AN ABSTRACT OF THE THESIS OF

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presented on April 29, 2005

Title: Residue Management and Yield Characteristics of Fine Fescue Seed Crops

Abstract approved:

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Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman] is a desired turfgrass with dense sod forming capabilities and superior shade tolerance. Thermal residue management (open-field burning) has traditionally been used to remove post-harvest residue and maintain seed yield over the life of the stand. However, alternative non-thermal residue management practices have been observed to produce adequate seed yields dependent upon cultivar.

Strong creeping red fescue red fescue (*F. rubra* L. subsp. *rubra*) is desired for its prolific tillering capacity and creeping rhizomatous growth habit. In contrast to Chewings fescue, maintenance of seed yield in strong creeping red fescue has only been profitably produced under thermal residue management. Slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)] is a desired turfgrass with a compact, less rhizomatous growth habit, similar to Chewings fescue in desirable turf attributes. However, little is known about the effects of post-harvest residue management in slender creeping red fescue.

The objectives of this study were: 1) to evaluate seed yield and yield components among different cultivars to thermal (open-burning), and non-thermal (flail low and flail high) post-harvest residue management; 2) to evaluate harvest index and percent cleanout to thermal and non-thermal residue management in different cultivars; and 3) and to provide an economic analysis of thermal and non-thermal residue management in all cultivars based on partial budgeting.

Three post-harvest residue management treatments (burn, flail low and flail high) were applied over the course of two years. Seed yield components measured included: total dry weight, fertile tiller number, spikelets per panicle, florets per spikelet, and panicle length. Final seed yield in each cultivar and residue management treatment method was determined after seed harvest and conditioning. Seed yield component analysis was conducted over three production seasons.

Chewings fescue, strong creeping red fescue, and slender creeping red fescue cultivars responded differently to residue management as indicated by a residue management by cultivar interaction. In 2003 and 2004, residue management by cultivar interactions were evident in seed number, seed weight, fertile tiller number, percent cleanout, harvest index, and seed yield. Residue management by cultivar interactions occurred in spikelets per panicle in 2003, whereas in 2004 a residue management by cultivar interaction occurred in panicle length and florets per spikelet. In 2004, non-thermal flail low, and thermal residue management resulted in significantly greater spikelets per panicle in all cultivars. Thermal residue management resulted in the greatest number of spikelets per panicle.

Results indicate that thermal residue management best maintained seed yield in most subspecies and cultivars across both years. However, in 2003, non-thermal flail low residue management produced profitable seed yield in only Marker slender creeping red fescue. In contrast, thermal residue management resulted in poor seed yields in Marker slender creeping red fescue and enhanced yields in Seabreeze slender creeping red fescue in 2003. However, following the second year of thermal treatment in 2004, Marker and Seabreeze both had lower seed yields, thus exhibiting the only negative impact of thermal management among the cultivars tested in this study. Moreover, upon review of an economic analysis, Marker slender red fescue was the only cultivar that produced a positive net return of \$78 and \$4 ha^{-1} under non-thermal residue management in 2003 and 2004, respectively. Furthermore, in 2003, thermal residue management net return increases ranged from \$104 ha^{-1} to -\$996 ha^{-1} in Barnica and Shademark, respectively. In 2004, thermal residue management net return increases ranged from \$115 ha^{-1} and \$1,332 ha^{-1} in Seabreeze and Shademark, respectively.

Poor seed yields were observed in all strong creeping red fescue cultivars under non-thermal residue management across both years of the study. This may be attributed to an observed reduction in fertile tiller number and seed yield. In addition, percent seed cleanout was increased with non-thermal residue management. In 2004, as stand age increased, thermal residue management resulted in greater seed yields in all cultivars and species, except both cultivars of slender creeping red fescue. Thus, this study provided substantial evidence that thermal residue management has the potential to maintain or increase fine fescue seed yield as stands age as well as to maintain stand profitability.

Residue Management and Yield Characteristics of Fine Fescue Seed Crops

by

Derek David Schumacher

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented April 29, 2005
Commencement June 2005

Master of Science thesis of Derek David Schumacher presented on April 29, 2005.

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ACKNOWLEDGEMENTS

I wish to thank my major professor Dr. Thomas G. Chastain for his support throughout this study. To Drs. William C. Young, III, Erik K. Fritzell, and Neil W. Christensen, I express my appreciation for your time involved in serving on my graduate committee as well as for your statistical and manuscript suggestions.

I would also like to thank Carol Garbacik and Tom Silberstein for their assistance over the last three years. In addition, my gratitude to the Hyslop Research Farm staff for your patience and assistance.

To my fellow graduate students: Krista, Maria, SK, and Craig. Thank you for all the time together. Your friendship is greatly appreciated.

To "Bobby" Doerfler, your memory will not be forgotten. I thank you for all your guidance and friendship over the last 15 years.

To T3 Farms (Ron, Larry, and Marie), thank you for all your support in friendship and in farming. You truly made this degree easier to achieve through all of your help. Also, Chuck and Nick Sherman, your help is greatly appreciated as well.

A particular recognition is owed to Glenn Jacklin for his support in believing that I could accomplish this task. In addition, to all the seed growers I conduct business with your patience is greatly appreciated.

I would like to thank my grandparents, parents (David and Sue) and all other family members and friends from all respects, you know who you are if you are reading this. Your support has been and is greatly appreciated. A special thanks to Steve Laux for all your support and friendship. Thanks bud.

To John George, you are a great friend and I appreciate all you have done for my family and I. To Craig King, you have been instrumental in mentoring, friendship, and technical advice in the preparation of this manuscript.

To Hal Rickman, I express my gratitude for your skills in critiquing this manuscript. You have been a mentor in my life since my freshman English class. You will not be forgotten.

Most importantly, I would like to thank my wife, Niki. She has endured tremendous stress in order for me to fulfill a dream to further my education. Your love and dedication helped me to persevere in completing this task. During this journey, our daughter Avari was born and my love for both of you is unimaginable. Thank you and I look forward to a bright future. I love you both.

Through it all, a great strength must remembered into which I subscribe- "I can do all things through Christ who strengthens me" (Philippians 4:13)

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INTRODUCTION

Fine fescues are a key group of Oregon's grass seed crops. Six to eight million kg of fine fescue seed is produced annually in Oregon (Young, 2005). Of the 203,945 ha grass seed produced in 2004, fine fescues were produced on 5,386 ha, or approximately 3% of the total grass seed acres in Oregon. The majority of this seed is certified by the Oregon Seed Certification Service for domestic and international consumption. Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*F. rubra* L. subsp. *rubra*), and slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)] have been used for turf and reclamation in cool, humid climates for many years. Fine fescue is superior to most cool-season turf grasses with respect to shade tolerance. Fine fescues are used in general turf mixtures with perennial ryegrass (*Lolium perenne* L.), tall fescue (*Festuca arundinacea* Schreb.), and Kentucky bluegrass (*Poa pratensis* L.). Enhanced breeding of new cultivars continue to develop desirable turf qualities and seed production characteristics.

Common post-harvest residue management of fine fescue seed crops in the Willamette Valley has consisted of open-field burning to remove crop residue. Open-field burning of cool-season grasses grown for seed production in Oregon has been practiced by growers since 1948. Burton (1944) indicated that sod burning increased seed yield in warm-season grasses. During the 1940s and 1950s, Hardison (1960) examined field burning as a residue management method in cool-season grasses.

Oregon State University agronomists recommended field burning as a residue management option to eliminate residue after harvest. Open-field burning became a solution to disease problems, weed control, nutrient cycling, maintenance of crown size, and seed yield stability (Chastain et al., 1993; Chilcote and Young, 1991). Open-field burning essentially removes stubble and straw residues that inhibit regrowth characteristics that otherwise would increase the chances for successful induction of flowering (Chastain, 2003). Open-field burning has been associated with acceptable seed yields in three commercially produced fine fescue subspecies: Chewings fescue, strong creeping red fescue, and slender creeping red fescue.

To date, effective alternatives to open-field burning have been found for all species produced in the Willamette Valley, except strong creeping red fescue (Young et al., 1984a; Chastain et al., 1993). Young et al. (1994a) reported seed yield reductions in Chewings fescue that were not as dramatic as previously reported. Nevertheless, Young et al. (1994) reported an average yield reduction of 8-11% in non-burned treatments, and results over the life of the stand indicate open-burning promoted greater seed yield than non-burned residue management.

Chewings fescue is classified as a bunch-type forming species. Strong creeping red fescue and slender creeping red fescues are rhizomatous subspecies and, as such, have a creeping growth habit. Previous studies indicate that seed yield is reduced in strong creeping red fescue following non-thermal residue management, with variable results in slender creeping red fescue. A growing body of evidence indicates that increased rhizome production occurs in fields under non-thermal residue management.

Nevertheless, non-thermal residue management has been directly linked to unacceptable yields (Meints et al., 1996).

In an effort to ascertain the difference between fine fescue subspecies and cultivars, an experiment was designed to compare Chewings fescue, strong creeping red fescue, and slender creeping red fescue seed yield and yield components. This study was conducted for three seed harvests and evaluated two non-thermal residue management treatments and one thermal residue management treatment characteristic of common practices in the Willamette Valley. It was hypothesized that non-thermal residue management would produce seed yields and seed quality equivalent to open-field burning.

LITERATURE REVIEW

Within the genus *Festuca*, those species and subspecies used as turf grasses are divided into two subgeneric groups based on leaf texture, these being coarse fescues and fine fescues (Turgeon, 1980). Fine fescues include Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*F. rubra* L. subsp. *rubra*), slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)], sheep fescue (*F. ovina* L. subsp. *ovina*), and hard fescue (*F. longifolia* Thuill.). This study examines the *F. rubra* L. group of the fine fescues. Measurable differences among and between species may be based on leaf blade anatomy, leaf sheath morphology, or root florescence (Hubbard, 1954). Several subspecies and cultivars of the fine fescue group are grown for seed production in Oregon. The taxonomic distinctions of the *F. rubra* L. members of the fine fescue group are as follows:

<u>Chewings Fescue</u>

As decribed by Hubbard (1984), Chewings fescue is a densely tufted perennial, 20-60 cm high, and is distinguished from strong creeping and slender creeping red fescue by the absence of creeping rhizomes. In addition, Chewings fescue exhibits (2n=6X=42) chromosome number and is considered a hexaploid (Huff and Palazzo, 1998). Seed number is approximately 804,825 kg^{-1}. Chewings fescue exhibits a cespitose (bunch-type) growth habit. Mr. Chewing brought Chewings fescue from New Zealand and introduced commercial production into the Willamette Valley in 1933. Due to its use as a turf grass and, to some extent, reclamation, Chewings fescue is now widely distributed.

Chewings fescue is desired for turf performance resulting from production of very fine-bladed, medium- to dark-green colored, dense turf (Meyer and Funk, 1989). Chewings fescue tolerates closer mowing than strong creeping or slender creeping red fescue; however, Chewings, strong creeping, and slender creeping red fescue have similar fertility requirements, disease resistance, shade tolerance, and drought tolerance. Chewings fescue is known to be the most desired turf grass within all the fine fescue subspecies groups. To a degree, fine fescues have been utilized in golf course fairways where disease in perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.) is often severe.

Strong Creeping Red Fescue

Strong creeping red fescue, as described by A.S. Hitchcock (1971), is a loosely tufted or occasionally closely tufted plant, 40 to 100 cm tall. In addition, strong creeping red fescue exhibits (2n=8X=56) chromosome number and is considered to be an octoploid (Huff and Palazzo, 1998). Seed number is approximately 882,000 kg^{-1}. Strong creeping red fescue exhibits a creeping growth habit due to the presence of rhizomes. This growth habit sets it apart from Chewings fescue for use as a turf grass. Desirable turf qualities include medium-fine leaf texture, dark green color, shade tolerance, and adaptability to low fertility and drought-type soil conditions (Meyer and Funk, 1989).

Slender Creeping Red Fescue

The third subspecies within *F. rubra* L. is slender creeping red fescue. Slender creeping red fescue is described by DaCosta et al. (1998) as having shorter, slender rhizomes compared to strong creeping red fescue, while forming a compact, dense turf. Plant height can reach 75 cm. In addition, slender creeping red fescue exhibits (2n=6X=42) chromosome number and is considered to be a hexaploid (Huff and Palazzo, 1998). Seed number is approximately 992,250 kg^{-1}. Slender creeping red fescue exhibits a less vigorous creeping growth habit than strong creeping red fescue. Turf qualities include a deep, dark-green color and very fine texture, as well as a reduced rate of vertical growth, resulting in the need for less mowing. In addition, slender creeping red fescue is tolerant of saline soil conditions and retains high quality turf characteristis under low fertility, high soil pH, and drought-type soil conditions (Meyer and Funk, 1989).

Plant Growth and Development

Perennial grasses begin their development as seedlings when the first leaf emerges from the soil. The interval between appearances of each successive leaf in the cool-season perennial grasses is approximately 100 growing degree days (GDD). Grass plants are composed of branches, known as tillers, the above-ground demographic unit of growth in a grass plant. The fate of tillers ultimately determines the productivity of a grass seed crop. Tillers are short lived; therefore, the ability of a grass plant to survive from year to year depends on the continued replacement of senescing tillers. When three leaves have fully emerged, the first tiller (T1) appears in the axillary bud of the first leaf. After 3.5 leaves have emerged, the second tiller (T2) appears in the axil of the second leaf (L2). T1 appears approximately 300 (GDD) after L1 had emerged, whereas T2 appears about 350 GDD after the emergence of L1 (Gamroth et al., 1996). Suzuki et al. (1999) observed that new seedlings do not spread spatially from the place of germination for some time and are subject to a higher mortality than established genets (plants spread from the mother plant), indicating there is a lag phase between seedling establishment and the beginning of effective spatial spreading.

Tillers appearing in the summer initiate spikelet primordia the same time as later appearing tillers and have earlier forming inflorescences, potentially indicating a difference in the size of the tiller apex where spikelet primordia are initiated. Late formed tillers may result in fewer spikelets and delayed inflorescence emergence (Anslow, 1963; Ryle, 1964). Compared with later appearing tillers, tillers appearing in the summer and autumn have additional sites for spikelets to develop (Ryle, 1964).

Intravaginal and Extravaginal Tillering

Festuca rubra L. subspecies have a complex branching system and form tillers in two ways: intravaginally and extravaginally. Tillers formed within the sheath of the mother shoots are considered to be intravaginal; tillers formed outside the sheath are considered extravaginal. These two forms of tillering are important to tussock formation (Stace et al., 1992).

Intravaginal tillers form close to their mother shoots and thus form dense tussocks, whereas extravaginal tillers form at a distance from mother shoots and contribute to clonal spreading (Herben et al., 2001). Extravaginal tillers are generally more vigorous, more highly reproductive, and persist longer than intravaginal tillers (Herben et al., 1994). Herben et al. (1994) found that lower tiller density may play a role in the growth rate of extravaginal tillers. Their observed reduction of extravaginal tiller formation and spread could be caused by higher tussock density.

In many grasses, only one mode of tiller formation is present, while others demonstrate the ability to shift from intravaginal to extravaginal tillering. Species that are able to form both modes may be able to exploit their environment by changing the proportion of extravaginal tillers to forage and spread into free spaces (de Kroon and Knops, 1990). Rytova (1971) reported that extravaginal tillering can be partially controlled by environment in *Festuca rubra* L.

The compactness of the tussocks of *Festuca rubra* L. is often due to the proportion of extravaginal tillers and rhizomes. Clones with a high proportion of extravaginal tillers generally have low final tiller density in the tussock. Herben et al. (1994) reported that the compactness of the tussock is not related to the proportion of extravaginal and intravaginal tillers, in spite of the large variation in this parameter. The absence of correlation shows that the spatial structure of vegetation is not related to the demographic processes within the tussock. Furthermore, the potential number of daughter tillers is limited by the number of axillary buds, a number equal to the number of formed leaves.

In addition to their morphological differences, extravaginal and intravaginal tillers also differ in the timing of their development. The peak of intravaginal growth corresponds to the period of intense growth in the spring and is a well known phenomenon (Colville and Marshall, 1984). Intravaginal tillers develop sylleptically (i.e., at the same time as a growing bud) and extravaginal tillers develop from dormant buds after a considerable delay (Rytova, 1971). Both tiller types are crucial to vernalization, floral induction, and reproductive plant operations.

Herben et al. (1994) concluded that intravaginal and extravaginal tillering types comprise an important component of the regulation of grass growth form and its functional growth dynamics.

Reproductive Plant Development

In the reproductive development of grasses, there are distinct phases that a grass plant must pass through in order to reproduce. These phases are juvenility, induction, initiation, inflorescence development, and seed development (Chastain, 2003).

Most cool-season perennial grasses have a dual floral induction requirement (Blondon, 1972; Heide, 1994). Dual induction consists of a primary and a secondary induction. Primary induction is controlled by low temperatures and short days (vernalization). Secondary induction is signaled by long days and higher temperatures (thermal induction). The most extreme requirements for primary induction are found in the genus *Festuca* (Aamlid, 1992), with these plants becoming day neutral at low temperatures of 0-6° C.

Photoperiodic induction, a part of primary induction, is the promotion of flowering by exposure to a critical photoperiodic length (daylength). The receptor pigment involved in photoperiodic induction is phytochrome (Chastain, 2003). As the temperature rises, the photoperiod becomes more important for primary induction to occur. After primary induction has been satisfied, long days are needed for inflorescence development. Secondary induction occurs when stimuli trigger floral initiation and the grass plant begins reproductive growth. A critical photoperiod is usually 12-15 hours, depending upon the latitudinal origin of the cultivars. In most grasses, no morphological change can be observed at the growth apex until plants are transitioned to long day conditions (Aamlid, 1992).

Floral induction is dependent upon induction and inductive stimuli (Canode, 1972; Heide, 1994). Cooper and Calder (1964) pointed out that many grass species must go through a juvenile stage before becoming receptive to floral inductive stimuli. Fairey and Lefkovitch (1996b) reported that strong creeping red fescue (*Festuca rubra* L.) has an obligatory juvenile period and vernalization requirement for floral induction. The duration of the juvenility period lasts six weeks in Kentucky bluegrass (*Poa pratensis* L.) and 12 to 15 weeks in strong creeping red fescue (Murray et al., 1973; Cooper and Calder, 1964). Winter wheat (*Triticum aestivum* L.) and winter barley (*Hordeum vulgare* L.) have no juvenility requirement, while perennial ryegrass exhibits very little juvenility requirement. The tillers of all of these species can be exposed to environmental stimuli that will later promote flowering; however, earlier formed inflorescences have more spikelets, regardless of species or juvenility requirements.

