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Title: Trinexapac-Ethyl and Open-Field Burning in Creeping Red Fescue (*Festuca rubra* L.) Seed Production in the Willamette Valley.

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Open-field burning has been an effective, economical, and widespread method of post-harvest residue management in creeping red fescue seed production in the Willamette Valley since the late 1940s. However, the use of field burning has been legislatively restricted due to air quality and safety issues. The foliar-applied plant growth regulator trinexapac-ethyl (TE), commercialized in the USA as Palisade™, has been accepted by producers as a yield enhancing agent and is considered here as an alternative to open-field burning over a four-year period.

The effects of open-field burning versus mechanical removal (flailing) of post-harvest residue, and spring versus fall applications of TE on seed yield, dry matter partitioning, and seed yield components were evaluated in a split-plot design. The response to the different treatment combinations differed across years. The young stand responded with a seed yield increase to spring TE

applications, regardless of residue management treatment. However, as the stand aged, field burning became critical for maintaining high yields and, in 2003 and 2004, only spring TE applications resulted in seed yield increases in burned plots.

The higher potential seed yield achieved in burned plots over flailed plots, as a result of a higher number of panicles per unit area and spikelets per panicle, was critical for maintaining high seed yields as the stand aged. Spring applications of TE, further increased seed yield over the untreated check by increasing the number of florets per spikelet, reducing fertile tiller height and lodging and consequently, favoring pollination and fertilization of the florets. Late spring TE applications also increased 1000-seed weight in 2003 and 2004.

Although spring applications of TE were a promising alternative to open-field burning early during the life of the stand, as the stand aged they did not increase seed yield on flailed plots. Fall TE applications did not have a consistent effect on seed yield, dry matter partitioning or seed yield components, and were found not to be a viable management practice.

Trinexapac-Ethyl and Open-Field Burning in Creeping Red Fescue (*Festuca rubra* L.) Seed Production in the Willamette Valley

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INTRODUCTION

Originally, post harvest open-field burning in the production of grass seed in the Pacific Northwest was originally started in 1946 for disease control (Canode and Law, 1978). Since that time, it has been adopted as a widespread practice in the region. Open-field burning has been successfully used as a management tool to remove post-harvest residue in seed production fields of creeping red fescue (*Festuca rubra* L.) and other cool-season grasses in order to maintain seed yield and seed quality. However, public concern over air pollution and safety issues related to smoke caused by open-field burning resulted in legislatively mandated reductions in the acreage burned per year in the Willamette Valley during the last ten years. Although field burning has considerable positive impacts on creeping red fescue seed yield, alternative practices have been tested for maintaining high yields as field burning is restricted, but without positive results. Nonthermal practices for removing post-harvest residue in creeping red fescue seed crops have been associated with yield loss when compared with field burning (Chastain et al., 1999; Meints et al., 2001).

The favorable conditions under which creeping red fescue seed is produced in the Willamette Valley make the crop susceptible to lodging, which causes reductions in seed yield. Reducing lodging is critical in order to achieve higher yields. There is evidence that the use of plant growth regulators (PGRs) is an effective way to reduce plant height and strengthen stems in grass crops grown for seed, thus reducing lodging. Plant growth regulators also appear to increase seed set and seed number, therefore increasing seed yield (Hebblethwaite et al.,1980; Albeke et al.,1983a,b; Hebblethwaite, 1987; Silberstein et al., 2001a, b; Chastain et al., 2001; Silberstein et al., 2002; Butler and Cambell, 2003; Chastain, 2003). However, PGRs have been consistently used in spring applications and the effect of fall applications of PGRs on cool-season grasses seed yield has not been evaluated.

The effects of different timings of the plant growth regulator trinexapac-ethyl (TE) were evaluated on burned and nonburned stands of creeping red fescue grown for seed production. It was hypothesized that fall applications of TE would control fall regrowth in nonburned plots, increase tillering, and result in seed yield increases comparable to those obtained by burning the post-harvest residue in creeping red fescue. Consequently, the use of PGRs, such as trinexapac-ethyl, applied in fall might be an alternative to lessen the need for open-field burning in creeping red fescue, and still get high yields and seed quality that characterize Willamette Valley grass seed production.

LITERATURE REVIEW

Development of Seed Yield

Seed yield in perennial grasses is a complex characteristic that depends on many physiologically and morphologically related attributes (Ibrahim and Frakes, 1984). Seed yield depends on the product of several yield components: plants per area, fertile tillers per plant, spikelets per fertile tiller, florets per spikelet, seeds per floret, and seed weight. Variation in the expression of one or more of these components may result in variation in seed yield. Increased or decreased expression of yield components may be compensated for by a change in yet another yield component, thereby neutralizing potential changes on seed yield. Perennial grasses are generally bred for high vegetative dry matter production if it is a forage type, or for turf quality in turfgrasses, and generally profuse flowering is not a desirable characteristic (Warringa and Kreuzer, 1996; Razec et al., 1999). Consequently, seed yield is a result of competition between vegetative and reproductive dry matter production (Hebblethwaite, 1987).

Hebblethwaite et al. (1980) identifies two distinct phases in the development of seed yield in cool-season perennial grass seed crops: the establishment of yield potential (manifested at anthesis), and the utilization of the yield potential, which is the actual yield at harvest.

Establishment of Potential Seed Yield

In general, vegetative tillers have to pass through a juvenility stage during which they are insensitive to environmental conditions that promote flowering, and therefore cannot be induced to flower. Once the plant reaches the adult stage, it is receptive to stimuli and is induced to flower. A stand of perennial grasses is typically composed of a heterogeneous mixture of annual and biennial tillers after the first year of growth; and Sylvester and Reynolds (1999) found that not all leafy tillers were induced to flower every year. The tiller's developmental age (Colvill and Marshall, 1984) influences its receptivity to floral induction signals. Only a fraction of tillers become fertile, and develop an inflorescence each year. Most cool-season perennial grasses, including creeping red fescue, have a dual induction requirement for flowering (Heide, 1994). Primary induction is mediated by low temperature (vernalization) and/or short day length, and enables the plant to initiate inflorescence primordia, whereas a secondary induction involves a transition to long days and increasing temperatures, and allows culm elongation, inflorescence development and anthesis. Since the primary induction effect is local, induced tillers cannot induce later-formed adjacent tillers (Heide, 1994). Floral induction of each tiller is therefore the key to unlocking the seed yield potential of cool-season grasses (Chastain and Young, 1998). According to Sylvester and Reynolds (1999), meristems that are not induced to flower over the winter would resume leaf development during the subsequent spring and fall.

Early events during vegetative development may have a profound impact on the plant's receptiveness to vernalization stimuli and therefore can influence tiller induction to flowering. Canode and Law (1979) suggested that Kentucky bluegrass (*Poa pratensis* L.) tillers must reach a threshold size or stage of development to be receptive to inductive stimuli. Also, stand age plays a major role in relationships among vegetative development, flowering, and final seed yield. Chastain and Young (1998) reported that the basal diameter of vegetative tillers in fall was related to flowering and seed yield on young stands of Kentucky bluegrass and creeping red fescue. Nevertheless, as stands aged, basal diameter was not a primary indicator of flowering and seed yield. In addition, they reported that tiller height at the end of the regrowth period was consistently related to flowering and seed yield, regardless of stand age, in both Kentucky bluegrass and creeping red fescue (r= -0.81 and r= -0.87, $P<0.01$ respectively).

Finally, carbohydrate reserves in tiller bases in fall were not related to flowering in creeping red fescue; nevertheless, an increase in the rhizome: root ratio caused a reduction of flowering (Meints et al., 1996; Chastain and Young, 1998). Although open-field burning may alter differentiation from rhizome formation to tillering and floral induction, the physiological stimulus which causes this change has not been reported (Meints, 1997).

The post-harvest regrowth period can strongly influence flowering since the conditions during this phase will determine the number of tillers in a receptive stage when floral induction begins. Meijer (1984) found that early tiller development in fall was essential for inflorescence production in red fescue due to juvenility. Tillers that originate during spring have a great potential of becoming fertile the following spring (Sylvester and Reynolds, 1999). Chastain and Grabe

(1988a, b) reported that seed yield of young stands of creeping red fescue increased as the number of vegetative tillers in the previous spring increased.

At anthesis, the number of fertile tillers per unit area, the number of spikelets per inflorescence, and the number of florets per spikelet will determine the potential yield. The utilization of the yield potential is determined by events at and after this stage (Hebblethwaite et al., 1980).

Utilization of Seed Yield Potential

Pollination is the transfer of pollen from the anthers to the stigma. Reduced number of pollen grains on the stigma may reduce fertilization (Elgersma, 1985). Therefore, factors that affect pollination, like early lodging which limits pollen transport (Elgersma, 1985), will definitely have an impact on seed number and seed yield. According to Marshall (1985) and Warringa et al. (1998a, b), approximately 60-65% of all florets set seed (i.e., they are successfully pollinated and fertilized). Mares Martins and Gamble (1993b) reported that 84% of the total florets of perennial ryegrass (*Lolium perenne* L.) were successfully pollinated at day two after anthesis. According to Hampton and Hebblethwaite (1983a), in perennial ryegrass seed crops which lodge, either before or during anthesis, seed number and therefore seed yield is largely dependent on the number of seeds per spikelet and not the number of fertile tillers. Griffiths et al. (1980) supports the idea that among the factors contributing directly to seed yield, seed set, a component which has manifested a surprising degree of heritable variation, is of foremost importance. A strong correlation between seed yield and number of seeds produced per unit area was found for Chewing's fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman; syn. *F. rubra* var. *commutata* Gaudin], tall fescue (*Festuca arundinacea* Schreb.) and orchardgrass (*Dactylis glomerata* L.) seed crops (Young et al., 1998b; Young et al., 1999). Young et al. (1998a) found that the number of fertile tillers per unit area, and therefore the number of florets, were the yield components most closely associated with seed yield of red fescue (*Festuca rubra* L.) in the Willamette Valley. However, according to Lamb and Murray (1999), panicle density is not always a reliable indicator of seed yield.

During the seed filling stage there is some seed abortion and shedding that reduces the number of seeds (Meijer, 1985). This seed development period is also critical for achieving high yields, since the final yield depends not only on the number of seeds per unit area, but also on the weight of those seeds.

In order to understand how a certain management strategy can influence seed yield, it is important to determine which of the yield components is being mainly affected and how the others change as a result.

Residue Management

Since the late 1940s post harvest open-field burning has been used as a widespread practice in the production of grass seed in the Pacific Northwest. Open-field burning has been a successful management tool to remove post-harvest residue in seed production fields of creeping red fescue, and other cool-season grasses, in order to maintain seed yield and seed quality (Hardison, 1980; Crowe et al., 1996; Rolston et al., 1997). In western Oregon, seed production of several species of grass was seriously depressed if the post-harvest residue was not removed after harvest (Chilcote et al., 1980).

Nevertheless, since the mid 1970s, concern for air quality has resulted in a high priority being placed on research to study alternatives to open field burning (Canode and Law, 1977). As a result, alternative practices have been found for maintaining high yields of perennial ryegrass, orchardgrass, tall fescue, Kentucky bluegrass, chewing fescues, dryland bentgrass (*Agrostis castellana* L.), and timothy (*Phleum pretense* L.) (Young et al., 1984; Entz et al., 1994; Chastain et al., 1996a; Chastain et al., 2000). However, no successful treatments have been found yet for maintaining high seed yield in creeping red fescue (Chastain et al., 1996a, b; Chastain et al. 2000). According to Young et al. (1998a) open-field burning is required to achieve maximum seed yield and seed quality of creeping red fescue.

The post-harvest residue management effect on seed yield of grasses has been shown to be species, cultivar, and stand age dependent (Hickey and Ensign, 1983; Young et al., 1984). Species with a bunch-type growth habit such as perennial ryegrass, tall fescue and orchardgrass, were more tolerant of residue management without straw removal, than those with a creeping growth habit such as Kentucky bluegrass and creeping red fescue (Chastain et al., 2000).

Although Young et al. (1984) concluded that continuous burning was the only treatment capable of maintaining perennial ryegrass seed yields over time in the Willamette Valley, Mueller-Warrant et al. (1994a, b) reported that, by properly choosing herbicide treatments when changing to nonburning methods of residue removal in perennial ryegrass, the impact on seed yields and seed quality is minimal. Chastain et al. (1996a) showed that high seed yield of perennial ryegrass and tall fescue could be achieved with nonthermal management of post-harvest straw and stubble, especially when more than 60% of the straw is removed. In addition, they reported no yield difference from diverse residue management practices on orchardgrass and Chewings fescue in the Willamette Valley. Previously, Canode (1972) had shown that burning post-harvest residue of orchardgrass did not result in increased seed yield when compared with raking and removing the residue (mechanical removal). Canode considered these results as representative of the effect of residue burning on most of the cool-season "bunch" grasses under conditions of eastern Washington.

When evaluating the same management strategies in Kentucky bluegrass grown in 91-cm rows, Canode (1972) reported that mechanical residue removal resulted in higher seed production than burning in the second and third seed crop. Nevertheless, burning gave higher seed yields in the fourth and fifth crops. Residue burning resulted in an increase in vegetative tillers, which suggested improved growing conditions in comparison to mechanical residue removal. These improved conditions may be due to previous stand thinning as a result of burning that allows areas for new growth, or to removal of thatch that interferes with vegetative growth. Chastain et al. (1996b) suggested that creeping red fescue might require complete removal of stubble to produce acceptable seed yields without burning.

Pumphrey (1965) found that, in red fescue, higher yields were produced where the residue was removed completely either by mechanical means or by burning early. These increases in yield ranged from 51 to 292%. He also found that seed yield was higher when the residue was burned in late summer (August) than in fall (October). The new growth in fall is apparently vital to high seed yields of red fescue and Kentucky bluegrass, and any injury it sustains reduces seed yield.

Affirming this theory, Meints et al. (2001) found that stubble removal to the plant crown is crucial for maximizing seed yield potential of creeping red fescue. Moreover, Chastain (2003) suggested that field burning has a direct stimulative influence on seed yield in creeping red fescue, which is not observed in other grass seed crops.

Pumphrey (1965) reported that where the residue was partly removed, by baling the straw which had gone through the combine, seed yields were much lower than where the residue was completely removed in red fescue. However, there was an apparent trend that partial removal was superior to no removal, since all seed yields where the straw was partially removed were higher than those where no residue was removed.

In accordance with Pumphrey (1965), Chastain et al. (1997) concluded that high seed yield and seed quality can be maintained in Kentucky bluegrass without open-field burning when straw removal is thorough and stubble height is reduced prior to crop regrowth.

Lamb and Murray (1999) reported no differences in seed yield between diverse residue management treatments in the second year with six cultivars of Kentucky bluegrass in Washington. However, in the third year, they found that three of the six cultivars they tested yielded 42 to 80% of the burned with rake and vacuum treatments, while the other three cultivars showed no significant yield differences. In addition, they reported that panicle density varied between post-harvest residue management treatments by 20 to 25%, with higher density in the burned treatment when compared with both the vacuum and rake treatments in the third year. Regarding aboveground biomass, different cultivars of Kentucky bluegrass responded differently to the residue management strategy. In some cases, the treatments did not influence aboveground biomass while in others there was a reduction by 24 to 36% with non-thermal treatments.

Similar results have been reported by Hickey and Ensign (1983) for Kentucky bluegrass in Idaho. They found that seed yield, and panicle and tiller numbers were greater for burned plots than for those where residue was mechanically removed to 2.5 or 7.6 cm.

Early work done by Canode and Law (1979) showed that the total number of primary tillers and the number of large tillers of Kentucky bluegrass were significantly greater following open and machine burning than when stubble was mechanically removed. Accordingly, burning resulted in larger (> 2.0 mm basal diameter), but not taller, fall tillers than the mechanical stubble-removal treatments in the second year crop in creeping red fescue (Meints et al., 2001). The ability of tillers to be induced to flower has been found to be associated with a minimum basal diameter of 2.0 mm in Kentucky bluegrass (Canode and Law, 1979; Chastain et al. 1997). However, Meints et al. (2001) did not find a similar relationship in creeping red fescue but stated that fertile tiller number is the most important component of seed yield potential in creeping red fescue, and is closely associated with yield.

Canode and Law (1978) found that red fescue seed yields in the third seed crop, and for the average of the second and third seed crops, were higher when residue was burned compared with mechanical removal. They did not find significant differences on the second crop between the management practices. Furthermore, the straw and stubble removal treatment resulted in higher yields than when only the straw was removed. Similar results were found for smooth bromegrass (*Bromus inermis* Leyss.), while crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link.) Schult.] did not show differences until the fifth year when residue burning resulted in the highest yields. Increasing the fertilization rate (from 90 to 112 and 135 kg N ha^{-1}) did not compensate for the seed loss observed when the residue was mechanically removed instead of being burned in situ. In burned plots, the autumn regrowth of tillers was more prostrate (rosette) with shorter, wider leaf blades, as opposed to plots with mechanical residue removal where growth was more upright, and leaves narrower, longer and lighter in color. There was a trend for burned treatments to produce more and larger tillers (Canode and Law, 1978; Canode and Law, 1979).

Open-field burning also extends the productive life of the stand. Canode and Law (1977) showed that with open-field burning in Kentucky bluegrass the stand remained productive for several years, but mechanical removal of straw ended the productive life of the stand after the fifth seed crop. Open burning after the fourth and fifth crops improved seed production compared with continuous removal; however, continuous removal still produced 52% less seed yield in the fifth crop and 32% less in the sixth seed crop than open-field burning every year.

In any case, the effect of the post-harvest residue management practice will depend on the species, cultivar and area where the crop is produced. Lamb and Murray (1999) and Johnson et al. (2003), reported a strong interaction between post-harvest residue management and different cultivars and accessions of Kentucky bluegrass. In addition, Fairey and Lefkovitch (2001) did not find any major differences on seed yield or quality between the residue management strategies in the Peace River region of northwestern Canada.

Plant Growth Regulators

Creeping red fescue grown for seed production is prone to lodging, especially under the wet conditions in the Willamette Valley, often resulting in lower seed yields (Chastain, 2003). It is well documented that lodging in cool-season grasses for seed production may result in restricted pollination, reduced rate of fertilization, and therefore lower seed set. In addition, lodging can inhibit seed filling due to self-shading of the lodged crop (Silberstein et al., 2001a, b; Chastain et al., 2001; Silberstein et al., 2002). Hebblethwaite et al. (1980) cites lodging as a major factor responsible for poor floret site utilization in perennial ryegrass. Finally, lodging may also increase disease pressure, since a lodged crop is a more favorable environment for fungal diseases development. According to Chastain (2003), control of lodging increases seed yield more than any other agronomic practice in grass seed crops, including weed and rust control, as well as, nitrogen fertilizer application. Considerable work has been done to determine the effects of plant growth regulators (PGRs) on seed production of creeping red fescue and other perennial cool season grasses (Rolston et al., 1997).

