Methods and Species for Conversion of Kentucky Bluegrass Rough to No-Mow, Low-Input Turfgrass Areas

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Abstract

With golf course water, fertilizer, and pesticide restrictions on the rise and labor costs continuing to increase, golf course superintendents are looking for ways to reduce maintained Kentucky bluegrass (*Poa pratensis* L.) rough. The objective of this study was to (i) compare several methods for converting Kentucky bluegrass roughs to no-mow, low-input grasses and (ii) determine the best turfgrass species that provides a playable and aesthetically pleasing turfgrass stand for this type of conversion.

Five grass species and five conversion methods were evaluated at two locations in Minnesota (Maple Grove, MN and St. Paul, MN). Data collected included visual stand quality, tendency for lodging, inflorescence counts, biomass production, Kentucky bluegrass regrowth, and broadleaf weed invasion. At Maple Grove, the fumigation treatment provided the highest visual stand quality ratings and the sod removal treatment at St. Paul provided the highest visual stand quality. Only sheep fescue (*Festuca ovina* L.) was able to provide acceptable visual stand quality by Year 2 and only at St. Paul. Chewing's fesuce (*Festuca rubra* L. ssp. *commutata* Gaudin) and strong creeping red fescue (*Festuca rubra* L. ssp. *rubra*) were best at resisting broadleaf weed invasion at both locations. Hard fescue (*Festuca brevipila* Tracey) was best at resisting lodging along with strong creeping red fescue in Year 2 at both locations.

Due to its perennial nature and rhizomatous growth habit, it may be difficult to obtain complete control of Kentucky bluegrass when converting to a no-mow, low-input area. Selective removal of Kentucky bluegrass regrowth may be needed when converting to low-maintenance grasses. Previous studies have shown that fine fescues (*Festuca* spp.) have a high tolerance to the herbicide sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-

(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) and it may provide the answer when needing to selectively remove Kentucky bluegrass from fine fescue. The objectives of this second study were (i) to compare the tolerance of cool-season turfgrass species and cultivars to sethoxydim and (ii) determine species tolerance at different application rates. Four herbicide rates (0.0, 1.315, 2.630, and 5.26 $L \cdot ha^{-1}$) were applied to fifteen cool-season grasses (5 Kentucky bluegrass cultivars, 3 tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.) cultivars and selections, 'Gator' perennial ryegrass (*Lolium perenne* L.), 'Plantation' tall fescue, (*Festuca arundinacea* Schreb.), a native prairie junegrass breeding line (*Koeleria macrantha* [Ledeb.] Schult.), and 4 species of fine fescues. All fine fescue species tested in the study were unharmed by all rates of sethoxydim. Surprisingly, tufted hairgrass showed some tolerance to sethoxydim in 2008 and performed better in 2009. Tall fescue was not tolerant in 2008, but showed some sethoxydim tolerance in 2009. All other species saw individual plant quality decline below acceptable levels by 5 WAT.

Table of Contents

Chapter 2.

Evaluation of cool-season turfgrass response to sethoxydim

List of Tables

Chapter 1.

LITURATURE REVIEW

Golf has become a large part of our environmental and economic landscape. With nearly 16,000 golf courses, player participation numbers reaching 26.1 million in 2010, and revenue of 76 billion in 2005, golf's popularity in the United States seems to be in good standing (24, 38). Golf course playing conditions are a top priority when trying to maintain participation. However, increasing costs and restrictions on water, fertilizer, and pesticides are prompting superintendents to consider maintenance programs that reduce inputs on golf courses and thus impact playing conditions. Since 2003, parts of Canada have enforced the Pesticide Management Code, which limits the non-essential use of pesticides on lawns (25). In 2004, Minnesota passed a law restricting the use of phosphorus lawn fertilizer unless new turf is being established, a soil or tissue test shows a need for phosphorus fertilization, or the application of phosphorus is made to a golf course by a trained golf course superintendent (37). Mandatory water use restrictions and monetary penalties have also challenged golf course operations (45). Golf course superintendents are continually looking for ways to provide the playing conditions golfers have come to expect, but do so under increasing restrictions on budgets and inputs.

Land area needed for golf is larger than any other sport; golf course rough areas account for 52% of the total maintained area and 42% of the irrigated turfgrass area (23, 35, 49). Golf course rough is generally defined as turf mowed at 5.1 cm or higher throughout the golf course (15). The most common turfgrass species planted in rough areas in the North Central Region (NCR) of the United States is Kentucky bluegrass (*Poa* *pratensis* L.), accounting for 63% of the total (35). Newer cultivars of Kentucky bluegrass have improved pest resistance, darker green color, higher turf density, improved uniformity, and high divot recovery potential (15, 42). However, they can require high levels of water, fertilizer, and pesticide inputs to maintain golf course quality (15). Higher levels of inputs increase the frequency of mowing, which results in higher labor, machinery, and fuel costs.

Recent annual golf course water use in the United States was estimated at 753 billion gallons of water and average annual water use rates for an 18-hole golf course in the NCR of the United States at 50 million gallons (50). In recent years there have been several examples of severe water restrictions on golf courses in the United States. The Environmental Protection Division of Georgia declared a Level 4 water restriction in September of 2007 that called for a 94% water reduction on golf courses, limiting irrigation only to greens (39). The South Florida Water Management District imposed a Phase 3 restriction in December of 2007 that mandated a 45 percent reduction in golf course water usage (39). Few golf courses in the United States are subject to such strict water restrictions, but most golf courses still must pay some sort of fee for their irrigation water. Expenditures for water use range from $4,700 to $107,800 per year depending on the region (50). Water restrictions and costs continue to increase throughout the United States and golf courses are often easy targets when looking at reducing water use. Golf courses account for 608,732 hectares of maintained turfgrass, 484,967 hectares of which is irrigated (50). Although this total area is much smaller than the total area of irrigated agricultural land, the non-golfing public may view water use on non food-producing areas to be a non-essential use of a precious resource.

The thirteen essential elements needed to maintain vigorous turfgrass growth are not always provided in the appropriate amounts by the soil. In these cases, the use of fertilizer is needed in order to maintain plant growth and health. Nitrogen, phosphorus, and potassium are needed in the highest amounts and nitrogen is generally the basis for most golf course fertility programs. In 2006, 91.7 million kg of nitrogen was applied to 530,543 hectares of golf course (172.87 $kg \cdot ha^{-1}$) and 14.5 million kg of nitrogen was applied to 122,094 hectares (118.99 $kg \cdot ha^{-1}$) in the NCR (49). Golf course rough, the largest maintained segment of a golf course, received 5.86 million kg of nitrogen to 61,876 hectares (94.70 $kg \cdot ha^{-1}$) in the NCR in 2006 (49). These fertilizer rates are within the guidelines set by university studies for turfgrass and the majority of golf course superintendents use a soil analysis as a guideline for their fertility program (49). To provide some perspective, in 2006, corn growers applied 4.25 billion kg of nitrogen to 30.8 million hectares (138.11 $kg \cdot ha^{-1}$) (54). Although turfgrass fertilizer rates mentioned above are not excessive, 74% of golf course fertilizer use from 2002 to 2006 stayed the same or increased (49). Lack of decline in fertilizer usage rates suggest that golf courses may be looking for ways to reduce their fertilizer input, but not at the sacrifice of golf course conditions.

Average prices for major fertilizer nutrients reached their highest level on record in September of 2008 and fuel costs have risen by 269 percent since 1992 (48, 55). The main nitrogen source in nitrogen fertilizers production is ammonia, which is produced with natural gas. From 1998 to 2008, natural gas prices have increased by 550% (30) causing a significant increase in the cost of nitrogen. High fuel prices have also increased the cost of importing fertilizers from outside the United States, which can be as high as

50% of the total cost of fertilizer (30). Although prices have come down from the highs of 2008, increasing ethanol demand, growing world food demand, and growing economies of China, India, and Brazil will continue to puts stress on world fertilizer prices (48).

Labor costs involved in golf course maintenance are also on the rise. The majority of the labor force on golf courses is classified as unskilled labor receiving at or near the federal minimum wage that rose to $7.25 in July 2009, putting further stress on golf course maintenance budgets (53). The labor budget for superintendents is generally between 50% and 70% of the total maintenance budget (7). The combination of large amounts of established Kentucky bluegrass rough and inputs required to maintain their playing quality have prompted many golf courses to questions the need for heavily maintaining their Kentucky bluegrass rough areas.

Golf course superintendents use many approaches for reducing golf course inputs. A long-standing approach includes using Integrated Pest Management (IPM). Integrated Pest Management involves determining a level of injury (thresholds) before pesticides are used, allowing for a reduction in pesticides and inputs while still provide the playing conditions superintendents and golfers want (44). Voluntarily reducing water use can reduce mowing and pesticide requirements and provide a firmer, faster golf course, but it is at the expense of the green color many golfers expect (56). Increasing mowing heights has also seen an increase in popularity. Increased mowing heights can reduces plant stress and requires less inputs to maintain plant health, but can come at the expense of playing conditions. An additional approach is the use of lower maintenance turfgrass species that require fewer inputs to maintain (60). One method superintendents are considering in order to reduce inputs is converting existing Kentucky bluegrass rough to no-mow, low-input grasses. However, at this time there are many unknowns about converting from Kentucky bluegrass rough to no-mow, low-input areas which has prevented superintendents from attempting conversion. It is often easier for superintendents to employ management techniques they are familiar with and continue to provide conditions golfers have come to know at the expense of their budget and resources. For example, from 2003 to 2008, only 9% of golf courses have reduced their amount of irrigated and heavily maintained turf in order to conserve resources in comparison with 25% that have increased these same areas primarily to meet golfers' demands for better playing conditions (50).

Species options for no-mow, low-input areas

Although very few studies have focused on converting Kentucky bluegrass rough to no-mow grasses, research has been done on the use of turfgrasses in low-input environments. Studies have shown that fine fescues (*Festuca* spp.) have greater tolerance to environmental stresses than Kentucky bluegrass. Aronson et al. (2) concluded that hard fescue (*Festuca brevipila* Tracey) and Chewing's fescue (*Festuca rubra* L. ssp. *commutata* Gaudin) are considerably more drought tolerant that Kentucky bluegrass. Graber (26) also determined that Kentucky bluegrass quality decreases and weeds increase over time if this species is managed at low-input levels. In a three year turf trial maintained with no supplemental irrigation or fertilizer after seedling emergence, Dernoeden et al. (19) tested the quality of three fescue species – 'Bighorn' blue fescue (*Festuca ovina* L. spp. *glauca*), 'Aurora' hard fescue, and 'Silverado' and 'Rebel II' tall fescue (*Festuca arundinacea* Schreber) – under three mowing regimes. Plots were mowed at 5.5 cm as needed (Regime I), 8.0 cm monthly (Regime II), or 8.0 cm monthly after seedhead senescence (Regime III). Blue fescue and hard fescue had better quality and a higher resistance to weed invasion than the tall fescue species, and mowing regimes I and II provided the highest turfgrass quality. Regime III had lower quality ratings due to seedhead presence and clippings not being removed. Under this low-input situation, tall fescue cultivars began to look yellow and undernourished. Spring and summer drought conditions caused tall fescue to turn brown, but blue and hard fescue stands remained green throughout the same period (19). The authors indicated that drought-induced dormancy of tall fescue stands provided an opportunity for smooth crabgrass (*Digitaria ischaemum* [Schreb.] Schreb. ex Muhl) to establish where as under the same conditions, blue and hard fescue stands were able to resist the same invasion (19). By the last summer of the study, blue and hard fescue cultivars had their highest stand quality ratings, showing how well a fine fescue species can perform under low-input conditions.