Canode and Perkins (1977) and Bean (1970) demonstrated that induction is not fulfilled by temperatures above or below an assumed vernalizing temperature of 0° to 10° C. Bean (1970) observed that strong creeping red fescue plants were not induced to flower more than 20% of the time, indicating that extreme conditions sometimes may be necessary to induce flowering. Temperatures greater than 20° C, coupled with low light intensity, may cause abortion of floral primordia, notably in northern cultivars (Heide, 1982). Each tiller has its own juvenile stage and floral induction requirement. This means that primary induction stimuli must be recognized by each individual tiller (Aamlid, 1992). Furthermore, vernalization operates upon tillers and cannot be translocated from a vernalized tiller to an unvernalized tiller (Lindsey and Peterson, 1964). Meijer (1984) reported that of the number of tillers that emerged before vernalization treatments, on average, 42% of Kentucky bluegrass and 22% of strong creeping red fescue produced inflorescences. Tillers remaining in the vegetative state experienced the full induction period. These tillers were unable to respond to induction during at least part, and perhaps all, of the period. Furthermore, tillers emerging closer in time to the vernalization treatment produced fewer inflorescences, thus indicating that tiller size and age are important factors contributing to floral induction and seed yield.

Anslow (1963) observed that plants with early emerging inflorescences had 67% heavier seed and reached harvestable seed moisture content more rapidly than seed produced in later inflorescences. Inflorescences produced by tillers originating in the fall have more primary branching and florets than those originating later in the season (Hill and Watkin, 1975). Meijer (1984) observed that many of the youngest tillers remained fully vegetative. Moreover, Meijer (1984) reported that in strong creeping red fescue, of the older tillers in each of the plant age groups studied, approximately 80% produced inflorescences. In addition, inflorescence production may decline if availability of assimilates limits floral induction or if stem or inflorescence growth are limited. Stand density can negatively affect inflorescence production by limiting assimilates availability during or after vernalization, leading to the senescence of these tillers.

Upon fulfillment of dual induction requirements, initiation and flowering is a prerequisite for seed production and is controlled by two factors: temperature and photoperiod (Aamlid, 1992). The double-ridge stage of the stem apex marks the beginning of visible floral development (Chastain, 2003). Elongation of the internodes of induced tillers provides the first externally visible indication of the development of a fertile tiller. The swelling of the node is known as a joint. The visible swelling of the leaf sheath by the developing inflorescence is known as the boot. The inflorescence emerges from the subtending leaf sheath during a period known as heading. When the flowers are expanded and the stigmas are receptive to pollen, the plant has entered the reproductive phase of anthesis.

The post-harvest regrowth period is a critical phase of development that can strongly influence flowering and seed yield of subsequent crop yields in cool-season perennial grasses (Canode and Law, 1978). The number, size, and condition of tillers prior to the onset of winter, a season conducive to floral induction, is limited by a relatively short regrowth period in late summer and early fall. In the autumn, when tiller regrowth is poor, fewer tillers will be receptive to floral induction (Chastain, 2003). Aamlid (1992) reported that the crucial point to unlocking yield potential is to establish a good population of receptive tillers by the time the combination of temperature and photoperiod becomes favorable for primary induction.

Residue Management

Common post-harvest residue management of fine fescue seed crops in the Willamette Valley consists of open-field burning of full straw load to remove crop residue. Open-field burning of cool-season grasses grown for seed production in the

Willamette Valley has been practiced by growers since 1948, as a result of the work done by Burton (1944) indicating that sod burning increased seed yield in warm-season grasses. Further research by Hardison (1960), conducted during the 1940s and 1950s, examined open-field burning as a residue management method in cool-season grasses. Oregon State University agronomists recommended field burning as a residue management option to eliminate residue remaining in the field after harvest. Open-field burning also became a solution to disease problems, weed control, recycling of nutrients, maintaining crown size, and increasing yields in subsequent crop years (Musser, 1947; Chastain et al., 1993; Young et al., 1998; Mueller-Warrant and Rosato, 2002a; Mueller-Warrant and Rosato, 2002b). This recommendation has been substantially supported by research on the effects on disease control (Hardison, 1976; Hardison, 1980; Evans and Canode, 1971; Canode and Law, 1975; Canode and Law, 1977; Chilcote et al., 1980; Ensign and Hickey, 1980; Ensign et al., 1983; Flessner et al., 1995; Coats et al., 1994; Pfender and Alderman, 2001), weed control (Rolston et al., 1997), and stimulation of seed yield (Chilcote and Young, 1991) in grass seed crops. Open-field burning essentially removes stubble and straw residues that inhibit regrowth characteristics that otherwise would increase the chances for successful induction of flowering (Chastain, 2003).

In the Willamette Valley, seed yields of many grasses were reported to be reduced if post-harvest residue was not removed after harvest (Chilcote et al., 1980). Pumphrey (1965) reported, in a study conducted in northeastern Oregon, that seed yields were highest when residue was removed prior to the initiation of fall regrowth. Pumphrey (1965) also concluded that the more complete the removal of residue, the greater the resulting seed yield, and that delaying burning after the onset of fall regrowth resulted in an injury detrimental to seed yield.

Trends in Open-Field Burning

The acreage of grass seed crops burned in the Willamette Valley reached a peak of 315,000 acres in 1968. A total of 144 complaints pertaining to the burning of those acres were received in that year. In 1975, an acreage reduction plan was implemented and field burning fees were increased. The Oregon Department of Environmental Quality (DEQ) was granted direct authority to enforce violations committed by seed growers. Violations included: burning too many acres, burning during active prohibition conditions, and burning without permits. In 1987, the Oregon Visibility Protection Plan, which restricted burning on weekends, was adopted. In 1988, a record number of 3,783 field burning-related complaints were recorded. A catastrophic accident, caused by poor visibility from field burning smoke on Interstate 5, killed 7 persons and injured another 38. In addition, concerns over air quality also prompted the need to find alternatives to open-field burning. Due to increasing complaints, smoke related problems, and the passage of HB 3343 in 1991, burnable acreage has been systematically reduced.

To date, effective alternatives to field burning have been found for most species produced in the Willamette Valley, except for strong creeping red fescue (Young et al., 1984a; Chastain et al., 1993). Young et al. (1994) reported seed yield reductions in Chewings fescue to be not as dramatic as previously reported. However, an average yield reduction of 8-11% was observed in non-burned treatments. Moreover, results over the life of the stand indicate open-burn treatments have greater yield than non-burned treatments. In Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman] an economic analysis may be beneficial in determining the impact of open-burning.

The response of grasses to post-harvest residue management has been shown to be dependent upon sowing rate, row spacing, species, stand age, cultivar, environment, and other agronomic practices (Musser, 1947; Hickey and Ensign, 1983; Meijer, 1984; McFarland and Mitchell, 2000; Chilcote et al., 1980). Transitory high temperatures were thought, at one time, to temporarily shock plants and initiate new tiller growth from dormant buds in contact with the soil (Chilcote et al., 1980). However, more recent studies (Chastain et al., 1997; Meints et al., 2001) have revealed that it is the removal of existing plant material and not a temperature shock that results in higher seed yields obtained with field burning. Species with a cespitose growth habit such as tall fescue (*Festuca arundinacea* Shreb.), perennial ryegrass (*Lolium perenne* L.), orchardgrass (*Dactylis glomerata* L.), and Chewings fescue are reported to be economically feasible to produce without the use of open-burning (Chastain et al., 2000; Canode, 1972; Chastain et al., 1996a; Young et al., 1999).

Upon evaluation of non-burn methods, some instances of higher weed and disease content have been observed. Young et al. (1998) reported that open-burning resulted in the fewest weed seeds and highest purity of harvested seed. Hardison (1980) stated that open-burning kills 95-99% of the weed seed present on the soil surface, resulting in a reduced dependence on herbicides. In contrast, Mueller-Warrant and Rosato (1994a and 1994b) reported that with the proper selection of herbicides, most weeds can be controlled with little effect on overall seed yield and quality in non-burned fields. Furthermore, Mueller-Warrant and Rosato (1994a and 1994b) and Chastain et al. (1996b) reported that seed quality was maintained in Chewings fescue, without burning, when residue management techniques removed most of the straw and stubble remaining after harvest. However, with an increase in inert matter, seed purity often declines, accompanied by an increase in percent seed cleanout. Seed purity and uniformity tends to intensify as stands age. Moreover, Chastain et al. (1999) reported that baling removes 75-82% of the straw remaining after harvest. In addition, Chastain et al. (1999) found that vacuum treatment was the most effective treatment for removing straw and reducing stubble height.

Pumphrey (1965) laid the foundation for complete residue removal prior to the initiation of fall growth. He reported that residue removal in late August, by either burning or mechanical means, was equally effective. However, delay of burning until after fall regrowth severely reduced seed yields the following year. In addition, partial removal of residue had an intermediate effect between no removal and complete removal. In conclusion, Pumphrey (1965) found that post-harvest residue removal increases seed yield in Kentucky bluegrass and strong creeping red fescue, with more complete removal being the most beneficial residue treatment. Moreover, removing the residue increased the value derived from applied fertilizers.

Meints et al. (2001) observed that complete stubble removal (to 0.0 cm) reduced rhizome production. This complete stubble removal allowed for greater partitioning to vegetative tillers in the fall and to fertile tiller number development in the spring. Rhizomes and fall tillers arose from the same crown buds during regrowth.

Therefore, rhizome production was lowest when stubble was completely removed or burned.

Natural production of ethylene in decaying stubble during crown bud differentiation, regrowth, and development may have a negative impact on maturation and floral induction in strong creeping red fescue. This effect is heightened in older stands where vegetative matter is greater. Thus, the complete removal of stubble, which alters tiller production and development and enhances the development of rhizomes, is needed to decrease ethylene production (Meints et al., 2001).

Hickey and Ensign (1983) reported that Kentucky bluegrass seed yield, during the first year of production, was unaffected by residue management. However, seed yields where stubble was clipped to 2.5 cm and 7.6 cm were reduced compared to burning in the following three years and were associated with a reduction in tiller and panicle number. Clipping at 2.5 cm removed some tiller apices, while clipping at 7.6 cm removed fewer tiller apices. Clipping at 7.6 cm may have resulted in increased apical control of the rhizomes compared to the 2.5 cm clipping height. In comparison, Evans (1980) reported that gapping (removal of alternate 30 cm sections of row in late summer of alternate years) served to remove rhizomes from tiller apical control and release the rhizomes to produce new tillers. This resulted in greater panicle production. In addition, removal of residue to 7.6 cm resulted in greater leaf sheath length compared to when residue was removed to 2.5 cm. This increase was attributed to decreased light penetration into the canopy, resulting in fewer rhizomes being developed and, subsequently, less fertile tillers. Root weights were not affected by residue management when averaged across all five cultivars. Evans (1980) concluded that burning residue functioned to reduce tiller apical control of rhizomes which, in turn, controlled the upturning of rhizomes to produce new tillers. In all cases, increased fertile tiller production was associated with a decrease in rhizome weight. Residue removal by clipping to 2.5 cm and 7.6 cm in the last two years of the study resulted in greater rhizome weights compared to open-burning.

Row Spacing

Studies have shown the effectiveness that manipulation of row spacing has in relation to residue management alternatives. Canode (1972) found that Kentucky bluegrass and orchardgrass can be grown in wider rows (91 cm) for seed production. Under these conditions mechanical residue removal resulted in higher yields than burning in the second and third seed crops, with less than favorable yields in the fourth and fifth seed crops. Canode and Law (1978) found similar results in Kentucky bluegrass, reporting highest yields in the first and second seed crops with 30 and 60 cm row spacing. As the stand aged, the greatest yields were observed in 90 cm rows. Data from this study showed no evidence that plant row spacing affected the typical decline in Kentucky bluegrass seed yield associated with stand age. Chilcote and Young (1991) reported that, in the absence of open-burning, wider rows in tall fescue maintained seed yield. Results for perennial ryegrass and strong creeping red fescue warrant further investigation. Chastain et al. (2001) reported no differences among row spacing for seed yield in strong creeping red fescue, slender creeping red fescue, and Chewings fescue. No interactions of residue management and row spacing were evident in the seed yield results of strong creeping red fescue or slender creeping red fescue. It was concluded that open-burned plots typically out yielded non-burned plots in older stands.

Stand Age

Stand age plays an important role in productivity of perennial ryegrass seed crops. Evans and Canode (1971) studied the influence of nitrogen fertilizer, gapping, and field-burning on seed production of Newport Kentucky bluegrass. They reported a characteristic age-associated seed yield decline.

Highest seed yields were reported in the range of 202 to 246 kg N/ha each year. The three highest N rates had few differences, indicating a near maximum N response being reached. However, increasing N rates could not stop seed yield decline with age.

Gapping did not maintain loss of productivity with stand age or retard aging. Yearly burning decreased vegetative spread of Kentucky bluegrass throughout the entire study, as indicated by narrower sod widths for burned plots compared to non-burned plots at each harvest. Evans and Canode (1971) concluded that open-burning helps to maintain reproductive potential as the stand aged.

In an economic analysis of mechanical and thermal residue removal, Wirth et al. (1977) reported that as stand age increased, seed yield decreased and production costs increased. Wirth et al. (1977) concluded that the only profitable alternative to open-burning was machine burning of residue at high temperatures (800-900° F). However, as reported by Miles (1976), machine burning was too costly of an alternative to use and mechanical removal was not feasible. Evans and Canode (1971) and Ensign and Hickey (1980) found that burning was more effective and profitable in older stands of Kentucky bluegrass with heavy residue accumulations. It was theorized that open-burning produces fewer rhizomes of less weight, and larger, more robust tillers that produce more seed. In addition, no plant-growth regulators were shown to be as effective as open-field burning (Ensign and Hickey, 1980).

Zapiola et al. (2003) supports the same observation of plant growth regulators (PGR) in relation to open-field burning. In a four-year study of strong creeping red fescue, Zapiola et al. (2003) found that as a stand aged, seed yield decreased. In the early years of the stand, PGR application mimicked open-field burning. However, as the stand aged, seed yield under non-thermal residue removal (regardless of PGR) was lower than open-burned plots. Differences between thermal and non-thermal residue removal could be attributed to reductions in both spikelets per panicle and panicle number. These differences could be attributed to a lower number of fertile tillers per unit area. In addition, fertile tiller number and total dry weight were greater for open-burned plots, leading to a greater floret number and, as a result, higher yields. Increased number of spikelets per panicle in burned plots was correlated with increased panicle length to accommodate a greater number of spikelets. Zapiola et al. (2003) reported that fall PGR application had no effect on seed yield. Spring PGR applications increased seed yields compared to an untreated, burned control. This effect was attributed to less incidence of lodging. Clearly, open-burning increased strong creeping red fescue reproductive potential (Zapiola et al., 2003).

Declines in seed yield due to stand age can be attributed to cultivar differences (Lamb and Murray, 1999; Canode and Law, 1977; Ensign et al., 1983; Coats et al., 1994). Aggressive cultivars that are strongly rhizomatous show an increased response to complete stubble removal in the early years of the stand. As the stand ages, aggressive cultivars require burning. In contrast, non-aggressive cultivars that are less rhizomatous may produce economic seed yield throughout the entire life of the stand with mechanical residue removal. Thus, knowledge of the cultivar aggressivity being produced is essential to grass seed producers.

Harvest Index

As described by Elgersma (1990), seed yield can be considered the product of biomass production and Harvest Index (HI). The (HI) is calculated as seed dry matter/total dry matter. In the first year of a study on 9 different perennial ryegrass cultivars, Elgersma (1990) reported that (HI) was associated with seed yield on a sandy soil, as the cultivars differed for seed yield, but had similar dry matter production. Elgersma (1990) reported that in other environments seed yield was also positively correlated with (HI).

In a post-harvest residue management study, Young et al. (1998) reported an interaction between treatment effects and years in two out of four years to be significant for (HI) with respect to strong creeping red fescue, but not in Chewings fescue.

In a residue management study of diverse Kentucky bluegrass germplasm, Johnson et al. (2003) reported that (HI) almost doubled in the burned treatment compared to the residue retained treatment, with the residue-removed treatment (HI) being intermediate. Thus, the efficiency of conversion of above-ground biomass to seed was increased as more residue from the previous crop year was removed, resulting in a higher (HI). The yield component most strongly correlated with (HI) was panicles per square meter (r=0.65, P<0.01, n=264). There was a weaker, but positive, correlation between (HI) and weight per seed (r=0.22, P<0.01, n=264), but seeds per panicle were negatively correlated with (HI) (r=-0.40, P<0.01, n=264). Johnson et al. (2003) suggests that the increased efficiency in conversion of biomass to seed yield, resulting in increased (HI), was most closely associated with increased panicles per square meter and, to a lesser extent, weight per seed.

Thatch

Canode and Law (1979) found that thatch accumulation was highly dependent upon residue management and that an increased thatch layer resulted in reduced seed yield. The greatest amount of thatch was produced in the first and second seed crops. Thatch production increased 2 to 3 times in non-thermal removal of residue as stands aged. Thermal residue removal with open-burning or propane flaming, after straw was removed, significantly reduced thatch in all stand ages. Therefore, the primary response of Kentucky bluegrass to burning was a decrease in the amount of thatch that interferes with the vigor of tiller regrowth. In addition, Canode and Law (1979) observed that the internode immediately below the bud forms the new crown in autumn and elongates until the bud is elevated through most of the thatch. Tillers that develop in thatch are more erect, elongated, narrower leafed, and were lighter green in color.

After burning, plants have a rosette-like appearance, with wider, shorter leaves, and a darker green color. These regrowth differences result in the number of large tillers produced where thatch had been removed by burning.