Plant growth regulators are synthetic or naturally occurring organic compounds, other than nutrients, applied in agronomic and horticultural crops to modify plants processes such as growth and development. According to Rademacher (2000), plant growth retardants represent the commercially most important group of plant growth regulators worldwide. Some growth retardants are ethylene-releasing compounds, but most act by inhibiting gibberellin (GA) biosynthesis. They are used to reduce the shoot length in a desired way without lowering plant productivity.

Early Use of Plant Growth Regulators

Early work by Hebblethwaite and Burbidge (1976), examined the effect of chlorocholine chloride (CCC) on ryegrass (*Lolium* sp. L.). Chlorocholine chloride belongs to the onium-type PRGs which block the gibberellins biosynthesis at its early stages by inhibiting the cyclization reaction of ent-kaurene precursors (Rademacher, 2000). Hebblethwaite and Burbidge (1976) found that CCC had little effect on length of fertile tillers or lodging but seed yield was slightly increased in some years, likely due to improved assimilate transfer to the seed.

Several studies examined the use of exogenous plant growth regulators to control stem elongation, and optimize seed production in cool-season grasses in the mid 1980s. Research at that time was focused on the use of paclobutrazol (PP333), a residual, soil applied PGR in the triazole family, introduced in 1979. This product inhibits gibberellic acid (GA) biosynthesis by blocking the enzymes catalyzing the oxidative steps from ent-kaurene to ent-kaurenoic acid (Rademacher, 2000). Paclobutrazol has been found to acceptably control lodging and improve seed yields in perennial ryegrass and other cool-season grasses (Albeke et al., 1983a, b; Hampton and Hebbletwaite, 1984; Hebblethwaite et al., 1986; Hebblethwaite, 1987). However, Hebblethwaite (1987) found wide variability in the response of perennial ryegrass to paclobutrazol applications, since yields increased from eight to 136% depending on year, cultivar, and rate. In all cases, seed yield increases were a direct result of higher number of seeds harvested per unit area, associated either with increases in number of fertile tillers or seed per spikelet. The variability in the yield response was reflected in the work of Mares Martins and Gamble (1993a, c) in Ontario, Canada. They found that even though paclobutrazol consistently prevented lodging in perennial ryegrass, it had inconsistent effects on yield components and seed yield; it caused a 25-35% yield reduction when applied at spikelet initiation in one of two experiments. The investigators thought this yield loss might be caused by increased seed retention in the spike at harvest on treated plots, causing incomplete threshing of the crop.

When comparing paclobutrazol with flurprimidol (EL500), another PGR with a similar mechanism of action, Hampton and Hebblethwaite (1985) found that both chemicals can substantially increase perennial ryegrass seed yields by reducing and delaying lodging, increasing fertile tiller production and reducing seed abortion. However, for comparable effects on growth and seed yield, flurprimodol had to be applied at double the active ingredient rate required for paclobutrazol. When analyzing timing of the application for both products, the double ridge and spikelet initiation application resulted, in general, in higher yields than an application at floret initiation (Hebblethwaite et al., 1985; Hebblethwaite et al., 1986).

Albeke et al. (1983b) reported that in Oregon a single paclobutrazol spring application on red fescue reduced lodging over a wide range of nitrogen rates (90, 120 and 150 kg N ha^{-1}) and consequently increased harvested seed yield at all nitrogen rates. In contrast, in a parallel study, Albeke et al. (1983a) observed that seed yields of fine fescue (*Festuca* sp. L.) with a single spring treatment of paclobutrazol were lower than that of the control. They hypothesized that the lack of seed yield enhancement by the chemical might be due to reduced lodging severity and delay in lodging until after anthesis in untreated plots, reducing the negative effects of lodging on tiller mortality, seed set, and seed filling. When evaluating paclobutrazol on tall fescue, Albeke and coworkers did find an increase in seed yield on treated plots, mainly due to a reduced culm length and a higher number of spikelets per panicle. When applied in Kentucky bluegrass, even though paclobutrazol produced a drastic growth reduction, there were no significant differences in yield (Albeke et al. 1983a).

Since neither paclobutrazol nor flurprimidol were commercially available in New Zealand, Hampton (1986) examined the effects of the widely used cereal growth retardant chlormequat chloride (=chlorocholine chloride CCC) on seed yield of perennial ryegrass. Chlormequat chloride applied at spikelet initiation increased seed yield between 34 and 44%, but, being consistent with Hebblethwaite and Burbidge (1976), and Mares Martins and Gamble (1993a), it did not alter stem length or prevent lodging. In this case, seed yield increases appear to be associated with higher tiller survival, in contrast to paclobutrazol which increased fertile tiller production.

In the 1990s, following the same trend, Young et al. (1996) reported that, in Oregon, application of lower rates of paclobutrazol increased seed yield in perennial ryegrass by controlling lodging and improving floret site initiation as a consequence. Similarly, Young et al. (1999) found that, paclobutrazol applications at floret initiation stage significantly improved Chewings fescue, and tall fescue seed yield, but did not improve orchardgrass seed yield. When examining the response of the crop to different rates of spring nitrogen applications (90, 120, 150, 180, and 210 kg N ha^{-1}), they acknowledged that paclobutrazol application did not improve the crop response to spring-applied nitrogen.

Even though there is an important body of evidence regarding the effectiveness of paclobutrazol for increasing seed yields of cool-season grasses, this chemical is not registered for use in grass seed production any longer (Gingrich and Mellbye, 2001). The suspension of the label is due to its great longevity in the soil, which caused serious problems in subsequent plantings in rotations that included grass crops grown for seed.

Currently Used Plant Growth Regulators

Looking for alternatives to paclobutrazol, in 1997 researchers at Oregon State University began experimental work with a new group of PGRs, the acylcyclohexanediones, on grass seed crops. Trinexapac-ethyl (TE) and prohexadione-calcium, two foliar applied PGRs commercialized in the USA and now broadly used as Palisade™ and Apogee®, respectively, belong to this group. They are known to interfere with the late steps of GA biosynthesis by mimicking the 2-oxoglutaric acid, which is a cofactor of the dioxygenases involved in the metabolic activation of GAs (Rademacher, 2000). Trinexapac-ethyl has been found to control plant height, hence reduce lodging problems in creeping red fescue, and other perennial cool season grasses grown for seed (Chastain et al., 2001; Gingrich and Mellbye, 2001; Silberstein et al., 2001b, 2002; Chastain et al., 2003; Rolston et al., 2003). Gingrich and Mellbye (2001) obtained significantly greater seed yields from applications of these PGRs on fine fescue, with a 32 to 48% increase in seed yield over the untreated checks, in large scale on-farm trials in the Willamette Valley. They also found responses to applications of these PGRs on perennial ryegrass (10-27%), tall fescue and orchardgrass, the latter being the least responsive to the applications. In addition, in Oregon, Silberstein et al. (2001b) reported seed yield increase of 25%, 61%, 62%, and 47% for spring TE applications on perennial ryegrass, tall fescue, creeping red fescue, and

Chewing's fescue, respectively. They also reported an increase of 5% in the harvest index (a ratio of seed yield to total biomass), as a result of a seed yield increase without a corresponding change in total biomass.

Chastain et al. (2001) found a 25% and 41% seed yield increase after TE application in the first and second year in perennial ryegrass production. They had pointed out that stand-age related decline in seed yield is a wide spread phenomenon in grass seed production, but TE treatment in the second year greatly lessened this yield loss. They found no effect of TE on spike number, above ground dry weight, or spikelets per spike in either year. Nevertheless, seed yield increase was manifested via a different mechanism in each of the years. During the first year, a greater number of florets per spikelet accounted for a portion of seed yield increase, while in the second year, TE application resulted in increased seed set.

Butler and Campbell (2003) ascertained that, in Oregon, TE applied at 200 g a.i. ha^{-1} when the second node was detectable, increased yields by 35% on Kentucky bluegrass and by 13 and 21% on rough bluegrass (*Poa trivialis* L.) compared to untreated plots. They found no differences among TE treatments, at different rates and dates, in 1000 seed weight, and seed germination was equal or greater in treated plots.

Finally, Rolston et al. (2003) reported an average seed yield increase of 61% with trinexapac-ethyl, over four years in seven field trials of forage tall fescue in New Zealand. The responses were associated with shorter stems, a marked reduction in lodging, and increased seed yield per panicle. Similarly, Chastain et al. (2003) evaluated the impact of annual and alternate year applications of trinexapac-ethyl in perennial ryegrass over a three year period in Oregon. They found that in accordance with previous results (Chastain et al. 2001), although seed yield declined as the stand aged regardless of the treatment, TE consistently increased seed yield in each year by improving floret production, seed set, or both, on the first, third, and second year, respectively. In general, no residual effect of TE from one year to the next was found.

Conclusion

Trinexapac-ethyl has the potential to increase seed yield in red fescue when applied in spring, but no studies have evaluated the effect of fall applications of TE on fall regrowth. Considering the previous discussion, we can say in accordance with Meints et al. (2001), that residue management in creeping red fescue must maximize fall regrowth early in the post-harvest period, promote short tiller height during fall regrowth and reduce allocation of resources to rhizome production to maintain economic yield. Therefore, it is hypothesized that fall applications of PGRs might enhance seed yield as the stand ages, by reducing fall plant height and rhizome production, in a similar way field burning does. In addition, spring PGR applications may increase seed yield in creeping red fescue by increasing panicle number, reducing lodging, and therefore increasing seed set.

MANUSCRIPT I: TRINEXAPAC-ETHYL AND OPEN FIELD BURNING IN CREEPING RED FESCUE (*Festuca rubra* L.) SEED PRODUCTION: I. SEED YIELD AND DRY MATTER PARTITIONING.

Abstract

Open-field burning has been an effective, economical method of post-harvest residue removal in creeping red fescue (*Festuca rubra* L.) seed crops. However, the use of open-field burning has been restricted due to air quality issues. The use of the plant growth regulator trinexapac-ethyl (TE) was evaluated as an alternative to open-field burning over a four-year period at Hyslop Experimental Research Farm near Corvallis, Oregon, USA. The effects of field burning and mechanical removal (flailing) of post-harvest residue, and those of fall and spring applications of TE on seed yield and dry matter partitioning were analyzed. Relatively small differences in seed yield between burned and flailed plots were found in the first year, but as the stand aged, open-field burning was critical for maintaining high yields. Trinexapac-ethyl application in spring further increased yield over the untreated check in burned plots for the four years. In flail plots, spring TE applications increased yield over the untreated check for the first two years, but no response to TE applications was observed as the stand aged and stand density increased. The rate of fall TE applications had no consistent effect on seed yield. Fall applications of TE did not replace the beneficial effect of field burning. Total dry matter production was lower for flailed plots than for burned plots in the second through fourth years. In addition, spring TE applications further reduced total dry matter production in the third and fourth

years. The increase in seed yield for residue management and TE application treatment combinations was paired with an increase in harvest index; indicating that burned and spring treated plots were more efficient in partitioning dry matter to seed yield than other treatments. Consequently, since neither fall nor spring TE applications are an effective alternative to replace field burning in creeping red fescue seed production over the life of the stand, high priority should be assigned to this crop when allocating the area permitted to be burned each year in the Willamette Valley.

Introduction

Management of post-harvest residue is an important factor in the production of creeping red fescue seed crops. Open-field burning is an effective, economical method of post-harvest residue removal in creeping red fescue seed crops in the Willamette Valley (Hardison, 1980; Chastain et al., 1996a, b; Rolston et al., 1997; Meints et al., 2001). Postulated reasons for the higher seed yields achieved with open-field burning versus nonthermal residue management practices have been less disease and insect infestation, stimulation of primordia growth essential to seed head formation, and greater efficiency of fertilizers, herbicides, and insecticides (Pumphrey, 1965). Regardless of the beneficial effect of burning on seed yield, legislative actions to improve air quality have greatly restricted the total area of grass seed crops burned each year.

Plant growth regulators (PGRs) have been shown to improve seed yields of creeping red fescue when applied in spring (Chastain et al., 2001; Gingrich and Mellbye, 2001; Silberstein et al., 2001a, b, 2002; Chastain et al., 2003; and Rolston et al., 2003). Trinexapac-ethyl (TE), a foliar-applied plant growth regulator from the acylcyclohexanediones family (Rademacher, 2000) commercialized in the USA as Palisade™, results in growth reduction when applied at actively growing stages in grass seed crops. Growth reduction is caused by reduced levels of biologically active gibberellin (GA_1), as a result of 3β-hydroxylation inhibition in the late steps of gibberellin (GA) biosynthesis, (King et al., 1997; Rademacher, 2000). This plant growth regulator has been used in spring applications on grass seed crops, but no work has evaluated the effect of fall applications of plant growth regulators on seed yield of cool-season perennial grasses.

The post-harvest regrowth period is a critical phase of seed crop development since it can strongly influence flowering and seed yield in cool-season perennial grasses (Canode and Law, 1978). According to Chastain et al. (1997), the number and condition of tillers that are exposed to floral inductive conditions rely on a relatively short regrowth period in late summer and early fall. Chastain et al. (1997) showed that the height of tillers in fall was inversely related to the seed yield harvested the following season; therefore, it was hypothesized that by applying TE in fall the height of fall regrowth could be controlled, and therefore, seed yield increased.

The objectives of this experiment were to: 1) evaluate different timings and rates of trinexapac-ethyl application to maximize seed yield; 2) evaluate the interaction between field burning and the use of TE; and ultimately 3) develop alternative management tools to replace field burning and maintain high seed yields in creeping red fescue in the Willamette Valley.

Materials and Methods

A stand of Shademaster creeping red fescue was established at Hyslop Experimental Research Farm (lat. 44° 40' N, long. 123° 11' 36" W) near Corvallis, Oregon, USA, on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll). The crop was seeded on May 12, 1999 using an equivalent of 9 kg seed ha^{-1} in 30 cm spaced rows, and was irrigated during establishment. Fertilizer (16-20-0) at a rate of 224 kg ha^{-1}, representing 36 kg N ha^{-1}, was broadcast applied and incorporated during seedbed preparation.

The experimental design was a split plot, with four replications, where residue management and trinexapac-ethyl [4-(cyclopropyl-α-hydroxy methylene)-3,5-dioxocyclohexane carboxylic acid ethyl ester] (Palisade™) (TE) applications were the main factors. Residue management treatments were the main plots and consisted of: 1) Burn, in which the full straw load was open burned after harvest, and 2) Flail, where straw was baled and stubble was flailed low (2-2.5 cm) soon after harvest. Trinexapac-ethyl treatments with different rates and dates of application were used as subplots, and consisted of: 1) Check, with no TE application (CK); 2) Early fall application of 200 g a.i. ha^{-1} (EF200); 3) Early fall application of 400 g a.i. ha^{-1} (EF400); 4) Late fall application of 200 g a.i. ha^{-1} (LF200); 5) Late fall application of 400 g a.i. ha^{-1} (LF400); 6) Early spring application of 400 g a.i. ha^{-1} (ES); and 7) Late spring application of 400 g a.i. ha^{-1} (LS).

Each subplot was 3 m wide by 15 m long. The residue management treatment was randomly assigned to main plots first, and within each main plot, the seven TE treatments were randomly assigned to each subplot. Having the residue management treatments as main larger plots (21 x 15 m) facilitated the open-field burning. In 2000, the plots were harvested in bulk, and residue management treatments were applied subsequently. The trial was then conducted for four harvest seasons (2001 to 2004).

Trinexapac-ethyl treatments were applied at walking speed using a bicycle-type boom sprayer operated at 138 KPa with XR Teejet 8003VS nozzles, as described by Silberstein et al. (2001b). Treatment dates (Table 1-1) were selected based on growing degrees days (GDD) for fall and on plant growth stages in spring. Early fall applications took place between 3474 and 3974 GDD when weather conditions allowed the application. Late fall applications were done approximately 4 to 5 weeks after the early fall applications. The early spring application was made when tillers were rapidly elongating, and had flag leaves and some panicles visible. Periodic tiller samples were taken to determine the point of active elongation of tillers. Late spring application took place 17 to 21 days (184-233 GDD) after the early spring application.

The plots were managed using techniques appropriate for creeping red fescue seed production in the Willamette Valley. Every fall, one application of approximately 45 kg N ha^{-1} was made uniformly across the plots. In spring 2001, a total of 134 kg N ha^{-1} was broadcast in two applications, and 90 kg N ha^{-1} was applied in the following three springs.

Fertile tiller number was determined from two adjacent 0.30 x 0.30 m samples taken prior to peak anthesis from each plot. The samples were dried for

Table 1-1. Application dates and corresponding growing degree days (GDD) for TE treatments in the first year (2000/2001), second year (2001/2002), third year (2002/2003), and fourth year (2003/2004).

TE application	2000/2001		2001/2002		2002/2003		2003/2004	
timing	Date	GDD	Date	GDD	Date	GDD	Date	GDD
Early Fall	Oct 11	3587	Oct 9	3474	Oct 14	3589	Oct 20	3974
Late Fall	Nov 6	3861	Nov 9	3775	Nov 21	3953	Nov 22	4256
Early Spring	Apr 16	642	Apr 11	656	Apr 8	744	Apr 6	686
Late Spring	May 3	826	Apr 30	840	Apr 28	947	Apr 27	919

48 h at 65°C in drying chambers and total dry weight was assessed. In addition, in the third and fourth years, fertile tillers were separated from vegetative ones and fertile tiller dry weight was recorded. Proportion of fertile tillers, in weight, was calculated by dividing the fertile tiller dry weight by the total aboveground dry matter and expressed as a percentage. In addition, individual fertile tiller weight was estimated based on the fertile tiller weight divided by the number of reproductive tillers per unit area. Also, in 2003 and 2004, reproductive tillers were measured in bulk to determine the average tiller height. Only three replications were measured for 2003 while all four were measured in 2004.

Lodging was assessed by using a numerical scale from one to four, four corresponding to totally lodged stands and one to erect stands. Observations were taken prior to swathing during 2003 and 2004. Lodging values were scored considering the general condition of each plot.

Plots were harvested when the moisture content of the seed was approximately 250 g kg^{-1}. The central 1.8 m of each plot was cut with a plot swather (modified John Deere 2280), and dried in windrows to approximately 120 g kg^{-1} seed water content. Dried windrows were threshed with a plot combine (Hege, model 180). An on-site scale was used to measure the bulk seed weight harvested from each plot. A seed subsample was taken at harvest and cleaned with an M-2B Clipper air-screen seed cleaner to determine clean-out. Percent clean-out of the subsamples was used to calculate clean seed yield. Cumulative seed yield was calculated by adding the four years seed yield for each plot.

