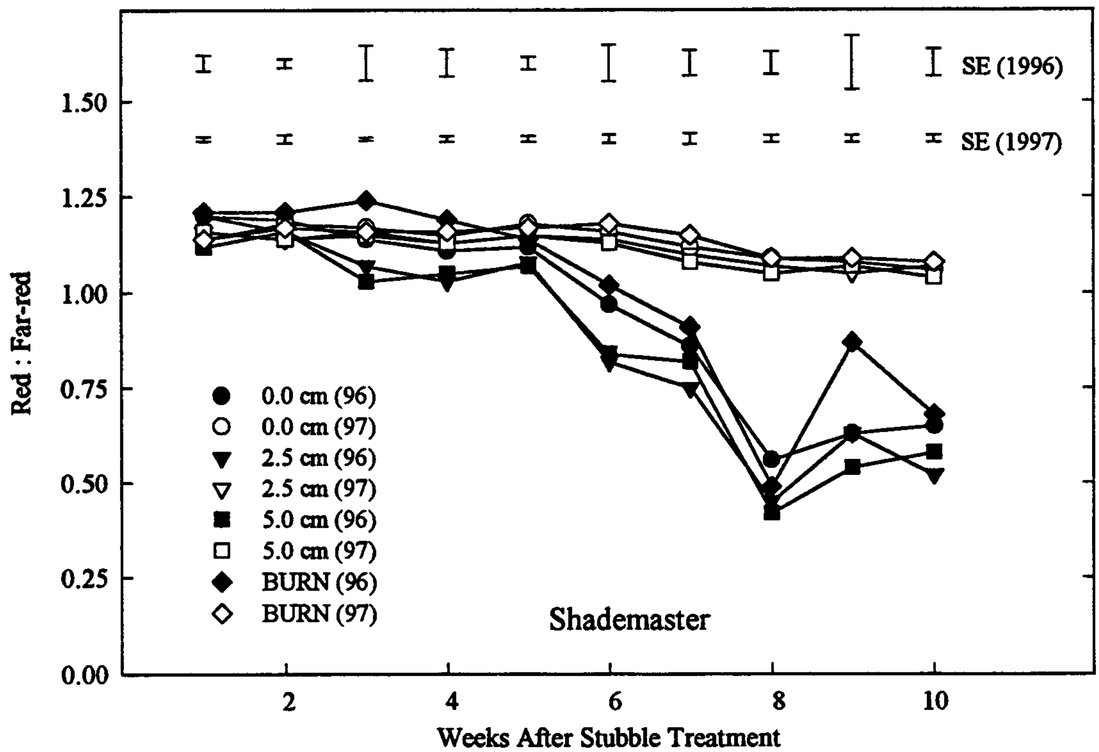

Figure III-1. Changes in the red : far-red ratio open field burn and three stubble heights in Shademaster creeping red fescue in 1996 and 1997.

Growth Chamber Experiment. Seedlings grown under controlled light quality showed differential responses that correlated with the change in R:FR (Table III-2). High red (R) environment resulted in taller vegetative tillers. These observations are similar to those reported by Casal et al. (1985) with *Lolium multiflorum* L. and by Kasperbauer and Karlen (1994) with maize. Seedlings retained more leaves under an enriched R environment and attained an advanced growth stage. Far-red light reduced tillering compared with R in all cultivars although the reduction was statistically significant only in Seabreeze. Similar results have been observed in *Lolium multiflorum* L. (Casal et al., 1985, 1987c), barley (Davis and Simmons, 1994a, 1994b), and in three species of cool season grasses (Frank and Hofmann, 1994). These results suggest that modification of the light environment by the presence of stubble or close neighbor vegetation could increase FR and reduce the amount of fall tillering and subsequent yield potential in seed production fields. Casal et al. (1985) reported no effect of light quality on above-round biomass in *Lolium multiflorum* L. and similar results were observed in this study.