Tiller Size

Canode and Law (1979) reported that burn treatments did not affect panicle production; however, burning did produce larger tillers, indicating an average panicle production of 70, 23, and 1 percent for tillers that were 2.0, 1.5, and 1.0 mm in base diameter, respectively. Small tillers (1.0 mm) produced essentially no panicles. Tillers of all sizes that did not produce panicles showed the apical primordia to be in a vegetative condition. There was no evidence of damage or deterioration. This indicates that these primordia had not transitioned to floral primordia. Canode and Law (1979) proposed that Kentucky bluegrass tillers must reach a certain size or growth stage before they are receptive to thermo-photoperiodic stimuli for induction. In conclusion, it was proposed that seed yield decline associated with stand age is primarily a result of thatch accumulation that inhibits tillering.

Non-Thermal Alternatives

Chastain et al. (1999 and 2000) reported the agronomic feasibility of non-thermal residue management alternatives for all species studied, except strong creeping red fescue. Chastain et al. (1999 and 2000) attributed the results to species with a bunch growth habit being more tolerant of non-thermal methods, even without straw removal, than species with a creeping growth habit. Seed yields of Kentucky bluegrass, dryland bentgrass (*Agrostis castellana* Boiss. and Reut.), and Chewings fescue that were raked and vacuumed were equivalent to open-field burning. Bale and flail treatment produced excellent yields in Chewings fescue, but not in dryland bentgrass. However, it was found that Chewings fescue and Kentucky bluegrass will not tolerate full straw load residue management. Chastain et al. (1999 and 2000) concluded that residue management, species, and stand age affected seed yield. Similar results were reported by Chastain (2000), where residue management and stand age effects on seed quality in cool-season perennial grasses were evaluated.

Canode (1965) and Chilcote et al. (1980) observed stand thinning, as a result of open-burning, maintaining seed yield productivity in aging stands. They attributed the stand thinning to the destruction of unproductive tillers and the improvement of the microenvironment surrounding each plant. Stand thinning promotes tillering at ground level, and the resulting change in microenvironment favors storage reserves in stem bases, as well as creating an increased opportunity for floral induction. Moreover, stand-thinning results in partitioning of carbon energy into tillers versus leaf sheath tissue, resulting in more panicles and higher seed yields being produced (Ensign and Hickey, 1980). Ensign and Hickey (1980) also observed, in unburned plots, an increase in organic matter and survival of non-reproductive tillers that compete with newly-formed reproductive tillers. Increased competition for light resulted in the elongation of stems and leaves due to etiolation. Consequently, tiller development is inhibited, resulting in delayed tillering. Furthermore, soil temperatures are cooler under residue cover in unburned treatments, which does not favor root growth or tillering. A deleterious effect of fewer developed and established tillers resulted in fewer tillers susceptible to floral induction. In regards to spring tillering, a lower amount of stored reserves and increased light competition may reduce the ability of tillers to produce an inflorescence.

Rotation

Miles (1976) suggested that shorter crop rotations can alleviate yield losses associated with stand aging in grasses. However, Miles (1976) found that shorter rotations were not profitable for grass seed producers. Chilcote and Young (1991) stressed difficulty in finding an alternative to open-burning that can stimulate the morphological and physiological regrowth patterns and maintain the pest control standards of a burned stand. It was noted that fine-leaf fescues, with respect to seed yield response, are particularly sensitive to burning. Large seed yield losses occurred under mechanical removal. Chilcote and Young (1991) concluded that shorter rotations may lead to altered row spacing and seeding rates. Concerns over the cost of crew-cutting were illustrated and new methods were proposed. Flail-chopping residue three to four times was thought to decrease residue particle size and help with disbursement between rows of stands with shorter rotations. Baling of straw and flail-chopping residue was also tested. Another residue management alternative would be grazing, in combination with non-thermal residue management, which may influence regrowth of tillers under different mechanical removal methods (Chilcote and Young, 1991). Grazing could possibly help decompose residue left on field more rapidly. However, the unavailability of livestock makes this option not feasible. In summary, crop rotations that are shorter are not currently profitable.

Timing of Thermal Residue Management

Timing of post-harvest residue removal is essential to maximize fall regrowth and subsequent crop yields (Musser, 1947; Pumphrey, 1965; Ensign and Hickey, 1980). Ensign and Hickey (1980) reported that late burning of residue (Sept-Oct) can result in seed yield reductions of 30-35% compared to early burning in August. It was observed that late burning destroys tillers, causing plants to use reserves for regrowth, subsequently reducing tillering and panicle number in the spring. Loepkey and Coulman (2001) demonstrated that immediate residue removal generally increased tiller density and development, as well as panicle density and percentage of panicle-producing tillers in meadow bromegrass. In addition, an increase in panicle production was observed when residue was removed early, rather than late.

Musser (1947) reported that spring burning did not produce a significant increase in seed yield in strong creeping red fescue (*Festuca rubra* L.). This may have been due to an inadequate burn as a result of dampness and severely matted conditions. Summer burning significantly increased seed yield and resulted in more effective disease control. Musser (1947) concluded that time of burning was important and that a reduction in seed set may be due to injury of regrowth if grass is burned too early in the spring. Furthermore, increased seed yields due to burning are directly related to a decrease in disease, insect injury, or both.

Fairey and Lefkovitch (2001) found that a double-burn treatment most influenced seed weight. In addition, the double-burn and power harrow treatment increased germination capacity.

Conclusions

Non-thermal residue management in fine fescue was theorized to produce seed yields equivalent to thermal management. Many studies have evaluated the effect of non-thermal management on fine fescue seed production. Upon review of literature, we can hypothesize that fine fescue subspecies response to residue management can be species, cultivar, and stand age dependent (Johnson et al., 2003; Lamb and Murray, 1999; Young et al., 1999). Chewings fescue is a cespitose grass and is more positively associated with non-thermal management (Young et al., 1998; Chastain et al., 1999). However, Young et al. (1994) showed that this response can also be cultivar-specific and stand age dependent. In contrast, strong creeping red fescue and slender creeping red fescue are rhizomatous grasses that exhibit prolific tillering. Therefore, it is hypothesized that non-thermal residue management might maintain seed yield as the stand ages by mimicking thermal residue management effects such as fall tiller height and reduced rhizome production in strong creeping and slender creeping red fescue.

MANUSCRIPT I: RESIDUE MANAGEMENT AND YIELD CHARACTERISTICS OF FINE FESCUE SEED CROPS

ABSTRACT

Field-burning based residue management after seed harvest has been an important but controversial tool in fine fescue grass seed cropping systems and has been associated with acceptable yields in three commercially produced fine fescue species {Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*Festuca rubra* L. subsp. *rubra*), and slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)]}. General concerns for air quality and safety issues have prompted finding alternative residue management to open-field burning of perennial grass seed crops in the Willamette Valley. The objective of this research was to examine the influence of thermal and non-thermal residue management from an economic, morphological, and physiological perspective.

Four cultivars of Chewings, strong creeping red, and two slender creeping red fescues were selected for this study. Residue management treatments conducted include: (i) open-field burning; (ii) bale and flail low; and (iii) bale and flail high. Seed yield components measured were: total dry weight, fertile tiller number, panicle length, spikelets per panicle, florets per spikelet, and seed yield. The effects of thermal and non-thermal management of post-harvest residue on percent seed cleanout, total dry weight, and harvest index were also evaluated. A partial budgeting technique was used for economic analysis of alternative residue management practices.

Response to residue management treatments was different between cultivars and years. In 2003, thermal residue management increased yields in SR5100 and

Southport Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. In 2004, thermal residue management increased yield in SR5100, Southport, Brittany, and Barnica Chewings fescue, and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue. A reduction in seed yield was seen in both Seabreeze and Marker slender creeping red fescue under thermal residue management.

In 2003, thermal residue management increased fertile tiller number in SR5100 and Brittany Chewings fescue, in Cindy strong creeping red fescue, and in Seabreeze slender creeping red fescue. In 2004, thermal residue management increased fertile tiller number in all Chewings and strong creeping red fescues.

In 2003, thermal residue management increased seed number in SR5100, Southport, and Brittany Chewings fescue, and in Shademaster, Cindy, and Silverlawn strong creeping red fescue. In 2004, thermal residue management increased seed number in all Chewings and strong creeping red fescues.

In 2003, thermal residue management increased seed weight in SR5100 Chewings fescue, in Shademaster and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. In 2004, thermal residue management increased seed weight in SR5100 Chewings fescue, in Shademaster, Shademark, and Cindy strong creeping red fescue, and in Seabreeze and Marker slender creeping red fescue.

In 2003, thermal residue management decreased percent seed cleanout in SR5100 Chewings fescue, in Shademaster, Silverlawn, and Shademark strong creeping red fescue, and in Marker slender creeping red fescue. In 2004, thermal residue management reduced percent seed cleanout in all cultivars except Marker slender creeping red fescue.

In 2003, thermal residue management increased harvest index in Southport Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. In 2004, thermal residue management increased yield in SR5100, Southport, Brittany, and Barnica Chewings fescue, and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue.

Results indicate poor yields in all strong creeping red fescue cultivars in both years of the study. Furthermore, results indicate that during the establishment period of a stand, residue management can be species and cultivar specific, and that adequate yields can be achieved with non-thermal residue management. It is theorized that the mechanism in which thermal residue management tends to maintain yields in fine fescue is not fully developed in the first year of seed production. Thus, thermal residue management becomes increasingly important following the second year of seed production. However, as stand age increases, open-field burning results in greater seed yields in all cultivars and species, except slender creeping red fescues. Thus, field burning is critical for attaining high seed yield over the life of a stand.

INTRODUCTION

Historic post-harvest residue management of fine fescue seed crops in the Willamette Valley consisted of open-field burning to remove post-harvest crop residue. Field burning is essential to produce profitable seed yields in fine fescue (Hardison, 1980).

Seed yield responses to open-field burning have been directly associated with volunteer crop and weed control, nutrient cycling, disease control, pest control, and plant microclimate enhancement.

In the Willamette Valley, seed yields of many grasses were reported to be reduced if post-harvest residue was not removed (Chilcote et al., 1980; Chastain et al., 1996b). The post-harvest regrowth period is a critical phase of subsequent seed crop development and strongly influences flowering and seed yield in cool-season perennial grasses (Canode and Law, 1978).

Open-field burning has been associated with acceptable seed yields in three commercially produced fine fescue subspecies {Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*F. rubra* L. subsp. *rubra*), and slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)]}.

Chewings fescue is classified as a bunch-type species. Seed yield of Chewings fescue has been previously observed to be in the acceptable range under non-thermal residue management practices (Chastain et al., 1999). Strong creeping red fescue and slender creeping red fescue are both rhizomatous subspecies and respond differently to thermal and non-thermal post-harvest residue management practices. Previous studies indicate seed yield following non-thermal residue management practices is reduced in strong creeping red fescue (Young et al., 1998; Meints et al., 2001), with variable results in slender creeping red fescue (Chastain et al., 1998). Nevertheless, increased rhizome production has been associated with non-thermal residue management in strong creeping red fescue and has been directly correlated with unacceptable seed yield (Meints et al., 2001).

An increased understanding of seed yield decline in fine fescue seed crops, over a period of time, is needed to develop profitable non-thermal residue management alternatives. The variability in seed yield response to different residue management practices in fine fescue subspecies and cultivars must be differentiated.

Chastain et al. (1996a) and Chastain and Young (1998) postulated there is evidence that field-burning is the most effective way to reduce fall tiller height, a factor positively correlated with subsequent seed yields.

Young et al. (1998) stated that in strong creeping red fescue and Chewings fescue the greatest effect of residue management was on the number of panicles produced. Young et al. (1998) observed that thermal residue management produced 90% more panicles than non-thermal residue management. In addition, Chilcote et al. (1980) reported a significant difference in mean number of panicles per plant, with 132 panicles per plant under thermal residue management and 82 panicles per plant in non-thermal residue management. Furthermore, thermal residue management significantly increased seed yield of Chewings fescue and strong creeping red fescue. Chilcote et al. (1980) concluded that thermal residue management was essential in maintaining profitable seed yields in Chewings fescue and strong creeping red fescue.

Lamb and Murray (1999) reported that seed production in Kentucky bluegrass (*Poa pratensis* L.) was strongly correlated with panicle number ($r = 0.77$); however, panicle number was not associated with above-ground biomass, rhizome biomass, or thousand seed weight.

Chastain et al. (1997) reported a stronger correlation ($r^2 = 0.70$, $P<0.01$) between seed yield and fertile tiller number in Kentucky bluegrass (*Poa pratensis* L.). In addition, seed yield was reported to be equivalent to field-burning when fertile tiller number accounted for 27% or approximately 2700 fertile tillers per m^2 of the spring fertile tiller number at anthesis.

Nevertheless, legislative mandates regarding air quality have necessitated research for alternatives to thermal residue management and have reduced the use of open-field burning of fine fescue seed crops in the Willamette Valley.

The objectives of this study were: 1) to evaluate crop yield and yield components among different cultivars in response to thermal (open-burning) and non-thermal (flail low and flail high) post-harvest residue management; 2) to evaluate harvest index and percent seed cleanout in relation to thermal and non-thermal residue management in different cultivars and; 3) to provide an economic analysis of thermal and non-thermal residue management in all cultivars based on partial budgeting.

MATERIALS and METHODS

Field trials were established at Hyslop Research Farm, Corvallis, Oregon in the fall of 2000 on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll), in an attempt to characterize the effects of residue management of fine fescue seed crops over a four-year period. The crop was drilled 15 October 1999 at a rate of 9 kg ha^{-1} by using an eight-row plot-sized drill with 30-cm spaced rows. The crop was irrigated during establishment. A pre-plant application of fertilizer (16-20-0) at a rate of 224 kg ha^{-1} was broadcast applied during general seedbed preparation.

The experimental design was a randomized complete block with a strip-plot arrangement of treatments in four replicates. Main plots were comprised of three residue management treatments and subplots consisted of ten fine fescue cultivars. Each main plot measured 30 m x 15 m; subplots were randomly assigned to each main plot. Each subplot in this experiment measured 3 m x 15 m. Four cultivars of Chewings fescue (SR5100, Southport, Brittany, and Barnica), four cultivars of strong creeping red fescue (Shademaster, Cindy, Silverlawn, and Shademark), and two cultivars of slender creeping red fescue (Seabreeze and Marker) were selected for the experiment. Selection of cultivars for the trial was based on representation of commercially grown cultivars of Chewings, strong creeping red fescue, and slender creeping red fescue. Residue management treatments were randomly assigned to main plots. Residue management treatments examined included: (i) removal of straw by thermal (Open Burning); (ii) non-thermal removal of straw by baling and flail chopping the stubble low (flail low); and (iii) non-thermal removal of straw by baling and flail chopping the stubble high (flail high). In 2001, plots were mowed as a consequence of the stand being too thin for a seed harvest.

Post-Harvest

The three post-harvest residue treatments were applied accordingly: 1) flail high on 22 July 2002 and 25 July 2003; 2) flail low on 22 July 2002 and 25 July 2003; and 3) Open-Burn on 22 July 2002 and 25 July 2003. In both non-thermal treatments straw residue was removed and crown stubble was flail chopped to either 2.5 cm (flail low) or 5.0 cm (flail high) above the soil surface. The thermal (open-burn) treatment was completed by igniting the full straw load and maintaining a steady uniform burn of plant residue to the soil surface.

Residue management treatment was conducted soon after harvest, as weather conditions allowed. The trial was then conducted for two harvest seasons, 2003 and 2004.

Seed yield components measured were: total dry weight, fertile tiller number, spikelets per panicle, florets per spikelet, and panicle length. Final seed yield resulting from each cultivar and residue treatment method was determined after seed harvest and seed conditioning.

Fifteen panicles were also collected prior to peak anthesis from each plot and frozen at -15° C prior to analysis. Fertile tiller number was determined on samples taken prior to peak anthesis in early spring. After drying the tillers, the total dry weight of the tillers was measured in order to determine total above-ground biomass.

Two samples were taken from each plot at ground level using a 30 cm^2 quadrat. Samples were placed in a dryer at 65° C for approximately 48 hours. Panicle length, spikelets per panicle, and florets per spikelet were determined on these samples. Two spikelets were randomly selected from the top, middle, and bottom of four panicles to determine floret per spikelet number.

Thousand seed weight was determined from a harvested subsample by using hand screens and a blower for cleaning. Each plot had two samples containing 1000 seeds that were counted with an electronic counter. The seeds were then subsequently weighed and then averaged. Seed number was calculated by using seed number per m^2 based on thousand seed weight.

Seed samples were taken in late June and early July of each year to determine seed moisture content for optimum swathing. The seed was oven-dried at 130° C for 24-hours for seed moisture content determination. The crop was harvested by swathing when seed moisture content level dropped to approximately 30% for each cultivar. In 2003, SR5100, Seabreeze, Barnica, and Southport were swathed on 28 June; all other cultivars were swathed on 30 June.

A plot combine was used to harvest seed when seed moisture had reached 12%. Seed yield was weighed directly in the field, with a subsample being collected for laboratory analysis. Bulk seed sacks on the combine were used to determine seed dirt weight harvested from each plot. A percentage of plot dirt seed weight and plot clean seed weight was used to calculate percent seed cleanout and overall seed yield.

In 2004, Barnica was swathed 18 June and harvested 1 July. SR5100, Seabreeze, Southport, and Silverlawn were swathed on 26 June. All other cultivars were swathed 28 June. SR5100 and Silverlawn were harvested 1 July. All others were combined 2 July. Total subplot area harvested in 2003 and 2004 was 28 m^2.

Seed was cleaned in a laboratory-sized M-2B clipper air-screen cleaner (A.T. Farrell, Saginaw, MI) prior to weighing. Seed cleaning methods used were similar to industry standards.

Crop management was based on common production practices of fine fescue in the Oregon's Willamette Valley. In both years, fall fertilizer (16-20-0) was applied at approximately 280 kg ha^{-1}, representing 45 kg N ha^{-1}. However, in 2003 approximately 291 kg ha^{-1}, representing 47 kg N ha^{-1} of (16-20-0) was applied. In March 2003, approximately 56 kg N ha^{-1} was applied as (33-0-0-12S). In March 2004, 90 kg N ha^{-1} was applied as (33-0-0-14). Chemicals applied were consistent with those used in fine fescue seed production in the Willamette Valley and were applied according to label directions. Residue management of post-harvest crop residue depended on treatment imposed.