Watkins et al. (60) determined that under low-maintenance conditions (no irrigation or fertilizer applications following establishment) and at higher mowing heights (5.1 cm and 10.2 cm) sheep fescue (*Festuca ovina* L.) and hard fescue performed well in the NCR of the United States. It was also noted that sheep and hard fescue performed well throughout the same region in no-mow situations (25). The authors also noted that tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.) showed potential as a low-input turfgrass in the NCR of the United States, but is mainly used as an ornamental grass in the NCR (8, 60).

Diesburg et al. (20) evaluated 12 turfgrass species for their use as low input sustainable turf (LIST) in the Upper Midwest (Illinois, Indiana, Iowa, Michigan, Missouri, Ohio, and Wisconsin). With pesticides kept to a minimum and no supplemental irrigation or fertilizer, LIST species are defined by their tolerance to environmental stresses, nutrient deficiencies, and weed competition. Twelve grass species were evaluated at three different mowing treatments: 3.8 cm, 7.6 cm, and no mowing. Because of the large geographical area the study covered, a large location effect was seen. Hard fescue, Canada bluegrass (*Poa compressa* L.), and crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Schult.) did well in Iowa. Colonial bentgrass (*Agrostis capillaris* L.) did best in Missouri and buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.) did very well in Ohio and Southern Illinois. All the fescues performed well throughout the region with tall fescue and common sheep fescue being the most widely adapted. Some species showed a smaller range of adaptation with buffalograss only performing well in the transition zone and crested wheatgrass only doing well in Iowa and central Illinois. The authors indicated the ideal mowing height for most species in the study was 7.6 cm, but when left as a no-mow situation, the top-performing species was hard fescue (20).

Ornamental value and playability (the ability to find and play the golf ball) in a no-mow, low-input site could potentially be the biggest factors in how golfers perceive these areas. Voigt and Tallarico (58) evaluated the quality of 10 cool and warm-season grasses for use in out-of-play areas on golf courses. In the study, out-of-play areas were mowed only twice during the growing season (May and October). The grasses included a fine fescue blend [Chewing's, hard, strong creeping red (*Festuca rubra* L. ssp. *rubra*) and sheep fescue], redtop (*Agrostis gigantea* Roth), timothy (*Phleum pratense* L.), 'Millennium' tall fescue, 'Kentucky-31' tall fescue, tufted hairgrass, orchardgrass

(*Dactylis glomerata* L.), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), switchgrass (*Panicum virgatum* L.), and little bluestem (*Schizachyrium scoparium* [Michx.] Nash). Results, based on plant height and playability, indicated that the fine fescue blend and tall fescues were best suited for out-of-play areas on golf courses (58). Orchardgrass, timothy, switchgrass, little bluestem, and sideoats grama were found to be too tall for use in no-mow situations. Fine fescues also provided the best overall aesthetic value with ornamental inflorescence; however, the species did not flower until the second year of establishment. The fine fescue species also tended to mat down later in the season reducing the aesthetic appeal of the stand. In the Midwestern climate, the spring and fall dormancy of the warm-season grasses provided an opportunity for cool-season weeds to invade the out-of-play areas and out-compete the warm-season grasses when there is a lack of weed control (58). The use of warm-season grasses in a northern U.S. climate may then result in an increase in herbicide use and maintenance of these areas.

Weed control in no-mow, low-input areas

Fertilization, irrigation, and mowing are the primary turfgrass cultural operations needed to sustain turfgrass quality (52). Because of their nature, these cultural management techniques are generally not available to turfgrass managers in no-mow, low-input areas, making weed management a challenge.

Actively growing turfgrass is often the first step toward weed suppression. Limiting weed pressure is generally the result of an increase in turf density which reduces the amount of light that penetrates the turfgrass canopy diminishing the germinating weeds' ability to compete for light. The appropriate fertilizer and timing can have a large impact on the quality and density of a turfgrass stand. Turfgrass stands are more competitive than they would be in the absence of fertilizer because it stimulates and increases growth. Low fertility generally produces a thin stand that can become an ideal area for weed seed germination. Johnson and Bowyer (32) indicated that after four years, dandelion (*Taraxacum officinale* F.H. Wigg.) cover was lower in plots that had received nitrogen compared to unfertilized plots and was also lower in plots receiving higher rates versus lower rates of nitrogen. Suppression of dandelion was also greater with fertilizer applications than with preemergent herbicides. In tall fescue, plots receiving no fertilizers had significantly more broadleaf weed and crabgrass invasion than fertilized plots (57).

When mowed at the proper heights, turfgrass stands are better able to withstand both grassy and broadleaf weeds. Mowing at heights that are too high or too low can increase weed populations. However, frequent mowing at proper heights can cut inflorescence and prevent weed seeds from maturing. Dernoeden et al. (18) indicated that in the absence of herbicides, smooth crabgrass establishment in tall fescue was reduced as mowing height was increased. Smooth crabgrass establishment was 18%, 6%, and <1% at 3.2, 5.5, and 8.8 cm mowing height respectively (18). Voigt et al. (57) indicated that in a tall fescue stand mowed at 3 different heights (2.5 cm, 5.1 cm, and 7.6 cm), crabgrass (*Digitaria* spp.) stand coverage was highest at the lowest mowing height. Most broadleaf weeds are not tolerant to continual mowing and eventually die back (9). However, at higher mowing heights, white clover (*Trifolium repens* L.) populations increased in tall fescue stands (18).

Inefficient irrigation practices can increase diseases and weeds in turfgrass stands and reduce the efficiency of fertilizers and mowing practices (27). For cool-season grasses, irrigating in a deep, infrequent manner is generally recommended (3, 22) because it benefits the existing turfgrass by promoting a deeper root system and a turfgrass stand that is better able to withstand environmental stresses. Infrequent watering hampers germination and development of weed seeds, while frequent, light irrigation promotes the germination of weed seeds (4, 16). In the absence of rain, irrigation helps prevent a loss in turfgrass stand vigor and dormancy. In a study evaluating low-maintenance turf sites without irrigation, a tall fescue stand entered dormancy during a prolonged drought and reduced its competitive ability allowing smooth crabgrass to establish (19). Conversely, Colbaugh and Elmore (16) found that frequent irrigation promotes the germination and survival of crabgrass.

Allelopathic potential of fine fescues

With no-mow, low-input areas, turfgrass managers are choosing to have an area that is subject to a lack of typical weed management choices. With a limited use of herbicides and cultural management practices (fertilization, mowing, and irrigation) for weed control, turfgrass managers will be looking for alternative methods of weed control, one of which is utilizing allelopathic potential of certain plants. Allelopathy is defined as any direct or indirect harmful effect by one plant on another through production of chemical compounds that escape into the environment (41). Nearly all plants produce chemicals with allelopathic capabilities and in the correct environmental conditions, these allelopathic chemicals can be released into the rhizosphere that affects the growth of neighboring plants (62).

Studies on allelopathy in the fine fescues started with their use as a cover crop in no-till systems (61). To determine weed supressive ability of cover crops, plants were allowed to establish for 7 months and then killed with glyphosate (N-[phosphonomethyl] glycine). Sixty days following glyphosate application, strong creeping red fescue residue provided greatest reductions in weed weight and in a laboratory setting strong creeping red fescue residue was strongly inhibitory to weed seed germination (61). Strong creeping red fescue used as a cover crop after organic soy bean production also resulted in a reduction of corn yields (28).

More recent studies have focused on the allelopathic abilities of fine fescues and their use in more traditional turfgrass applications. Initial field studies were conducted on fine fescues entered in the National Turfgrass Evaluation Program (NTEP) to determine which cultivars showed weed suppressing abilities (5). Two years of observations showed 3 cultivars of the 78 entered were highly weed suppressive ('Oxford' hard fescue, 'Intrigue' Chewing's fescue, and 'Sandpiper' Chewing's fescue) and 4 others showed moderate weed suppressive ability ('Reliant II' hard fescue, 'Rescue 911' hard fescue, 'Columbra' Chewing's fescue, and 'Treazure' Chewing's fescue) (5). These seven cultivars were then evaluated for their allelopathic potential under laboratory settings in a separate study.

Allelopathic potential was assessed by growing 30 individual fescue seedlings with large crabgrass (*Digitaria sanguinalis* [L.] Scop.) and curly cress (*Lepidium sativum* L.) in agar medium. In the presence of developing fine fescue seedlings, mean root and shoot length of the developing large crabgrass weed species were reduced by 46% and 80%, respectively, and reductions in curly cress mean root and shoot length were 21% and 58%, respectively, with the highest reductions seen with 'Intrigue' Chewing's fescue (5). In a subsequent study, exudates taken from 'Intrigue' Chewing's fescue seedlings were evaluated. The researchers found that meta-tyrosine was the major component of the exudates responsible for the weed suppression (6). Meta-tyrosine is also produced by strong creeping red fescue, but not by sheep or hard fescue (6).

Kentucky bluegrass re-growth

A limiting factor in successful conversion from Kentucky bluegrass to low-input species is re-growth of Kentucky bluegrass from rhizomes (13). Conversion to low-input species can be to either maintained/mowed turfgrass areas or as no-mow turfgrass areas that are left to grow. Superintendents often use a combination of both allowing areas that are more out-of-play to be left unmowed and areas that are more in-play to be mowed. Selective perennial grass control in cool-season turfgrass is difficult to achieve without mechanical removal or the use of non-selective herbicides like glyphosate or glufosinate (Glufosinate-ammonium) (52). In these two situations, the desirable turf species may also be harmed or may be to slow to recover before additional weed invasion occurs. Fine fescues have become popular for use in golf course rough and research has shown there is potential for selective removal of Kentucky bluegrass and other cool-season grasses in fine fescue turf with the use of sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) (10, 11, 29, 36, 47, 64).

Sethoxydim is a post-emergence graminicide that has been historically used as a selective herbicide in broadleaf cropping systems such as soybean (*Glycine max* (L.) Merr) (11). Sethoxydim is a lipid synthesis inhibitor that specifically targets the acetyl-coenzyme A carboxylase (ACCase inhibitor) (47, 51). Dicot species have an alternate site of action for the acetyl-coenzyme A carboxylase allowing them to be unharmed by the effects of sethoxydim while the production of fatty acids is inhibited in the susceptible monocots (51). Inhibition of fatty acid production causes cell membrane failure that result in a stoppage of shoot and rhizome growth, which in turn causes necrosis and death of shoot meristems and rhizome buds leading to eventual plant death (51).