Greenhouse Experiment. Seedlings grown in sunlight enriched with red or far-red light showed results similar to those in controlled chamber environments (Table III-3). Mean tiller height and developmental stage was not different up to 107 DAP. Plants were adequately separated so that neighboring vegetation did not interfere with the light quality received by each plant. Sunlight enriched with FR likely contained adequate R to maintain normal growth. Casal et al. (1987c) reported that sunlight supplemented with continuous FR promoted increased tiller elongation in *Lolium multiflorum* L., *Sporobolus indicus* L.,

Table III-2. Influence of light quality on tiller height, mean stage by count, tiller number, and vegetative dry weight in three creeping red fescue cultivars.

	Red : far-red ratio					
Trait	0.75	1.65	0.75	1.65	0.75	1.65
	Shademaster		Seabreeze		4DR	
TH (cm) †	22.0 a ††	32.6 b	20.2 a	29.2 b	18.5 a	19.0 a
MSC	3.6 a	5.4 b	2.9 a	4.9 b	3.5 a	4.1 b
TN	1.1 a	1.2 a	1.1 a	1.4 b	1.4 a	1.6 a
VDW (g)	0.03 a	0.01 a	0.02 a	0.01 a	0.01 a	0.01 a

† TH, MSC, TN, and VDW stand for tiller height, mean stage by count, tiller number, and vegetative dry weight, respectively.
†† Means in rows and cultivars followed by the same letters were not significantly different (LSD 0.05).

Table III-3. Influence of accumulated red or far-red enriched sunlight on tiller height, mean stage by count, vegetative dry weight, root dry weight, and ramet number on Shademaster creeping red fescue.

	Red:far-red ratio									
	0.86	1.39	0.86	1.39	0.86	1.39	0.86	1.39	0.86	1.39
DAP †	TH (cm)		MSC		VDW (g)		RDW (g)		RN	
30	17.9 a††	12.8 a	2.8 ab	2.4 a	0.02 a	0.02 a	0.01 a	0.01 a	0	0 a
37	17.0 a	22.5 ab	2.4 a	3.1 c	0.07 a	0.07 a	0.01 a	0.01 a	0	0 a
44	23.5 abc	24.4 b	2.6 ab	2.9 bc	0.23 a	0.18 a	0.03 a	0.02 a	0	0 a
51	34.3 d	26.5 b	2.6 ab	2.5 ab	0.68 a	0.47 a	0.09 a	0.08 a	0	0 a
58	22.5 abc	20.9 ab	2.6 ab	2.6 ab	1.18 a	1.20 a	0.19 ab	0.21 a	0	0 a
65	28.9 cd	25.2 b	2.9 b	3.0 c	2.03 a	1.94 a	0.36 ab	0.46 a	0	0 a
72	19.5 ab	25.3 b	2.7 ab	2.4 a	3.54 a	4.52 ab	0.84 ab	1.53 ab	0	1 ab
79	21.3 abc	27.2 b	2.7 ab	2.5 a	8.24 b	9.99 b	2.86 bc	2.62 b	0	1 ab
86	27.2 bcd	26.7 b	2.4 a	2.7 abc	13.77 b	17.31 c	5.10 c	5.69 c	0	1 ab
93	32.2 d	30.9 b	2.9 b	2.4 a	24.50 c	26.21 d	5.17 c	7.30 c	0	2 b
100	28.4 cd	30.0 b	2.8 ab	2.7 abc	23.79 c	23.65 d	10.36 d	12.15 d	0	0 a
107	28.0 bcd	28.9 b	2.8 ab	2.6 ab	24.16 c	32.41 e	8.73 d	12.63 d	0	5 c
Grand mean	25.1	25.1	2.7	2.7	8.51	9.83	2.81 a	3.56 b	0 a	1 b

† DAP, TH, MSC, VDW RDW, RN stands for days after planting, tiller number, mean stage by count, vegetative dry weight, root dry weight, and ramet number, respectively.

†† Means within a column or grand mean within a row followed by the same letters were not significantly different (LSD 0.05).

and *Paspalum dilatatum.* The lighting used in this study did not produce similar results in creeping red fescue. Seedlings exposed to FR enriched sunlight had greater root biomass than R enriched seedlings. Casal et al. (1985) found no affect of light quality on below-ground or above-ground biomass in *Lolium multiflorum* L. in a controlled environment study. Mean vegetative biomass did not differ for either R or FR enriched sunlight (Table III-3). Seedlings produced no ramets when exposed to FR enriched sunlight whereas R enriched sunlight promoted increased ramet number after 72 DAP.