Statistical analysis was done using SAS, Version 6.12 (SAS Institute Inc., 1991). Treatment effects were analyzed using ANOVA and, with the exception of interaction, means were separated by Fisher's protected LSD values. In 2003 and 2004, contrast statements were analyzed to observe which cultivars responded differently to residue management treatments.

RESULTS and DISCUSSION

In this study, the propensity of fine fescue to respond to residue management, with respect to several measured parameters, was cultivar-dependent. In 2003, a residue management by cultivar interaction was observed in seed yield, total dry weight, harvest index, and thousand seed weight. A significant residue management treatment effect was observed in seed number. In 2004, a residue management by cultivar interaction was observed in seed yield, harvest index, fertile tiller number, seed number, thousand seed weight, and percent seed cleanout. Significant residue management treatment effects were observed in total dry weight, spikelets per panicle, florets per spikelet, and panicle length. An analysis of variance of these observations is presented in Table 1-1.

Environmental Implications

Environmental conditions in 2003 and 2004 were different during the period corresponding to seed fill in June (Table 1-2). Fine fescue is predominantly produced in dryland cropping systems in the Willamette Valley and is highly dependent upon adequate spring rainfall to produce economically viable crops. In 2003, April-June precipitation patterns were 213%, 79%, and 27% of normal (Table 1-2). In contrast, 2004 April-June precipitation patterns were 80%, 75%, and 114% of normal (Table 1-2). The observed precipitation differences between years may explain lower yields in 2004. Below average precipitation in April and May of 2004 could potentially explain lower seed yields due to lower seed set from early season moisture stress. This would be logical, as increased precipitation in June of 2004 did not occur in time to alleviate stress caused by inadequate moisture in April and May (Table 1-2).

Table 1-1. Analysis of variance of post-harvest residue management treatments and cultivars of fine fescue in 2003 and 2004.

	d.f.	Seed yield	TDW[1]	HI[2]	FTN[3]	Spklts. per panicle	Florets per spikelet	Pan. length	Seed no.	1000 seed Wt.	Percent cleanout
2003											
Residue (A)	2	***	NS	***	NS	NS	NS	NS	**	***	NS
Cultivar (B)	9	***	***	***	NS	***	***	***	*	NS	***
A x B	18	***	*	***	NS	NS	NS	NS	NS	*	NS
2004											
Residue (A)	2	***	***	***	***	***	***	***	***	***	***
Cultivar (B)	9	***	***	***	***	***	***	***	***	***	***
A x B	18	***	NS	***	***	NS	NS	NS	***	***	***

[1]TDW = total dry weight
[2]HI = harvest index
[3]FTN = fertile tiller number
*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.
NS = not significant.

Table 1-2. Weekly summary of maximum temperature and daily precipitation measured at Hyslop Farm, Corvallis, Oregon. Average values are long-term.

Month	Week	Mean Max Temperature					Daily Precipitation				
		Avg.	2001	2002	2003	2004	Avg	2001	2002	2003	2004
		----------°C----------					----------mm----------				
March	1	12	14	11	11	11	3.52	0.98	6.20	8.71	3.47
	2	13	12	9	16	18	3.77	2.76	8.71	3.45	0.07
	3	13	16	10	13	17	3.27	0.36	3.70	9.33	0.07
	4	13	14	14	13	16	3.63	4.25	1.85	4.06	3.34
April	1	15	12	17	15	17	2.79	1.85	0.76	4.68	0.54
	2	16	12	16	15	19	2.50	3.92	3.08	4.90	0.00
	3	16	15	13	15	18	2.18	0.62	2.58	5.59	3.56
	4	17	20	16	14	14	1.81	1.38	0.29	8.09	4.86
	5	18	17	17	18	24	1.92	1.56	0.00	0.62	0.00
May	1	19	22	14	15	22	1.81	0.00	0.25	1.38	1.81
	2	20	17	20	18	19	1.60	3.08	1.52	1.74	0.58
	3	20	27	18	22	20	1.38	0.00	3.16	1.23	1.05
	4	21	23	22	23	21	1.31	0.22	1.42	0.47	1.16
June	1	22	21	22	28	23	1.12	1.45	0.04	0.00	0.22
	2	22	21	26	24	19	1.09	1.63	0.22	0.58	5.01
	3	23	25	22	24	26	1.12	0.00	2.00	0.04	0.36
	4	24	21	25	25	26	0.91	4.10	2.10	0.69	0.00
	5	25	27	24	32	28	0.65	0.00	0.00	0.00	0.00

Fertile Tiller Number & Total Dry Weight

In 2003, fertile tiller numbers were not affected by residue management, nor were significant cultivar differences observed. In 2004, a residue management by cultivar interaction was observed with respect to fertile tiller number. Each cultivar was evaluated independently to determine the effect of residue management (Table 1-3). In 2004, non-thermal residue management increased fertile tiller number over thermal management in Seabreeze and Marker slender creeping red fescue (Table 1-3). The remaining cultivars of Chewings fescue and strong creeping red fescue responded more favorably to thermal over non-thermal residue management, with greater fertile tiller number per unit area (Table 1-3).

The number of fertile tillers present at anthesis has been shown to be a function of the number and developmental state of vegetative tillers present prior to floral induction (Chastain and Young, 1998). In fine fescue, fertile tiller number has been shown to be directly related to seed yield (Chilcote et al., 1980). Meints et al. (2001) investigated stubble management effects on three strong creeping red fescue cultivars and observed that fertile tiller number increased 25% when stubble was completely removed thermally or mechanically to ground level in both Shademaster and Hector strong creeping red fescue. In contrast, fertile tiller number in Seabreeze slender creeping red fescue was unaffected by stubble removal. Meints et al. (2001) theorized that a reallocation of resources to fertile tiller production and the subsequent initiation of fertile tillers, rather than rhizomes, was the result of differentiation being controlled at the crown axillary meristems in response to stubble removal.

Table 1-3. Interaction means for residue management by cultivar fertile tiller number in 2004.

Subspecies	Cultivar	2004 Non-thermal	 Thermal
		--------no. per m^2---------	
Chewings	SR5100	145	287
	Southport	133	255
	Brittany	146	283
	Barnica	294	381
Strong Creeping	Shademaster	151	283
	Cindy	145	216
	Silverlawn	181	283
	Shademark	229	333
Slender Creeping	Seabreeze	190	175
	Marker	302	157
	§ S.E.	6.52	7.87

§ S.E. = standard error of the mean. Appropriate for comparisons within column.

In 2003, residue management did not impact total dry weight, although cultivar differences were observed (Table 1-4). In 2004, a treatment effect occurred with respect to total dry weight. Thermal residue management significantly increased total dry weight over both flail low and flail high non-thermal residue management treatments (Table 1-4); thus, as stands age total dry weight among all cultivars was equally dependent upon residue management due to increased total dry weight under thermal residue management compared to non-thermal residue management.

Canode and Law (1978) investigated the effects of thatch accumulation in relation to size of tillers produced in a residue management study of Kentucky bluegrass (*Poa pratensis* L.) and reported that thermal residue management reduced thatch accumulation about 50%. In addition, Canode and Law (1978) reported that the total number of primary tillers and the number of large tillers was significantly increased following thermal residue management. Therefore, in this study, it seems logical to agree with Canode and Law (1978) since we have reported similar findings.

Table 1-4. Residue management treatment and cultivar means for total dry weight in 2003 and 2004.

Residue Management	Total dry weight ----g per m^2----
	2003
Thermal	NS
Flail Low	NS
Flail High	NS
	2004
Thermal	1190a
Flail Low	1053b
Flail High	986c
LSD 0.05	123

Cultivar	Total dry weight ----g per m^2----
	2003
Shademaster	1331a
Shademark	1193cab
Silverlawn	1183cab
Southport	1341a
Cindy	1268ab
SR5100	1094cb
Barnica	1265ab
Brittany	1172cab
Seabreeze	1048c
Marker	1027c
LSD 0.05	182
	2004
Shademaster	1269a
Shademark	1191a
Silverlawn	1181a
Southport	1181a
Cindy	1164a
SR5100	1062ba
Barnica	1056ba
Brittany	927bc
Seabreeze	904bc
Marker	830c
LSD 0.05	224

Seed Yield of Fertile Tiller g Unit Area^{-1}

Seed crops exhibited the highest seed yield potential in 2003, as expressed by the large number of fertile tillers per unit area (Table 1-3), and seed yield was mostly much higher in 2003 compared to 2004. A distinctly high seed yield was exhibited in Brittany and Shademark in thermal residue management in 2003 and 2004 and was strongly correlated with seed yield per fertile tiller per unit area (Figure 1-1, 1-2). Non-thermal residue management had a strong correlation to seed yield of fertile tiller per unit area in 2003; however, no correlation was observed in 2004 (Figure 1-2). Despite relatively similar seed yields within all Chewings fescue cultivars across both non-thermal and thermal residue management treatments in 2003, overall seed yield was reduced in 2004 and may be directly associated to seed yield per fertile tiller (Figure 1-1). Moreover, drier than normal weather conditions in April and May of 2004 could have contributed to lower seed set, thus lowering overall expected yield potential (Table 1-2).

Seed yield per fertile tiller was highest in 2003 for non-thermal and thermal residue management and was closely related to seed yield (Figure 1-1). In contrast, seed yield per fertile tiller was lowest in 2004 non-thermal residue management as well as having the lowest seed yield (Figure 1-2). Thermal residue management in 2004 had lower seed yields compared to 2003, but had superior seed yield compared to non-thermal residue management. In addition, seed yield per fertile tiller was maintained in thermal residue management in 2004 and was strongly correlated to maintaining seed yield (Figure 1-2).

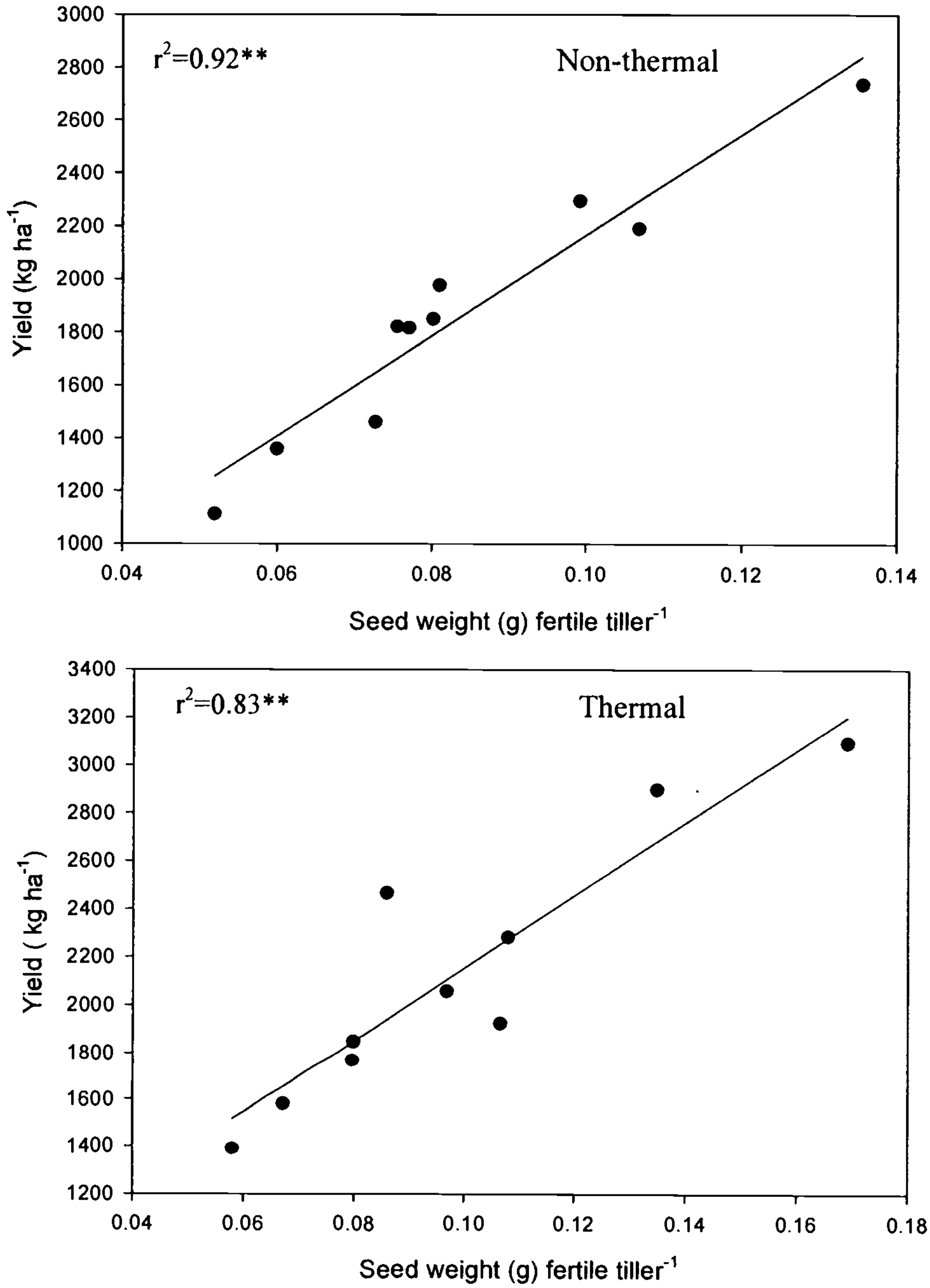
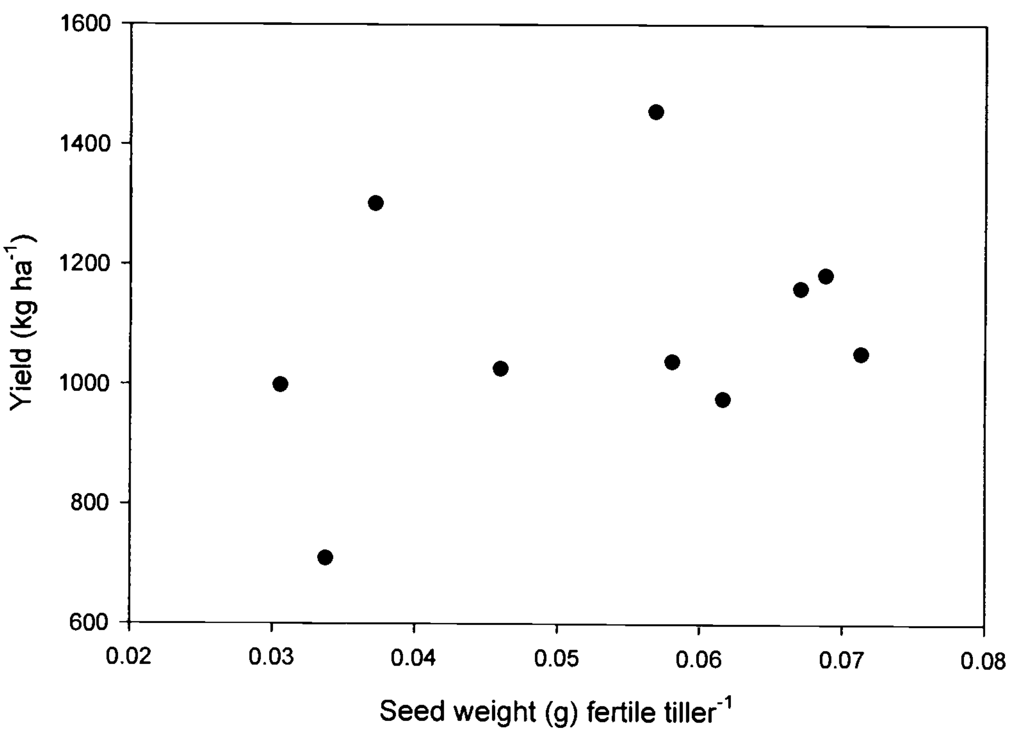


Figure 1-1. Relationship of seed weight per fertile tiller and seed yield with non-thermal and thermal residue management in 2003.



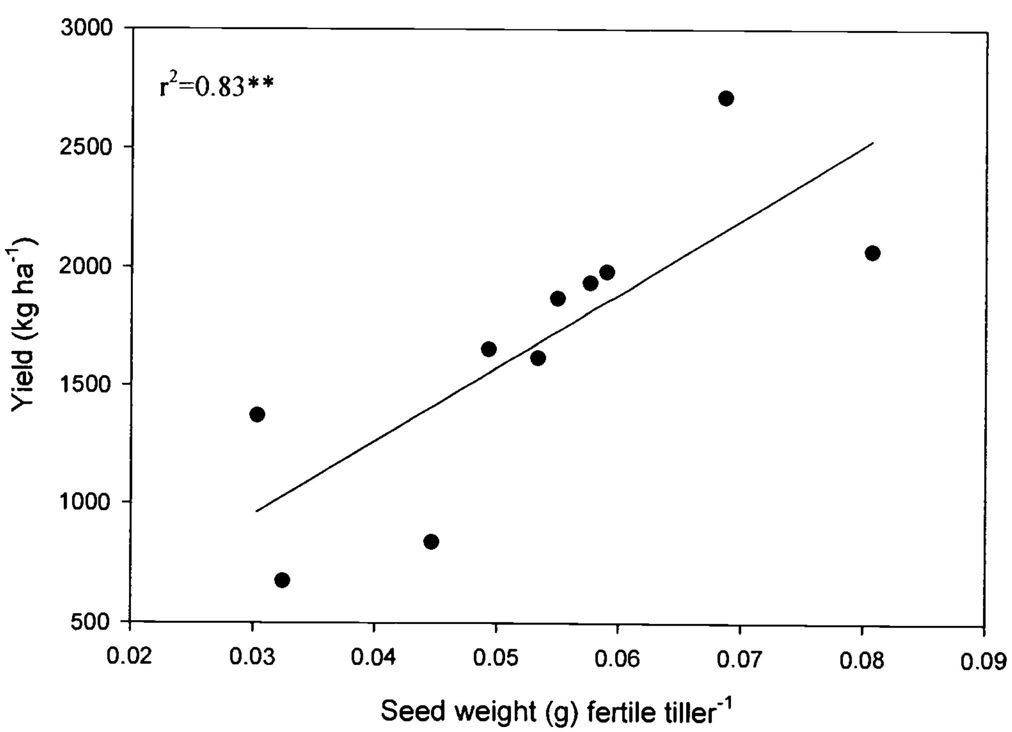


Figure 1-2. Relationship of seed weight per fertile tiller and seed yield with non-thermal and thermal residue management in 2004.