The majority of cool-season grasses are not tolerant to sethoxydim applications; however, studies have shown strong creeping red fescue tolerance is similar to that observed in such dicots as garden pea (*Pisum sativum* L.), spinach (*Spinacia oleracea* L.), and mung bean (*Vigna radiata* (L.) R. Wilczek) (10, 12, 47, 64). Studies involving the use of sethoxydim in turfgrass have focused on grassy weed control in fine fescue seed production (10, 47), which would be a similar management situation found with no-mow roughs on golf courses. In a seed production system, strong creeping red fescue was 2000 times more tolerant to sethoxydim than was tall fescue (47). Butler and Appleby (10) determined in a greenhouse setting that strong creeping red fescue was not injured with high applications rates (10 $kg \cdot ha^{-1}$) of sethoxydim and strong creeping red fescue was actually stimulated by lower application rates (.5 $kg \cdot ha^{-1}$) of sethoxydim.

Although current sethoxydim labels do not list Kentucky bluegrass as a controlled species (1), researchers have found that Kentucky bluegrass is susceptible to sethoxydim applications. Hosaka et al. (29) found 100% control of 53 grass species in the seedling stage including Kentucky bluegrass (3-4 leaf stage), tall fescue (3-5 leaf stage), and creeping bentgrass (*Agrostis stolonifera* L.) (4-5 leaf stage), and concluded that sethoxydim has the potential of controlling grass species in pastures planted with strong creeping red fescue or hard fescue. McCullough et al. (36) showed varying control of four Kentucky bluegrass cultivars with sethoxydim over four locations (Indiana, New

Jersey, Virginia, and Maryland). Single applications rates of 0.53 $kg \cdot ha^{-1}$ yielded 7, 44, 73 and 75% control of Kentucky bluegrass 8 weeks after treatment (WAT) in Indiana, New Jersey, Virginia, and Maryland, respectively (36). Moreover, single applications made 4 weeks apart provided control of 93, 98, 64, and 73% at Indiana, New Jersey, Virginia, and Maryland, respectively at 8 WAT (36). Although results vary by location, second applications of sethoxydim may provide acceptable control of Kentucky bluegrass.

RESEARCH OBJECTIVES

Converting from Kentucky bluegrass to no-mow, low-input grasses require conversion methods that allow for adequate turfgrass establishment and provide long-term success. Methods for turfgrass conversion used in the golf course industry include non-selective herbicides and fumigants, tillage or sod removal, and interseeding (31, 33, 34, 40). Although low-input grass species development is in its infancy, studies continue to identify species that are potential candidates for use in no-mow, low-input situations (19, 20, 56, 57, 60). The fine fescue species have continually risen to the top as a turfgrass that may lend itself to use in no-mow, low-input situations. Fine fescue species are naturally tolerant to shade, drought, and low pH, and have a low fertility requirement, all of which make them a natural low-maintenance grass (3, 43). With a lack of weed management tactics available in these areas, some fine fescues have shown allelopathic ability that could prove useful in no-mow, low-input systems. Each golf course is unique, but superintendents know specific areas that are great candidates for conversion that would allow for a reduction of inputs and manpower while increasing the golf course's environmental stewardship.

Therefore, the objective of the first study was to (i) compare several methods for converting Kentucky bluegrass roughs to no-mow, low-input grasses and (ii) determine the best turfgrass species that provides a playable and aesthetically pleasing turfgrass stand for this type of conversion.

Recommended conversion methods to transition from Kentucky bluegrass to low-input grasses may not provide complete Kentucky bluegrass control. Subsequent regrowth of Kentucky bluegrass may reduce playability, uniformity, and aesthetic value of the turf stand that has been converted. Studies have shown that some fine fescues are highly tolerant to the herbicide sethoxydim while Kentucky bluegrass has shown to be susceptible, thus providing a possible herbicide to selectively remove Kentucky bluegrass from fine fescue areas (10, 11, 29, 36, 47, 64). There is a lack of information in the scientific literature on the sethoxydim tolerance of both sheep fescue and Chewing's fescue. In addition to these species, prairie junegrass and tufted hairgrass; which have shown potential for use as low-input turf (60), but have not been evaluated for sethoxydim tolerance.

Therefore, the objective of the second study was (i) to compare the tolerance of cool-season turfgrass species and cultivars to sethoxydim and (ii) determine species tolerance at different application rates.

Conversion of Kentucky bluegrass rough to no-mow, low input grasses

INTRODUCTION

The most common turfgrass species planted in rough areas in the NCR of the United States is Kentucky bluegrass (*Poa pratensis* L.), accounting for 63% of the total (16). Newer Kentucky bluegrass cultivars have been a popular choice for golf course rough due to their improved pest resistance, darker green color, higher turf density, improved uniformity, and high divot recovery potential (8, 20). However, these improved cultivars can require high levels of water, fertilizer, and pesticide inputs to maintain golf course quality which comes at a higher cost (8). Higher levels of inputs also increase the frequency of mowing, which results in higher labor, machinery, and fuel costs.

Increasing costs and restrictions on water, fertilizer, and pesticides are prompting superintendents to consider maintenance programs that reduce inputs on golf courses. Restrictions on home lawn fertilizer and pesticide use are more common than for golf courses (25, 37). However, golf course fertilizer and pesticide restrictions are becoming more prevalent. In 2010, a stop sale was issued for pentachloronitrobenzene (PCNB) which is a low cost fungicide that is used at many golf courses for snow mold control in the winter (21). Superintendents will be forced to find higher cost alternative fungicides for use in their snow mold programs. Many municipalities enforce odd/even watering days to reduce the amount of water that business and homeowners use. Water use restrictions are also finding their way into the golf course setting. Mandatory water use restrictions in areas with severe drought conditions, monetary penalties if water use is above a set level, and proposals for increases in water use appropriation fees are also on the rise in areas such as Minnesota (39, 45).

Converting rough areas of a golf course to no-mow, low-input grasses can reduce inputs, which results in monetary and labor savings without reducing the functionality of the golf course. The benefits of fine fescues (*Festuca* spp.) natural low-input requirement have been shown in several research studies and there tolerance to shade, drought, and low pH soils make them a great candidate for use in no-mow, low-input areas (1, 2, 9, 22).

MATERIALS AND METHODS

Plot areas were established at the Turfgrass Research, Outreach, and Education Center on the St. Paul campus of the University of Minnesota and at Maple Grove, Minnesota on the grounds of Rush Creek Golf Club. Soil at the St. Paul site was a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludoll). Soil at Maple Grove was a mix of Cordova loam (Fine-loamy, mixed, superactive, mesic Typic Argiaquolls) and Lester loam (Fine-loamy, mixed, superactive, mesic Mollic Hapludalfs). The experimental design was a two-way factorial consisting of four replications. The two factors were conversion method and turfgrass species and each factor included five treatments.

Individual plots were a combination of one of five conversion methods and one of five turfgrass species (Table 1.1). Plots were established during the fall of 2007 and again in the fall of 2008 on established Kentucky bluegrass that had been mowed at 5.7 cm. Individual plots (one conversion method x one species combination) were 3.1 m x

3.1 m for the 2007 establishment and the size was reduced to 1.5 m x 1.5 m for the 2008 establishment.

Plots were seeded in both years between Sept. 6^{th}-8^{th} with a Gandy drop spreader (Gandy Company, Owatonna, MN) and seed was raked into the soil with a leaf rake. Starter fertilizer (19N-25P_2O_5-5K_2O) was applied at 49 kg P_2O_5 ha^{-1} after seeding and then watered. Treatments were kept moist by overhead irrigation from seeding date until the onset of winter. A late-season nitrogen application (46N-0P_2O_5-0K_2O) was applied at 49 kg N ha^{-1} in November of the establishment year, but was not applied in subsequent years. After fall of the first seeding, no supplemental irrigation, fertilizer, or pesticides were applied.

The five conversion methods described below were timed such that seeding of all plots at a single site took place at on the same day:

(1) Glyphosate/Seed treatment: Glyphosate (N-[phosphonomethyl] glycine) (Razor Pro, Nufarm USA, Burr Ridge, IL) was applied with a backpack sprayer (Solo, Newport News, VA) at a rate of 4.7 L ha^{-1} at 207 kPa with an 8002 flat fan nozzle (Teejet, Wheaton, IL). After 7 d, the treatment area was core aerified with 16 mm tines set on 5.1 cm x 5.1 cm spacing (Toro Greens Aerator, The Toro Company, Bloomington, MN); cores were left on site, and seeding followed aerification.

(2) Seed/Glyphosate treatment: Plots were aerified with 16 mm tines set on 5.1 cm x 5.1 cm spacing and cores were left on site. Seed was then applied and raked in. Five days after seeding, glyphosate was applied to the treatment area as previously described.

(3) Fumigation treatment: Plots were core aerified with 16 mm tines set on 5.1 cm x 5.1 cm spacing and the cores were left on site. After aerification, the soil fumigant dazomet (Tetrahydro-3,5,-dimethyl-2H-1,3,5-thiadiazine-2-thione) (Basamid Granular, Certis U.S.A., Columbia, MD) was applied at a rate of 392 kg ha^{-1} and immediately irrigated with 0.64 - 1.27 cm of water applied incrementally for 60 to 90 minutes to avoid ponding and runoff (34). After application of water, treatment areas were covered with 1 mm clear plastic for 7 d. Plastic was removed and plots were aired-out for 7 d prior to seeding.

(4) Sod removal treatment: Existing turf was removed with a sod cutter (Ryan sod cutter, Schiller Grounds Care, Inc., Johnson Creek, WI) to a depth of 2.5 cm to expose bare soil, which was then tilled to a depth of 5 to 8 cm. The plots were then seeded.

(5) Mowing treatment: Existing turf was removed with a sod cutter and soil tilled in the same manner as treatment 4; however, during the first growing season this treatment was kept mowed at 5.7 cm and was unmowed during the second growing season. It was hypothesized that one season of mowing prior to allowing the stand to become no-mow would reduce the amount of broadleaf weeds and enhance turfgrass establishment; therefore, data was only collected during the second growing season.

Except for initial seedling germination counts (collected in 2007 and 2008), growing season data was collected in 2008 and 2009. Data collected the growing season following establishment (2008 for plots established in 2007 and 2009 for plots established in 2008) is referred to as Year 1. Data collected during the second growing season after establishment (2009 for plots established in 2007) is referred to as Year 2.

Year 2 growing season data for plots established in 2008 was not collected in 2010 due to study time constraints.

With the exception of treatment 5 in Year 1, treatments were mowed once in October at 5.7 cm using a Toro 3500-D (The Toro Company, Bloomington, MN). Clippings were removed.