Statistical analysis was conducted on a plot mean basis with the SAS statistical package. Analyses of variance were carried out to test residue management and TE application effects. Fisher's protected least significant difference (LSD) values were used for mean comparisons.

Results

Seed Yield

Residue management and TE treatment effects on seed yield were different across years (Fig. 1-1). Overall, there was a tendency for decreasing seed yield as the stand aged, especially in non-burned plots.

First Year (2001)

In the first year, there was a TE-residue management interaction for seed yield (Table 1-2). Both early and late spring treatments showed an increase in seed yield when compared with the rest of the treatments whether plots were flailed or burned (Fig. 1-1). There was no difference for seed yield between the two spring applications within each residue management (Table 1-3).

No differences were found in seed yield between flailed and burned plots with spring applications. However, in flailed plots the increased yield due to spring application of TE averaged 40% for the two timings, while in burned plots yield increases averaged 28%, when compared with the untreated control within each residue management treatment. The effect of spring TE applications was greater within flailed plots than in burned plots. As one of our objectives was to look for an alternative practice for open field burning, when we used the burned untreated plots as a reference check, the increase in seed yield for the flailed spring-treated plots was 29%.

None of the fall applications of TE resulted in seed yield increases when compared with the untreated check within each residue management treatment.

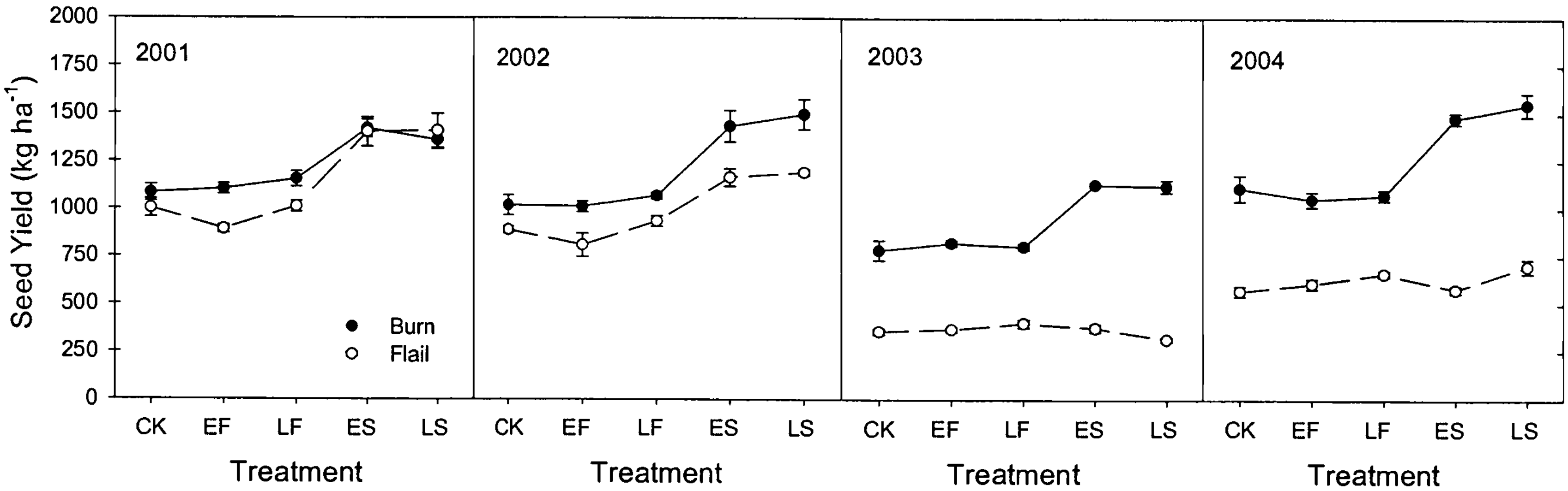

Fig. 1-1. Effect and interaction of residue management and TE treatment on seed yield in first year (2001), second year (2002), third year (2003), and fourth year (2004). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

Table 1-2. Analysis of variance for the effects of post-harvest residue management (Residue) and trinexapac-ethyl (TE) treatments on seed yield, dry matter production, and partitioning for the four years of the study.

	Seed yield	Total dry matter	Harvest index	Fertile tiller weight	Fertile tiller proportion	Individual fertile tiller weight	Tiller height	Lodging
2001								
Residue (A)	NS	NS	NS	-	-	-	-	-
TE (B)	***	NS	NS	-	-	-	-	-
A x B	*	NS	NS	-	-	-	-	-
2002								
Residue (A)	*	**	NS	-	-	-	-	-
TE (B)	***	NS	***	-	-	-	-	-
A x B	NS	NS	NS	-	-	-	-	-
2003								
Residue (A)	***	**	**	**	**	**	NS	NS
TE (B)	***	*	***	NS	NS	NS	***	***
A x B	***	NS	**	NS	NS	NS	NS	NS
2004								
Residue (A)	***	NS	**	***	**	*	NS	**
TE (B)	***	NS	***	NS	NS	*	***	***
A x B	***	*	***	NS	NS	NS	NS	NS

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels respectively.
NS= not significant.
- = not measured.

Table 1-3. Cumulative and yearly seed yield responses to residue management and TE treatment combinations for four years. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

	2001		2002		2003		2004		Cumulative	
Treatment	Burn	Flail	Burn	Flail	Burn	Flail	Burn	Flail	Burn	Flail
	---------- kg ha^{-1} ----------									
Untreated	1083 a*	1001 b	1271 §	1109	782 a	355 ab	1108 a	569 a	4245 a	3035 abc
EF										
200 g a.i./ha	1111 a	863 a	1259	1095	825 a	372 ab	1046 a	606 ab	4241 a	2936 ab
400 g a.i./ha	1094 a	920 ab	1268	925	818 a	364 ab	1054 a	609 ab	4234 a	2818 a
LF										
200 g a.i./ha	1136 a	994 b	1337	1191	814 a	383 ab	1033 a	654 ab	4320 a	3222 bc
400 g a.i./ha	1172 a	1026 b	1332	1144	793 a	417 b	1112 a	668 ab	4409 a	3254 c
ES										
400 g a.i./ha	1419 b	1401 c	1791	1455	1127 b	376 ab	1476 b	580 ab	5813 b	3811 d
LS										
400 g a.i./ha	1358 b	1407 c	1869	1488	1119 b	316 a	1550 b	702 b	5896 b	3913 d
Mean	1196	1088	1447	1201	897	369	1197	627	4737	3284

* Means in columns, followed by the same letter are not significantly different by Fischer's protected LSD values (*p=0.05*).

§ Residue management and TE treatment effects were observed in 2002, but there was no interaction between the factors.

There generally was no difference for seed yield between burned and flailed plots for each TE treatment, with the exception of lower seed yield in early fall-treated flailed plots. Burned plots without spring application of TE showed a tendency to higher seed yield when compared with flailing without spring application of TE.

Second Year (2002)

In the second year, there was no interaction between residue management and TE treatment (Table 1-2), therefore the response pattern to TE treatments was similar in both burned and flailed plots. There was a significant effect of field burning on seed yield (Fig. 1-1). Burned plots resulted in higher seed yield than failed ones regardless of TE application. The difference between burned and flailed plots in seed yield was 246 kg ha^{-1} on average (Table 1-3).

There was also a TE treatment effect on seed yield (Fig. 1-1). Both early and late spring applications of TE resulted in higher seed yields when compared with the control and fall treatments. The early spring application resulted in a 433 kg ha^{-1} increase in seed yield, and the late spring one showed an increase of 488 kg ha^{-1} over the control, regardless of residue management (Table 1-3). There were no differences between spring treatments. The seed yield increase observed after a spring TE application represented, on average, 44% for burned plots and 33% for flailed plots when compared with the respective untreated check. When compared with the burned-untreated check, flailed spring treated plots showed an increase in yield of 15.7%.

Even though there was no difference between late fall TE applications and the untreated check, there was a trend for plots with late fall TE treatments to yield more than the untreated check (Fig. 1-1). In the same way, there was a trend for plots with early fall TE applications to yield less than the untreated check. There was no difference between the two fall rates. As a result of residue management and TE treatment effects, open-field burning plus spring application of TE showed an increase in seed yield of 706 kg ha^{-1} over the untreated, flailed check in the second year of the trial (Table 1-3).

Third Year (2003)

In the third year, seed yields generally decreased from that observed in previous years, a phenomenon also observed in aging stands of creeping red fescue (Canode and Law, 1975) (Fig. 1-1). The normal aging pattern was magnified by the dry weather conditions experienced at the end of May and the beginning of June (Table 1-4), which coincided with flowering. There was an interaction between residue management and TE treatment (Table 1-2), which was reflected by a differential response to TE applications in burned versus flailed plots.

Open-field burning plus spring application of TE showed the highest seed yields again in the third year (Fig. 1-1). In addition, burned plots resulted in greater seed yields than flailed plots, regardless of TE application. There was generally no difference among the TE treatments within flail plots.

Table 1-4. Weekly summary of mean maximum temperature and daily precipitation measured daily at Hyslop Farm, Corvallis, Oregon. Long –term averages for this site are compared with the four years of the experiment.

		Mean Max Temperature					Daily Precipitation				
Month	Week	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

Burned plots responded positively to spring applications of TE resulting in higher yields than fall-treated and the untreated check (Fig. 1-1). Seed yield was increased by 44% with early spring applications and by 43% with late spring applications on burned plots, while no increase was found for the same treatments on flailed plots (Table 1-3), contradicting the previous years' results. On average, flailed plots resulted in 53% lower seed yield than the untreated burned check, and in 67% lower seed yield than the spring-treated, burned plots.

Fourth Year (2004)

In the fourth year, there was also an interaction between residue management and TE treatment for seed yield (Table 1-2). Surprisingly, for the fourth year of the study, seed yields were, in general, higher than those of the third year and, in some cases, even higher than in the first year (Table 1-3).

Burned plots had higher seed yields than flailed ones, regardless of TE application (Fig. 1-1). Within burned plots, spring applications of TE resulted in higher seed yields than the untreated check and fall applications. There was a 33% increase in seed yield for the early spring application and a 40% seed yield increase for the late spring application, when compared with the untreated check in burned plots (Table 1-3). Among flailed plots, treatments in late spring showed a 23% seed yield increase when compared with the untreated flailed check, but still represented a 37% lower seed yield than in untreated burned plots.

Cumulative Seed Yield

There was an interaction (p= 0.002) for cumulative seed yield when analyzed across the four years (Fig. 1-2). Burned and spring TE treated plots showed the highest seed yield. A total seed yield increase of 1569 and 1652 kg ha^{-1} was found for the early and late spring treatments, respectively over the burned untreated check. This yield increase represented, on average, a 38% improvement in the cumulative yield of seed over the four-year period. There was no difference between the untreated check and fall TE treated plots for cumulative yield within burned plots.

Spring TE treated flail plots showed higher cumulative seed yield than the untreated flail check. Even though there was no difference between the two spring treatments, early spring TE treated flailed plots yielded 777 kg ha^{-1} more than the untreated flailed check, while the increase in cumulative yield for late spring TE treated flailed plots was 878 kg ha^{-1}. These yield increases averaged 27% of the untreated flail check. Neither of the fall TE treatments resulted in higher cumulative seed yield than the untreated check. The late spring TE application was the only treatment in flail plots that was not different from the burned untreated check.

Total Aboveground Dry Matter

In the first year, there was no effect of the treatments and their combinations on aboveground total dry matter production (Table 1-2). However, in the second and third years, there was a residue management effect on the total

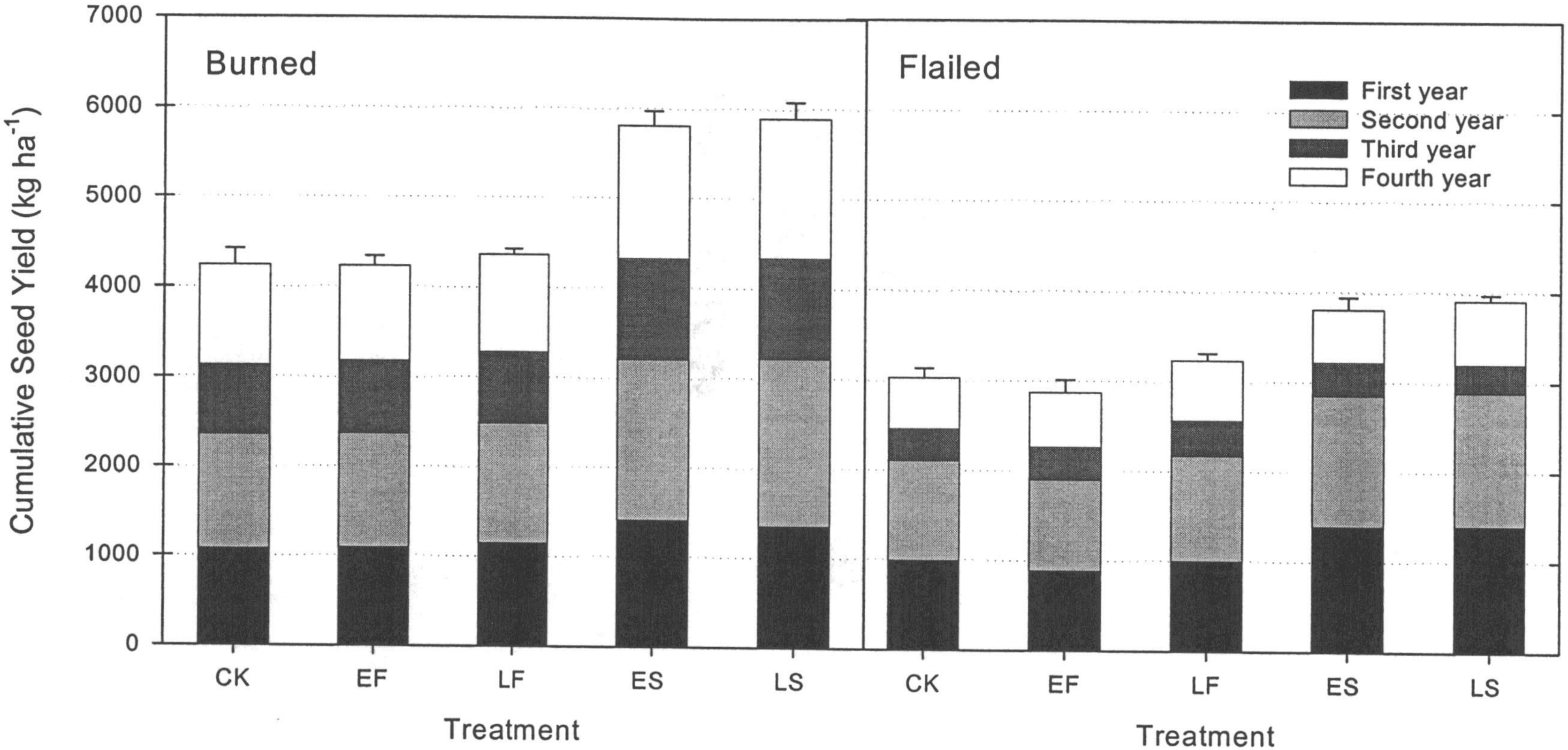

Fig. 1-2. Cumulative seed yield for residue management and TE treatment combinations. As no differences between the two fall TE rates were noted, fall treatment effects were averaged over the two rates. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. T bars represent one standard error of the cumulative yield mean for each of the treatment combinations.

aboveground dry weight (Fig. 1-3). Burned plots produced 34 and 56% greater dry matter than flailed plots in 2002 and 2003, respectively. In 2003, there was also a TE treatment effect on total dry matter (Table 1-2) where early spring treated plots produced 27% less total dry weight than the untreated check, regardless of the residue management treatment. Late spring TE application followed the same trend but was not different than the untreated check.

Contrary to the results in previous years, there was an interaction between residue management and TE treatment for total aboveground dry matter in 2004 (Table 1-2). Although fall treatments and the check in general resulted in higher dry matter when burned than when residue was mechanically removed, spring applications of TE in burned plots resulted in the lowest total biomass production (Fig. 1-3). There was a 31% reduction in total aboveground dry matter for spring-treated, burned plots over the untreated burned check. There were no differences in total aboveground dry matter between TE treatments within the flailed plots.

Fertile Tiller Dry Matter

Reproductive dry matter was recorded for 2003 and 2004. In 2003, field burning affected fertile tiller dry matter (Table 1-2), which was 193% higher in burned plots than in flailed plots (Fig. 1-4a). Consequently, field burning caused a greater proportion of the total aboveground dry matter to be represented by fertile tillers than in the non-thermal treatment, regardless of TE application (Fig. 1-4b). In burned plots, 65% of the total aboveground dry matter was accounted for by fertile tillers, while in flailed plots fertile tillers were only 35% of the total weight.