Inflorescence Components

Inflorescence components consist of panicle length, spikelets per panicle, and florets per spikelet. All of these components contribute to seed yield and are set during floral induction prior to anthesis. Significant differences among cultivars were observed for these characteristics in both years (Table 1-5).

In 2003, spikelets per panicle, florets per spikelet, and panicle length were not affected by residue management (Table 1-5). In 2004, a significant residue management treatment effect on florets per spikelet, spikelets per panicle, and panicle length was observed. Thermal residue management significantly increased florets per spikelet, with a mean of 7 florets per spikelet, while flail low and flail high resulted in a mean of 6 florets per spikelet, respectively (Table 1-5). Thermal residue management significantly increased spikelets per panicle, with a mean of 34 spikelets per panicle and a corresponding mean of 30 and 28 spikelets per panicle in flail low and flail high non-thermal residue management, respectively. Panicle length was significantly affected by residue management treatments. Mean panicle length was 13 cm in flail low and flail high non-thermal residue management treatments, while the mean panicle length under thermal residue management was 14 cm. Thus, it is theorized that thermal management enhances plant microclimate and, consequently, increases the floral inductive capacity of individual fertile tillers, ultimately resulting in higher seed yield. It is theorized that increased panicle length in thermal residue management can be associated with higher seed yields due to a plant response to support greater seed number and to a lesser extent seed weight.

Table 1-5. Residue management treatment and cultivar means for inflorescence components in 2003 and 2004.

Treatment	Panicle length	Spikelets/panicle	Florets/spikelet
	cm	no.	no.
		2003	
Thermal	NS	NS	NS
Flail Low	NS	NS	NS
Flail High	NS	NS	NS
		2004	
Thermal	14a	34a	7a
Flail Low	13b	28c	6b
Flail High	13b	30b	6b
LSD 0.05	0.47	2.17	0.35

Cultivar	Panicle length	Spikelets/panicle	Florets/spikelet
	cm	no.	no.
		2003	
SR5100	14dc	40ab	7ecd
Southport	15dcb	38cab	6ed
Brittany	13ef	38cab	6e
Barnica	15dcb	23f	6ed
Shademaster	14de	35cd	7cd
Cindy	16a	31e	8a
Silverlawn	15cb	41a	6ed
Shademark	15ab	37cb	7cb
Seabreeze	12g	24f	7cb
Marker	13f	31de	8ab
LSD 0.05	0.80	3.77	0.64
		2004	
SR5100	13bc	39a	6bc
Southport	15a	32cb	6b
Brittany	13dc	35ab	6bc
Barnica	12d	22e	6c
Shademaster	13bc	33cb	6c
Cindy	15a	26d	7a
Silverlawn	13bc	33cb	6bc
Shademark	14b	29cd	6bc
Seabreeze	12d	25ed	7a
Marker	13bc	33cb	7a
LSD 0.05	0.85	3.95	0.63

Seed Weight

In 2003 and 2004, a residue management by cultivar interaction was observed with respect to seed weight. In 2003, non-thermal residue management increased seed weight over thermal residue management in Brittany Chewings fescue and in Silverlawn and Cindy strong creeping red fescue. Thousand seed weight in these cultivars ranged from 1.13 to 1.16 g in Silverlawn and Cindy, respectively (Table 1-6). Seed weight was greater under thermal residue management in SR5100, Southport, and Barnica Chewings fescue, in Shademaster and Shademark strong creeping red fescue, and in both Seabreeze and Marker slender creeping red fescue. Increased seed weight in these cultivars ranged from 1.14 to 1.20 g 1000^{-1} in Barnica and Marker; and in Shademaster, respectively (Table 1-6). In 2004, non-thermal residue management increased seed weight over thermal residue management in Brittany Chewings fescue and in Silverlawn strong creeping red fescue. Seed weight for these cultivars ranged from 1.15 to 1.20 g 1000^{-1} in Silverlawn and Brittany, respectively (Table 1-6). Seed weight was greater under thermal residue management in SR5100 and Southport Chewings fescue, in Shademaster, Cindy, and Shademark strong creeping red fescue, and in Seabreeze and Marker slender creeping red fescue. Seed weight for these cultivars ranged from 1.13 to 1.36 g 1000^{-1} in SR5100 and Shademaster, respectively (Table 1-6). Barnica remained constant across both residue treatments in 2004.

Table 1-6. Interaction means for residue management by cultivar seed weight of ten fine fescue cultivars in 2003 and 2004.

Subspecies	Cultivar	2003 Non-thermal	2003 Thermal	2004 Non-thermal	2004 Thermal
		---g 1000^{-1}---			
Chewings	SR5100	1.11	1.18	1.12	1.13
	Southport	1.10	1.14	1.18	1.20
	Brittany	1.14	1.12	1.20	1.13
	Barnica	1.11	1.14	1.10	1.10
Strong Creeping	Shademaster	1.08	1.20	1.26	1.36
	Cindy	1.16	1.10	1.30	1.31
	Silverlawn	1.13	1.12	1.15	1.13
	Shademark	1.10	1.17	1.27	1.35
Slender Creeping	Seabreeze	1.14	1.17	1.10	1.17
	Marker	1.10	1.14	1.08	1.26
	§ S.E.	.00943	.00881	.00945	.00901

§ S.E. = standard error of the mean. Appropriate for comparisons within column.

Marshall (1985) found that seed weight remained relatively constant over a variety of conditions. Seed weight in perennial ryegrass (*Lolium perenne* L.) was determined by two factors: ovule dry weight at anthesis and duration of seed growth. Sixty percent of variation in seed weight could be attributed to variation in ovule dry weight at anthesis (Warringa et al., 1998). Another thirty percent of the variation in seed weight could be attributed to a variation in the duration of seed growth and development.

Hyde et al. (1959) reported that rapid endosperm cell division takes place during a lag phase that persists for 10 days after fertilization. This phase is associated with a slight increase in seed mass and the establishment of final seed mass, or total sink capacity. With regard to sink competition, resource limitation, and assimilate allocation, Marshall (1985) concluded that seed set in perennial ryegrass is often substrate limited. However, Marshall and Ludlum (1989) contradicted this by stating that lack of assimilate supply in developing florets after anthesis resulted in seed abortion. Marshall and Ludlum (1989) hypothesized that if the degree of seed abortion is related to assimilate supply to the developing inflorescence, then improving photosynthetic efficiency through controlling lodging or disease control could be expected to reduce seed abortion and increase seed yield.

In this study, thermal management may have improved photosynthetic activity by improving plant microclimate activity, subsequently increasing photoassimilate supply to the inflorescence. This would be in agreement with McFarland and Mitchell (2000), who reported that thermal residue management is critical for reducing litter in weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees]. In addition, McFarland and

Mitchell (2000) reported that burning increased light quantity, improved light quality, and increased nutrient availability to the plant. Chastain and Young (1999) investigated post-harvest residue management in fine fescue seed crops and reported that bale and flail non-thermal treatments resulted in increased quantities of straw and greater stubble height. Greater stubble height may increase shading and may have reduced the quality of light at the plant crown, resulting in subsequent etiolation of fall tillers. Chastain and Young (1999) reported that thermal residue management removes organic residue and reduces stand density, resulting in an enhanced light environment that subsequently reduces inter-tiller competition. As a result, less energy is used for leaf growth, resulting in more stored reserves being available for increased and earlier tillering (Chilcote et al., 1980).

The work of Ensign et al. (1983) demonstrated that light reduction, due to either shading from post-harvest residue accumulations or by artificial means, affected Kentucky bluegrass (*Poa pratensis* L.) growth and development. Moreover, it was assumed that thermal residue management removed residue surrounding the plant crown, allowing for greater light penetration into the canopy. Thus, thermal residue management was thought to promote tiller growth and improve seed yield. Therefore, it may be possible that thermal residue management increases thousand seed weight due to more favorable plant microclimates resulting from an increase in photosynthetic capacity and utilization of available assimilates.

Seed Number

In 2003, there was a significant residue management treatment effect on seed number. Seed number in flail low and flail high non-thermal residue management treatments were significantly lower than seed number in thermal residue management (Table 1-7). Mean seed number under thermal residue management was 140 x 10^3, while the mean seed number in flail low and flail high was 119 x 10^3, and 138 x 10^3 per m^2, respectively (Table 1-7).

In 2004, there was a residue management by cultivar interaction. Non-thermal residue management increased seed number over thermal residue management in Seabreeze and Marker slender creeping red fescue. Seed number ranged from 81 x 10^3 seed per m^2 to 117 x 10^3 seed per m^2 in Seabreeze and Marker, respectively (Table 1-7). Thermal residue management resulted in greater seed number in SR5100, Southport, Brittany, and Barnica Chewings fescue, and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue. Seed number in these cultivars ranged from 156 x 10^3 seed per m^2 to 251 x 10^3 seed per m^2 in Barnica and Shademark, respectively (Table 1-7).

Table 1-7. Interaction means for residue management by cultivar seed number in ten cultivars of fine fescue in 2003 and 2004.

		2003			2004	
Subspecies	Cultivar	Flail High	Flail Low	Thermal	Non-thermal	Thermal
		--no. x 10^3 per m^2--				
Chewings	SR5100	135	136	150	133	208
	Southport	130	96	152	103	169
	Brittany	135	135	139	122	214
	Barnica	148	127	124	150	156
Strong Creeping	Shademaster	116	111	125	103	183
	Cindy	120	124	131	102	198
	Silverlawn	147	124	157	112	184
	Shademark	126	91	104	144	251
Slender Creeping	Seabreeze	124	132	125	81	72
	Marker	178	110	176	117	84
	Overall means	138a[1]	119b	140a	2.45§	5.29§

[1] LSD 0.05 = 16.4 for means in row

§ Standard error of the mean. Appropriate for comparisons within column.

Young et al. (1999) observed that seed number in perennial ryegrass (*Lolium perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.) was significantly affected by thermal and non-thermal residue management. Thermal residue management is reported to reduce stand density (Chilcote et al., 1980). Fairey and Lefkovich (1996) reported that seed number decreased exponentially as stand density increased. Therefore, stand density is important in relation to seed number per unit area.

Elgersma (1990) observed differences in seed yield of nine cultivars of perennial ryegrass and concluded that seed yield was more closely related to an increase in seed number per unit area than to seed weight. In conclusion, Elgersma (1990) found there to be a close relationship between the number of seeds produced per unit area and seed yield.

Mares Martins and Gamble (1993) stated that photoassimilates in crop plants is unevenly partitioned among metabolic sinks. Their study investigated seed abortion and yield in perennial ryegrass following selective pre-anthesis defoliation of reproductive and vegetative tillers.

Seed yield

In 2003 and 2004, a residue management by cultivar treatment interaction was observed with respect to seed yield. In 2003, non-thermal residue management increased seed yield over thermal residue management in Barnica Chewings fescue and in Marker slender creeping red fescue. Seed yields ranged from 1,817 kg ha^{-1} to 1,822 kg ha^{-1} in Barnica and Marker, respectively (Table 1-8). Under thermal residue management, seed yield was greater in, SR5100, Southport, and Brittany Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. Seed yield in thermal residue management ranged from 1,391 kg ha^{-1} to 3,094 kg ha^{-1} in Seabreeze and Shademark, respectively (Table 1-8). Figure 1-3 clearly illustrates the residue management by cultivar interaction with respect to seed yield in 2003 and 2004.

In 2004, non-thermal residue management increased seed yield over thermal residue management in Seabreeze and Marker slender creeping red fescue (Table 1-8). Seed yield was 715 kg ha^{-1} and 934 kg ha^{-1} in Seabreeze and Marker, respectively. Seed yield was greater under thermal residue management in SR5100, Southport, Brittany, and Barnica Chewings fescue, and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue (Table 1-8). Yield under thermal residue management ranged from 1,370 kg ha^{-1} to 2,714 kg ha^{-1} in Barnica and Shademark, respectively (Table 1-8).

Table 1-8. Interaction means for residue management by cultivar seed yield of ten fine fescue cultivars in 2003 and 2004.

		2003		2004	
Subspecies	Cultivar	Non-thermal	Thermal	Non-thermal	Thermal
		--------------------kg ha^{-1}	----------------------		
Chewings	SR5100	2295	2466	1184	1874
	Southport	1851	1924	976	1617
	Brittany	2738	2900	1161	1939
	Barnica	1817	1769	1302	1370
Strong Creeping	Shademaster	1358	2058	1039	1984
	Cindy	1462	1849	1052	2072
	Silverlawn	1980	2282	1026	1654
	Shademark	2194	3094	1456	2714
Slender Creeping	Seabreeze	1112	1391	715	673
	Marker	1822	1580	934	835
	§ S.E.	44.65	51.01	23.37	55.75

§ S.E. = standard error of the mean. Appropriate for comparisons within column.

Upon setting of seed yield potential, grass plants enter the second phase of reproductive development, as outlined by Hampton et al. (1983). During this phase, seed yield potential is determined by critical events following anthesis. This phase includes pollination, fertilization, seed set, and seed growth. In addition, Marshall (1985) reported that the degree to which reproductive potential is realized depends on the proportion of florets that produce seed and the size of individual seed. Moreover, agronomic studies suggest that there is a relationship between the number of seeds produced per unit area and seed yield; seed yield is a direct function of floret number per spikelet and fertile tiller number.

Young et al. (1984a and 1984b) reported similar findings with respect to number of seeds produced per unit area and seed yield in Chewings fescue under similar residue management treatments. In contrast, Chastain et al. (1998) observed reduced seed yields in Seabreeze slender creeping red fescue under thermal and non-thermal residue management during the second year of stand establishment.

Chilcote and Young (1991) reported similar results in Chewings fescue and found that discovering an alternative to thermal residue management in Chewings fescue was difficult. Zapiola et al. (2003), Young et al. (1998), and Chastain and Young (1999) reported similar seed yield increases in strong creeping red fescue in the second harvest following thermal residue management. The results of this research support the work done by Chastain et al. (1998), which reported that thermal residue management provided the poorest seed yield in Seabreeze slender creeping red fescue. However, unlike these previous studies, this research capitalizes on the ability to compare seed yield response of four cultivars of Chewings fescue, four cultivars of strong creeping red fescue, and two cultivars of slender creeping red fescue to non-thermal and thermal residue management practices. Such a comparison highlights the observed residue management by cultivar interaction.

Hebblethwaite et al. (1980) outlined two distinct phases in the development of seed yield: 1) the establishment of seed yield potential (manifested at anthesis), and 2) the utilization of seed yield potential (actualized at harvest). Seed yield components that determine seed yield potential in cool-season grasses include fertile tiller number, spikelets per panicle, and florets per spikelet. Seed yield components that determine actual seed yield include seed number and seed weight, the product of which determines final seed yield at harvest.

Harvest Index

In 2003 and 2004, a residue management by cultivar interaction occurred with respect to harvest index (HI). In 2003, non-thermal residue management increased (HI) over thermal residue management in Marker slender creeping red fescue (Table 1-9). (HI) was greater under thermal residue management in Southport Chewings fescue, in Shademaster, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue (Table 1-9). SR5100, Brittany, and Barnica Chewings fescue, as well as Cindy strong creeping red fescue, had equal (HI) values across both residue management treatments in 2003. (HI) under thermal residue management ranged from 6% in Seabreeze to 12% in both Brittany and Shademark (Table 1-9). In 2004, non-thermal residue management increased (HI) in Seabreeze and Marker slender creeping red fescue (Table 1-9). (HI) was greater under thermal residue management in SR5100, Southport, Brittany, and Barnica Chewings fescue and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue (Table 1-9). (HI) under thermal residue management ranged from 15% in Southport to 23% in both Brittany and Shademark (Table 1-9).

As described by Elgersma (1990), seed yield can be considered the product of biomass production and harvest index, calculated as seed dry matter/total dry matter. (HI) simply measures the ratio of clean seed produced to dry matter produced. (HI) was analyzed to ascertain the effects of residue management on allocation of plant resources to reproduction and dry matter production.

Table 1-9. Interaction means for residue management by cultivar harvest index of ten fine fescue cultivars in 2003 and 2004.

		2003		2004	
Subspecies	Cultivar	Non-thermal	Thermal	Non-thermal	Thermal
		------------------------%------------------------			
Chewings	SR5100	10	10	18	19
	Southport	6	7	12	15
	Brittany	12	12	19	23
	Barnica	7	7	16	18
Strong Creeping	Shademaster	5	8	12	17
	Cindy	6	6	13	22
	Silverlawn	7	10	12	18
	Shademark	9	12	18	23
Slender Creeping	Seabreeze	5	6	12	9
	Marker	9	7	17	13
	§ S.E.	0.24	0.26	0.43	0.52

§ S.E. = standard error of the mean. Appropriate for comparisons within column.

Percent Seed Cleanout

In 2003, there was no significant difference in percent seed cleanout in any residue management treatment.

In 2004, a residue management by cultivar interaction occurred with respect to percent seed cleanout. In 2004, non-thermal residue management increased percent seed cleanout in SR5100, Southport, Brittany, and Barnica Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue (Table 1-10). Increased seed cleanout ranged from 15 to 31% in Brittany and Silverlawn, respectively (Table 1-10). Percent seed cleanout was the same for both thermal and non-thermal residue management in Marker slender creeping red fescue (Table 1-10).

Table 1-10. Interaction means for residue management by cultivar percent seed cleanout of ten fine fescue cultivars in 2003 and 2004.

		2003		2004	
Subspecies	Cultivar	Non-thermal	Thermal	Non-thermal	Thermal
		%			
Chewings	SR5100	15	14	20	12
	Southport	7	8	16	9
	Brittany	5	5	15	9
	Barnica	8	8	18	10
Strong Creeping	Shademaster	12	9	30	12
	Cindy	9	10	21	9
	Silverlawn	8	7	31	21
	Shademark	9	7	22	6
Slender Creeping	Seabreeze	11	11	28	26
	Marker	26	22	27	27
	§ S.E.	0.61	0.45	0.58	0.73

§ S.E. = standard error of the mean. Appropriate for comparisons within column.