To quantify establishment success, initial seedling germination counts were taken 7 weeks after treatment (WAT) and again on May 11 the following spring after establishment at both locations using the line intersect method (30 cm x 30 cm box was arranged with fishing line crossing vertically and horizontally across the box every 2.5 cm to make 121 intersections where the strings met; counts were taken when the desirable species was directly under any of the 121 intersections). The grid was randomly placed at two locations on each treatment area. Counts were taken for both desirable and weed species.

Inflorescence counts were taken to assign an aesthetic value to the treatment area. A 30 cm x 30 cm frame was randomly placed at three locations within the treatment area and individual inflorescences were counted. Counts were taken between the last week of May and the first week of June during Year 1 and Year 2.

Visual stand quality ratings were taken monthly starting in June and ending in October during both years. Stand quality components included disease incidence (primarily rust [*Puccinia spp*.]), weed pressure, amount of lodging, percentage of desirable species, percentage of Kentucky bluegrass re-growth, and level of inflorescence formation. Moderate inflorescence formation was considered desirable because of color contrast to mowed areas of a golf course; however, dense inflorescence can reduce playablility of no-mow areas and too little inflorescence will not have an appealing aesthetic value. If any of the stand quality components were not optimum then stand quality rating was reduced. A 1 to 9 scale was used to quantify visual stand quality: 1 represented poor stand quality (near complete broadleaf weed invasion, high levels of lodging, high levels of Kentucky bluegrass re-growth; limited desirable species, high disease incidence and/or none or excessive inflorescence); 6 represented acceptable stand quality (some broadleaf weed invasion, some lodging, limited Kentucky bluegrass re-growth, limited disease incidence, and/or limited or high levels of inflorescence), and 9 represented the best stand quality (no broadleaf weed invasion, no lodging, complete stand of desirable species with no Kentucky bluegrass re-growth, freedom from disease, and moderate inflorescence levels).

Turfgrass biomass was collected to determine a playability rating of each treatment and species; plots with lower levels of biomass were considered more playable due to ease of finding a ball and ability to swing a club through the grass. Collections were taken in June, August, and October of both years. The 30 cm x 30 cm frame was used and randomly placed in the treatment area at two locations. All plant material within the frame was cut just above the soil surface. Wet weight was determined immediately and samples were then dried at 60ºC for 96 h and weighed again.

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with turfgrass species and conversion method as fixed effects and location and year of data collection as random effects (Table 1.2). Treatment mean separation was conducted using Tukey's (HSD) test at the $P \leq 0.05$ level.

RESULTS

Germination & establishment

Effective establishment of a newly seeded no-mow, low-input area is very important for long-term success. Treatments resulting in quick stand establishment can prevent broadleaf weed invasion and Kentucky bluegrass re-growth. The fumigation, sod removal, and mowing treatments provided significantly higher desirable species germination counts at both locations (Table 1.3). Chewing's fescue (*Festuca rubra* L. ssp. *commutata* Gaudin) had a significantly higher percentage of desirable species (81%) than the other grasses (≤ 60.0%) at the Maple Grove location while tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.) had significantly lower desirable species (48.2%) than other grasses (≥ 72%) at the St. Paul location (Table 1.3).

Inflorescence abundance

There was a significant year of data collection x location x conversion x species interaction for inflorescence abundance (Table 1.2). During April and May of 2008, rainfall totals were 12.3 and 12.5 cm at St. Paul and Maple Grove, respectively, and in April and May of 2009, 3.8 and 4.0 cm at St. Paul and Maple Grove, respectively. These lower rainfall amounts may have attributed to the 63% overall reduction in inflorescence numbers in Year 2 compared to Year 1 (Table 1.4). Although inflorescence production of perennial cool-season grasses tends to decline with stand age (6), it is unlikely to see this within the first two growing seasons. In Year 1 and Year 2, St. Paul had 39% and 60% more inflorescence respectively over Maple Grove (Table 1.4). During Year 1, the seed/glyphosate conversion method had lower inflorescence counts than the other conversion methods. However, the seed/glyphosate conversion method was the only method to consistently have more inflorescences in Year 2 than Year 1 unless the other conversion methods were in combination with sheep fescue (*Festuca ovina* L.) (Table 1.4). During Year 2 sheep fescue had the most inflorescence across all conversion methods at both locations and was the only species to increase its inflorescence production during Year 2, except when in combination with the sod removal treatment (Table 1.4). During Year 1, hard fescue (*Festuca brevipila* Tracey) produced significantly more inflorescence than the other species in St. Paul, but Chewing's fescue set the most inflorescence in Maple Grove, with strong creeping red fescue (*Festuca rubra* L. ssp. *rubra*) statistically similar on three of the conversion methods. Tufted hairgrass did not produce any inflorescence at either location during the study.

Visual stand quality

There was a significant year of data collection x location x conversion method x species interaction for visual stand quality (Table 1.2). Visual stand quality at St. Paul was better than at Maple Grove. This may be due to the St. Paul area being fumigated five years prior to the initiation of this study resulting in a lower broadleaf weed seed bank compared to the Maple Grove site. As a result, broadleaf weed invasion strongly impacted visual stand quality ratings at Maple Grove. Overall the fumigation treatment at Maple Grove consistently provided the best visual stand quality, though various other conversion methods were statistically similar to fumigation in both years among most species (Table 1.5). At St. Paul, the sod removal treatment during Year 1 had the highest visual stand quality ratings with all the fine fescues but not tufted hairgrass (Table 1.5). This is very different from Maple Grove where the sod removal treatment produced areas that were often inundated with broadleaf weeds, which lowered its visual stand quality.

The historical fumigation may have played a role in making the sod removal treatment more successful at St. Paul during Year 1. Year 2 results were more variable with similarities seen among several of the conversion methods (Table 1.5).

At St. Paul, there were a limited number of species x conversion method combinations that provided acceptable visual stand quality (≥6.0) (Table 1.5). During Year 1, only hard fescue and strong creeping red fescue (with the sod removal treatment) were able to maintain acceptable visual stand quality (Table 1.5). During Year 2, only sheep fescue (with seed/glyphosate, sod removal, and mowing treatments) was able to maintain acceptable visual stand quality (Table 1.5). There was no species x conversion combination at Maple Grove that averaged an acceptable rating in either year (Table 1.5).

Broadleaf weed invasion

Broadleaf weed invasion was 77% higher at Maple Grove than St. Paul, which was likely attributed to the aforementioned historical fumigation application at the St. Paul site (data not shown). Weed pressure allowed visualization of how each conversion method worked and which species were most resilient to broadleaf weed invasion. There was a significant year of data collection x location x species interaction but not a significant year of data collection x location x conversion method interaction (Table 1.2). Chewing’s and strong creeping red fescue were significantly better at resisting broadleaf weed invasion across all conversion methods during Year 1 (Table 1.6). This may be due to the natural weed suppression ability that has been documented in Chewing’s and strong creeping red fescue (5). The differences between species weed suppression lessened in Year 2 (Table 1.6). The fumigation treatment was best at resisting broadleaf weed invasion at both locations for both years while the glyphosate/seed and seed/glyphosate treatments were adequate at resisting broadleaf weed invasion (data not shown). Due to higher weed pressure, the sod removal treatment was least effective at resisting broadleaf weed invasion at Maple Grove but was successful at St. Paul (data not shown).

Lodging

Lodging in no-mow situations can decrease aesthetics and playability. Plots at Maple Grove exhibited 16% more lodging than the St. Paul location (data not shown). Additionally, plots showed 28% more lodging in Year 1 than Year 2 (data not shown). There was a significant year of data collection x species interaction allowing for locations to be pooled (Table 1.2). Tufted hairgrass was the most resistant to lodging; however, this was primarily because tufted hairgrass did not produce any inflorescence during the study and its low growing habit was not susceptible to lodging. Hard fescue showed significantly less lodging than other species in Year 1, and in Year 2 strong creeping red fescue and hard fescue were significantly better at resisting lodging (Table 1.7).

Kentucky bluegrass re-growth

Due to the perennial nature of Kentucky bluegrass and its ability to re-grow from rhizomes, it can be difficult to achieve complete control when eliminating the species. It was hypothesized that Kentucky bluegrass re-growth after conversion would reduce desirable species establishment because of its competitive advantage, resulting in reduced stand quality. There was a significant year of data collection x location x conversion method for Kentucky bluegrass re-growth (Table 1.2). All conversion methods performed very well in controlling Kentucky bluegrass re-growth except for the seed/glyphosate conversion method (Table 1.8). The seed/glyphosate conversion method had the lowest desirable species counts and the highest amount of Kentucky bluegrass re-growth in Year 1 (Table 1.3, Table 1.8). However, the seed/glyphosate treatment in Year 2 saw a general reduction in Kentucky bluegrass re-growth and an increase in desirable species and visual stand quality compared to Year 1 (Table 1.3, Table 1.5, Table 1.8).

Biomass production

A higher amount of biomass translates into a thicker sward and makes it difficult for golfers to find a golf ball and play from no-mow areas. There was a significant year of data collection x conversion method interaction and also a significant year of data collection x species interaction (Table 1.2). Biomass weights differed from Year 1 to Year 2 with a 41% overall reduction in biomass at both locations, which could be attributed to no supplemental fertilizer applications after the initial fall of establishment (data not shown). The fumigation treatment resulted in the largest amount of biomass in Year 1; however, in Year 2 many conversion methods showed similar biomass production and all were reduced from Year 1 (Table 1.9). Sheep fescue produced the most biomass while tufted hairgrass produced the smallest amount of biomass both years and again there was a reduction in species biomass production in Year 2 compared to Year 1 (Table 1.9).

DISCUSSION

Conversion methods

In terms of weed control, the fumigation conversion method was the most successful with minimal to no weed invasion throughout the study period. The fumigant's ability to kill weed seeds in the soil profile resulted in reduced competition with broadleaf weeds which allowed for high initial germination of desirable species and reduced broadleaf weed invasion during the growing season. The sod removal treatment was least effective at controlling weed invasion, especially at the Maple Grove site, with areas often being completely covered with broadleaf weeds. At Maple Grove, sod removal provided an opportunity for weed seeds to germinate; however, the sod removal conversion method was successful at the St. Paul site, which may have been due to fumigation five years prior to initiation of this study. The glyphosate/seed and the seed/glyphosate conversion methods were moderately successful at controlling broadleaf weed invasion.

The fumigation conversion method produced areas that were very dense with desirable species and had higher rates of lodging compared to the other conversion methods, especially during Year 1. When coming in contact with moist soil or water, the active ingredient in Basamid (dazomet, tetrahydro-3,5,-dimethyl-2H-1,3,5-thiadiazine-2) breaks down into several products, most notably the gas methyl isothiocyanate (MITC), which provides the fumigant activity, and also a readily available form of ammonium nitrate. The soil fumigant also causes a mineralization of nitrogen from the death of microorganisms that were immobilizing nitrogen, adding nitrogen into the soil profile (14). The increase in available nitrogen may have added to the large increase in growth in comparison to the other conversion methods in Year 1, but there was a leveling off and many conversion methods became similar in Year 2, possibly due to low-input management.