Tillering in R or FR enriched environments was not influenced by spatial or nutrient competition because both populations continued to increase exponentially through the end of the measurement period (Figure III-2). Red enriched sunlight promoted tillering over FR similar to earlier findings and significantly increased rhizome formation as seedlings aged beyond 72 DAP (Figure III-2). Although enriched FR caused relatively small reductions in tiller production, it caused near total inhibition of rhizome formation.

The impact of FR on tillering has been well documented, but prior investigations have not examined FR effects on rhizome production. It is possible that phytochrome also plays an important and previously unknown role in the formation of rhizomes in grasses. Rhizome production appears to be more sensitive to reductions in light quality than tiller production in creeping red fescue. Rhizome production in sunlight enriched with FR was nearly completely inhibited and plants also produced fewer ramets from rhizomes.

Change in light quality at the crown was not correlated with presence of stubble in the field plots. Nevertheless, the observations that tiller etiolation and elongation correlated with stubble presence suggests the possibility that R:FR influence may result

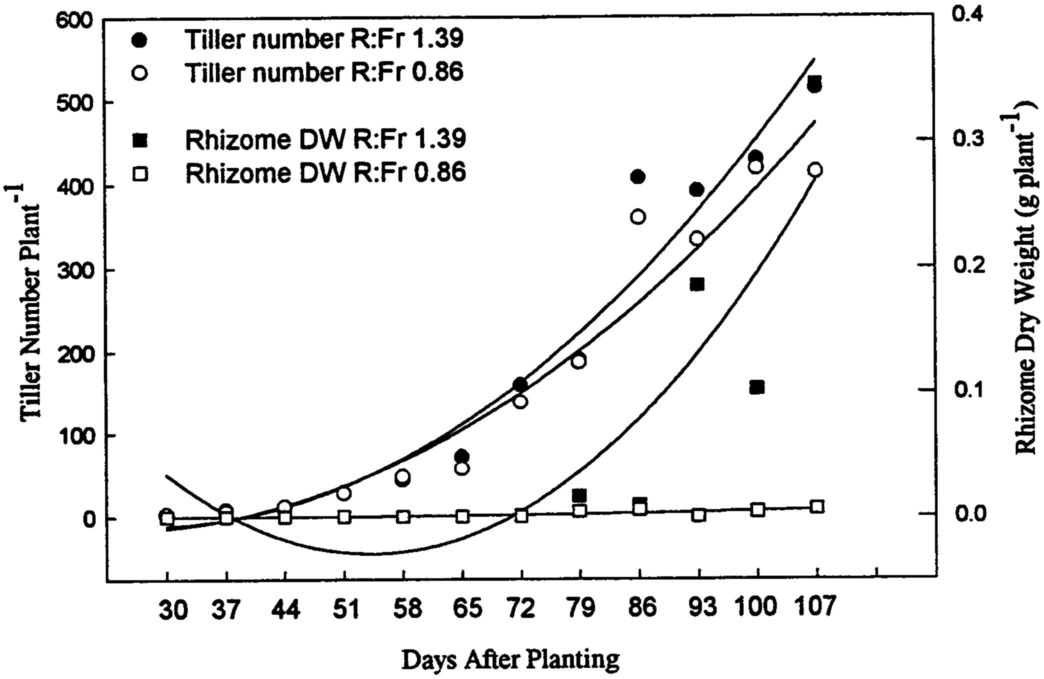

Figure III-2. Tiller number and rhizome dry weight over days after planting for two light quality regimes in Shademaster creeping red fescue. Regression equation for the fitted line of tiller number under R:FR 1.39 is $Y = -8.95 - 6.08X + 4.37X^2$; $R^2 = 0.95$. Regression equation for the fitted line of tiller number under R:FR 0.86 is $Y = -16.96 + 0.21X + 3.39X^2$; $R^2 = 0.94$. Regression equation for the fitted line of rhizome dry weight under R:FR 1.39 is $Y = 0.08 - 0.05X + 5.27X^2$; $R^2 = 0.80$. Regression equation for the fitted line of rhizome dry weight under R:FR 0.86 is $Y = 1.48 - 2.41X + 5.65X^2$; $R^2 = 0.59$.

from accumulated exposure or at other specific time of day. Although it has been reported that stubble reflects far-red light and lowers the R:FR at the crown, this was not observed in mid-day measurements of creeping red fescue managed for seed production. Stubble did cause etiolation of early regrowth and caused the canopy to be taller during the first ten weeks after stubble treatment. Changes in R:FR were associated with regrowth canopy reflectance from etiolated tillers.