In this study, it can be hypothesized that increased percent seed cleanout in non-thermal residue management can be attributed to a reduction in plant reproductive capacity from inter-tiller competition for water, light, and nutrients, resulting in lighter, less uniform seed. Lack of seed uniformity, size, and weight can create adverse harvesting and seed conditioning, resulting in greater seed losses in actual seed yield.

The above observations may be attributed to a change in partitioning of dry matter, that is, source-sink relations. Thermal management did more than simply remove barriers to vegetative growth associated with post-harvest residue (Johnson et al., 2003). Johnson et al. (2003) hypothesized that improvement in source-sink relations may be responsible for increased seed weight and uniformity of seed size, both of which can be related to lower percent seed cleanout.

Residue Management by Cultivar Interaction

In 2003 and 2004, a residue management by cultivar interaction was observed in fertile tiller number, seed number, thousand seed weight, harvest index, percent seed cleanout, and seed yield. Contrast statements were used to compare seed yield of cultivars under thermal and non-thermal residue management treatments (Table 1-11). Seed yield component contrasts within subspecies were analyzed to evaluate cultivar differences within subspecies (Table 1-12).

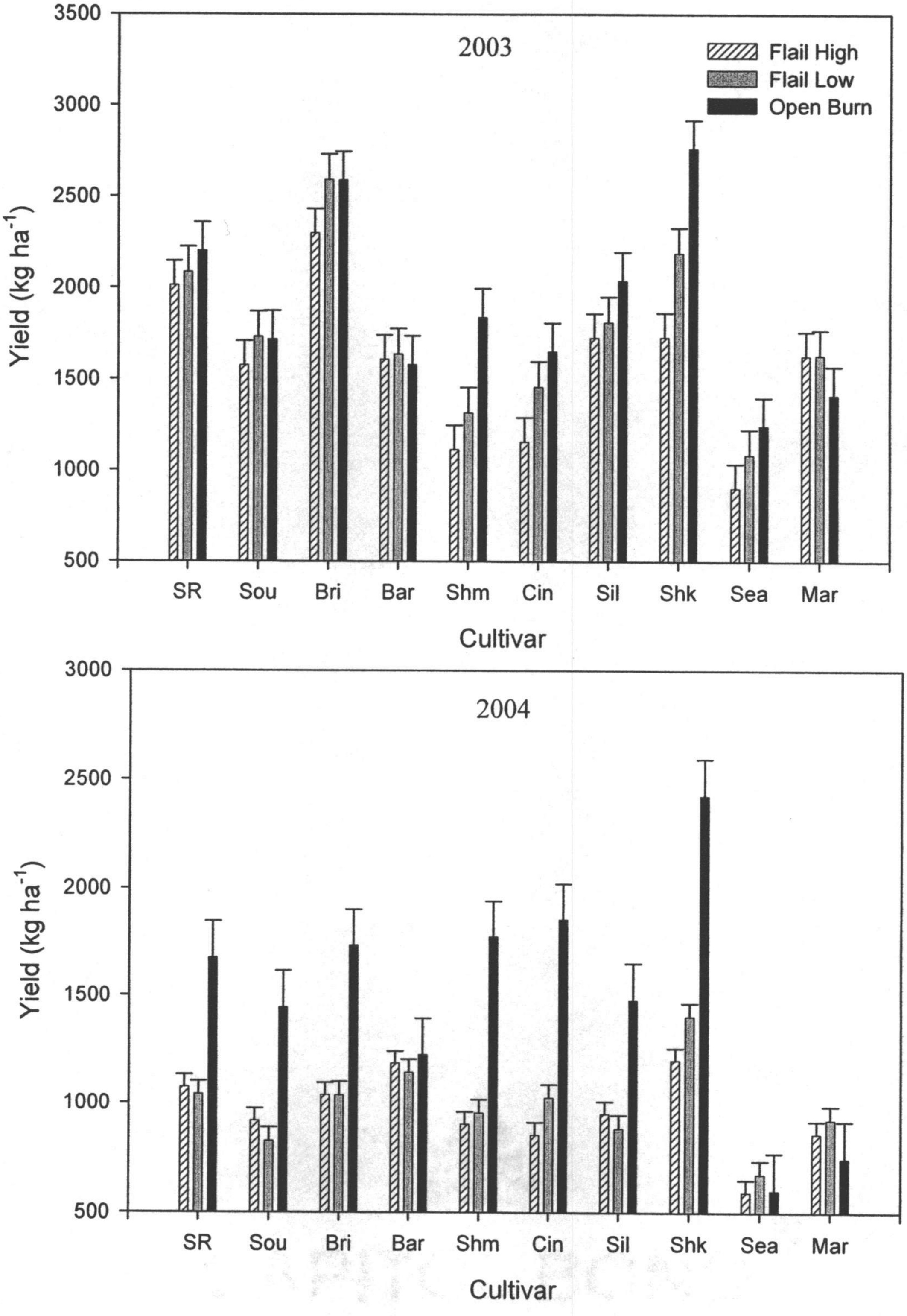


Figure 1-3. Effect of non-thermal and thermal residue management on seed yield of ten cultivars of fine fescue in 2003 and 2004. Vertical bars represent ± standard error.

Table 1-11. ANOVA table for seed yield contrasts of ten fine fescue cultivars under three residue management treatments in 2003 and 2004. "Thermal vs. Non-thermal" compares thermal management to any flail treatment (flail low or flail high). Flail low vs. flail high compares two flail heights.

		2003		2004	
Source	df	F-ratio	p-value	F-ratio	p-value
Residue Management	2				
Cultivar	9				
Residue Management x Cultivar	18				
Thermal vs. Flail					
Shademaster vs. Barnica	1	2	0.2	18**	0.0
Shademaster vs. Brittany	1	323**	0.0	1 ns	0.3
Shademaster vs. Cindy	1	0.7 ns	0.4	2 ns	0.2
Shademaster vs. Marker	1	0.0 ns	0.9	235**	0.0
Shademaster vs. Seabreeze	1	55**	0.0	446**	0.0
Shademaster vs. Shademark	1	230**	0.0	218**	0.0
Shademaster vs. Silverlawn	1	49**	0.0	20**	0.0
Shademaster vs. Southport	1	9*	0.0	31**	0.0
Shademaster vs. SR5100	1	119**	0.0	0.2 ns	0.7
Flail Low vs. Flail High					
Shademaster vs. Barnica	1	41**	0.0	41**	0.0
Shademaster vs. Brittany	1	375**	0.0	7*	0.0
Shademaster vs. Cindy	1	2 ns	0.2	0.1 ns	0.8
Shademaster vs. Marker	1	42**	0.0	0.8 ns	0.4
Shademaster vs. Seabreeze	1	12*	0.0	54**	0.0
Shademaster vs. Shademark	1	137**	0.0	86**	0.0
Shademaster vs. Silverlawn	1	76**	0.0	0.0 ns	0.8
Shademaster vs. Southport	1	48**	0.0	2 ns	0.2
Shademaster vs. SR5100	1	172**	0.0	11**	0.0

n.s. non-significant at p = 0.05
* significant at p = 0.05
**significant at p = <0.01

Table 1-12. Contrast ANOVA table for seed yield components of ten cultivars and three subspecies of fine fescue comparing nonthermal vs. thermal residue management in 2003 and 2004.

			2003				2004			
	Source	d.f.	FTN[1]	Seed yield	Seed no.	Seed wt.	FTN	Seed yield	Seed no.	Seed wt.
	Residue Management	2								
	Cultivar	9								
	Residue Mgt. X Cultivar	18								
Chewings	Southport vs. SR5100	1	NS	**	NS	**	**	**	**	NS
	Southport vs. Brittany	1	NS	**	NS	NS	**	**	**	**
	Southport vs. Barnica	1	**	NS	**	NS	**	NS	**	NS
Strong creeping	Shademaster vs. Cindy	1	*	NS	NS	**	NS	NS	**	**
	Shademaster vs. Silverlawn	1	NS	**	*	**	NS	**	**	NS
	Shademaster vs. Shademark	1	**	**	NS	NS	NS	**	*	NS
Slender creeping	Seabreeze vs. Marker	1	*	**	**	**	**	**	**	NS

Percent Seed Yield Increase

In 2003, non-thermal residue management increased seed yield over thermal residue management in Barnica Chewings fescue and Marker slender creeping red fescue (Table 1-13). Seed yield increase ranged from 3 to 15% in Barnica and Marker, respectively (Table 1-13). Seed yield was greater under thermal residue management in SR5100, Southport, and Brittany Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue (Table 1-13). Seed yield in these cultivars ranged from 4 to 34% greater than non-thermal residue management in Southport and Shademaster, respectively.

In 2004, seed yield was increased in non-thermal over thermal residue management in Seabreeze and Marker slender creeping red fescue (Table 1-13). Increased seed yield, which ranged from 5 to 20% in Seabreeze and Marker, respectively, could be attributed to a 14 to 40 % increase in seed number. Seed yield component compensation was evident as corresponding seed weight was reduced 7 and 14 % in Seabreeze and Marker, respectively (Table 1-13). Seed yield was greater in thermal residue management over non-thermal residue management in SR5100, Southport, Brittany, and Barnica Chewings fescue and in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue. Seed yield in these cultivars ranged from 5 to 49% greater than non-thermal residue management in Barnica and Cindy, respectively (Table 1-13).

Table 1-13. Difference in yield, seed number, and seed weight expressed as a percentage of non-thermal and thermal residue management in ten cultivars of fine fescue over a two year period.

	2003			2004		
Cultivar	Seed yield	Seed number	Seed weight	Seed yield	Seed number	Seed weight
	----------	----------	----------%	----------	----------	----------
SR5100	-7	-10	-6	-37	-36	-1
Southport	-4	-26	-3	-40	-39	-2
Brittany	-21	-3	2	-40	-43	6
Barnica	3	11	-2	-5	-4	-1
Shademaster	-34	-9	-10	-48	-44	-7
Cindy	-21	-7	6	-49	-48	-1
Silverlawn	-13	-14	2	-38	-39	2
Shademark	-29	4	-7	-46	-43	-6
Seabreeze	-20	2	-5	5	14	-7
Marker	15	-18	-3	20	40	-14

Stand Age

The above data illustrates the capacity of fine fescue subspecies and cultivars to respond differently to non-thermal and thermal residue management. However, seed yield trends can be observed within cultivars of the same subspecies in response to thermal residue management, with such seed yield trends becoming more pronounced as stands age. This is in agreement with Canode and Law (1975), who stated that perennial cool-season grasses generally show a characteristic seed yield decline as stands age. Canode and Law (1975) reported highest seed yields in Kentucky bluegrass being attained in the first and second seed crops at 30 cm and 60 cm row spacing, and in fourth seed crop at 90 cm row spacing. However, decline in seed yield of Kentucky bluegrass, over a period of time, could not be attributed to row spacing affect, but rather forage yield, plant height, panicle number, root and rhizome production, and etiolated re-growth.

Chastain et al. (1997) investigated stand age and residue management affect on seed quality in Kentucky bluegrass (*Poa pratensis* L.), Chewings fescue, tall fescue (*Festuca arundinacea* Shreb.), strong creeping red fescue (*Festuca rubra* L.), perennial ryegrass (*Lolium perenne* L.), orchardgrass (*Dactylis glomerata* L.), and dryland bentgrass (*Agrostis castellana* Bois. Reut.) from 1992 to 1997 and found no interaction between stand age and residue management practice for any of the species tested. In contrast, Coats et al. (1994) reported that seed yield under bale, vacuum, and vacuum with propane-flaming residue management in Kentucky bluegrass declined as the stand aged. Thermal residue management (open-burning) was the only treatment that resulted in high seed yields throughout the entire duration of the three year study.

Young et al. (1984a) reported no decline in Encota Chewings fescue seed yield over a three-year period of close-clip stubble removal. In the same study, Young et al. (1984a) reported Kentucky bluegrass seed yields being maintained through two years, but declining in the third year when stubble was close-clipped or flail chopped. This is in agreement with current findings which indicate that species that are rhizomatous in growth habit respond negatively to all non-thermal residue management practices. Since this research, further research has provided evidence of acceptable seed yields following non-thermal residue management in Chewings fescue. In our study, seed yield of all Chewings fescue cultivars declined from 2003 to 2004, regardless of residue management treatment (Table 1-8). However, decline in seed yield associated with increasing stand age was clearly less severe in all cultivars of Chewings fescue and strong creeping red fescue under thermal residue management. Non-thermal residue management did not maintain subsequent seed yields in the two years residue management treatments were imposed.

Economic Analysis

In 2004, 5,386 certified ha produced approximately 4,620 metric tons of certified fine fescue seed in Oregon. A partial budgeting technique was used to evaluate the economic implications of alternative residue management. As described by Castle et al. (1987), partial budgeting involves change of existing farm practices and estimating the effects on expenses and revenue. In this study, net change in income between non-thermal and thermal residue management was evaluated.

In 2003, non-thermal residue management increased net income over thermal residue management \$78 ha^{-1} in Marker slender creeping red fescue (Table 1-14). Net income was greater under thermal residue management in SR5100, Southport, Brittany, and Barnica Chewings fescue, in Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. Reduced income in non-thermal over thermal residue management ranged from -\$104 to -\$996 ha^{-1} in Barnica and Shademark, respectively (Table 1-14).

In 2004, non-thermal residue management increased net income over thermal residue management \$4 ha^{-1} in Marker slender creeping red fescue (Table 1-14). Net income was greater under thermal residue management in SR5100, Southport, Brittany, and Barnica Chewings fescue, in, Shademaster, Cindy, Silverlawn, and Shademark strong creeping red fescue, and in Seabreeze slender creeping red fescue. Increased income over non-thermal residue management ranged from \$115 to \$1,332 ha^{-1} in Seabreeze and Shademark, respectively (Table 1-14).

The above range in net income between non-thermal and thermal residue management further provides evidence that fine fescue seed yield response to residue management is clearly subspecies and cultivar dependent. However, in both 2003 and 2004, non-thermal residue management provided increased net income in only one cultivar, Marker (Table 1-14). Thus, losses resulting from non-thermal residue management illustrate the importance of thermal residue management with respect to economic sustainability in fine fescue seed production.

Table 1-14. Net return of non-thermal and thermal residue management practices in ten cultivars of fine fescue in 2003 and 2004.

		2003			2004		
Subspecies	Cultivar	Non-thermal	Thermal	Non-thermal vs. thermal	Non-thermal	Thermal	Non-thermal vs. thermal
		---------------------	---------------------	U.S. dollars ha^{-1}	---------------------	---------------------	---------------------
Chewings	SR5100	2082	2393	-311	1038	1836	-798
	Southport	1666	1883	-217	843	1594	-751
	Brittany	2499	2800	-301	1017	1897	-880
	Barnica	1633	1737	-104	1149	1362	-213
	Means	1970	2203	-233	1012	1672	-661
Strong Creeping	Shademaster	1202	2009	-807	902	1939	-1037
	Cindy	1299	1813	-514	914	2022	-1108
	Silverlawn	1786	2220	-434	889	1629	-740
	Shademark	1987	2983	-996	1294	2626	-1332
	Means	1569	2256	-688	1000	2054	-1054
Slender Creeping	Seabreeze	971	1382	-411	707	592	-115
	Marker	1638	1560	78	863	859	4
	Means	1305	1471	-167	728	783	-56

Conclusions

Thermal residue management in diverse fine fescue subspecies has the ability to maintain or increase seed yields. This research concluded that increased seed yield as a result of thermal residue management can be attributed to observed increases in fertile tiller number in 2004, and actualized with increases in seed number and thousand seed weight. The mechanism of this process is essential to maximizing actual seed yield potential of fine fescue seed crops.

In addition, percent seed cleanout clearly plays a role in explaining seed yield loss associated with non-thermal residue management. Thermal residue management had reduced percent seed cleanout, thus illustrating the importance of thermal residue management to increase seed purity through the reduction of light seed, empty seeds, and partial seeds.

As data from 2004 clearly showed, thermal residue management becomes increasingly effective with increasing stand age. With respect to seed yield, cultivars responded differently to residue management, as seen by a residue management by cultivar interaction in 2003 and in 2004. Cultivar response to residue management was dependent upon cultivar. However, such differences in seed yield among fine fescue cultivars within subspecies could be partially explained by innate genetic differences between cultivars and not entirely derived from any specific treatment imposed upon them.

Thermal residue management is critical in maintaining profitable seed yield in Chewings fescue, strong creeping red fescue, and slender creeping red fescue as the stand increases in age. Complete removal of the straw and stubble by thermal residue management is essential in determining the number and size of fall tillers developed prior to floral induction. Higher potential and actual seed yield is associated with thermally managed plots versus non-thermally managed plots, with increasing significance as stand age increases.

Non-thermal residue management did not produce profitable seed yield; hence, it cannot be considered as a viable alternative to thermal residue management.

An economic analysis clearly indicates the importance of thermal residue management and why it is continually practiced. Thus, without profitable non-thermal residue management alternatives, fine fescue seed growers in the Willamette Valley will continue to use thermal residue management as a tool in maintaining fine fescue seed yields.

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MANUSCRIPT II: CHARACTERISTICS OF SEED YIELD AND YIELD COMPONENTS IN FINE FESCUE

ABSTRACT

In commercial grass seed production, seed yield varies among three subspecies of fine fescue: Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*Festuca rubra* L. subsp. *rubra*), and slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)]. Often, only ten to twenty percent of the potential seed yield in grass seed crops is harvested. There is sufficient evidence that cool-season grass seed cultivars have the capacity to respond differently to agronomic and cultural practices and yield differently. An understanding of innate genetic factors that regulate seed yield components, and the influence of environmental and cultural practices upon them, could increase actual seed yield. The objective of this research was to evaluate seed yield components of ten fine fescue cultivars over three harvest years and environments to elucidate genetic variability in seed yield and its relationship to change in year and environment.

Seed yield, fertile tiller number, seed number, seed weight, and the mass of seed produced per fertile tiller were evaluated. Each year was evaluated as an individual environment specific to that year and the corresponding seed yield components evaluated during that year.