Kentucky bluegrass re-growth was not as severe a problem as expected. With the exception in Year 1 of the seed/glyphosate conversion method, all other treatments virtually eliminated any re-growth of Kentucky bluegrass. However, Year 2 of the seed/glyphosate conversion method saw an increase in the desirable species counts which may have been due to the fact that the Kentucky bluegrass could not tolerate the low-maintenance conditions over the two years and allowed the fine fescues to become the dominant species in this conversion method (26).

Although the fumigation treatment greatly reduces broadleaf weed invasion compared to the other treatments, the cost may deter superintendents from using this method. The glyphosate/seed conversion method is the most cost effective conversion method at $\$8 \cdot ha^{-1}$ for product cost versus $\$260 \cdot ha^{-1}$ for labor needed for sod removal and mowing treatments and $\$850 \cdot ha^{-1}$ for the fumigation treatment product costs. The glyphosate/seed conversion method had an adequate ability to control broadleaf weed invasion and Kentucky bluegrass re-growth and provided sufficient desirable species counts and inflorescence numbers.

Species

There were very few species x conversion method combination that were considered acceptable (≥6.0) (Table 1.5). Only hard fescue and strong creeping red fescue at St. Paul (with the sod removal treatment) during Year 1 and sheep fescue (with seed/glyphosate, sod removal, and mowing treatments) at St. Paul during Year 2 were able to maintain acceptable visual stand quality. Although very few species combinations were able to provide acceptable visual stand quality, there were differences in attributes that make certain species better than others.

Chewing's fescue was the most successful species during initial establishment at Maple Grove and St. Paul, along with hard and sheep fescue at St. Paul. Better establishment will result in a stand that is more resilient to weed invasion. After establishment, Chewing's fescue and strong creeping red fescue produced stands with the least amount of broadleaf weed invasion. The success of both Chewing's and strong creeping red fescues at resisting broadleaf weed invasion may also be due to the documented allelopathic abilities of these two species. Bertin et al., (5) determined that mean root and shoot length of developing weed species was reduced most when grown with 'Intrigue' Chewing's fescue. It was also found that 'Intrigue' produced the metabolite meta-tyrosine, which is the main constituent in its allelopathic traits; this compound is also produced by strong creeping red fescue but not by sheep or hard fescue (6).

Hard fescue produced the greatest number of inflorescences during Year 1 at St. Paul and Chewing's produced the most inflorescences at Maple Grove. However there was a shift in Year 2 with sheep fescue becoming the species that produced the most inflorescence across all conversion methods. Sheep fescue was also the only species to consistently increase inflorescence during Year 2. The large decline in inflorescence numbers may again be due to the difference in spring rainfall amounts from 2008 to 2009. Along with high inflorescence numbers, hard fescue had a better ability to remain standing during Year 1 and Year 2, as did strong creeping red fescue in Year 2.

CONCLUSION

This study was developed to give golf course superintendents recommendations for converting Kentucky bluegrass rough to no-mow, low-input grasses that are playable and aesthetically pleasing. Very few conversion x species combinations produced an area that was visually acceptable, but there were noteworthy individual traits. Weed control is very important in maintaining the aesthetic value of these areas. Initial seedling germination counts were significantly higher for the fumigation, sod removal, and mowing treatments and Chewing's fescue providing a better head start against broadleaf weed invasion. While established, Chewing's and strong creeping red fescue were significantly better at resisting broadleaf weed invasion in Year 1 but few differences were seen in Year 2. In terms of Kentucky bluegrass re-growth, all conversion methods except the seed/glyphosate treatments prevented any significant re-growth.

Inflorescence production, resistance to lodging, and biomass production all add to the beauty and playability of these areas. There was a large reduction in inflorescence production in Year 2 compared to Year 1, which may be due to reduced rainfall in the spring of Year 2 compared to Year 1. The only treatment to increase its inflorescence numbers in Year 2 was seed/glyphosate and the only species was sheep fescue. In Year 1, hard fescue was significantly better at resisting lodging and in Year 2 hard fescue was joined by strong creeping red fescue as being significantly better at resisting lodging. The fumigation treatment produced significantly more biomass in Year 1 but in Year 2 there was an overall decline and leveling of biomass production across conversion methods. Sheep fescue produced the most biomass and tufted hairgrass produced the least biomass.

In a short-term research trial, it is difficult to evaluate the long-term success of each species and conversion method but some differences were seen over the two years. Future research should focus on the following: using lower seeding rates to increase playability; using seed mixes to gain multiple advantages from different species; identifying additional species acceptable for no-mow, low-input areas; and testing different methods of conversion. In addition to the seeding issues, other areas to investigate are long-term maintenance issues such as biomass removal to maintain stand productivity, supplemental fertilizer and water applications to increase inflorescence counts, and use of limited herbicides to establish and maintain a healthy stand.

Table 1.1. Turfgrasses seeded at Maple Grove and St. Paul, MN in 2007 and 2008 for a no-mow, low-input study.

Common name	**Scientific name**	**Cultivar**	**Seeding rate ($kg·ha^{-1}$)[z]**
Strong creeping red fescue	*Festuca rubra* L. ssp. *Rubra*	Celestial	142.5
Chewing's fescue	*Festuca rubra* L. ssp. *Commutata* Gaudin	Intrigue	142.5
Hard fescue	*Festuca brevipila* Tracey	Minotaur	142.5
Sheep fescue	*Festuca ovina* L.	Common	142.5
Tufted hairgrass	*Deschampsia cespitosa* (L.) Beauv.	SR6000	48.8

[z]All seeding rates are given as pure live seed except for the tufted hairgrass species which is given as kg of seed as no percent germination was given on the seed tag.

Table 1.2. Analysis of variance for data collection attributes taken for conversion methods and turfgrass species used in the no-mow, low-input study.

Sources of variation	**Initial seedling germination counts**	**Inflorescence abundance**	**Visual stand quality**	**Broadleaf invasion**
Year of data collection (Y)	N/A	***	***	*
Location (L)	**	***	**	**
Y x L	N/A	N/S	**	***
Conversion (C)	***	***	***	***
Y x C	N/A	***	***	***
L x C	***	**	***	***
Y x L x C	N/A	***	***	N/S
Species (S)	***	***	***	***
Y x S	N/A	***	***	**
L x S	**	***	***	**
Y x L x S	N/A	***	***	**
C x S	***	***	**	N/S
Y x C x S	N/A	***	**	N/S
L x C x S	N/S	*	N/S	N/S
Y x L x C x S	N/A	**	*	N/S

Sources of variation	Lodging rating	Kentucky bluegrass invasion	Biomass
Year of data collection (Y)	***	***	***
Location (L)	*	N/S	**
Y x L	**	N/S	N/S
Conversion (C)	***	***	***
Y x C	*	***	***
L x C	***	*	***
Y x L x C	N/S	***	N/S
Species (S)	***	***	***
Y x S	***	N/S	***
L x S	N/S	N/S	***
Y x L x S	N/S	N/S	N/S
C x S	**	***	N/S
Y x C x S	N/S	N/S	N/S
L x C x S	N/S	**	N/S
Y x L x C x S	N/S	N/S	N/S

N/A=Data not available.

N/S=Not significant.

*, **, *** Significant at the 0.05, 0.01, 0.001 probability level respectively.

Table 1.3. Conversion method and desirable species germination coverage 7 WAT and the following spring after establishment from Kentucky bluegrass to no-mow, low-input grasses at Maple Grove and St. Paul, MN.

Conversion Method	**Plot Area with Desirable Species (%)**[y]	
	Maple Grove	**St. Paul**
Sod removal	79.6 a[z]	86.0 a
Mowing	78.7 a	86.9 a
Fumigation	76.4 a	87.2 a
Glyphosate/Seed	53.7 b	76.3 b
Seed/Glyphosate	23.4 c	15.2 c
Species	**Maple Grove**	**St. Paul**
Chewing's fescue	81.0 a[z]	77.4 a
Hard fescue	58.7 b	76.6 a
Sheep fescue	60.0 b	77.4 a
Strong creeping red fescue	59.8 b	72.0 b
Tufted hairgrass	53.3 b	48.2 c

[y]Data collection was taken 7 WAT and again on May 11th the following spring after establishment. Data were averaged over the four rating dates, two per establishment year.

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 1.4. Inflorescence counts of no-mow, low-input grasses and corresponding conversion methods in Year 1 and Year 2 at Maple Grove and St. Paul, MN.

Species	**Maple Grove**[y]					
	Glyphosate/Seed		**Seed/Glyphosate**		**Fumigation**	
	Year 1	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Chewing's fescue	69.9 aA[z]	1.6 cA	9.6 Ab	8.6 abA	56.9 aA	2.1 bA
Hard fescue	29.6 bB	5.4 bA	3.4 Bb	17.3 abA	31.3 bAB	16.7 abA
Sheep fescue	3.1 cB	11.2 aA	0.3 bB	21.3 aA	11.7 cAB	26.0 aA
Strong creeping red fescue	46.6 abA	0.1 cA	2.4 Bb	3.8 abA	60.1 aA	0.0 bA
Tufted hairgrass	0.0 dA	0.0 cA	0.0 Ba	0.0 bA	0.0 cA	0.0 bA

Species	**Maple Grove**[y]			
	Sod removal		**Mowing**	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Chewing's fescue	46.6 abA[z]	1.1 bA	N/A	5.5 bA
Hard fescue	64.1 aA	4.5 abA	N/A	24.5 aA
Sheep fescue	28.1 bA	7.4 aA	N/A	22.2 aA
Strong creeping red fescue	63.1 aA	0.0 bA	N/A	1.3 bA
Tufted hairgrass	0.0 cA	0.0 bA	N/A	0.0 bA

Species	St. Paul[y]					
	Glyphosate/Seed		Seed/Glyphosate		Fumigation	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Chewing's fescue	62.1 bcAB[z]	9.1 bA	5.0 abC	58.0 bA	78.0 abA	11.4 bA
Hard fescue	109.8 aA	8.9 bB	8.0 aB	56.2 bA	106.0 aA	14.4 bB
Sheep fescue	32.6 cdB	48.5 aAB	1.3 cdC	79.7 aA	60.5 bA	38.9 aAB
Strong creeping red fescue	71.4 bA	1.3 bB	3.8 bcB	27.9 cA	87.7 abA	0.67 bB
Tufted hairgrass	0.0 dA	0.0 bA	0.0 dA	0.0 dA	0.0 cA	0.0 bA

Species	St. Paul[y]			
	Sod removal		Mowing	
	Year 1	Year 2	Year 1	Year 2
Chewing's fescue	51.9 cB[z]	0.9 bA	N/A	11.4 bA
Hard fescue	84.6 aA	7.2 bB	N/A	13.3 bB
Sheep fescue	28.9 dB	17.8 aB	N/A	37.8 aAB
Strong creeping red fescue	68.7 bA	0.33 bB	N/A	4.0 bB
Tufted hairgrass	0.0 eA	0.0 bA	N/A	0.0 bA

[y]Inflorescence counts were taken between the last week of May and the first week of June during Year 1 and Year 2 using a 30 cm x 30 cm frame that was randomly placed at three locations within the treatment area and individual inflorescence was counted.