Further investigation is needed to elucidate the relationship of light quality to crown bud differentiation and rhizome initiation. Complete stubble removal has been shown to reduce rhizome initiation in field studies (Meints et al., 1997), but the nature of changes in light quality due to stubble or neighboring vegetation on rhizomes has not been reported.

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SUMMARY AND CONCLUSIONS

Open field burning in cool season grass seed production has enabled farmers to grow high quality seed by reducing the potential for disease, pests, and volunteer seedlings. Legislated reductions in open field burning have precipitated research to find alternatives that will maintain seed yield and seed quality. In many of the cool-season perennial grasses, non-thermal residue and stubble management protocols were identified which allowed yield and seed quality to be maintained. In creeping grasses such as Kentucky bluegrass and creeping red fescue, non-thermal management often results in yield reduction and thus loss in profitability to the producer. Physiological responses of creeping red fescue to burning and non-thermal management have been largely unknown.

Studies were conducted in the Willamette valley of western Oregon to determine how stubble removal and exogenous application of plant growth regulators affect regrowth, plant development, and flowering in creeping red fescue. Light quality and the availability of carbohydrates for regrowth were also evaluated under field and controlled environments to measure stubble management impact on these parameters.

Carbohydrate reserves were reduced when stubble was removed below five cm in all cultivars examined, but was particularly evident in Seabreeze which produces few rhizomes. Rhizomes are a source of re-mobilized sugars that are utilized in vegetative regrowth but results suggest that re-mobilization from stem tissue also makes contributions to early regrowth. Hector and Shademaster produce many rhizomes, yet carbohydrate availability was also reduced when stubble was removed. First-year stands not only exhibited less rhizome development than older stands, but also had lower available carbohydrates when stubble was burned or removed. In the stand establishment year of grass seed crops, this degree of stubble management is not customarily practiced and thus stand stress due to complete stubble removal would seldom be encountered. Reduction in available carbohydrate may have initially reduced regrowth but differences did not persist into late fall and were not manifested during flowering. Such reductions in carbohydrate may only result in loss of yield potential if in combination with other stresses, such as drought, and this did not occur.

Reduction in stubble height caused fall tillers to be shorter. Fall tiller height was a strong indicator of yield potential the following spring. Reduction in stubble height also reduced rhizome formation. Since tillers and rhizomes originate from the same crown buds, stubble management practices which reduce rhizome initiation and fall tiller height would likely result in the greatest yield potential the following spring. Although other growth and development indicators were not consistently affected by stubble treatments short fall tiller height and reduction in rhizomes were nearly always predictors of yield potential across cultivars and locations. Management practices that removed stubble to the crown immediately after harvest might have yield potentials similar to that observed in this study. Seed producers do not currently have field scale machinery that can economically perform complete stubble removal, thus open burning remains the only feasible alternative to maintaining yield in creeping red fescue seed crops in Oregon's Willamette valley.

Application of exogenous plant growth regulators gave inconsistent results in measured regrowth and development parameters. Application of an ethylene releasing compound most closely mimicked standing stubble typical of non-thermal residue management. Ethylene treatments had the lowest fall tiller height over locations as well as fall tiller number and percent fertile tiller number during the following spring. Rhizome dry weight was increased under ethylene treatment compared with burning but not as sharply as percent fertile tiller was decreased. This suggests that the natural release of ethylene by stubble during early fall regrowth may have an adverse effect on other developmental processes including reproductive differentiation of the stem apex. When compared with open field burning, ethylene produced by decaying stubble may also have the same impact on these important developmental processes thus yield potential is reduced without burning. Further research to measure and isolate an ethylene source in both field and controlled environments is necessary to determine whether ethylene released by stubble does reduce yield potential in this crop.