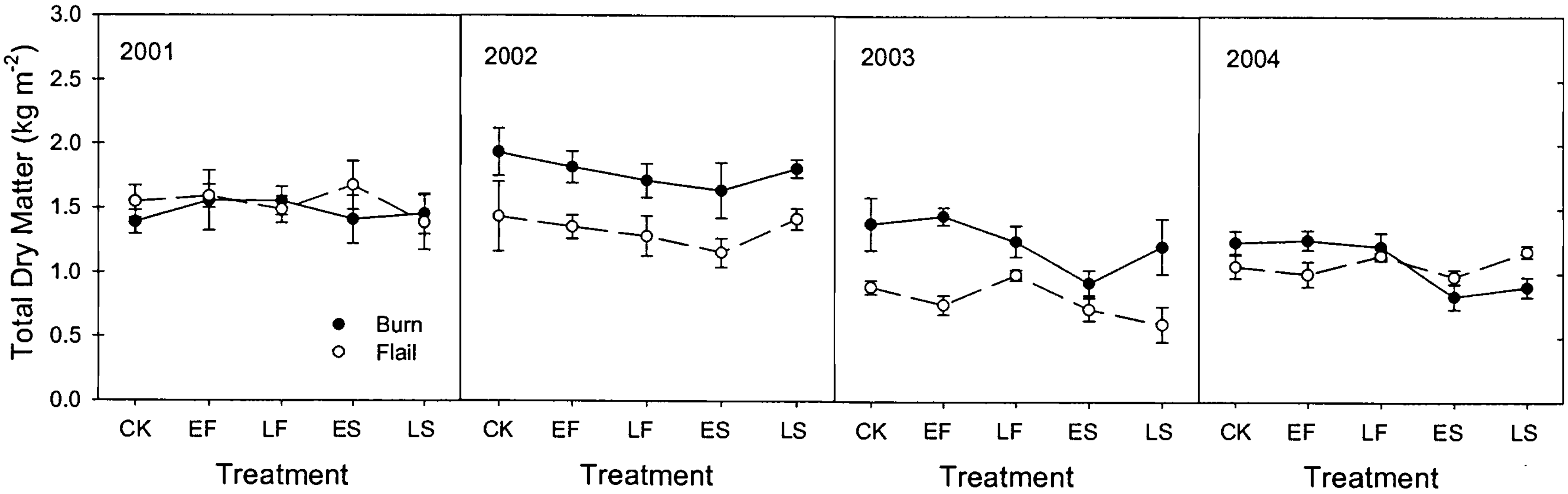

Fig. 1-3. Effect and interaction of residue management and TE treatment on total aboveground dry matter in first year (2001), second year (2002), third year (2003), and fourth year (2004). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

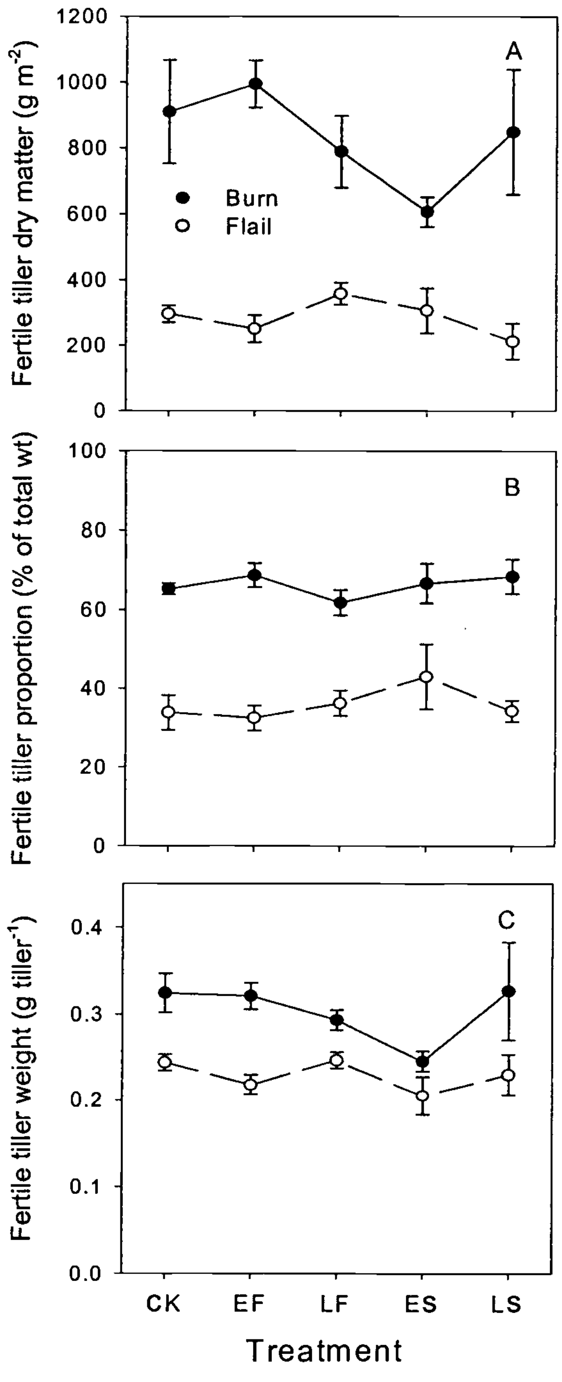

Fig. 1-4. Effect of residue management and TE treatment in 2003 on A) Fertile tiller dry matter; B) Fertile tiller proportion; and C) Fertile tiller individual weight. As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of two late fall treatments; ES=early spring treatment; LS=late spring treatment. Vertical bars represent one standard error of the mean for each treatment combination.

As in 2003, fertile tiller dry matter increased by 102% as a result of open-field burning in 2004 (Fig. 1-5a); thereby causing a difference in fertile tiller proportion between burned and flailed plots (Fig. 1-5b). Burned plots had 70% of the aboveground total dry matter accounted for by fertile tillers, while in flailed plots only 36% of the total aboveground dry matter was comprised of fertile tillers.

Individual Fertile Tiller Weight

When individual fertile tiller weight was calculated, a residue management effect was found for 2003 and 2004 (Table 1-2). In 2003, burned plots produced fertile tillers that were 32% heavier than in flailed plots (Fig. 1-4c). Similarly, in 2004, individual fertile tillers from burned plots weighed 19% more than those from flailed plots (Fig. 1-5c). There was also a TE treatment effect on individual fertile tiller weight for 2004. Early spring TE treatment showed a 15% reduction in dry weight over the untreated check, regardless of residue management.

Harvest Index

In 2001, there was no effect of residue management or TE treatment on harvest index (HI) (Table 1-2); nevertheless, spring-treated plots and burned plots exhibited a trend toward higher HI values (Fig. 1-6). In 2002, there was an effect of TE treatment on HI. Spring treated plots had a 48% increase in HI over the untreated check, regardless of residue management.

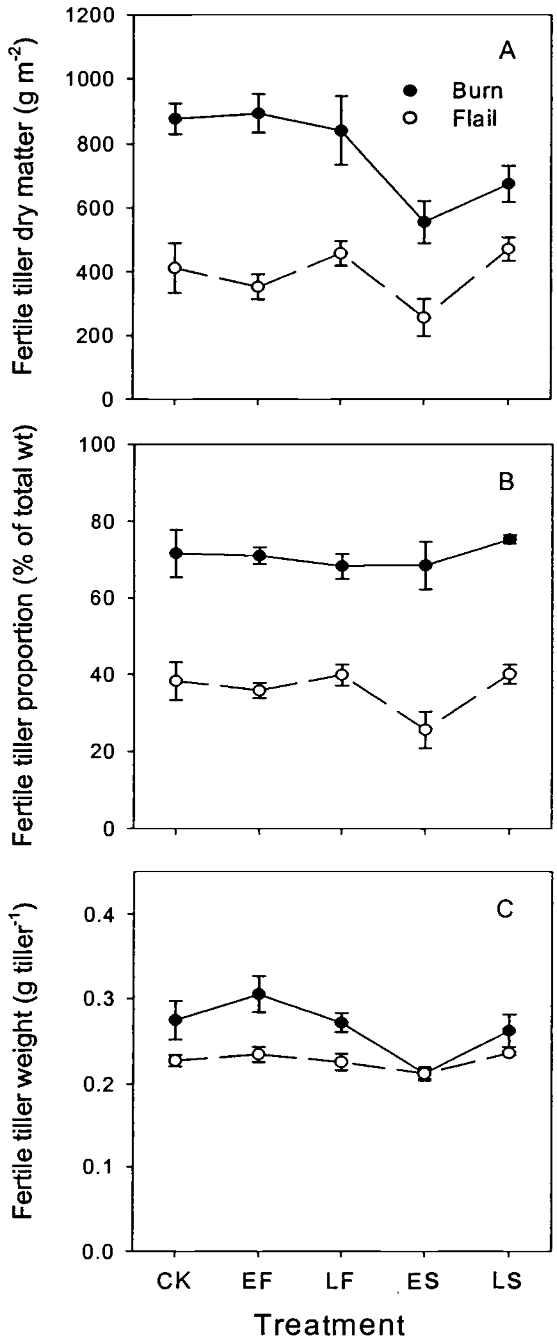

Fig. 1-5. Effect of residue management and TE treatment in 2004 on A) Fertile tiller dry matter; B) Fertile tiller proportion; and C) Fertile tiller individual weight. As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of two late fall treatments; ES=early spring treatment; LS=late spring treatment. Vertical bars represent one standard error of the mean for each treatment combination.

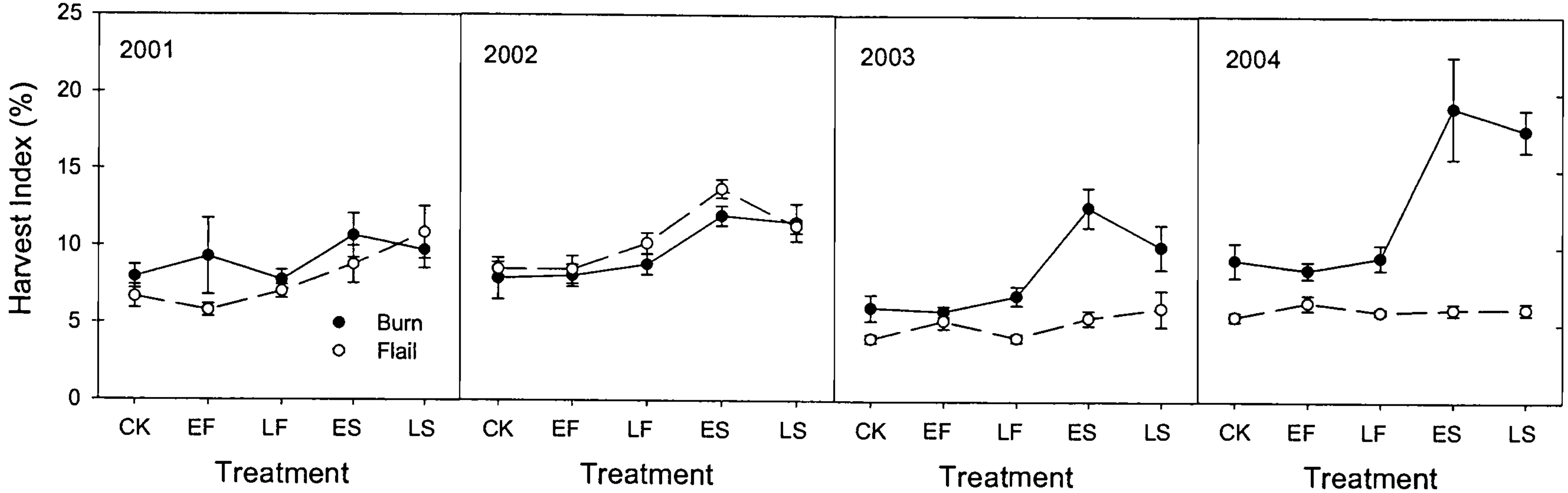

Fig. 1-6. Effect and interaction of residue management and TE treatment on harvest index in first year (2001), second year (2002), third year (2003), and fourth year (2004). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

In the third and fourth years, there was an interaction of residue management and TE application for HI (Table 1-2). The response of HI to the different treatment combinations (Fig. 1-6) was similar to that found for seed yield (Fig. 1-1). Burned plots treated with TE in the spring showed a greater HI than the other burned plots. Harvest index for spring-treated, burned plots was 88 and 100% greater than the untreated burned check for 2003 and 2004, respectively. There was no difference in HI within nonburned plots. Burned and spring treated plots exhibited the greatest HI. Nevertheless, HI tended to be greater for burned plots, regardless of TE application.

Discussion

Spring TE applications increased seed yield in creeping red fescue in agreement with the findings of others (Chastain et al., 2001; Gingrich and Mellbye 2001; Silberstein et al., 2001b, 2002; Chastain et al., 2003; Rolston et al., 2003). However, seed yield response to spring TE applications was different for flailed and burned plots as the stand aged. The hypothesis that regulating tiller growth in fall with TE would increase seed yield, was not valid. No difference in seed yield between the two fall rates of TE was found.

In the first two years, while the stand was still young, seed yield increases between 28 and 44% were consistently achieved with spring TE applications, regardless of residue management. In addition, in the first year of the trial there was almost no difference in seed yield between burned and flailed plots, especially when spring applications of TE were made, but in the second year there was an increase in seed yield as a result of field burning. Our results confirm previous reports of increased seed yield as a result of open-field burning in creeping red fescue (Pumphrey, 1965; Chilcote et al., 1980; Young et al., 1998a). Better conditions for fall regrowth of burned plots, resulted in higher potential seed yield, in conjunction with the reduction of lodging demonstrated elsewhere for spring TE applications, produced the greatest seed yields for spring treated burned plots in the second year.

As the stand aged and flailed plots increased in stand density, the differences in seed yield between burned and flailed plots were greater and flailed plots no longer responded to spring TE applications. Fairey and Lefkovitch

(1996a) showed that seed yield was closely related and dependent on stand density in creeping red fescue, and reported lower seed yields for denser stands as the stand ages. In addition, Canode (1972) and Lamb and Murray (1999) reported that although mechanical residue removal resulted in greater or no difference in seed production for the first two years in Kentucky bluegrass (*Poa pratensis* L.), burning produced higher seed yields in the following two years. The creeping growth habit of Kentucky bluegrass is comparable to that of creeping red fescue. Both species are less tolerant to residue management without thorough straw and stubble removal than bunch-type species like perennial ryegrass and tall fescue (Chastain et al. 2000). Even though post-harvest residue was largely removed with the mechanical method, field burning ensured a more complete removal of the residue.

Meints et al. (2001) stated that stubble removal to the plant crown is crucial for maximizing seed yield in creeping red fescue. Accordingly, in 2003 and 2004, when flailed plots had greater stand density and rows were almost not detectable, only burned plots had a yield increase of 44% and 37% for early spring and late spring TE applications, respectively, over the untreated check. In addition, seed yields from burned non-spring treated plots were consistently higher than those of flailed plots with and without spring applications of TE. Confirming the results of Chastain et al. (1996b) and Young et al. (1998a), seed yield in creeping red fescue could not be maintained over time without open burning post-harvest residue.

Overall, the third year produced low seed yield, but still open-field burning and spring TE applications had a positive effect in overcoming a portion of the seed yield depression in the aging stand over years (Chastain et al., 2001). Open-field burning and TE spring applications helped maintain seed yield as the stand aged. The low seed yields harvested in the third year may have been exacerbated by the dry late spring, which could have impacted fertilization and seed filling. Interestingly, in the third year, the late spring treatment in flailed plots produced the lowest seed yield, while in the fourth year, the same treatment resulted in the highest seed yield for flailed plots.

Plots that did not receive TE in spring had higher lodging scores than spring-treated plots, regardless of residue management. There is an increasing body of evidence that suggests that lodging in cool-season grasses for seed production may result in restricted pollination, reduced rate of fertilization, and therefore lower seed set. In addition, lodging can result in inhibition of seed filling due to self-shading of the lodged crop (Silberstein et al., 2001a, b; Chastain et al., 2001; Silberstein et al., 2002).

When the cumulative seed yield was analyzed, it was not surprising to find that burned and spring-treated plots demonstrated significantly higher seed yield at the end of the four years. The increase in seed yield of spring-treated, burned plots over the untreated burned check represented the equivalent of 1.5 additional seed harvests for burned plots by the end of the fourth year. However, fall TE treatments did not result in a cumulative seed yield increase, showing that TE is not effective in fall applications and should be applied only in spring if a significant seed yield increase is to be expected. These findings are in accordance with Chastain et al. (2003) who reported that TE does not have a residual effect.

Following the pattern of the burned plots, neither fall TE treatment resulted in greater cumulative seed yield than the untreated check within flailed plots. Furthermore, none of the fall TE treatments showed cumulative seed yield comparable to those of the untreated burned check, confirming that fall TE applications are not a viable and sustainable option to replace open-field burning in creeping red fescue seed production, at least if the stand is expected to be productive for four years. Even though the spring TE treatments increased yield by an amount comparable, on average, to one extra production year of flailed plots, the increase was not enough to outyield the untreated burned check. Although the late spring TE treatment in flailed plots was found not different from the untreated burned check, the early spring flailed treatment resulted in lower cumulative yield than the untreated burn check. No differences were found between early and late spring applications within each residue management treatment, confirming that creeping red fescue has a wide application window for TE (Silberstein et al., 2002).

Not only was field burning associated with an increase in seed yield, but it was also associated with an increase in harvest index as noted in the earlier findings of Chilcote et al. (1980) and Young et al. (1998a). Spring applications of TE were related to higher harvest index as well, implying that spring-treated, burned plots were more efficient in partitioning dry matter to seed yield than fall treated and untreated plots, especially as the stand aged.

Total aboveground dry matter production responded to field burning in the second and third year, similar to the findings of Lamb and Murray (1999), who reported a 24 to 36% reduction in aboveground biomass in some cultivars of Kentucky bluegrass with non-thermal residue management. Even though in the first two years there was no effect of TE on total dry matter, during the third year early spring treated plots produced less biomass than the check, regardless of residue management. The lack of reduction in dry matter for late spring treated plots could be due to the fact that reproductive tillers were more developed at the time of TE application. In the fourth year, it was interesting to observe a residue management x TE treatment interaction, where spring-treated burned plots produced the lowest total dry matter production.

The important difference in fertile tiller proportion between burned and flailed plots may imply a differential partitioning of photoassimilates, favoring fertile tillers in burned plots, which exhibited higher dry matter of fertile tillers. The increased fertile tiller dry matter in burned plots was not only due to a greater number of fertile tillers per area, but also to a greater individual fertile tiller dry weight. Fertile tillers from burned plots were larger and had higher dry matter partitioning than those from flailed plots. The higher seed yields obtained in burned plots, coincident with heavier fertile tillers at the time of anthesis is in agreement with Canode and Law (1979), and Sylvester and Reynolds (1999), who reported that tiller size was positively correlated with high potential productivity.

Conclusion

Although it was hypothesized that fall TE applications might increase seed yield by replacing field burning in manipulation of fall regrowth, fall applications of TE did not increase seed yield. Open-field burning is critical for maintaining seed yield in creeping red fescue as the stand ages, and fall TE applications are not a viable alternative.

Spring applications of TE contributed to higher yields in burned and flailed stands the two first years, and positively interacted with open-field burning, fostering the seed yield increase caused by open field burning as the stand aged. When the cumulative yields were analyzed, burning and applying TE both early and late in spring resulted in an equivalent of 1.5 additional seed harvests by the end of the four years. Both open-field burning and spring TE application resulted in a more efficient crop, reflected in the greater harvest index.

Spring TE applications were promising as a potential alternative to open-field burning during the two first years of the trial, but as the stand aged, open-field burning became critical for maintaining high seed yields, and spring TE applications did not increase yield on flailed plots. According to these results, a high priority should be given to creeping red fescue when allocating the area that is allowed for open-field burning each year.

Considering that Lamb and Murray (1999) and Johnson et al. (2003), reported a strong interaction between post-harvest residue management and different cultivars and accessions of Kentucky bluegrass, it must be noted that only one cultivar of creeping red fescue was used in this experiment.

Extrapolation of these results to other production environments and cultivars should be done with caution.

Comparing continuous open-field burning, with mechanical removal of post-harvest residue during the first two years and burning after the second seed production year of creeping red fescue, merits further investigation. In addition, the use of TE spring applications on flailed plots might be considered as an alternative to open-field burning if shorter stand life is economically feasible. If open-field burning is banned, studies should be conducted to evaluate the economic viability of shorter-lived stands.