[z]Means in the same column followed by the same lowercase letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level. Means in the same row within the same year followed by the same uppercase letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

N/A=Data not available.

Table 1.5. Visual stand quality average ratings for Year 1 and Year 2 in conversion from Kentucky bluegrass to no-mow, low-input grasses at Maple Grove and St. Paul locations.

Conversion method	Maple Grove[y]					
	Chewing's fescue		Hard fescue		Sheep fescue	
	Year 1	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Glyphosate/Seed	2.9 abA[z]	2.6 aA	2.7 bA	2.6 aA	2.9 aA	2.9 bA
Seed/Glyphosate	2.6 bA	2.3 aA	1.7 cAB	3.1 aA	1.8 bAB	2.4 bcA
Fumigation	3.7 aA	2.8 aA	4.4 aA	3.9 aA	3.3 aA	3.9 aA
Sod removal	3.3 abA	2.2 aA	2.8 bA	2.6 aA	2.6 abA	1.9 bcA
Mowing	N/A	2.8 aA	N/A	3.3 aA	N/A	2.3 bcA

Conversion method	Maple Grove[y]			
	Strong creeping red fescue		Tufted hairgrass	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Glyphosate/Seed	3.2 abA[z]	2.8 bA	2.6 bA	3.0 aA
Seed/Glyphosate	2.3 bAB	2.8 abA	1.4 cB	1.8 bA
Fumigation	4.2 aA	3.9 aA	3.9 aA	3.4 aA
Sod removal	3.2 abA	1.9 bA	2.2 bA	1.8 bA
Mowing	N/A	2.4 aA	N/A	1.9 bA

Conversion method	St. Paul[y]					
	Chewing's fescue		Hard fescue		Sheep fescue	
	Year 1	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
Glyphosate/Seed	3.9 bB[z]	3.1 cC	5.4 bA	4.6 aB	3.9 abB	5.8 abA

Seed/Glyphosate	2.0 cAB	5.9 aA	1.7 cBC	5.5 aA	2.4 cA	6.6 aA
Fumigation	3.9 bBC	3.3 bcB	5.4 bA	5.1 aA	3.5 bcBC	5.4 bA
Sod removal	5.4 aBC	3.3 bcC	6.4 aAB	5.1 aB	4.9 aC	6.1 aA
Mowing	N/A	4.2 bBC	N/A	5.3 aB	N/A	6.9 aA

Conversion method	**St. Paul**[y]			
	Strong creeping red fescue		**Tufted hairgrass**	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Glyphosate/Seed	4.5 bAB[z]	3.1 abC	2.0 bcC	2.0 aD
Seed/Glyphosate	2.0 cAB	3.9 aB	1.4 cC	1.9 aC
Fumigation	4.8 bAB	2.9 bB	3.2 aC	2.3 aB
Sod removal	6.8 aA	3.3 abC	2.4 bD	2.3 aD
Mowing	N/A	3.8 aC	N/A	2.3 aD

[y]A 1-9 scale was used to rate each individual plot with 9 being best visual stand quality, 6 being minimal acceptable visual stand quality, and 1 being poor visual stand quality.

[z]Means in the same column followed by the same lowercase letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level. Means in the same row within the same year followed by the same uppercase letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

N/A=Data not available.

Table 1.6. Broadleaf weed invasion averages for five grass species in Year 1 and Year 2 in conversion from Kentucky bluegrass to no-mow, low-input grasses at Maple Grove and St. Paul, MN.

Species	**Broadleaf weed invasion**[xy]			
	Maple Grove		**St. Paul**	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Chewing's fescue	6.5 a[z]	5.0 a	7.4 a[z]	7.9 ab
Hard fescue	5.1 b	4.3 a	6.9 b	8.0 ab
Sheep fescue	5.1 b	4.2 a	6.9 b	8.1 a
Strong creeping red fescue	6.0 a	4.8 a	7.4 a	7.8 b
Tufted hairgrass	4.7 b	4.6 a	6.3 c	6.7 c

[x]A 1-9 scale was used to rate each individual plot with 9 being no weed invasion, 6 being moderate but minimally acceptable weed invasion, and 1 being complete weed invasion.

[y]Data was collected once per month from May to October in both 2008 and 2009 at both locations.

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 1.7. Lodging of no-mow, low-input grasses over two years in conversion from Kentucky bluegrass rough.

Species	**Lodging**[y]	
	Year 1	**Year 2**
Chewing's fescue	5.4 a[z]	7.3 a[z]
Hard fescue	7.5 c	8.0 b
Sheep fescue	6.3 b	7.1 a
Strong creeping red fescue	6.5 b	7.8 b
Tufted hairgrass	8.5 d	8.5 c

[y]A 1-9 scale was used to rate each individual plot with 9 being no stand lodging, 6 being moderate but minimally acceptable stand lodging, and 1 being complete stand lodging.

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 1.8. Kentucky bluegrass re-growth into no-mow, low-input conversion method stands over two years at Maple Grove and St. Paul, MN.

Conversion Method	**Kentucky bluegrass re-growth**[xy]			
	Maple Grove		**St. Paul**	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Glyphosate/Seed	9.8 b[z]	0.3 b	2.9 b[z]	0.9 b
Seed/Glyphosate	58.8 a	46.6 a	71.1 a	34.4 a
Fumigation	4.0 b	0.0 b	1.1 b	0.0 b
Sod removal	8.3 b	1.6 b	1.9 b	0.0 b
Mowing	N/A	1.1 b	N/A	0.0 b

[x]Percent of Kentucky bluegrass re-growth was estimated visually.

[y]Data collection was taken 7 WAT and again on May 11th the following spring after establishment. Data were averaged over the four rating dates, two per establishment year, prior to analysis.

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

N/A=Data not available.

Table 1.9. Average yearly wet biomass production of conversion methods and species over two years in conversion from Kentucky bluegrass to no-mow, low-input grasses.

Conversion Method	**Biomass (g)[y]**	
	Year 1	**Year 2**
Glyphosate/Seed	107.4 b[z]	60.7 a[z]
Seed/Glyphosate	66.8 d	54.2 b
Fumigation	136.5 a	61.1 a
Sod removal	76.2 c	50.1 b
Mowing	N/A	55.8 ab
Species	**Year 1**	**Year 2**
Chewing's fescue	104.2 b[z]	47.3 c[z]
Hard fescue	101.9 b	65.5 b
Sheep fescue	113.5 a	72.9 a
Strong creeping red fescue	100.2 b	50.8 c
Tufted hairgrass	63.8 c	45.3 c

[y]Biomass collections were taken in June, August and October of both years with locations being statistically similar and being combined for analysis.

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

N/A=Data not available.

Evaluation of cool-season turfgrass response to sethoxydim

INTRODUCTION

The selective control of perennial grass species in a turfgrass stand is difficult to accomplish because they possess physiological similarities to the desired turf species (15). Control is generally accomplished by mechanical removal or with the use of nonselective herbicides with the area then needing to be reestablished (15). Kentucky bluegrass (*Poa pratensis* L.), a perennial cool-season grass species, is the most widely used cool-season turfgrass species in the United States (15). Kentucky bluegrass is often used in golf course rough for its quick divot recovery through rhizomatous growth habit and high quality playing surface (22, 35). However, Kentucky bluegrass typically requires a significant amount of water, fertilizer, and labor costs associated with higher maintenance turf (8). A popular trend for golf course superintendents is to convert areas of Kentucky bluegrass rough to no-mow, low-input grasses

Using nonselective or mechanical control methods to convert Kentucky bluegrass rough to no-mow, low-input grasses may not provide complete control of Kentucky bluegrass. Re-growth of Kentucky bluegrass from rhizomes can reduce the aesthetic value of newly establish no-mow, low-input areas. Current sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) labels do not specify Kentucky bluegrass as a controlled species (1), but research has shown Kentucky bluegrass susceptibility to sethoxydim (29, 36). Research has also shown that fine fescues (*Festuca* spp.) are highly tolerant of sethoxydim applications (12, 29, 47, 64). Research has even indicated that fine fesuces can be stimulated by applications of sethoxydim (10). Studies have looked at the tolerance of some fine fescue species (10, 12, 29, 47, 64), but sheep fescue (*Festuca ovina* L.) and Chewing's fescue (*Festuca rubra* L. ssp. *commutata* Gaudin) have not been included in previous studies. Prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.) and tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.) have also shown potential as low-input species (60). However, their tolerance to sethoxydim has not been evaluated. Therefore, the objective of this study was: (i) to compare the tolerance of cool-season turfgrass species and cultivars to sethoxydim and (ii) determine species tolerance at different application rates.

MATERIALS AND METHODS

Field experiment plots were established in August 2008 and again in August 2009 at the Turfgrass Research, Outreach, and Education Center on the St. Paul campus of the University of Minnesota. Soil at the site was a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludoll). Plots were arranged as a randomized complete block design with four replications.

Each of the 15 cool-season grasses selected (Table 2.1) were represented in each replication by nine individual plants. Plants were initially established in the greenhouse from seed on May 14th 2008 and 2009 and allowed to grow in the greenhouse for 11 wk in 72-cell flats. Individual plants were then transplanted into the field and allowed to establish for an additional 4 wk prior to herbicide treatment initiation. No supplemental fertilizer was applied after field transplant and plants were mowed 1 week prior to herbicide application at 5.7 cm.

In 2008, single applications of sethoxydim (Poast Plus, BASF Corp., Research Triangle Park, NC) were applied on Sept. 6 (Trial 1) and Sept. 15 (Trial 2). In 2009, single applications of sethoxydim were made on September 12th (Trial 3) and September

17th (Trial 4). Sethoxydim was applied with a CO_2 backpack sprayer at 206.84 kPa with 8002 flat fan nozzles at rates of 0.0, 1.315, 2.630, and 5.26 $L \cdot ha^{-1}$ (control, 0.5x, 1.0x, and 2.0x rate respectively). Methylated seed oil at 2.15 $L \cdot ha^{-1}$ was used with all rates except the control rate. With the formulation of sethoxydim that was chosen it is recommended to use methylated seed oil with sethoxydim to increase its effectiveness (63).

Individual plant quality ratings were taken using a visual 1 to 9 scale with 9 indicating optimum individual plant quality (absence of discoloration and plant decline), 6 indicating minimum acceptable plant quality (some discoloration and plant decline), and 1 indicating plant death (complete discoloration and plant death). In 2008, individual plant quality ratings were taken 2, 3, 4, and 5 weeks after treatment (WAT). In 2009, individual plant quality ratings were taken 2, 3, and 5 WAT.

Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with turfgrass species and herbicide rate as fixed effects and date of treatment application as the random effect (Table 2.2). Year of data collection and date of treatment application were significant allowing for all trials to be analyzed separately. There was also a significant year x date of treatment application x treatment x species interaction; (Table 2.2). Treatment mean separation was conducted using Tukey's (HSD) test at the $P \leq 0.05$ level.

RESULTS

Visual turfgrass quality for 2008 (Trials 1 & 2)

In 2008, the control treatments maintained acceptable turfgrass quality through 5 WAT (Table 2.3, Table 2.4). Some visual decline was exhibited with the Kentucky bluegrass entries, perennial ryegrass (*Lolium perenne* L.), and tufted hairgrass entries due to powdery mildew (*Erysiphe graminis*) and/or rust (*Puccinia* spp.) incidence, but all were able to maintain acceptable turfgrass quality.

All Kentucky bluegrass entries receiving the 0.5x and 1.0x rates had unacceptable visual turfgrass quality by 3 WAT (Data not shown). At the 2.0x rate all Kentucky bluegrass entries had unacceptable visual quality by 2 WAT (Table 2.3, Table 2.4). Although plant decline was severe and increased with higher treatment rates, complete plant death was not often the outcome with the Kentucky bluegrass entries in 2008 by 5 WAT.

One tufted hairgrass entry (12836) was able to maintain acceptable turfgrass quality at the 0.5x treatment by 5 WAT in both Trial 1 & 2, but not at the 1.0x and 2.0x treatments (Table 2.3, Table 2.4). ‘SR6000’ tufted hairgrass maintained visual quality in Trial 1 at the 0.5x treatment, but declined to below acceptable quality by 5 WAT at the 1.0x and 2.0x treatments in Trial 1 and declined to below acceptable quality by 5 WAT in Trial 2 at all treatments (Table 2.3, Table 2.4). ‘10922’ tufted hairgrass was not able to maintain acceptable turfgrass quality in 2008 at any of the treatment rates (Table 2.3, Table 2.4). All of the tufted hairgrass entries were unable to maintain acceptable quality at the 1.0x and 2.0x treatment rates by 5 WAT (Table 2.3, Table 2.4). Declines were less severe at the 1.0x rate than with the 2.0x rate which showed significant injury, but not complete plant death.

Perennial ryegrass, tall fescue (*Festuca arundinacea* Schreb.), and prairie junegrass were not tolerant to any herbicide treatment and all fell below minimum acceptable visual turfgrass quality ratings by 5 WAT (Table 2.3, Table 2.4). Perennial ryegrass had the most complete plant death at the 1.0x and 2.0x treatments. All four fine fescue species were unharmed by sethoxydim in all treatments; the only declines were seen in plants that were overtaken with some broadleaf weeds or annual grasses that had encroached thus reducing plant quality.

Visual turfgrass quality for 2009 (Trials 3 & 4)

There was higher disease pressure during the 2009 study period (September/October) than during the same period in 2008 which may be due to the increased rainfall in 2009 (17.1 cm) compared to 2008 (11.2 cm) (46). The additional rain and overcast skies may have increased leaf wetness causing an increase in disease pressure. As a result, 2009 trials had significant powdery mildew and rust which caused all Kentucky bluegrass entries, ‘Gator’ perennial ryegrass, ‘062194’ prairie junegrass, and ‘SR6000’ tufted hairgrass to fall below minimal acceptable quality by 5 WAT of the control treatment (Table 2.5, Table 2.6).

Kentucky bluegrass entries were unable to maintain acceptable turfgrass quality by 5 WAT with any of the sethoxydim treatment rates. Like in 2008, severe decline was exhibited with Kentucky bluegrass, but complete plant death was seldom the outcome by 5 WAT.

Tall fescue was more tolerant to sethoxydim in 2009 compared to 2008 with acceptable plant quality ratings seen at the 0.5x rate in Trial 3 & 4 and at the 1.0x rate in Trial 4, but not to the 1.0x rate in Trial 3 and 2.0x rate in Trial 3 & 4 by 5 WAT (Table 2.5, Table 2.6).

As in 2008, perennial ryegrass and prairie junegrass were not tolerant of any herbicide treatment (Table 2.5, Table 2.6). However, less complete plant death was seen at the 1.0x and 2.0x rates with perennial ryegrass in 2009.

Tufted hairgrass species exhibited a higher tolerance to all treatment rates of sethoxydim during 2009. In fact, more plant decline was seen with the control treatment than with the herbicide treatments to tufted hairgrass species. The tufted hairgrass entries exhibited some turfgrass decline, but were able to maintain acceptable turfgrass quality at all rates by 5 WAT (Table 2.5, Table 2.6).

Like 2008, the fine fescue species were unharmed by all treatment rates of sethoxydim and maintained acceptable turfgrass quality through 5 WAT (Table 2.5, Table 2.6).

DISCUSSION

Turfgrass response to sethoxydim applications were generally less severe in 2009 compared to 2008 and may be a result of annual climatic variation. The 2008 growing season had warmer condition with less rainfall compared to 2009. Coupland (17) found that increases in humidity and temperature noticeably increased the performance of sethoxydim when used on quackgrass [*Elymus repens* (L.) Gould]. In 2008, mean average temperature was 15.3°C and in 2009, mean average temperature was 11.9°C (46). Differences in turfgrass response from 2008 and 2009 may be representative of differences in weather conditions.

The difference in herbicide tolerance of the tufted hairgrass entries in 2009 compared to 2008 was unexpected. Although some tolerance was seen in 2008 with the ‘12836’ and ‘SR6000’ tufted hairgrass, most rates and dates resulted in below minimum acceptable quality by 5 WAT. However, in 2009 all the tufted hairgrass entries were very tolerant to all rates of sethoxydim. The documented lack of drought tolerance with the tufted hairgrass species (59) in combination with less rainfall in 2008 may have contributed to the difference seen between 2008 and 2009.

Tall fescue also exhibited better tolerance in 2009 compared to 2008, but not to the extent of the tufted hairgrass entries. In 2009, tolerance was seen at the 0.5x and 1.0x rates, but not the 2.0x rate. Herbicide labels indicate that sethoxydim can be used on established tall fescue, but should not be used when the species is less than one year old or in areas where discoloration is not acceptable (1). Hosaka et al. (29) found 100% control of tall fescue at the 3-5 leaf stage; although the plants used in this study were beyond the 3-5 leaf stage, they were still less than one year old which may be the reason for the response we saw.

Overall, the results from 2008 to 2009 were consistent for the other cool-season species. Although less complete plant death was seen in 2009 with perennial ryegrass, visual plant quality by 5 WAT was very low. The Kentucky bluegrass entries were not tolerant to any herbicide rate during both years but complete plant death was not often the outcome by 5 WAT. Like with all the declining species, Kentucky bluegrass began to show visible herbicide effects by 2 WAT with purpling leaf blades and reduced plant growth.

CONCLUSION

Chewing's fescue, hard fescue (*Festuca brevipila* Tracey), strong creeping red fescue (*Festuca rubra* L. ssp. *rubra*), and sheep fescue were all unaffected by all rates of sethoxydim throughout the study period. Mixed results were seen with tall fescue with tolerance seen at the 0.5x and 1.0x rates in 2009, but not 2008. The only other species to show any tolerance to sethoxydim was tufted hairgrass. Tufted hairgrass showed some tolerance in 2008 at the 0.5x treatment rate and in 2009 showed tolerance at all herbicide treatment rates.

Tufted hairgrass has shown some potential as a low-maintenance turfgrass species in the North Central Region of the United States (60). The ability to selectively remove other cool-season grasses from tufted hairgrass could prove very useful in both turf and seed production management systems. Although more testing and information is needed, tufted hairgrass' tolerance to sethoxydim may prove to be useful as there are breeding programs developing new cultivars of this species for turf use (60).

All the remaining cool-season species exhibited severe plant decline by 5 WAT during both years. Perennial ryegrass was the most susceptible species to sethoxydim applications. When there was complete plant death of perennial ryegrass, it was often a combination of the herbicide and large amounts of rust accumulating on the leaf blade. During both years, tall fescue, prairie junegrass, and all of the Kentucky bluegrasses showed dramatic individual plant declines by 5 WAT, but complete plant death was seldom the outcome by 5 WAT. Much like perennial ryegrass, Kentucky bluegrass decline was often a combination of the herbicide and the onset of powdery mildew and/or rust. However, the lack of complete control of Kentucky bluegrass may require one or more additional applications of sethoxydim to achieve complete control.

Future studies should evaluate subsequent application of sethoxydim for additional control of Kentucky bluegrass and other grasses that can occur in low-input areas, especially areas that are not going to be mowed. These grasses include reed canarygrass (*Phalaris arundinacea* L.), quackgrass, and orchardgrass (*Dactylis glomerata* L.). Additional studies can also look at the effect of applications during the spring and summer. There is also need for a more thorough evaluation of tolerance in tufted hairgrass species.

Table 2.1. Turfgrass species selected for sethoxydim tolerance.

Common name	Scientific name	Cultivar/Selection
Prairie junegrass	*Koeleria macrantha* (Ledeb.) Schult.	062194[x]
Tufted hairgrass	*Deschampsia cespitosa* (L.) Beauv.	12836[y]
Tufted hairgrass	*Deschampsia cespitosa* (L.) Beauv.	10922[z]
Tufted hairgrass	*Deschampsia cespitosa* (L.) Beauv.	SR6000
Kentucky bluegrass	*Poa pratensis* L.	Award
Kentucky bluegrass	*Poa pratensis* L.	Baron
Kentucky bluegrass	*Poa pratensis* L.	Broadway
Kentucky bluegrass	*Poa pratensis* L.	Kenblue
Kentucky bluegrass	*Poa pratensis* L.	Washington
Strong creeping red fescue	*Festuca rubra* L. ssp. *Rubra*	Celestial
Chewing's fescue	*Festuca rubra* L. ssp. *commutata* Gaudin	Intrigue
Hard fescue	*Festuca brevipila* Tracey	Minotaur
Sheep fescue	*Festuca ovina* L.	Common
Tall fescue	*Festuca arundinacea* Schreb.	Plantation
Perennial ryegrass	*Lolium perenne* L.	Gator

[x]Germplasm from the University of Minnesota breeding program. Initial selection originated from North Dakota. Not commercially available.

[y]Germplasm from the University of Minnesota breeding program. Initial selection originated from the Pyrenees region of Southwest Europe. Not commercially available.

[z]Germplasm from the University of Minnesota breeding program. Initial selection originated from Germany. Not commercially available.

Table 2.2. ANOVA tables for data collection attributes of cool-season turfgrasses treated with sethoxydim.

Sources of variation	**Individual plant quality ratings**
Year of data collection (Y)	***
Date of treatment application (D)	***
Treatment (T)	***
Species (S)	***
Y x D	***
Y x T	***
Y x S	***
D x T	***
D x S	***
T x S	***
Y x D x T	***
Y x D x S	***
Y x T x S	***
D x T x S	***
Y x D x T x S	***

*, **, *** Significant at the 0.05, 0.01, 0.001 probability level respectively.