Change in light quality at the crown was not correlated with presence of stubble in the field plots. Although it has been reported that stubble reflects far-red light and lowers the red : far-red ratio (R:FR) at the crown, this was not observed in creeping red fescue managed for seed production. Stubble did cause etiolation of early regrowth and caused the canopy to be taller during the first ten weeks after stubble treatment. Changes in R:FR were associated with regrowth canopy reflectance from etiolated tillers.

Light quality did impact development of seedlings in controlled environments. Far-red light decreased tiller height and growth stage during early seedling development.

When seedlings were grown for longer periods in sunlight enriched with FR height of seedlings was not affected but they had fewer roots. Rhizome production in sunlight enriched with FR was nearly completely inhibited and thus plants also had fewer ramets from rhizomes. In early seedling establishment the presence of stubble, residue, or neighboring plants may alter the light environment of the seedling and result in young stands with reduced vigor compared with clean fields. In older stands, changes in light quality from stubble or canopy does not seem to be a major factor influencing late fall development, floral induction, or flowering in creeping red fescue.

In creeping red fescue seed production, only open field burning resulted in highest yield potential. With advances in field-scale residue equipment, practices that include removal of residue by baling followed by reduction in stubble to the crown might enable producers to grow this crop without catastrophic reductions in yield. Chemical manipulation by exogenous plant growth regulators to counteract the effect of stubble on fall tiller production and flowering may be possible, but no PGR to accomplish this was identified by this study. Further research is recommended to determine what effects ethylene has on floral induction in creeping red fescue as well as specific sources of ethylene under non-thermal field management.

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APPENDICES

Appendix I.

Plant growth regulators and preparations for field trials.

Growth Regulator		$mL\ L^{-1}$ - X treatment	$mL\ L^{-1}$ - 10X treatment
Ethylene	(Ethrel)*	1.46	14.6
ABA	(Sigma A-7383)	1.01	10.1
CYT [BA]	(Sigma B-6790)	1.01	10.1
IAA	(Sigma I-2886)	1.01	10.1
GA	(Sigma G-3250)	1.01	10.1

Application rate equivalent to 0.313 L M^{-1}.
Ethrel is a product of Amchem Products, Inc. (A Rorer-Amchem Company). Ambler, PA. EPA Regulation Number 264-267 AA.

Growth Regulator	M.W.	Mg 10 mL^{-1} of 10^{-3} M	Mg	Total mL
ABA	264.3	2.64	43.6	163.00
CYT [BA]	225.2	2.25	53.7	239.00
IAA	175.0	1.75	31.7	181.00
GA	346.4	3.46	66.5	192.00

ABA, CYT, BA, IAA, and GA stand for abscisic acid, cytokinin, benzyl-adenine, indole-acetic acid, and gibberellic acid respectively.

These provided 1000x stock solutions. Diluting each 1:100 and 1:1000 resulted in 10X and X solutions of 10^{-5} and 10^{-6} M solutions, respectively. Preparation involved dissolving each regulator in 4 mL of methanol and restoring to final volume. BA was dissolved in 10 mL of methanol and restored to final volume as indicated.

Appendix II.

P-values for plant growth regulator rate of application over regrowth, development, and flowering measurements over 1995, 1996, and 1997 in creeping red fescue.

Trait	1995	1996	1997
Fall tiller height (cm)	0.3357	0.1086	0.8369
Mean stage by count	0.4763	0.7731	0.3251
Fall vegetative dry weight (g)	1.0000	0.9418	0.6491
Root dry weight (g)	0.6451	0.5078	1.0000
Rhizome dry weight (g)	0.2972	0.5045	0.4930
Fall tiller number	0.6797	0.9379	0.8071
Small tiller number (< 2 mm)	0.6631	0.2850	0.8741
Large tiller number (> 2 mm)	0.6555	0.4044	0.9345
Fertile tillers (%)	0.8365	1.0000	1.0000
Spring vegetative dry weight (g)	0.0230	1.0000	1.0000