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MANUSCRIPT II: TRINEXAPAC-ETHYL AND OPEN FIELD BURNING IN CREEPING RED FESCUE (*Festuca rubra* L.) SEED PRODUCTION: II. SEED YIELD COMPONENTS.

Abstract

Open-field burning has been successfully used as a management tool to remove residue in order to maintain seed yield and quality in seed production fields of creeping red fescue (*Festuca rubra* L.). However, public concern over air pollution caused by open-field burning resulted in significant, legislatively mandated reductions in the area burned per year in the Willamette Valley. The use of the plant growth regulator trinexapac-ethyl (TE) was evaluated as a potential alternative to open-field burning, over a four-year period, in a stand of creeping red fescue at Hyslop Experimental Research Farm near Corvallis, Oregon, USA. The effects of open-field burning versus mechanical removal (flailing) of post-harvest residue, and spring versus fall applications of TE on seed yield and seed yield components were evaluated. The response to the treatment combinations was different across years and, as the stand aged, open-field burning was critical for maintaining high potential seed yields. Field burning generally increased the numbers of spikelets per panicle and panicles per unit area over the flailing treatment, and resulted in higher seed yields. Spring TE applications positively affected the number of florets per spikelet in the first, third, and fourth year. Fertile tiller height and lodging score were reduced by spring TE applications, which were postulated to improve the crop environment around anthesis and showed a trend towards greater floret site utilization than non-spring treated plots. Consequently, field burning is critical for attaining high potential

seed yield over the life of the stand, and TE applied in spring favors high seed yields, regardless of residue management on young stands, and on burned older stands. Fall TE applications were not an effective alternative to open-field burning in creeping red fescue seed production.

Introduction

Open-field burning, an economical and effective practice to manage crop residue of post harvest residue in creeping red fescue in the Willamette Valley (Hardison, 1980; Chastain et al., 1996a, b; Rolston et al., 1997; Meints et al., 2001), has been greatly restricted by legislative actions due to air quality and safety issues. Alternative residue management practices have been tested for maintaining high yields as field burning is limited in creeping red fescue, but no effective alternative practices were found (Chastain et al., 1999). Trinexapac-ethyl (TE), a foliar-applied plant growth regulator, commercialized in the USA as Palisade™, has been shown to improve seed yields of creeping red fescue when applied in spring (Gingrich and Mellbye, 2001; Silberstein et al., 2001b, 2002; Zapiola and Chastain, 2004); nevertheless, contrary to open-field burning and spring TE applications, TE applied in fall have not increased seed yield.

Seed yield in perennial grasses is a complex characteristic that depends on closely interacting components (Ibrahim and Frakes, 1984). Seed yield is ultimately the product of seed number per unit area and the individual seed weight; however, the number of fertile tillers per unit area, spikelets per inflorescence, florets per spikelet, and floret site utilization influence the number of seeds per unit area, which is closely related to seed yield (Hebblethwaite et al., 1980; Elgersma, 1990; Young et al., 1998a). In general, seed yield is positively correlated with fertile tiller number up to a point where greater fertile tiller number does not result in higher seed yield (Hampton and Fairey, 1997). Young et al. (1998a) and Meints et al. (2001) found that the number of fertile tillers was closely related to seed yield of creeping red fescue. Failey and Lefkovitch (1996b) found that seed yield in creeping red fescue was closely correlated with the number of panicles per m^2, which increased with density in the first year, but decreased as density increased with the aging stand. However, Lamb and Murray (1999) reported that, in Kentucky bluegrass (*Poa pratensis* L.), panicle density is not always a reliable indicator of seed yield.

Spikelets per fertile tiller usually do not affect seed yield, but when tiller number is reduced, it may have a greater impact in seed yield (Hampton and Fairey, 1997). Tillers emerging early in fall will accumulate more leaf primordia in the apex and therefore will have higher number of spikelets per inflorescence (Anslow, 1963; Hebblethwaite et al., 1980). The number of florets per spikelet is not usually correlated with seed yield, but is known to be influenced by the environment, tiller age, and number (Hampton and Fairey, 1997). The utilization of the yield potential is determined by events at and after anthesis (Hebblethwaite et al., 1980). Seed yield is largely dependent on the degree of floret site utilization, i.e., percentage of florets that result in viable seed (biological sense) or in harvested seed (economical sense) (Elgersma, 1985). Seed weight depends mainly on the position of the seed within the spikelet (Hampton and Fairey, 1997), and is usually not affected by management practices (Marshall, 1985).

Open-field burning resulted in higher number of panicles per unit area and seed yield than nonthermal management practices in creeping red fescue (Chilcote et al., 1980; Chastain et al., 1999; Meints et al., 2001). Young et al. (1998) found a greater number of panicles , and consequently more floret sites and seeds produced per unit area when open-field burning was compared with three other methods of post-harvest residue management in creeping red fescue. Spikelets per panicle and florets per spikelet were unaffected.

There is an increasing body of evidence demonstrating the seed yield enhancing effect of TE spring applications in creeping red fescue (Gingrich and Mellbye, 2001; Silberstein et al., 2001b, 2002); however, little information is available about how TE applications affect yield components. Silberstein et al. 2002 observed that fertile tiller number and 1000 seed weight were not affected by TE applied in spring in creeping red fescue, but lodging was reduced and harvest index increased. Spring applications of TE increased seed yields in Kentucky bluegrass and rough bluegrass (*Poa trivialis* L.) over the untreated plots, and the yield increase was associated with reduced plant height and lodging, but no change in 1000 seed weight was observed (Butler and Campbell, 2003). When evaluated in perennial ryegrass (*Lolium perenne* L.), spring TE applications increased seed yield as a result of greater number of florets per spikelet and improved seed set (Chastain et al., 2001, 2003). Rolston et al. (2003) reported a seed yield increase after TE was spring-applied in forage tall fescue (*Festuca arundinacea* Schreb.), which was associated with shorter stems, a marked reduction in lodging, and increased seed yield per panicle.

The objective of this experiment was to evaluate the effect and interaction of open-field burning and fall and spring applications of TE on seed yield components of creeping red fescue, in order to understand how seed yield is affected by these practices.

Materials and Methods

A stand of Shademaster creeping red fescue was established in 1999 at Hyslop Experimental Research Farm (lat. 44° 40' N, long. 123° 11' 36" W) near Corvallis, Oregon, USA, on a Woodburn silt loam soil (fine-silty, mixed, mesic, Aquultic Argixeroll). The experimental design was a split plot, with four replications, where residue management and trinexapac-ethyl [4-(cyclopropyl-*α*-hydroxy methylene)-3,5-dioxocyclohexane carboxylic acid ethyl ester] (Palisade™) (TE) applications were the main factors. Residue management treatments were used as main plots and consisted of: 1) Burn, in which the full straw load was open burned after harvest time, and 2) Flail, where straw was baled and stubble was flailed low (2-2.5 cm) soon after harvest. Trinexapac-ethyl treatments with different rates and dates of application were used as subplots, and consisted of: 1) Check, with no TE application (CK); 2) Early fall application of 200 g a.i. ha^{-1} (EF200); 3) Early fall application of 400 g a.i. ha^{-1} (EF400); 4) Late fall application of 200 g a.i. ha^{-1} (LF200); 5) Late fall application of 400 g a.i. ha^{-1} (LF400); 6) Early spring application of 400 g a.i. ha^{-1} (ES); and 7) Late spring application of 400 g a.i. ha^{-1} (LS).

Each subplot was 3 m wide by 15 m long. The residue management treatment was randomly assigned to main plots first, and within each main plot, the seven TE treatments were randomly assigned to each subplot.

Details of planting, crop management, and TE treatment timing were described previously (Zapiola and Chastain, 2004).

Fertile tiller number was determined from two adjacent 0.30 x 0.30 m samples taken prior to peak anthesis from each plot. In 2003 and 2004, reproductive tillers were measured in bulk to determine the average tiller height. Only three replications were measured for 2003 while all four were measured in 2004.

Seed yield components, spikelets per panicle and florets per spikelet, were ascertained from samples consisting of 16 randomly chosen panicles for each plot taken before peak anthesis. The number of spikelets per panicle was determined for 10 of the 16 panicles, averaged, and a plot mean was used for the analysis. Floret number per spikelet was determined by counting the florets in two spikelets positioned at the bottom, middle, and top of four randomly selected panicles from each sample. The mean from the three positions for the four panicles constituted the number of florets per spikelet. Following Warringa et al. (1998a), small, top florets in a spikelet were regarded as nonfertile and omitted if they did not protrude beyond the subtending floret.

Lodging was assessed by using a numerical scale from one to four, four corresponding to totally lodged stands and one to erect stands. Observations were taken before swathing for 2003 and 2004. Lodging values were scored considering the general condition of each plot.

One thousand seed weight was determined from a harvested subsample cleaned by using hand screens and a blower during 2003 and 2004. For each plot, two samples of 1000 seeds were counted with an electronic counter, weighed, and averaged.

Number of seeds per unit area at harvest was calculated for 2003 and 2004 by dividing the clean seed weight per unit area by the individual seed weight. Floret site utilization (FSU), in the economical sense, is the percentage of florets present at anthesis that contribute to the amount of harvested seed (Elgersma, 1985) and was calculated for the third and fourth year. Floret site utilization, in the economical sense, was estimated by dividing the seeds harvested per unit area by the number of florets sites present at anthesis and expressed as a percentage. The economical sense represents a lower value than the FSU in the biological sense, which is defined by Elgersma (1985) as the percentage of florets, present at anthesis, resulting in viable seeds and therefore does not consider the loss of shattered or small seed during harvest.

Statistical analysis was conducted on a plot mean basis with the SAS statistical package. Analyses of variance were carried out for each character to test residue management and TE application effects. Fisher's protected least significant difference (LSD) values were used for mean comparisons. In order to elucidate the nature of relationships between yield components and seed yield, we conducted regression analyses.

Results

The different yield components showed differential responses to residue management and TE treatments in the different years as the stand aged. Some yield components varied in their response to residue management and TE more than others.

Panicles per Square Meter

During the first and second years, there was no evidence of a residue management or TE application effect on the number of panicles per m^2 (i.e., fertile tiller number) (Table 2-1).

In the third and fourth year, the number of panicles per unit area was affected by residue management treatment (Fig. 2-1). In 2003, the 56% increase observed in fertile tiller dry matter (Zapiola and Chastain, 2004) was matched with a 120% increase in panicle number for burned plots versus flailed plots (Table 2-2). In 2004, the number of panicles per m^2 for burned plots was 69% greater than in flailed plots. Burned plots did not show a correlation between panicle number per unit area and seed yield; however, panicle number was correlated with seed yield (r^2= 0.69) in flailed plots (Fig. 2-2) when the four years were considered.

Spikelets per Panicle

The number of spikelets per panicle, as well as the panicle length, were not affected by residue management or TE treatment in the first year (Table 2-1), but burning exhibited a trend of greater spikelets per panicle. In the following

Table 2-1. Analysis of variance for the effects of post-harvest residue management (Residue) and trinexapac-ethyl (TE) treatments on seed yield and yield components of creeping red fescue for the four years of the study.

	Seed yield	Total dry matter	HI[1]	Panicles per unit area	Spikelets per panicle	Florets per spikelet	Florets per panicle	Seeds Per panicle	Panicle length	Florets per unit area	Seeds per unit area	FSU	1000 seed weight	Lodging score	Tiller height
2001															
Residue (A)	NS	NS	NS	NS	NS	NS	*	-	NS	NS	-	-	-	-	-
TE (B)	***	NS	NS	NS	NS	*	NS	-	NS	NS	-	-	-	-	-
A x B	*	NS	NS	NS	NS	NS	NS	-	NS	NS	-	-	-	-	-
2002															
Residue (A)	*	**	NS	NS	**	NS	NS	-	**	*	-	-	-	-	-
TE (B)	***	NS	***	NS	NS	NS	NS	-	NS	NS	-	-	-	-	-
A x B	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	-	-	-	-	-
2003															
Residue (A)	***	**	**	***	*	NS	**	NS	*	***	***	NS	**	NS	NS
TE (B)	***	*	***	NS	NS	**	*	NS	***	NS	***	NS	**	***	***
A x B	***	NS	**	NS	NS	NS	NS	NS	NS	NS	***	NS	**	NS	NS
2004															
Residue (A)	***	NS	**	***	**	NS	**	NS	*	***	***	NS	**	**	NS
TE (B)	***	NS	***	NS	NS	**	*	*	***	NS	***	NS	**	***	***
A x B	***	*	***	NS	NS	NS	NS	NS	NS	NS	***	NS	***	NS	NS

[1] HI=harvest index, FSU=floret site utilization.

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels respectively. NS= not significant.

- = not measured.

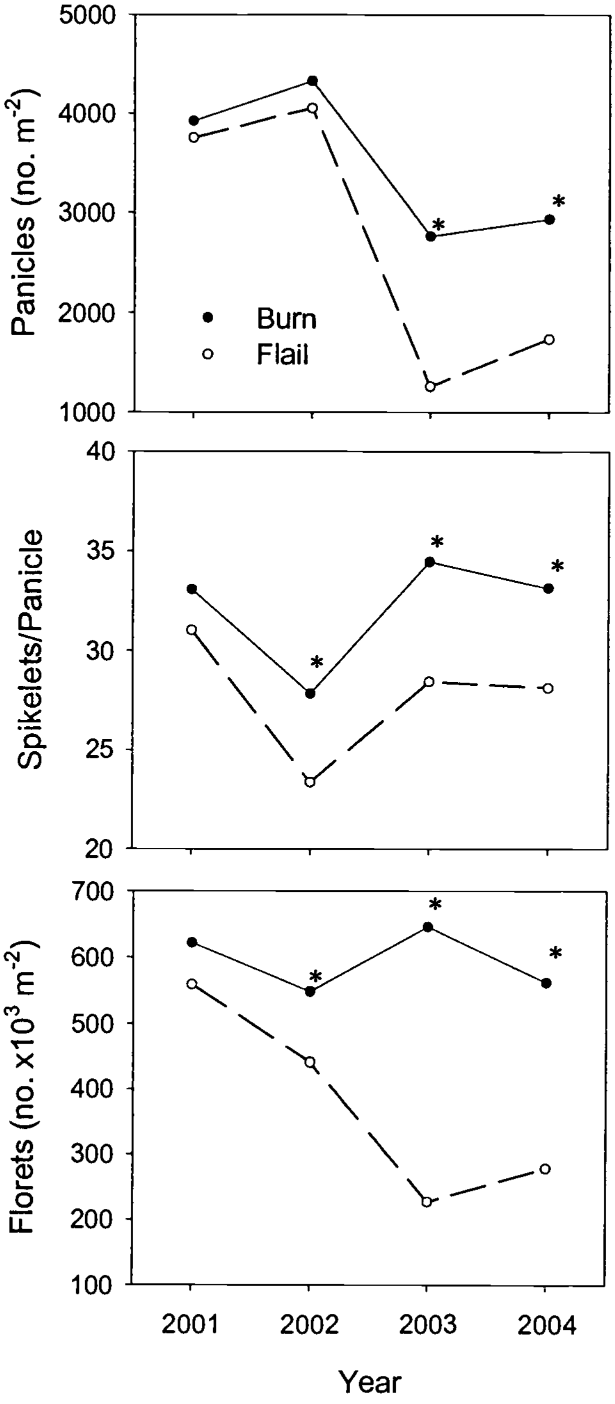

Fig. 2-1. Effect of residue management on seed yield components over four years. Each point represents the average for that characteristic of all TE treatments in that residue management. (*) Means within each year were separated by Fisher's protected LSD (p=0.05).

Table 2-2. Effect of residue management on yield components in Shademaster creeping red fescue, for the first (2001), second (2002), third (2003), and fourth (2004) year.

Characteristic	Residue	2001	2002	2003	2004
Panicles (no. m^{-2})	Burn	3922	4330	2758 a	2932 a
	Flail	3750	4052	1254 b	1733 b
Spikelets/Panicle	Burn	33	28 a*	34 a	33 a
	Flail	31	23 b	28 b	28 b
Florets/Spikelet	Burn	4.8	4.6	6.9	5.9
	Flail	4.8	4.7	6.4	5.8
Florets (no. x 10^3 m^{-2})	Burn	622	548 a	646 a	562 a
	Flail	559	442 b	227 b	278 b
Florets/Panicle	Burn	159 a	127	236 a	194 a
	Flail	149 b	110	181 b	162 b
Panicle length (cm)	Burn	13.4	11.9 a	13.1 a	12.9 a
	Flail	12.9	10.4 b	11.7 b	11.3 b
Above-ground dry weight (g m^{-2})	Burn	1495	1775	1270 a	1130 §
	Flail	1539	1496	818 b	1065

* Means in columns, within each characteristic, followed by the same letter are not significantly different by Fisher's protected LSD values ($p = 0.05$).

§ In 2004 there was an interaction between residue and TE treatments for above ground dry weight.