A relationship between seed yield mass and fertile tiller number was established across all three years. Actual seed yield increased in cultivars that had the greatest seed yield mass per fertile tiller. This would indicate that cultivars have the genetic ability to control and partition the allocation of resources to fertile tiller

number and seed yield development. During fertile tiller and inflorescence development, there is a point when plants shift resource allocation to seed development. Cultivars that can shift this resource allocation to seed development appear to have an advantage over cultivars that maintain allocation of assimilate to the fertile tiller well into seed development.

Differences in this shift in resource allocation between years would indicate that environmental and genetic components may play a critical role in the shift of the allocation itself. An increased understanding of seed yield components and specific environment by cultivar interaction may provide plant breeders and grass seed producers with an increased ability to maintain and even increase actual seed yield.

INTRODUCTION

Seed yield of three commercially produced fine fescue subspecies {Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], strong creeping red fescue (*F. rubra* L. subsp. *rubra*), and slender creeping red fescue [*F. rubra* L. var. *littoralis* (Vasey)]} can vary between cultivars. Seed yield among commercial cultivars can be influenced by many factors. Agronomic practices, soil type, disease tolerance, and climate can impact species and cultivar performance within subspecies. Innate genetic components and genotype by environment interactions can also explain many differences within specific cultivars. There is sufficient evidence that cool-season grass seed cultivars have the capacity to respond differently to agronomic and cultural practices, and yield differently, due to these genetic differences.

Cultivar selection in cool-season perennial grasses is typically made on the basis of desirable turf characteristics. Seed yield components, and maintenance of these components, are rarely included in the selection process. Therefore, an understanding of how seed yield components interact and change over time is essential in determining the ability of a cultivar to produce adequate seed yields.

Canode and Law (1975) reported a year by row spacing interaction influenced the changing relationships among seed yield components and seed production associated with age of stand. In Kentucky bluegrass, Canode and Van Keuren (1963) postulated that regardless of seed production practices, seed yield in grass species that are rhizomatous and sod forming in nature decline rapidly, over a period of time, after initial establishment of the stand. Lamb and Murray (1999) suggested that seed yield of Kentucky bluegrass was cultivar-dependent and directly related to an innate genetic propensity to produce abundant panicles, utilize fertilizer efficiently, and have reduced above-ground biomass production. Meints et al. (2001) reported that seed yield in strong creeping red fescue was dependent on rhizome production and correlated to specific cultivars.

Chewings fescue is not rhizomatous and is classified as a bunch-type forming species (Meyer and Funk, 1989). Seed yield of Chewings fescue cultivars has been noted to be acceptable across various cultural practices. Therefore, differences in Chewings fescue seed yield may be more correlated to specific genetic differences and less related to environment.

Strong creeping red fescue and slender creeping red fescue are both rhizomatous subspecies of fine fescue. Previous studies have indicated that seed yield in rhizomatous grass species is highly dependent on cultural practices. A growing body of evidence indicates that increased rhizome production inhibits seed yield (Ensign and Weiser, 1975; Meints et al., 2001).

In a root and rhizome development study in Kentucky bluegrass and strong creeping red fescue, Ensign and Weiser (1975) stated that rhizome weight in relation to seed yield was critical. In addition, Ensign and Weiser (1975) concluded that rhizome weight was influenced significantly by mowing, whereas unmowed plots generally produced fewer roots and far less rhizome weight.

An increased understanding of seed yield decline in fine fescue subspecies and cultivars is needed to develop and employ alternate cultural practices that can maintain seed yield as stands age. Over a period of time, observation of seed yield components and the specific genetic capacity of several cultivars of fine fescue would aid in this understanding.

The objective of this research was to evaluate seed yield components of ten fine fescue cultivars over three harvest years and environments to elucidate genetic variability in seed yield and its relationship to year and environment.

MATERIALS and METHODS

Field trials were established at Hyslop Research Farm, Corvallis, Oregon in the fall of 2000 on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll) in order to characterize the genetic variation within components of seed yield and harvest index which contribute to potential and actual harvested seed yield within fine fescue seed crops over a three-year period. The crop was drilled 15 October 1999 at a rate of 9 kg ha^{-1} by using an eight-row plot-sized drill with 30-cm spaced rows. The crop was irrigated during establishment. A pre-plant application of fertilizer (16-20-0) at a rate of 224 kg ha^{-1}, representing 36 kg N ha^{-1}, was broadcast applied during general seedbed preparation.

The experimental design was a randomized complete block with a strip-plot arrangement of treatments in four replicates. Cultivar data were pooled over residue management treatments in 2003 and 2004. Data also came from 2002, prior to the implementation of residue management treatments. Main plots were years (production environment); subplots were fine fescue cultivars. Each subplot measured 3 m x 15 m. An analysis of variance was conducted on the pooled data for fine fescue cultivars and years. Four cultivars of Chewings fescue (SR5100, Southport, Brittany, and Barnica), four cultivars of strong creeping red fescue (Shademaster, Cindy, Silverlawn, and Shademark), and two cultivars of slender creeping red fescue (Seabreeze and Marker) were selected for the experiment. Selection of cultivars for the trial was based on representation of commercially grown cultivars of Chewings, strong creeping red fescue, and slender creeping red fescue.

In 2002, seed yield components measured were total dry weight and fertile tiller number. In 2003 and 2004, seed yield components measured were total dry weight, fertile tiller number, spikelets per panicle, florets per spikelet, and panicle length. It is important to note that final seed yield resulting from each year and cultivar was determined after harvest and seed conditioning.

Fifteen panicles were also collected prior to peak anthesis from each plot and frozen at -15° C prior to analysis. Fertile tiller number was determined from samples taken early spring prior to peak anthesis. Tillers, after drying, were weighed to determine total above-ground biomass.

Two samples were taken from each plot at ground level using a 30 cm^2 quadrat. Samples were placed in a dryer at 65° C for approximately 48 hours. Panicle length, spikelet number, and floret number were determined on these samples. Two spikelets were selected from the top, middle, and bottom of four panicles to determine floret number.

In 2003 and 2004, thousand seed weight was calculated from a harvested sub-sample by using hand screens and a blower for cleaning. Each plot had two samples containing 1000 seeds that were counted with an electronic counter. The seeds were then subsequently weighed and averaged. Seed number was calculated by using seed number per m^2 based on thousand seed weight.

Seed samples were taken in late June and early July of each year to determine seed moisture content for optimum swathing. The seed was oven dried at 130° C for 24 hours for seed moisture content determination. The crop was harvested by swathing when seed moisture content levels dropped to approximately 30% for each cultivar, with subsequent harvest occurring approximately 7 to 10 days later. In 2003, SR5100, Seabreeze, Barnica, and Southport were swathed on 28 June; all other cultivars were swathed on 30 June.

A plot combine was used to harvest seed when seed moisture had reached 12%. Seed yield was weighed directly in the field, with a sub-sample being collected for laboratory analysis. Bulk seed sacks on the combine were used to determine bulk seed dirt weight harvested from each plot. Cleanout from seed conditioning was used to calculate clean seed yield.

In 2004, Barnica was swathed 18 June and harvested 1 July. SR5100, Seabreeze, Southport, and Silverlawn were swathed on 26 June; all other cultivars were swathed 28 June. SR5100 and Silverlawn were harvested 1 July; all others were combined 2 July. Total subplot area harvested in 2003 and 2004 was 28 m^2.

Seed was cleaned in a laboratory sized M-2B clipper air-screen cleaner (A.T. Farrell, Saginaw, MI) prior to weighing. Seed cleaning methods were similar to industry standards.

Crop management was based on common production practices for Oregon's Willamette Valley. In 2002, fall fertilizer (16-20-0) was applied at approximately 280 kg ha^{-1}, representing 45 kg N ha^{-1}. However, in 2003 approximately 291 kg ha^{-1}, representing 47 kg N ha^{-1} of (16-20-0) was applied. Approximately 56 kg N ha^{-1} (33-0-0-12S) was applied. In March 2003 and 2004, 90 kg N ha^{-1} (as 33-0-0-14) was applied. Chemicals applied were consistent with those used in fine fescue seed production in Willamette Valley and were applied according to label instructions. Contrasts were used to evaluate the differential responses of subspecies and cultivars.

Seed yield trends were examined over the production environments in 2002, 2003, and 2004.

Statistical analysis was done using SAS, Version 6.12 (SAS Institute Inc., 2001). Treatment effects were analyzed using ANOVA and, with the exception of interaction, means were separated by Fisher's protected LSD values.

RESULTS and DISCUSSION

The phenotypic plasticity of fine fescue cultivars in response to different environments was examined over three years. In 2002, there was a year by cultivar interaction in total dry weight and seed yield. Cultivar response to year of seed production was dependent upon cultivar. In 2003 and 2004, there were year by cultivar interactions in total dry weight, harvest index, fertile tiller number, spikelets per panicle, florets per spikelet, panicle length, seed number, thousand seed weight, and seed yield. An analysis of variance of these results is presented in Table 2-1.

Silvertown and Charlesworth (2001) postulated that phenotypic variation in plants can be partitioned into environmental and genetic variability by growing plants in a uniform environment. Phenotypic differences between plants could then be primarily attributed to innate genetic differences (Silvertown and Charlesworth, 2001). In our study, the intent to examine these genetic variations among fine fescue cultivars was conducted through observations of several key seed yield component relationships and seed yield components over three years.

Table 2-1. Analysis of variance for the effects of year and cultivar in ten cultivars of fine fescue in 2002, 2003, and 2004.

	d.f.	Seed yield	TDW[1]	HI[2]	FTN[3]	Spklts. per pan.	Florets per Spklt.	Pan. length	Seed no.	1000 seed weight
Year (A)	2	***	***	***	***	***	***	***	***	NS
Cultivar (B)	9	***	***	***	***	***	***	***	***	***
A x B	18	***	***	***	***	***	***	***	***	***

[1]TDW = total dry weight
[2]HI = harvest index
[3]FTN = fertile tiller number
*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.
NS = not significant

Environmental Implications

Environmental conditions in 2003 and 2004 were different during the period corresponding to seed fill in June (Table 2-2). Fine fescue is predominantly produced in dryland cropping systems in the Willamette Valley and is highly dependent upon adequate spring rainfall to produce economically viable crops. In 2003, April-June precipitation patterns were 213%, 79%, and 27% of normal (Table 2-2). In contrast, 2004 April-June precipitation patterns were 80%, 75%, and 114% of normal (Table 2-2). The observed precipitation differences between years may explain lower yields in 2004. This would be logical, since precipitation in April and May of 2004 was lower than normal, possibly reducing seed yield potential. In addition, it is possible that increased precipitation in June of 2004 did not occur in time to alleviate stress caused by inadequate moisture in April and May (Table 2-2).

Table 2-2. Weekly summary of maximum temperature and daily precipitation measured at Hyslop Farm, Corvallis, Oregon. Average values are long-term.

Month	Week	Mean Max Temperature					Daily Precipitation				
		Avg.	2001	2002	2003	2004	Avg	2001	2002	2003	2004
		°C					mm				
March	1	12	14	11	11	11	3.52	0.98	6.20	8.71	3.47
	2	13	12	9	16	18	3.77	2.76	8.71	3.45	0.07
	3	13	16	10	13	17	3.27	0.36	3.70	9.33	0.07
	4	13	14	14	13	16	3.63	4.25	1.85	4.06	3.34
April	1	15	12	17	15	17	2.79	1.85	0.76	4.68	0.54
	2	16	12	16	15	19	2.50	3.92	3.08	4.90	0.00
	3	16	15	13	15	18	2.18	0.62	2.58	5.59	3.56
	4	17	20	16	14	14	1.81	1.38	0.29	8.09	4.86
	5	18	17	17	18	24	1.92	1.56	0.00	0.62	0.00
May	1	19	22	14	15	22	1.81	0.00	0.25	1.38	1.81
	2	20	17	20	18	19	1.60	3.08	1.52	1.74	0.58
	3	20	27	18	22	20	1.38	0.00	3.16	1.23	1.05
	4	21	23	22	23	21	1.31	0.22	1.42	0.47	1.16
June	1	22	21	22	28	23	1.12	1.45	0.04	0.00	0.22
	2	22	21	26	24	19	1.09	1.63	0.22	0.58	5.01
	3	23	25	22	24	26	1.12	0.00	2.00	0.04	0.36
	4	24	21	25	25	26	0.91	4.10	2.10	0.69	0.00
	5	25	27	24	32	28	0.65	0.00	0.00	0.00	0.00

Chewings fescue

All cultivars of Chewings fescue exhibited increased seed yield from 2002 to 2003 and decreased seed yield from 2003 to 2004 (Table 2-3). Seed yield increase from 2002 to 2003 ranged from 878 to 1,386 kg ha^{-1} in Barnica and Brittany, respectively. Similarly, seed yield decline from 2003 to 2004 ranged from 476 to 1,322 kg ha^{-1} in Barnica and Brittany, respectively (Table 2-3). Southport was the fourth best yielding Chewings fescue cultivar for 2002 and 2003, but was the lowest yielding cultivar in 2004 (Table 2-3). Barnica showed the lowest Chewings fescue seed yield in 2002 and 2003 (Table 2-3). All Chewings fescue cultivars exhibited seed yield differences across all years of the study.

Strong creeping red fescue

Strong creeping red fescue seed yield trends over a 3-year period were similar to that exhibited by Chewings fescue. Between 2002 and 2003, seed yield increased in all strong creeping red fescue cultivars and ranged from 607 to 966 kg ha^{-1} in Cindy and Shademark, respectively (Table 2-3). Seed yield declined in all cultivars of strong creeping red fescue between 2003 and 2004 and ranged from 199 to 845 kg ha^{-1}in Cindy and Silverlawn, respectively (Table 2-3). Overall, seed yields in all strong creeping red fescue cultivars exhibited seed yields that peaked in 2003, followed by seed yield decline in 2004 (Table 2-3).

Shademark was the highest yielding strong creeping red fescue cultivar in all three years of the study (Table 2-3). Silverlawn had the second highest strong creeping red fescue seed yield in 2002 and 2003, with a dramatic seed yield reduction exhibited in 2004 (Table 2-3). In contrast, Cindy was fourth in strong creeping red fescue seed yield potential in 2002 and dropped to a tie for least seed yield in 2003, with a small recovery to third in 2004 (Table 2-3). This illustrates the genetic potential of Cindy to respond differently to environmental changes such as precipitation and temperature patterns (Table 2-2 and Table 2-3). Shademaster was the poorest seed yielding strong creeping red fescue cultivar in 2002, tie for last in 2003, and was fourth best in 2004 (Table 2-3), thus showing poor seed yielding potential across varied years and environments.

Slender creeping red fescue

Slender creeping red fescue yields were inversely related to Chewings fescue and strong creeping red fescue over the course of the study (Table 2-3). Between 2002 and 2003, seed yield declined in Seabreeze and increased in Marker (Table 2-3). Between 2003 and 2004, seed yield declined in Seabreeze and increased in Marker (Table 2-3). It should be noted that the observed decline in Seabreeze seed yield all three years, from the year of establishment to 2004, is more characteristic of commonly exhibited seed yield trends in fine fescue seed production fields.

In general, slender creeping red fescue seed yields were greatest in the early years of the stand, declining rapidly with stand age (Table 2-3). This conclusion is in agreement to similar findings reported by Chastain et al. (1998).

Fertile Tiller Number

In 2002, fertile tiller number was greatest in slender creeping red fescue, ranging from 5,607 to 4,346 fertile tillers per m^2 in Marker and Seabreeze, respectively (Table 2-3). Chewings fescue exhibited a mean fertile tiller number of 2,982 per m^2, with SR5100 having the greatest Chewings fescue fertile tiller number with 3,025 per m^2. Barnica and Southport produced the least Chewings fescue fertile tiller number with 2,964 fertile tillers per m^2 (Table 2-3). Strong creeping red fescue fertile tiller number ranged from 1,894 to 3,240 fertile tillers per m^2 in Cindy and Silverlawn, respectively (Table 2-3).

The results from 2003 were similar to 2002, with slender creeping red fescue producing the greatest fertile tiller number with a mean of 1,088 fertile tillers per m^2. In slender creeping red fescue, fertile tiller number ranged from 2,164 per m^2 in Marker to 2,013 per m^2 in Seabreeze (Table 2-3). Chewings fescue had the second greatest subspecies fertile tiller number production with a mean of 2,039 fertile tillers per m^2. Individual cultivars ranged from 1,867 to 2,262 fertile tillers per m^2 in Brittany and SR5100, respectively (Table 2-3).

In 2004, Chewings fescue produced the greatest fertile tiller number with a mean of 2,367 fertile tillers per m^2. Strong creeping red fescue followed Chewings fescue with 2,212 fertile tillers per m^2, and slender creeping red fescue had produced the fewest fertile tiller number with an average of 2,211 tillers per m^2 (Table 2-3).

In 2004, cultivar differences in Chewings fescue indicated that Barnica was superior to all Chewings fescue cultivars in the third year with 3,472 fertile tillers per m^2. However, this may indicate Barnica's ability to compensate for reductions in maintenance of fertile tiller production, but not in subsequent yield. Nevertheless, high fertile tiller production as stand age increases is only meaningful if it contributes to actual seed yield. Southport Chewings fescue produced the fewest fertile tillers within Chewings fescue in 2004 with 1,870 tillers per m^2, which also corresponded to the lowest seed yield (Table 2-3).

In 2004, strong creeping red fescue fertile tiller number ranged from 1,664 to 2,736 tillers per m^2 in Cindy and Shademark, respectively (Table 2-3). In 2004, Shademark demonstrated an ability to recover and produce fertile tiller numbers superior to that produced in 2003. This finding may be indicative of a cultivar response to weather conditions or other environmental factors. Nevertheless, Shademark was consistently able to generate the highest Chewings fescue actual seed yield in all years except 2002. Interestingly, Cindy maintained a consistent fertile tiller number production across all three years. This may indicate that Cindy has a genetic advantage to maintain fertile tiller number and, subsequently, maintain seed yield as the stand ages (Table 2-3). Shademaster appeared to also be relatively constant in fertile tiller production, with 2002 being the lowest seed production year, yet producing the highest number of fertile tillers across all years of the study (Table 2-3).

Langer (1980) observed that seed yield in perennial ryegrass was dependent on fertile tiller number, indicating a correlation of ($r=0.90$, $p<0.01$). In contrast, Hebblethwaite et al. (1981) reported that fertile tiller number accounted for only 7% of observed variance in perennial ryegrass seed yield.