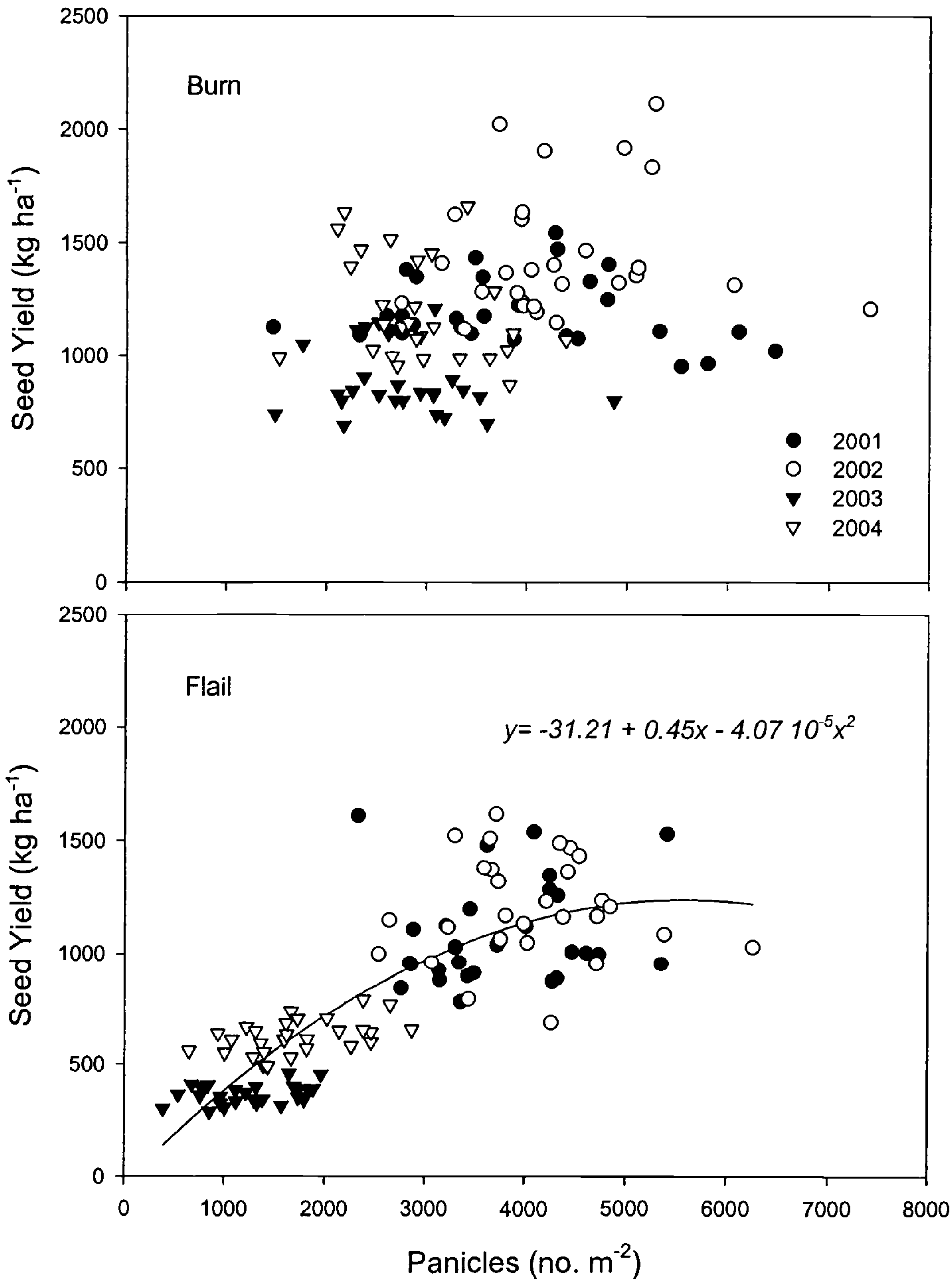

Fig. 2-2. Relation between panicle number per m^2 and seed yield for burned and flailed plots. The determination coefficient for the fitted line in flail was (r^2=0.69).

years, there was an effect of residue management on the number of spikelets per panicle. The number of spikelets per panicle was greater in burned plots when compared with flailed plots, regardless of TE treatment (Fig. 2-1).

Increases in spikelets per panicle were 22, 21, and 18% for 2002, 2003, and 2004, respectively (Table 2-2). In order to accommodate the larger number of spikelets, panicle length was also increased by residue management (Table 2-1), and resulted in 16, 12 and 14% larger panicles for burned plots in 2002, 2003, and 2004, respectively.

In addition, panicle length was affected by TE treatment in 2003 and 2004 (Table 2-1), and early spring treated plots had 9 and 12% shorter panicles than the untreated check respectively, regardless of residue management. The reduction in panicle length due to TE treatment was not coincident with an effect on the number of spikelets per panicle, since there was no effect of TE treatment on this yield component in any year.

Florets per Spikelet

There was a TE treatment effect on the number of florets per spikelet in the first year (Table 2-1) (Fig. 2-3). The early spring TE application resulted in a 14% increase in the number of florets per spikelet with respect to the untreated check, regardless of residue management (Table 2-3). The late spring application was not different from the early one, but was not different from the untreated check either. Fall treatments were not different from the untreated check.

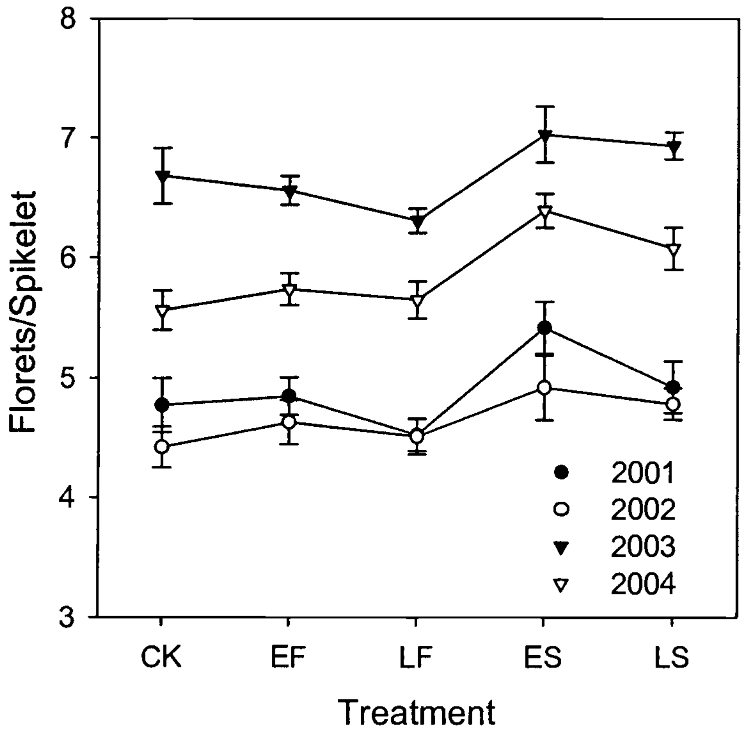

Fig 2-3. TE treatment effect on florets per spikelet in first year (2001) (●), second year (2002) (O), third year (2003) (▼), and fourth year (2004) (▽). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

Table 2-3. Trinexapac-ethyl treatment effect on florets per spikelet, and floret site utilization (FSU) in Shademaster creeping red fescue for the first (2001), second (2002), third (2003), and fourth (2004) year. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

Treatment	Florets/spikelet				FSU	
	2001	2002	2003	2004	2003	2004
	------------------ no. spikelet^{-1} ------------------				---------- % ---------	
Untreated	4.8 b*	4.4	6.7 abc	5.6 b	11.8	17.1
EF						
200 g a.i./ha	4.7 b	4.5	6.6 bcd	5.8 b	12.0	18.6
400 g a.i./ha	5.0 ab	4.8	6.5 bcd	5.6 b	15.1	18.0
LF						
200 g a.i./ha	4.4 b	4.4	6.2 d	5.6 b	12.5	16.7
400 g a.i./ha	4.6 b	4.6	6.4 cd	5.7 b	13.8	16.5
ES						
400 g a.i./ha	5.4 a	4.9	7.0 a	6.4 a	12.9	23.8
LS						
400 g a.i./ha	4.9 ab	4.8	6.9 ab	6.1 ab	16.2	19.8

*Means in columns, followed by the same letter are not different by Fisher's protected LSD values ($p = 0.05$).

Contrary to the first year results, there was no response in the number of florets per spikelets to residue management or TE application in the second year (Table 2-1). However, there was a trend for spring treatments to show a greater number of florets per spikelet than fall treatment.

During the third and fourth year, the number of florets per spikelet again demonstrated a TE treatment effect (Fig. 2-3). In 2003, the early spring TE application resulted in 8% more florets per spikelet than in fall treatments. The late fall 200 g a.i. ha^{-1} application produced lower number of florets per spikelet than the untreated check (Table 2-3).

In 2004, early spring treated plots produced the highest number of florets per spikelet (15% more than the untreated check) and, even though it was not different from the late spring application, it was the only treatment that was different from the other treatments. Burned plots had a trend of greater number of florets per spikelet than flailed plots in 2003. However, no residue management effect was detected on the number of florets per spikelet for any of the four years (Table 2-1).

<u>Florets per Panicle</u>

Even though neither spikelets per panicle nor florets per spikelet were affected by residue management in the first year, there was a residue management effect on the number of florets per panicle (Table 2-1, Fig. 2-4). Burned plots produced 7% more florets per panicle than non-burned plots (Table 2-2). In 2002, there was no residue management effect on the number of florets

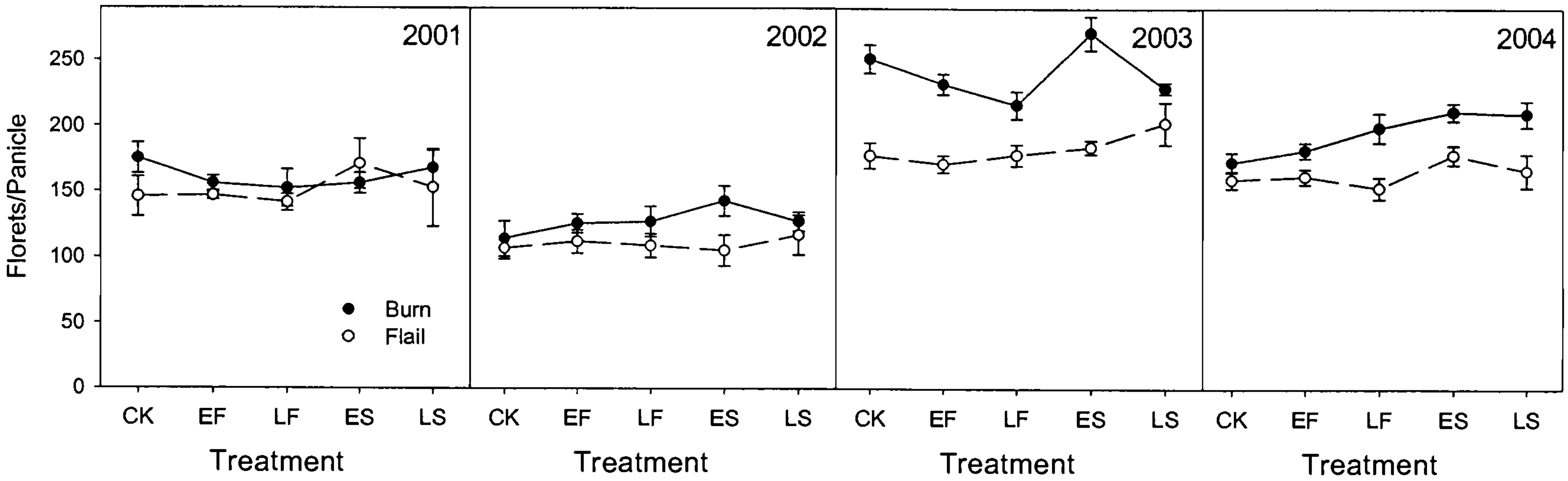

Fig. 2-4. Effect of TE treatment on the number of florets per panicle for the first (2001), second (2002), third (2003), and fourth (2004) year. As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

per panicle. However, burned plots tended to have higher number of florets per panicle. While there was no significant effect of TE treatment on the number of florets per panicle, in either of the two first years, there was a trend for spring treated plots to have a more florets per panicle (Table 2-4).

In the third and fourth year, there was a residue management and TE treatment effect on the number of florets per panicle (Table 2-1). In 2003, burning significantly increased the number of florets per panicle by 31% (Table 2-2). Although spring-treated plots were not significantly different from the untreated check, the early spring application showed a 6% increase in the number of florets per panicle over the check, and was significantly different from the early fall treatments (Table 2-4). In 2004, burning resulted in 20% more florets per panicle, and TE spring applications caused an average 15% increase over the check, regardless of residue management.

Potential Seed Yield

The number of florets per m^2 is an indicator of the potential seed yield. Pollination and fertilization conditions, as well as conditions during seed filling will influence how much of the potential yield is actually achieved at harvesting (Warringa et al. 1998b). No effect of residue management or TE application was observed in the first year for number of florets per m^2 (Table 2-1). In the three following years there was a residue management effect on the number of florets per m^2 (Fig. 2-1), but no TE treatment effect was found.

Table 2-4. Effect of TE treatment on the number of florets per panicle for the first (2001), second (2002), third (2003), and fourth (2004) year. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

Treatment	2001	2002	2003	2004
	----------------	no. florets panicle^{-1}		----------------
Untreated	160	110	215 ab	166 c
EF				
200 g a.i./ha	149	117	201 bc	168 bc
400 g a.i./ha	153	120	204 bc	176 abc
LF				
200 g a.i./ha	138	116	210 ab	186 abc
400 g a.i./ha	155	119	185 c	167 c
ES				
400 g a.i./ha	164	124	228 a	195 a
LS				
400 g a.i./ha	160	122	216 ab	188 ab

*Means in columns, followed by different letters are significantly different by Fisher's protected LSD values ($p = 0.05$).

In 2002, there was a 25% increase in the number of florets per m^2 as a result of field burning (Table 2-2). During the third year, the number of florets per m^2 in burned plots was 185% greater than in flailed plots and, in the fourth year, the increase was 102% for field burning over flailing.

<u>Seed Number per Square Meter</u>

The seed number per m^2 harvest was calculated for 2003 and 2004. In both years, there was an interaction between residue management and TE application for seed number per area (Table 2-1). Burned plots responded positively to spring applications of TE, resulting in greater seed numbers per m^2 than in fall treated plots and the untreated check (Fig. 2-5). In addition, burned plots had higher seed number per m^2 than flailed plots, regardless of TE application. Therefore, not surprisingly, burned and spring-treated plots had the greatest number of seed per m^2.

In 2003, seed number per m^2 was increased by 37% with an early spring application and by 32% with a late spring application of TE on burned plots, while no increase was found for the same treatments on flailed plots (Table 2-5). There was no difference between the TE treatments within flailed plots, other than the one existing between the late fall treated (400 g a.i. ha^{-1}) and the late spring treated with the same rate.

In the fourth year, seed number per m^2 was increased by 31% with the early spring application and by 33% with the late spring application of TE on burned plots (Table 2-5). The only difference for TE treatments within flail plots,

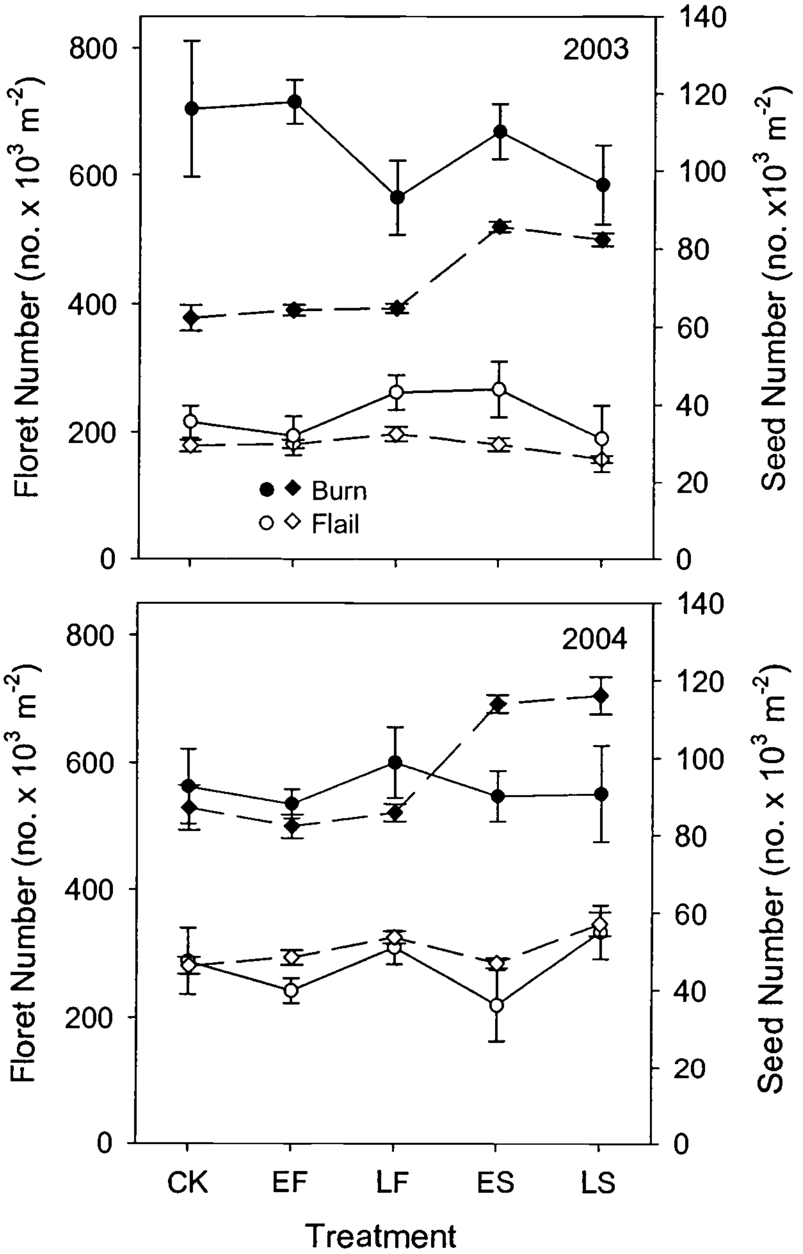

Fig. 2-5. Residue management and TE treatment effect and interactions on floret number (—) and seed number (- -) per unit area in 2003 and 2004. There were no differences between the two fall rates; therefore, an average of the two rates is presented for both fall treatments. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

Table 2-5. Interaction of residue management and TE treatment on the number of seeds per unit area for the third (2003) and fourth (2004) year. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

	2003		2004	
Treatment	Burn	Flail	Burn	Flail
	---------------------- no. x 10^3 m^{-2} ----------------------			
Untreated	62.4 a*	29.5 ab	87.1 a	46.3 a
EF				
200 g a.i./ha	64.7 a	30.2 ab	81.7 a	48.5 ab
400 g a.i./ha	64.0 a	29.7 ab	82.9 a	48.3 ab
LF				
200 g a.i./ha	64.7 a	31.1 ab	82.9 a	52.7 ab
400 g a.i./ha	64.9 a	34.0 b	88.7 a	54.6 ab
ES				
400 g a.i./ha	85.6 b	29.8 ab	114.0 b	47.0 ab
LS				
400 g a.i./ha	82.3 b	26.0 a	116.1 b	57.2 b

*Means in columns, followed by the same letter are not significantly different by Fisher's protected LSD values ($p = 0.05$).

was between the untreated check and the late spring application, the latter showing 23% more seed per m^2. Seeds per m^2 was closely correlated with seed yield (*r*= 0.997; *p* <0.001) (Fig. 2-6).

<u>Floret Site Utilization</u>

Floret site utilization (FSU), in the economical sense, was estimated for the third and fourth year. Since the coefficient of variation for this parameter was high, 40% in 2003 and 32% in 2004, we were not able to detect a statistically significant effect of residue management or TE treatments for FSU (Table 2-1). However, there was a tendency for spring-treated plots to produce higher FSU in both years (Table 2-3; Fig. 2-5 and 2-7). In addition, there was suggestive but inconclusive evidence (*p*=0.074 for 2003 and *p*=0.067 for 2004) of greater FSU for flailed plots than for burned plots, which can be observed in Fig. 2-7 as well.

<u>Seed Weight</u>

We found an interaction between residue management and TE treatment for one thousand seed weight in both 2003 and 2004 (Table 2-1). Seed weight was greater for spring TE treatments than in the untreated check in burned plots (Fig. 2-8).

In 2003, TE application in early spring increased seed weight by 5%, and in late spring by 9% over the untreated check (Table 2-6). The late fall 400 g a.i. ha^{-1} treatment resulted in lower seed weight than early fall and spring treatments. Flailed plots responded differently; only the early spring treatment was affected,

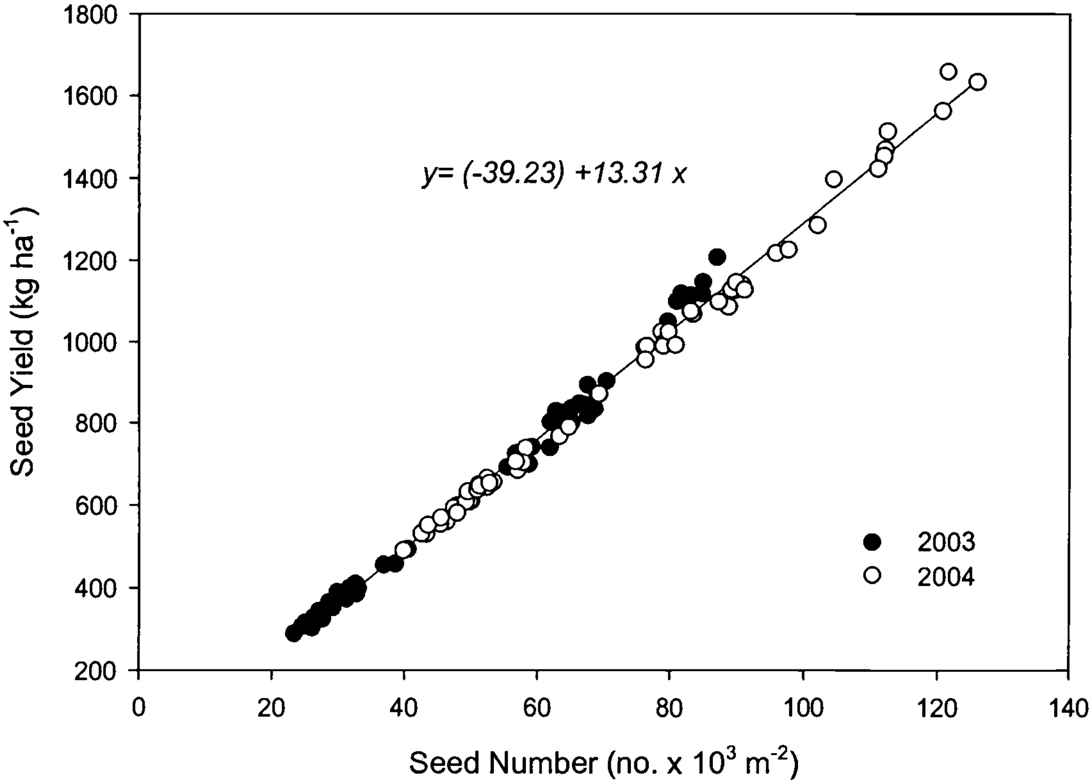

Fig. 2-6. Correlation between seed yield and seed number per unit area for the third (2003) and fourth (2004) year (r^2= 0.99). All treatment combinations were considered.

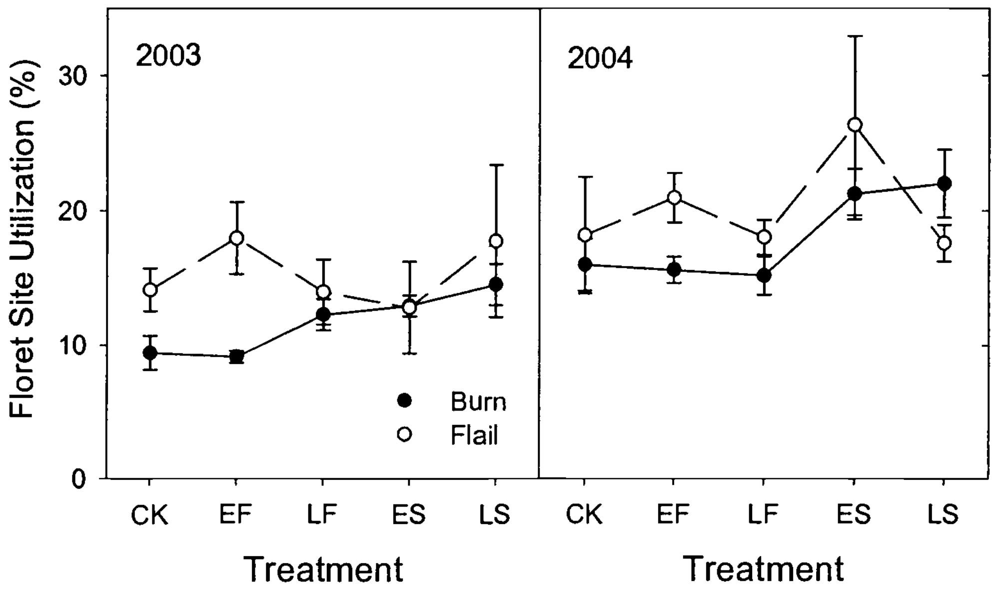

Fig 2-7. Residue management and TE treatment effect on floret site utilization for third year (2003), and fourth year (2004). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Vertical bars represent one standard error of the mean for each treatment combination.

producing 5% greater seed weight than the untreated check although it was not different from the rest of the treatments.

For the untreated check, TE applied in early fall at 400 g a.i. ha^{-1}, and in both spring treatments, seed weight was greater in burned plots than in flailed plots. There were no differences in seed weight between flailed and burned plots for the rest of the treatments. Burned and late-spring treated plots produced the greatest seed weight.

In 2004, the late spring treatment in burned plots also resulted in the highest seed weight, followed by the early spring treatment, which was not different from early fall treatments, and the untreated check (Fig. 2-8; Table 2-6). Also, within burned plots, late fall treatments showed the lowest seed weight, even though they were not different from TE in early fall at 400 g a.i. ha^{-1} and the untreated check. In flailed plots, seed weight resulting from the 400 g a.i. ha^{-1} rate was greater with early fall application than the late fall application, the late spring treatment, and the untreated check. The rest of the treatments did not exhibit statistically significant differences for seed weight. Seed yield was positively correlated with 1000 seed weight in 2003 (r=0.68; p <0.001) and in 2004 (r=0.73; p <0.001) (Fig. 2-9). In 2004, a change in seed weight had greater impact in seed yield than that in 2003.

Fertile Tiller Height and Lodging

There was an effect of TE treatment on tiller height and lodging in 2003 and 2004 (Table 2-1). Spring TE applications reduced both fertile tiller height and

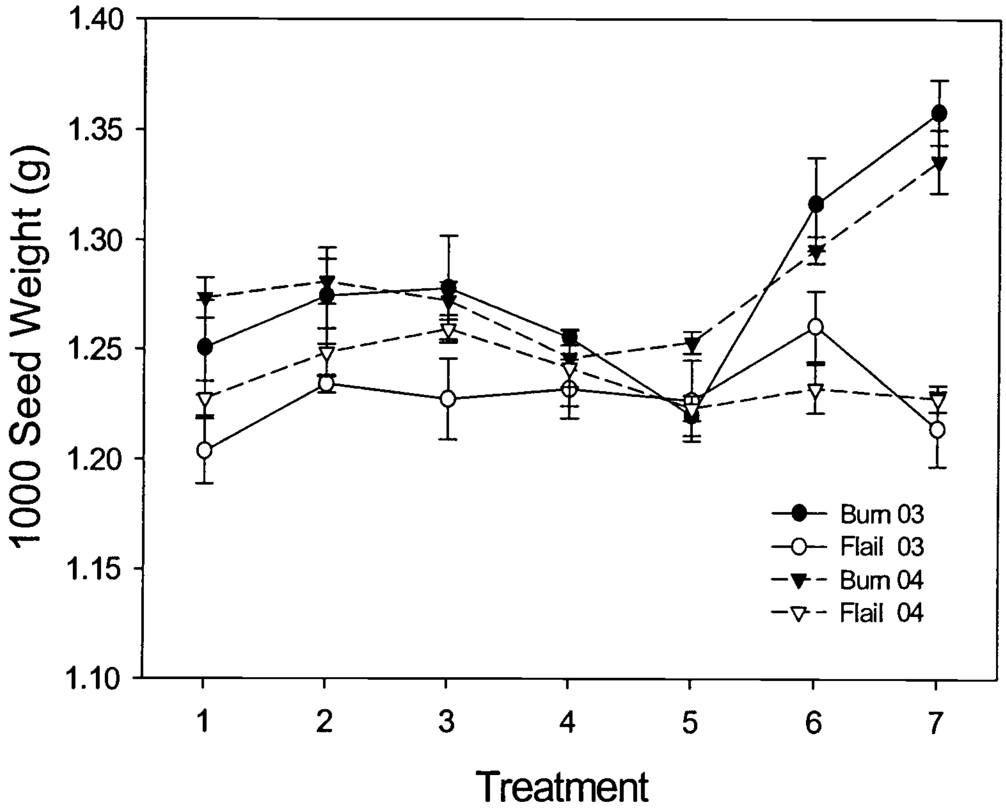

Fig. 2-8. Residue management and TE treatment effect on seed weight for third (2003) and fourth (2004) year. Treatment legend: 1= Untreated check; 2= Early fall 200 g a.i. ha^{-1}; 3= Early fall 400 g a.i. ha^{-1}; 4= Late fall 200 g a.i. ha^{-1}; 5= Late fall 400 g a.i. ha^{-1}; 6= Early spring 400 g a.i. ha^{-1}; 7= Late spring 400 g a.i. ha^{-1}. Vertical bars represent one standard error of the mean for each treatment combination.

Table 2-6. Interaction of residue management and TE treatment on thousand seed weight for the third (2003) and fourth (2004) year. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

	2003		2004	
Treatment	Burn	Flail	Burn	Flail
	------------------- g 1000 seeds^{-1} -------------------			
Untreated	1.251 ab*	1.204 a	1.274 abc	1.228 a
EF				
200 g a.i./ha	1.274 bc	1.234 ab	1.281 bc	1.248 ab
400 g a.i./ha	1.278 bc	1.227 ab	1.272 abc	1.259 b
LF				
200 g a.i./ha	1.255 ab	1.232 ab	1.246 a	1.241 ab
400 g a.i./ha	1.220 a	1.227 ab	1.253 ab	1.223 a
ES				
400 g a.i./ha	1.316 cd	1.261 b	1.296 c	1.232 ab
LS				
400 g a.i./ha	1.358 d	1.214 ab	1.336 d	1.228 a

*Means in columns, followed by the same letter are not significantly different by Fisher's protected LSD values ($p = 0.05$).

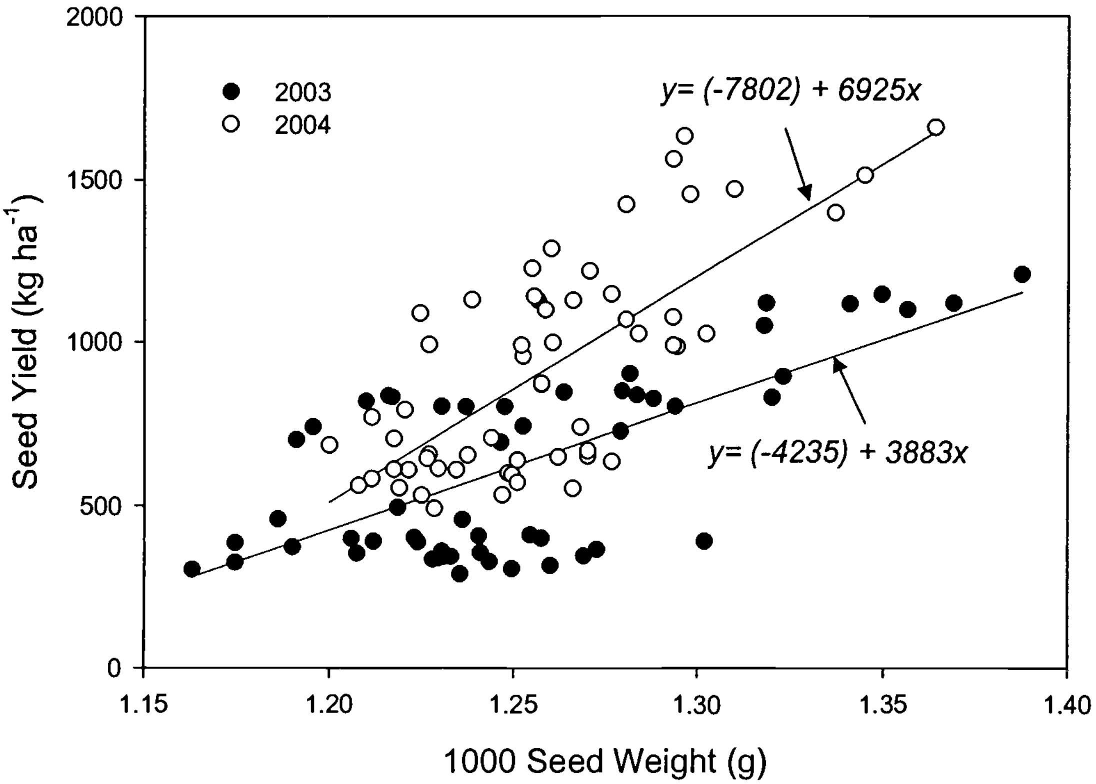

Fig. 2-9. Correlation between seed yield and 1000 seed weight for 2003 and 2004. The determination coefficients for the fitted line in 2003 *(r^2=0.46)* and for the fitted line in 2004 *(r^2=0.53)*.

lodging (Fig. 2-10). None of the fall TE treatments showed tiller height or lodging scores different from the untreated check.

In 2003, the reduction in tiller height for spring-treated plots averaged 34% versus the untreated check and was accompanied by a 63% reduction in lodging (Table 2-7). In 2004, spring TE treated plots produced tillers that were 30% shorter than those in the untreated check. Lodging was reduced by 58% in 2004.

Although residue management did not affect tiller height or lodging in 2003, it had an effect on lodging score, but not in tiller height in 2004. Burning increased the lodging score by 28% over flailing, regardless of TE treatment.

Tiller height was negatively correlated with seed yield in burned plots in 2003 and 2004 (r= -0.85 and r= -0.85; p <0.001, respectively) (Fig. 2-11). Shorter tillers were associated with a higher seed yield in burned plots for both years. However, flailed plots presented a positive correlation between tiller height and seed yield in 2003 (r=0.58; p =0.005), but no correlation was found in 2004 (r=0.09 p=0.643).

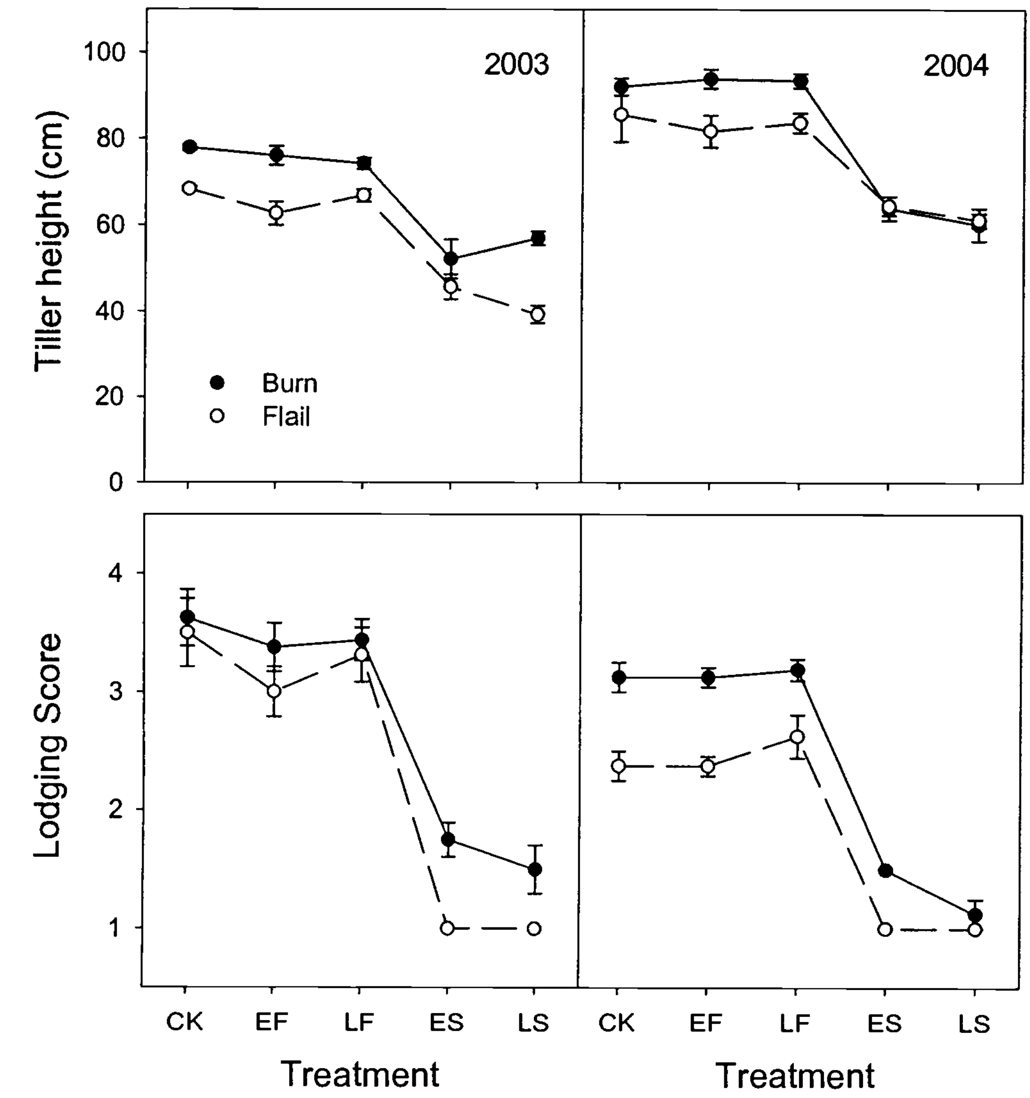

Fig. 2-10. Residue management and TE treatment effect on tiller height and lodging in third year (2003), and fourth year (2004). As there were no differences between the two fall rates, an average of the two rates is presented for both fall treatments for graphing purposes. Treatment legend: CK=untreated check; EF=average of two early fall treatments; LF=average of the two late fall treatments; ES=early spring; LS= late spring. Lodging score: 1= erect - 4= completely lodged. Vertical bars represent one standard error of the mean for each treatment combination.