Hampton and Fairey (1997) provided an explanation for the above contradiction in two steps. Initially, seed yield increases as fertile tiller number increases, and this relationship, as reported by Langer (1980), can produce positive and highly significant correlations. However, a continued increase in fertile tiller number subsequently increases seed yield until an optima population is achieved. After this optima population has been reached, an inverse relationship between fertile tiller number and seed yield develops. Hampton and Fairey (1997) concluded that seed yield can be attained from a relatively wide range of fertile tiller populations.

Seed Yield of Fertile Tiller g Unit Area $^{-1}$

All seed crops exhibited high seed yield potential in 2002, as expressed by the large number of fertile tillers per unit area (Table 2-3), but seed yield potential was mostly much lower in 2003 and 2004 than in 2002. Notable exceptions were observed in Barnica and Shademark in 2004 and in Cindy in both 2003 and 2004.

Despite the high seed yield potential in 2002, overall seed yield was lower than in 2003, where fertile tiller number was much lower than in 2002. Wetter than normal conditions in the last two weeks of May 2002 may have reduced pollination and consequently prevented the seed crops from attaining their expected yield potential (Table 2-3).

Analysis of the seed yield of individual fertile tillers helps to explain some of the differences among fine fescue subspecies and cultivars over the years of the study (Table 2-3). Seed yield per fertile tiller was lower for all seed crops in 2002 and 2004 than in 2003. Seed yields were also greater in 2003 than in 2002 and 2004. The crops were more efficient in seed production in 2003 than in 2002 and 2004. Chewings fescue and strong creeping red fescue both produced greater amounts of seed per fertile tiller and seed yield than were observed for slender creeping red fescue. Fertile tiller number per se did not seem to be related to seed yield, but seed yield per fertile tiller appears to be an important determinant of seed yield (Figure 2-1).

Seed crops that exhibited the highest seed yields across years, Shademark strong creeping red fescue and Brittany Chewings fescue, also consistently produced the greatest seed yield per fertile tiller. Cultivars having low or average seed yields produced low or variable seed yield per fertile tiller across years. High yielding Shademark and Brittany also had the highest harvest index among the cultivars tested in this study.

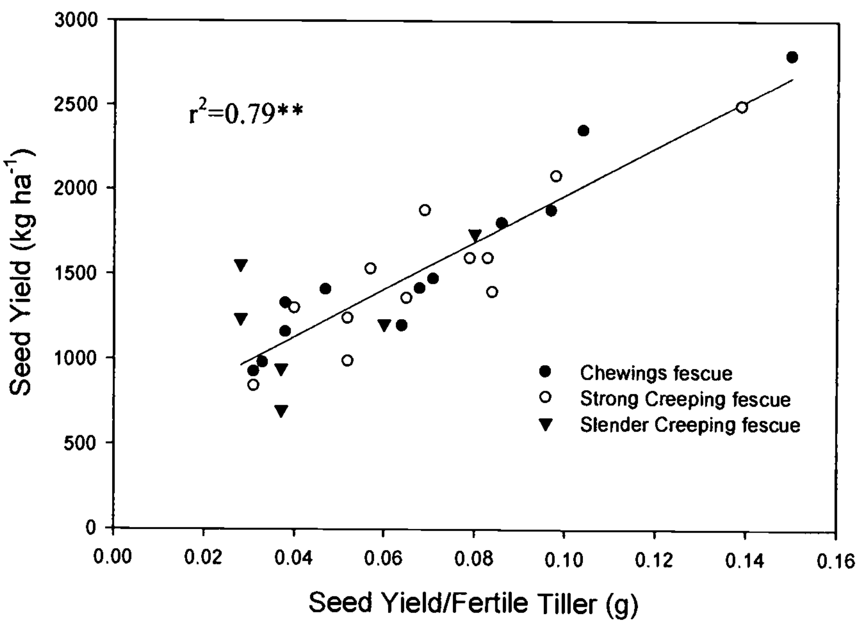

Figure 2-1. Relationship of seed yield per fertile tiller and seed yield in three subspecies of fine fescue in 2002, 2003, and 2004.

In 2002, there was a year by cultivar interaction in all parameters measured specifically fertile tiller number and seed yield (Table 2-3). Total dry weight, harvest index, fertile tiller number, spikelets per panicle, florets per spikelet, panicle length, seed number, and thousand seed weight were seed yield components measured in 2003 and 2004. Interactions of these characteristics and seed yield were observed. Seed yield of fine fescue was dependent upon subspecies, cultivar, and year in this study. The above observed year by cultivar interactions could be partially explained by differences in environmental conditions between years (Table 2-3).

Seed Number and Seed Weight

In 2003, seed number in SR5100 was 141 x 10^3 per m^2, with corresponding seed weight of 1.13 g 1000^{-1} (Table 2-3). Weather data indicates that during the period of seed set average temperature was 14% greater than historic average temperature during that period. In addition, precipitation during this period was 70% less than the historic average for precipitation. During seed fill, precipitation was 58% less than the historic average for that period. Thus, conditions during seed set and seed fill, which corresponds to final seed number and thousand-seed weight, were less than ideal in 2003. In 2004, weather data during seed set indicated that precipitation during seed set was 82% greater than normal for that period, while temperature was near average. During seed fill, precipitation was 72% greater than normal. In 2004, SR5100 seed number was 158 x 10^3 per m^2, with a corresponding seed weight of 1.12 g 1000^{-1} (Table 2-3). The radically different environments in 2003 and 2004, together with the subsequent differences in seed number and seed weight, provide evidence that SR5100 is highly dependent on optimum environmental conditions for determining seed yield.

Furthermore, the fact that seed number was more affected by the different environments than seed weight would indicate that seed set in SR5100 may be more sensitive to environmental differences than seed fill.

A trend of increased seed number is also observed in Brittany, Barnica, Shademaster, Cindy, and Shademark, with Shademark exhibiting the greatest increase in seed number between 2003 and 2004 (Table 2-3). Increased seed weight in 2004 over 2003 occurred in Southport, Brittany, Shademaster, Cindy, Silverlawn, Shademark, and Marker (Table 2-3).

In Shademark, the highest seed yielding cultivar in 2004, both seed number and seed weight were substantially greater in 2004 than 2003. Seed number for Shademark was 107 and 180 x 10^3 per m^2, with a corresponding seed weight of 1.11 and 1.29 g 1000^{-1} in 2003 and 2004, respectively (Table 2-3). This data would indicate that cultivars such as Shademark may be particularly sensitive to environmental extremes during both seed set and seed fill. Despite these increases in seed number and seed weight, seed yield in 2004 was lower than 2003. Therefore, seed yield component compensation with increased seed number and seed weight was not enough to increase seed yield above that of 2003 (Table 2-3). Furthermore, other factors outside of the scope of this study must be involved in determining seed yield.

Seed number in Southport, Silverlawn, Seabreeze, and Marker did not follow similar trends as Shademark, which may suggest that the genetic propensity of these cultivars is more dependent on stand age than environmental factors. Similarly, seed weight in SR5100, Barnica, and Seabreeze did not exhibit an increase in 2004 over 2003. This may indicate that with these cultivars seed fill, and subsequently seed weight, is not as sensitive to environmental extremes as other seed yield components (Table 2-3).

Seed yield in grass is the product of seed number per unit area and individual seed weight (Elgersma, 1991). Seed number is dependent on number of fertile tillers per unit area, the number of spikelets per panicle, the number of florets per spikelet, and floret site utilization (Elgersma, 1991). Young et al. (1998) reported that the number of panicles per unit area and number of florets per panicle were the yield components most associated with strong creeping red fescue. Fairey and Lefkovitch (1996) reported that seed yield was closely correlated with the number of panicles per unit area.

Since seed yield in grasses is the product of seed number per unit area and the individual seed weight, the final weight of an individual seed depends mainly on the position within a spikelet (Anslow, 1964). Seed weight can be negatively correlated with fertile tiller number and seeds per spikelet (Hampton et al., 1985). In this study, small variations in seed weight from year to year reflect the plasticity of fine fescue cultivars to adjust seed yield components in relation to various environmental factors.

Harvest Index

In 2003, harvest index (HI) of Chewings fescue cultivars ranged from 11% in Brittany to 7% in both Southport and Barnica. (HI) in strong creeping red fescue ranged from 6% in both Shademaster and Cindy to 10% in Shademark (Table 2-3). Cultivar (HI) differences within slender creeping red fescue ranged from 5% to 8% in Marker and Seabreeze, respectively.

The (HI), in relation to subspecies group in 2004, was increased compared to the (HI) in 2003 (Table 2-3). Strong creeping red fescue (HI) doubled from 2003 to 2004. A similar trend of (HI) increase within Chewings fescue between years was observed (Table 2-3). A range of 13% to 20% in (HI) was seen in Chewings fescue in Southport and Brittany, respectively (Table 2-3). A range of 13% to 20% in (HI) was seen in strong creeping red fescue in Shademaster and Shademark, respectively. Slender creeping red fescue had the lowest (HI) of all subspecies in 2004 with a range of 10% to 15% in Seabreeze and Marker, respectively.

(HI) is defined as the ratio of yield biomass to the total cumulative biomass at harvest. A large (HI) would be representative of plants allocating more resources to reproduction than dry matter accumulation. Plant breeders of various crops selectively choose new germplasm with (HI) as a desirable trait. In this study, an increase in (HI) was observed in the final seed harvest, indicating that fine fescue subspecies have the potential to increase the (HI) as stand age increases.

<u>Seed Yield Trends</u>

In 2002, seed yield trends between subspecies ranged from 1,115 to 1,395 kg ha^{-1} in Chewings fescue and slender creeping red fescue, respectively (Table 2-3). In 2003, average seed yield trends ranged from 1,473 to 2,205 kg ha^{-1} in slender creeping red fescue and Chewings fescue, respectively (Table 2-3). In 2004, seed yield differences between subspecies ranged from 820 to 1,464 kg ha^{-1} in slender creeping red fescue and strong creeping red fescue, respectively (Table 2-3).

Seed yield trends of grass seed crops over years can be variable between species, subspecies, and cultivars within subspecies. Canode and Van Keuren (1963) postulated that seed yield declines rapidly in grasses that are more rhizomatous and produce sod quickly, regardless of management practices. In addition, Canode and Law (1975) reported seed yield decline to be independent of management practices and attributed this noticeable seed yield decline as early as the second seed crop. Young et al. (1999) reported lower seed yields in the third crop compared to the second crop in perennial ryegrass and tall fescue. Elgersma (1990) related perennial ryegrass genetic differences in seed yield to the growth and development of the seed crop and to the components of seed yield.

In this study, we observed seed yield trend differences between cultivars within all subspecies. This further provides evidence that seed yield in fine fescue subspecies is cultivar-dependent.

Table 2-3. Comparison of seed yield, fertile tiller number (FTN), seed number, seed weight, and harvest index (HI) across three years in ten cultivars and three subspecies of fine fescue.

		2002		2003					2004				
		FTN	Yield	FTN	Yield	Seed no.	Seed wt.	HI	FTN	Yield	Seed no.	Seed wt.	HI
Subspecies	Cultivar	per m^2	kg ha^{-1}	per m^2	kg ha^{-1}	* per m^2	g 1000^{-1}	%	per m^2	kg ha^{-1}	* per m^2	g 1000^{-1}	%
Chewings	SR5100	3025	1155	2262	2352	141	1.13	10	2066	1414	158	1.12	17
	Southport	2964	975	1937	1875	126	1.11	7	1870	1190	125	1.19	13
	Brittany	2974	1406	1867	2792	136	1.13	11	2059	1470	153	1.18	20
	Barnica	2964	922	2091	1800	133	1.12	7	3472	1324	152	1.09	17
	Means	2982	1115	2039	2205	134	1.12	9	2367	1350	147	1.14	17
Strong creeping	Shademaster	2686	838	2006	1591	117	1.12	6	2092	1354	130	1.29	13
	Cindy	1894	984	1911	1591	125	1.14	6	1664	1392	134	1.29	16
	Silverlawn	3240	1296	2112	2080	143	1.13	8	2356	1235	136	1.14	14
	Shademark	2678	1527	1788	2493	107	1.11	10	2736	1875	180	1.29	20
	Means	2624	1161	1954	1939	123	1.12	8	2212	1464	145	1.25	16
Slender creeping	Seabreeze	4346	1238	2013	1205	127	1.16	5	1891	697	78	1.12	10
	Marker	5607	1551	2164	1741	154	1.12	8	2531	943	106	1.14	15
	Means	4977	1395	2088	1473	141	1.14	7	2211	820	92	1.13	13

* Actual values x 10^3

Seed Yield Decline

Seed yield decline effects, in relation to seed yield components and seed yield, were subspecies and cultivar specific. Canode and Law (1975) reported a decline in seed yield of Kentucky bluegrass as the plants aged, together with associated seed yield declines in forage yield, plant height, number of panicles, root and rhizome production, and etiolated growth. In addition, seed weight did not show a decrease associated with stand age, but tended to have a negative association with seed yield (Canode and Law, 1975).

Work of Majerus (1988) stated that perennial grasses show a characteristic decline in seed production with age of stand, regardless of the conditions under which they are grown. Much less seed was produced during the first growing season, reached a peak in the second or third season, and then gradually declined as the stand aged. Moreover, Majerus observed that the ability of plants to maintain seed production at acceptable levels was dependent on numerous environmental conditions and cultural practices. Majerus concluded that proper cultural management plays an important role in prolonging the productivity of cool-season grass stands. However, after four years it was reported that most cool-season grasses declined to such low production levels that continued culture could not be justified.

Conclusions

This study concludes that cultivar differences with respect to seed yield components and seed yield decline over time, proving that specific genetic differences in fine fescue cultivars exist and greatly affect seed yield. Similar relationships in other cool-season grass seed species can be illustrated in other studies (Majerus 1988).

Law (1979) found that in *Poa annua* L., high rates of reproduction early in the plant life leads to lower rates of reproduction and smaller plants thereafter, and is a genetic trade-off. This genetic trade-off can be generalized for each cultivar in this study. Each fine fescue cultivar exhibited differences in ability to produce high numbers of fertile tillers and, subsequently, enhance seed yield, or vice-versa. Some cultivars had high fertile tiller populations and low overall seed yields. The ability of fine fescue cultivars to convert potential seed yield into actual seed yield must be considered by plant breeders interested in improving seed production; hence, seed yield per fertile tiller is a key characteristic for consideration in selection programs.

Inferences from this study can be applied to the specific cultivars tested and grown under similar production conditions in the Willamette Valley. This knowledge may aid producers in their rotation schedules because cultivars that yield greater in the first three years, and then decline rapidly in the fourth and fifth years, could be incorporated into shorter rotation cycles. Similarly, a cultivar that maintains economic seed yield for five years could be incorporated into a five-year rotation schedule with other crops.

This research further finds that the contributions to seed yield in subspecies, and cultivars within subspecies, of fine fescue can be measured from observed variation in fertile tiller number, seed number, and seed weight. Moreover, fertile tiller number clearly plays a role in maintaining seed yield. Cultivars that have the genetic ability to maintain a constant fertile tiller number or increase fertile tiller number in the early years of a stand have the ability to maintain reproductive and agronomic stability.

To maximize seed production, an adequate tiller number and size must be produced to favor floral induction. Meijer (1984) reported that fertile tiller number in strong creeping red fescue is directly related to fertile tillers that begin development in mid-November. Fewer inflorescences were produced from fertile tillers that originated later in the spring. Later formed fertile tillers may not have been formed soon enough for floral induction to take place, resulting in reduced inflorescence production. The manner in which three subspecies of fine fescue respond to crop management and environment, over a period of time, may be manifestations of genetics, survival mechanisms, or seed yield component compensation.

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SUMMARY and CONCLUSIONS

Unlike previous studies that investigated residue management in few cultivars of fine fescue, this study evaluated the effects of residue management within ten cultivars of fine fescue. The author's intent is that this study will contribute and build upon the knowledge of other studies, contributing to both the scientific and agricultural community.

Seed yield increase as a result of thermal residue management can be attributed to observed increases in fertile tiller number, seed number, and thousand seed weight. Moreover, percent seed cleanout clearly plays a role in explaining seed yield loss associated with non-thermal residue management. In contrast, thermal residue management had reduced percent seed cleanout, thus illustrating the importance of thermal residue management to increased seed purity by reducing numbers of light, empty, and partial seeds. Cultivar response to residue management was dependent upon cultivar. Thermal residue management becomes increasingly important as the stand ages. With respect to seed yield, cultivars responded differently to residue management, as seen by a residue management by cultivar interaction in 2003 and 2004. Thermal residue management is critical in maintaining profitable seed yield in Chewings, strong creeping red fescue, and slender creeping red fescue as the stand ages.

Non-thermal residue management did not produce profitable seed yield; hence, it cannot be considered a viable alternative to thermal residue management.

Cultivar differences with respect to seed yield components, seed yield, and seed yield decline over time were investigated and proved that innate genetic differences in fine fescue cultivars exist and greatly influence yield over time. Each fine fescue cultivar exhibited differences in ability to produce high numbers of fertile tillers and, subsequently, enhanced seed yield, or vice-versa. A few cultivars had high fertile tiller populations and low seed yields. Seed yield per fertile tiller proved to be a key characteristic in explaining seed yield differences among cultivars.

Inference from this study can be applied to the specific cultivars tested and grown under similar production conditions within the Willamette Valley. This knowledge may assist producers in selecting cultivars to fit appropriate rotation schedules. Moreover, contributions to seed yield in subspecies, and cultivars within subspecies, of fine fescue can be measured from observed variation in fertile tiller number, seed number, and seed weight. Furthermore, fertile tiller number clearly plays a role in maintaining seed yield. Cultivars that have the genetic ability to maintain constant fertile tiller number or increase fertile tiller number in the early years of a stand have the ability to maintain reproductive and agronomic stability.

With regard to this existing study it would be appropriate to extend the study through a fourth and even fifth year to truly ascertain stand age effects.

In the future, an experimental treatment that consists of thermal management in one of four years, two of four years, three of four years, and four of four years with a new stand being planted in every year as well to elucidate the effects of thermal management across various cultivars as stand ages would be beneficial.

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