Table 2-7. Effect of residue management and TE treatment on tiller height and lodging score for the third (2003) and fourth (2004) year. Treatment legend: EF= early fall; LF= late fall; ES= early spring; LS= late spring.

	Tiller height		Lodging score	
Treatment	2003	2004	2003	2004
	----------- cm -----------		(1 - 4)ŧ	
Residue management				
Burn	70 a*	84 a	2.9 a	2.6 a
Flail	59 a	77 a	2.6 a	2.1 b
TE treatment				
Untreated	73 a	89 a	3.6 a	2.8 a
EF				
200 g a.i./ha	70 a	88 a	3.3 a	2.8 a
400 g a.i./ha	68 a	88 a	3.1 a	2.8 a
LF				
200 g a.i./ha	71 a	90 a	3.4 a	2.9 a
400 g a.i./ha	70 a	87 a	3.4 a	2.9 a
ES				
400 g a.i./ha	49 b	64 b	1.4 b	1.3 b
LS				
400 g a.i./ha	48 b	61 b	1.3 b	1.1 b

*Means in columns, followed by the same letter are not significantly different by Fisher's protected LSD values ($p = 0.05$).
ŧ Lodging scale: 1= erect; 4= completely lodged.

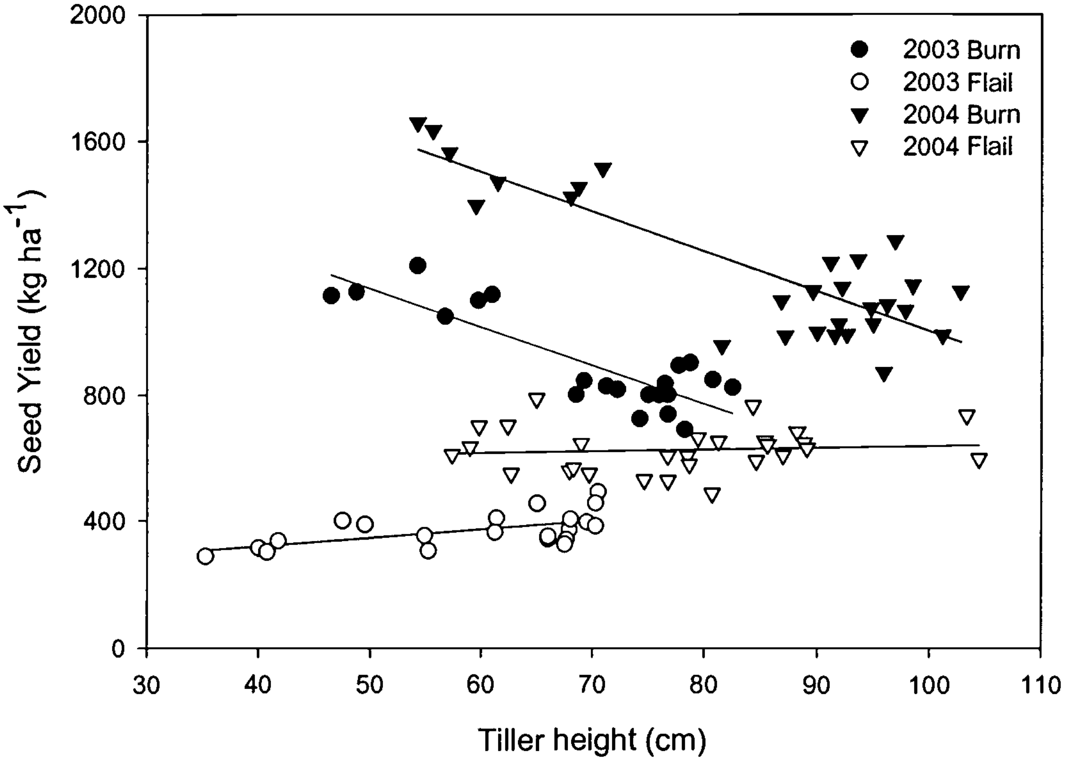

Fig. 2-11. Correlation between seed yield and tiller height for burned (●▼) and flail plots (○▽) the third year (●○) and fourth year (▼▽). Equations for the fitted lines: (●) y=1743-12.14x (r^2=0.73); (▼) y=2252-12.49x (r^2=0.72); (○) y=213+2.68x (r^2=0.34); (▽) y=585+0.53x (r^2=8.40e-3).

Discussion

The effects of residue management and TE treatments changed with increasing age of the stand. As the stand aged, field burning become more critical, supporting previous findings that showed seed yield reductions resulting from nonthermal management practices in creeping red fescue (Chastain et al., 1996b).

In the first year, the stand was still young so open-field burning did not impact the number of panicles per unit area, but instead resulted in an increased number of florets per panicle. This effect may be due to a multiplication of small non-significant increases in spikelet number per panicle by the number of florets per spikelet. However, the increase in florets per panicle was neither reflected in an increase in florets per unit area, nor in a generalized increase in seed yield for burned plots. In fact, there was a significantly higher seed yield for burned over flailed plots only for early fall applications of TE.

The only seed yield component, among the ones measured, affected by TE treatment in 2001 was florets per spikelet. The increase in the number of florets per spikelet for spring-treated plots seems to explain, at least in part, the increase in seed yield with early and late spring applications of TE in both burned and flailed plots. However, this increase in florets per spikelet was not accompanied by an increase in florets per m^2 as a result of TE applications.

In the second year, field burning caused an increase in number of spikelets per panicle, possibly due to an earlier development of fertile tillers, which might have resulted in a longer spikelet differentiation period (Chilcote et al., 1980; Colvill and Marshall 1984). In order to accommodate the higher number of spikelets per panicle, burned plots produced larger panicles.

The increase in number of spikelets per panicle was not accompanied by an increase in number of florets per panicle, but resulted in a higher number of florets per unit area (i.e., potential seed yield) in burned plots. This can be explained because even though there was no residue management effect on the number of panicles per unit area on the second year, burned plots tended to produce more panicles, presumably as a result of a better environment for fall development of new tillers. The multiplicative effect of a non-statistically significant increase in panicle number per m^2 on the potential seed yield agrees with previous findings which consider panicle number per unit area as one of the most important seed yield components (Fairey and Lefkovitch, 1996b). Therefore, it seems that the increase in seed yield observed in burned plots in comparison with flailed ones in 2002 was mainly due to anincrease in spikelets per panicle and a trend for higher panicle number per unit area, reflected in higher potential seed yield.

Although there was a TE treatment effect on seed yield in 2002, none of the yield components analyzed revealed a TE application effect. Therefore, it is hypothesized that the increase in seed yield could have been due to higher floret site utilization (Chastain et al., 2003) enabled by a more erect crop at the time of anthesis in spring treated plots. Nevertheless, we are limited to conclude this since seed number per unit area was not calculated in 2002. Lodging scores, which might reflect crop environment conditions around anthesis, were not recorded either. Seed weight could also have been affected by spring TE applications, but it was not evaluated for 2002.

In the third and fourth year, the increases in spikelets per panicle and panicle length as a result of open-field burning were accompanied by an increase in panicle number per unit area. This resulted in a greater seed yield of burned plots over flailed plots, regardless of TE application. There is an increasing body of evidence showing that higher sowing densities in creeping red fescue are detrimental for seed production as the stand ages (Fairey and Lefkovitch, 1996a; Deleuran and Boelt, 1997). Fairey and Lefkovitch (1996b) showed that seed yield is highly dependent on panicle density, and they stated that the probability of producing a third seed crop of creeping red fescue in the Peace River region of Canada decreases, due to a smaller number of panicles, as the density of the stand is increased (Fairey and Lefkovitch, 1996a).

We observed that flail plots had greater plant density and soil coverage in fall than burned plots, especially in the third and fourth year. The greated red: far-red ratio, characteristic of less dense canopies (Deregibus et al., 1983), could have contributed to enhanced fall tillering resulting in higher number of panicles per unit area in burned plots.

Following the reasoning of Chilcote et al. (1980), the greater plant density of flailed plots, as well as the sizable accumulation of dead material around the stand crown, seem to have negatively impacted the development of new, strong, and vigorous tillers in early fall. Chastain et al. (1997) found that field burning removed straw and stubble that inhibit regrowth, therefore improving the chances of successful induction to flowering in burned plots.

Furthermore, the exposure of a greater amount of soil with open-field burning has been shown to be associated with greater temperature fluctuations (Chilcote et al., 1980). Warmer temperatures during the day might have stimulated earlier tillering, and cooler temperatures during the night could have contributed to more effective floral induction (Chilcote et al., 1980), thus resulting in higher number of panicles per unit area. Hebblethwaite et al. (1980) reported that later-formed fall tillers have reduced floret number per spikelet and spikelet number per spike with later date of ear emergence. Tillers that are not induced to flower, as a result of emerging too late in the fall or later in spring, remain leafy and have the potential to become reproductive the following season, as they are exposed to a longer inductive period during the winter (Sylvester and Reynolds, 1999). Furthermore, they found that larger tillers were older and flowered in two years rather that one year, produced longer inflorescence stalks, larger panicles, and more spikelets per panicle, therefore suggesting a higher potential yield than newer leafy tillers grown from axially buds.

Therefore, any treatment which affects the contribution of different tiller age groups to the panicle population can also affect the number of florets per unit area of the crop. Potential seed yield was greatly influenced by residue management treatments in 2003 and 2004. The greater potential seed yield for burned plots, regardless of TE applications, was presumably influenced by the combination of greater numbers of panicles per m^2 and spikelets per panicle than in nonthermal treatments as the stand ages. The fewer number of panicles per unit area in flailed plots during 2003 and 2004 limited seed yield in those plots.

In 2003 and 2004, an increase in the number of florets per spikelet for both spring TE treatments was found, regardless of residue management. However, in flailed plots the greater number of florets per spikelet was not enough to compensate for the drastic reduction in panicles per unit area and spikelets per panicle; therefore, flailed plots did not demonstrate a TE effect on seed yield. On the other hand, the increase in florets per spikelet due to spring TE applications in burned plots was further enhanced by the greater number of panicles per m^2 and spikelets per panicle, thereby contributing to the seed yield increases over untreated and fall-treated, burned plots. Therefore, the increase in seed yield in both years for spring TE applications on burned plots versus other treatments was explained, in part, by a greater number of florets per spikelet, especially for the early spring TE treatment.

Meijer (1985) found that paclobutrazol increased potential seed yield in perennial ryegrass and Chastain et al. (2003) reported that an increased number of florets per unit area was likely to account for a portion of the seed yield increase resulting from TE treatments in perennial ryegrass. Nevertheless, the effect of TE application on the number of florets per spikelet in 2003 and 2004, as well as for 2001, was not reflected in a greater number of florets per m^2 for spring TE treatments. Trinexapac-ethyl seems not to affect the potential seed yield in creeping red fescue. It is hypothesized that the effect of a greater number of florets per spikelet on seed yield in spring TE treated plots might be due to a better relation of the florets within the spikelets, presenting a better condition for increasing the number of harvestable seeds.

The response pattern to residue management and TE treatments for number of seeds per m^2 strongly followed that found for seed yield in 2003 and 2004, a consequence of those two characteristics being closely correlated. Seeds per m^2 was the yield component best correlated with seed yield, supporting previous findings for perennial ryegrass (Elgersma, 1990), and creeping red fescue and Chewing's fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman; syn. *F. rubra* var. *commutata* Gaudin] (Young et al., 1998a). Seed number per unit area explained much of the variation in seed yield in response to both residue management and TE application. Therefore, even though we were unable to detect differences between florets per unit area that could explain the greater seed yields achieved in spring TE treated burned plots, it seems that spring TE applications have an effect on the conversion of potential yield in harvestable seed, which could be explained by the better crop conditions during flowering time (Hampton and Hebblethwaite, 1983a; Hebblethwaite, 1987; Rolston et al., 2003). We were not able to detect any effect of TE application on FSU, this may be due to how FSU was calculated; however, we reported a trend for spring TE treatments to result in grater FSU in both years. Previous studies showed an increase in FSU by paclobutrazol (Hebblethwaite et al., 1980; Hebblethwaite, 1985) and by TE (Chastain et al., 2003) in perennial ryegrass. The suggestive, but inconclusive, evidence of a higher FSU for flailed plots can be explained by the significantly fewer number of florets per unit area recorded in flailed plots when compared with burned plots, regardless of TE application.

In accordance with Rolston et al. (2003), the reduced tiller height of spring TE treated plots, coupled with reduced lodging scores, which was closely associated with seed yield in burned plots, could have improved crop environment conditions by presenting more erect fertile stems at the time of anthesis, therefore favoring cross pollination, resulting in higher fertilization of florets. Griffith (2000) reported that seed yield decreased with lodging and this decline in yield was associated with a reduction in the number of seeds per spike and an increase in seed mass in perennial ryegrass. Lodging also implies shading, which was shown to reduce seed set from 68% to 57% in one clone of perennial ryegrass (Warringa et al. 1998b). The greater lodging score for burned plots over flailed plots observed in 2004 could be due to the greater fertile tiller weight (Zapiola and Chastain, 2004) and larger panicles in burned plots.

Although seed weight is a yield component that is usually not affected by management practices (Marshall, 1985), open-field burning and TE spring applications resulted in greater seed weight, which contributed to greater seed yield in spring TE treated, burned plots. This could have been due to a longer filling period for spring TE treated plots since they reached harvest maturity seven and two days later than untreated plots in 2003 and 2004, respectively. In addition, Warringa et al. (1998b) reported that shading by 75% reduced seed dry weight by about 10% in perennial ryegrass. Therefore, shading due to lodging, could have negatively impacted seed filling, and be one of the causes of the higher seed weight for burned spring treated plots. The reason of the lower seed weight for the late fall TE at 400 g a.i. ha^{-1} treatment is unknown.

In accordance with Hampton and Hebblethwaite (1983b) and Elgersma (1990), the variation in seed yield can be mainly attributed to the varying number of seeds per unit area that are harvested, and not to the variation in the average seed weight (Warringa et al. 1998a). There were no differences in yield response to the different timing of spring applications for any of the four years. This confirms Silberstein et al. (2001b) findings that there is a broad timing window for spring application of TE in creeping red fescue.

Conclusion

High seed yields of creeping red fescue can be obtained in the early years of a stand with nonthermal residue management by using spring applications of TE in the Willamette Valley. However, as the stand ages, the total removal of the straw and stubble by field burning seems to play a critical role in establishing the number of tillers that are induced to flower in the following spring. Therefore, open-field burning is necessary to ensure greater numbers of fertile tillers and spikelets per panicle, which result in a higher number of florets per m^2 for burned plots than for flailed plots. Higher potential seed yield is associated with a higher seed yield for burned plots versus flailed ones, especially as the stand ages. Plant growth regulators applied in fall or spring cannot be used as a substitute for open-field burning as it was hypothesized. In addition, the use of spring TE application to increase the number of florets per spikelet, reduce stem length and therefore lodging, and consequently favor pollination and fertilization of the florets, is vital to further increase seed yield, and is postulated to increase seed set. A broad window exists for spring application of TE in creeping red fescue since there were no differences in yield response to timing of spring application. Fall TE applications did not affect any seed yield component and therefore had no effect on seed yield. Open-field burning of post-harvest residue together with spring application of TE is the best option for achieving high seed yield in creeping red fescue in the Willamette Valley over the entire life of the stand.

Since only one variety was tested at a single site, caution must be exercised in extrapolating these results to other situations. Additional work needs to be done in order to identify an alternative to open-field burning for creeping red fescue seed production. Experiments analyzing combinations of mechanical removal of straw and stubble on the first years of the stand and field burning as the stand ages would be useful to try to find a promising management alternative to continuous open-field burning in creeping red fescue seed production.

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SUMMARY AND CONCLUSIONS

Although it was hypothesized that fall applications of trinexapac-ethyl (TE) might increase seed yield in creeping red fescue by replacing open-field burning in manipulation of fall regrowth, TE applied in fall did not result in any increase in seed yield when compared with the untreated check within each residue management treatment. Fall TE applications are not a viable alternative to replace open-field burning in creeping red fescue seed production.

Spring TE applications were promising as potential alternative to open-field burning during the early life of the stand, as TE applied both in early and late spring, resulted in higher yields in burned and flailed stands the first two years. However, as the stand aged, open-field burning became critical for maintaining high seed yields, and spring TE applications did not increase yield on flailed plots. The response was different in burned plots, since TE applied in spring positively interacted with field burning, fostering the seed yield increase caused by open-field burning as the stand aged. Consequently, burning and applying TE both early and late in spring resulted in the equivalent of 1.5 additional seed harvests when the cumulative yields where analyzed. Both open-field burning and spring TE application resulted in a more efficient crop, reflected in the higher harvest index they presented.

Open-field burning is critical for maintaining seed yield in creeping red fescue as the stand ages. The total removal of the straw and stubble by open-field burning seems to play a imperative role in establishing the number of tillers that are induced to flower in the following spring. Therefore, open-field burning is necessary to ensure greater numbers of panicles per unit area and spikelets per panicle, which result in a greater number of florets per unit area for burned plots than for flailed plots. Higher potential seed yield is associated with a higher seed yield for burned plots versus flailed ones, especially as the stand ages.

Fall TE applications did not affect any seed yield component and hence had no effect on seed yield. Therefore, TE applied in fall cannot replace open-field burning's positive effects on potential seed yield as it was hypothesized. In addition, the use of spring TE application to increase the number of florets per spikelet, reduce stem length and therefore lodging, and consequently favor pollination and fertilization of the florets, is vital to further increase seed yield, and is postulated to increase seed set. Seed number per unit area was the yield component most closely related to seed yield. A broad window exists for spring application of TE in creeping red fescue since there were no differences in yield response to timing of spring application.

Open-field burning of post-harvest residue together with spring application of TE seems to be the best option for achieving high seed yield in creeping red fescue in the Willamette Valley over the entire life of the stand. Yet, only one cultivar of creeping red fescue was used in this experiment; therefore, extrapolation of these results to other production environments and cultivars should be done with caution. According to these results, a high priority should be given to creeping red fescue when allocating the area that is allowed for open-field burning each year.

Additional work needs to be done in order to identify a feasible alternative to open-field burning. Comparing continuous open-field burning, with mechanical removal of post-harvest residue during the first two years and burning after the second seed production year of creeping red fescue, might be considered. The use of spring TE applications on flailed stands could be regarded as an alternative to open-field burning if shorter stand life is economically viable.

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