Table 2.3. Cool-season visual turfgrass quality ratings in response to sethoxydim herbicide treatments at 2 and 5 WAT of the September 6th, 2008 spray date (Trial 1).

Cultivar or Selection	**Spec***	**2008 Cool-Season Turfgrass Ratings**			
		Spray date: September 6th, 2008 (Trial 1)			
		2 WAT			
		Treatment[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	9.0 a[z]	6.9 ab	5.2 bcd	4.3 bc
Baron	Kentucky bluegrass	8.9 a	6.4 b	6.0 bc	4.8 b
Broadway	Kentucky bluegrass	9.0 a	6.1 bc	4.7 cd	3.7 bcd
Kenblue	Kentucky bluegrass	8.6 ab	5.5 bc	4.8 cd	3.7 bcd
Washington	Kentucky bluegrass	8.9 a	4.8 bc	3.5 d	2.8 cd
Celestial	Strong creeping red fescue	9.0 a	9.0 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	9.0 a	9.0 a	9.0 a
Intrigue	Chewing's fescue	9.0 a	9.0 a	9.0 a	8.9 a
Minotaur	Hard fescue	8.8 a	9.0 a	9.0 a	8.6 a
SR6000	Tufted hairgrass	9.0 a	7.4 ab	5.1 bcd	3.2 bcd
Germany	Tufted hairgrass	8.3 ab	6.0 b	4.7 cd	3.0 bcd
Pyrenees	Tufted hairgrass	8.8 a	7.7 ab	6.9 b	4.8 b
Gator	Perennial ryegrass	9.0 a	3.6 c	3.3 d	2.1 d

North Dakota	Prairie junegrass	7.8 b	4.1 bc	3.4 d	2.3 d
Plantation	Tall fescue	9.0 a	4.0 bc	3.6 d	2.5 cd
Cultivar or Selection	**Spec***	**2008 Cool-Season Turfgrass Ratings (Continued)**			
		Spray date: September 6th, 2008 (Trial 1)			
		5 WAT			
		Treatment[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	7.7 abcde[z]	4.5 bc	3.1 cde	2.1 cd
Baron	Kentucky bluegrass	6.7 cde	3.9 cd	3.1 cde	2.5 bcd
Broadway	Kentucky bluegrass	7.1 bcde	3.3 cde	2.6 def	2.1 cd
Kenblue	Kentucky bluegrass	6.1 e	3.5 cd	2.9 cde	2.0 cd
Washington	Kentucky bluegrass	8.1 abcd	2.6 de	2.2 ef	1.8 de
Celestial	Strong creeping red fescue	8.8 ab	9.0 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	9.0 a	9.0 a	9.0 a
Intrigue	Chewing's fescue	9.0 a	9.0 a	8.8 a	8.9 a
Minotaur	Hard fescue	8.7 ab	8.8 a	8.8 a	8.7 a
SR6000	Tufted hairgrass	8.5 abc	7.4 a	4.3 bc	2.8 bc
Germany	Tufted hairgrass	7.6 abcde	5.7 b	3.8 cd	1.9cde

Pyrenees	Tufted hairgrass	8.9 ab	7.6 a	5.5 b	3.3 b
Gator	Perennial ryegrass	7.7 abcde	1.6 e	1.0 f	1.0 e
North Dakota	Prairie junegrass	6.5 de	3.2 cde	2.3 def	1.7 de
Plantation	Tall fescue	9.0 a	2.4 de	2.1 ef	1.8 cde

*Spec=Species

[x]Sethoxydim was applied at rates of 0.0, 1.315, 2.630, and 5.26 $L\cdot ha^{-1}$ (control, 0.5x, 1.0x, and 2.0x rate respectively). Methylated seed oil at 2.15 $L\cdot ha^{-1}$ was used with all rates except the control rate.

[y]Individual plant quality ratings were taken using a visual 1 to 9 scale with 9 indicating optimum individual plant quality (absence of discoloration and decline), 6 indicating minimum acceptable plant quality (some discoloration and decline), and 1 indicating plant death (complete discoloration and plant death).

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 2.4. Cool-season visual turfgrass quality ratings in response to sethoxydim herbicide treatments at 2 and 5 WAT of the September 15th, 2008 spray date (Trial 2).

Cultivar or Selection	**Spec***	**2008 Cool-Season Turfgrass Ratings**			
		Spray date: September 15th, 2008 (Trial 2)			
		2 WAT			
		Treatment[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	8.7 a[z]	5.3 bcde	5.1 cd	4.2 bc
Baron	Kentucky bluegrass	7.9 a	4.7 cde	4.8 cd	4.2 bc
Broadway	Kentucky bluegrass	7.8 a	4.2 de	4.1 de	3.6 c
Kenblue	Kentucky bluegrass	8.6 a	4.9 cde	4.9 cd	4.0 bc
Washington	Kentucky bluegrass	8.3 a	4.1 e	5.3 cd	3.9 bc
Celestial	Strong creeping red fescue	8.5 a	8.9 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	9.0 a	9.0 a	9.0 a
Intrigue	Chewing's fescue	8.9 a	9.0 a	9.0 a	9.0 a
Minotaur	Hard fescue	9.0 a	8.9 a	9.0 a	8.9 a
SR6000	Tufted hairgrass	8.6 a	6.2 bcd	6.6 bc	4.7 bc
Germany	Tufted hairgrass	8.5 a	6.5 bc	6.3 bc	4.8 bc
Pyrenees	Tufted hairgrass	8.7 a	7.3 ab	7.9 ab	5.7 b
Gator	Perennial ryegrass	8.1 a	5.3 bcde	3.8 de	2.9 c

North Dakota	Prairie junegrass	7.4 a	3.6 e	2.9 e	3.5 c
Plantation	Tall fescue	9.0 a	5.2 cde	4.3 de	3.8 bc
Cultivar or Selection	**Spec***	**2008 Cool-Season Turfgrass Ratings (Continued)**			
		Spray date: September 15th, 2008 (Trial 2)			
		5 WAT			
		Treatment[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	8.3 abc[z]	3.0 c	3.3 cd	2.3 bcd
Baron	Kentucky bluegrass	6.9 c	2.5 c	2.4 de	2.4 bc
Broadway	Kentucky bluegrass	7.5 abc	2.6 c	2.6 cde	2.2 cd
Kenblue	Kentucky bluegrass	7.5 abc	2.5 c	2.1 de	2.4 bc
Washington	Kentucky bluegrass	8.3 abc	2.3 c	2.2 de	1.9 cd
Celestial	Strong creeping red fescue	8.3 abc	8.9 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	8.9 a	9.0 a	9.0 a
Intrigue	Chewing's fescue	8.9 a	8.9 a	9.0 a	9.0 a
Minotaur	Hard fescue	9.0 a	9.0 a	9.0 a	9.0 a
SR6000	Tufted hairgrass	8.6 ab	5.7 b	5.1 b	3.0 bc
Germany	Tufted hairgrass	8.6 ab	5.4 b	4.4 bc	3.4 b

Pyrenees	Tufted hairgrass	8.7 ab	6.1b	5.1 b	3.4 b
Gator	Perennial ryegrass	8.2 abc	2.2 c	1.4 e	1.2 d
North Dakota	Prairie junegrass	7.2 bc	2.4 c	2.6 cde	2.1 cd
Plantation	Tall fescue	9.0 a	3.3 c	2.5 de	2.0 cd

*Spec=Species

[x]Sethoxydim was applied at rates of 0.0, 1.315, 2.630, and 5.26 $L \cdot ha^{-1}$ (control, 0.5x, 1.0x, and 2.0x rate respectively). Methylated seed oil at 2.15 $L \cdot ha^{-1}$ was used with all rates except the control rate.

[y]Individual plant quality ratings were taken using a visual 1 to 9 scale with 9 indicating optimum individual plant quality (absence of discoloration and decline), 6 indicating minimum acceptable plant quality (some discoloration and decline), and 1 indicating plant death (complete discoloration and plant death).

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 2.5. Cool-season visual turfgrass quality ratings in response to sethoxydim herbicide treatments at 2 and 5 WAT of the September 12th, 2009 spray date (Trial 3).

Cultivar or Selection	**Spec***	**2009 Cool-Season Turfgrass Ratings — Spray Date: September 12th, 2009 (Trial 3) — 2 WAT — Treatment**[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	3.6 f[z]	4.7 cd	3.5 e	3.4 ef
Baron	Kentucky bluegrass	5.2 ef	4.6 d	4.2 de	4.4 def
Broadway	Kentucky bluegrass	7.0 bcd	6.4 abcd	4.3 de	4.9 de
Kenblue	Kentucky bluegrass	8.5 ab	8.1 ab	6.9 abc	6.0 cd
Washington	Kentucky bluegrass	8.1 abc	7.2 abcd	6.1 bcd	6.8 bc
Celestial	Strong creeping red fescue	8.9 a	9.0 a	8.6 a	9.0 a
Common	Sheep fescue	8.8 a	8.1 ab	8.8 a	8.0 ab
Intrigue	Chewing’s fescue	9.0 a	9.0 a	9.0 a	8.8 a
Minotaur	Hard fescue	9.0 a	9.0 a	8.9 a	9.0 a
SR6000	Tufted hairgrass	8.5 ab	7.3 abc	7.6 ab	8.2 ab
Germany	Tufted hairgrass	9.0 a	8.8 a	8.9 a	8.8 a
Pyrenees	Tufted hairgrass	9.0 a	8.8 a	8.6 a	8.2 ab
Gator	Perennial ryegrass	5.7 cde	4.9 cd	3.3 e	3.0 f

North Dakota	Prairie junegrass	6.4 cde	5.5 bcd	5.0 cde	4.9 de
Plantation	Tall fescue	8.9 a	8.1 ab	7.6 ab	7.4 abc
Cultivar or Selection	**Spec***	**2009 Cool-Season Turfgrass Ratings (Continued)**			
		Spray Date: September 12th, 2009 (Trial 3)			
		5 WAT			
		Treatment[xy]			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	2.0 d[z]	2.3 d	2.1 d	1.9 e
Baron	Kentucky bluegrass	2.2 d	2.2 d	2.0 d	2.1 e
Broadway	Kentucky bluegrass	2.8 cd	3.6 d	2.2 d	2.1 e
Kenblue	Kentucky bluegrass	4.3 bc	4.3 cd	3.3 d	2.6 de
Washington	Kentucky bluegrass	4.9 b	4.1 d	3.1 d	2.5 de
Celestial	Strong creeping red fescue	9.0 a	8.7 ab	8.4 ab	8.9 a
Common	Sheep fescue	8.4 a	7.6 ab	8.1 ab	8.7 ab
Intrigue	Chewing's fescue	9.0 a	9.0 a	9.0 a	9.0 a
Minotaur	Hard fescue	9.0 a	8.4 ab	8.8 ab	9.0 a
SR6000	Tufted hairgrass	7.3 a	6.4 bc	6.9 bc	7.0 c
Germany	Tufted hairgrass	8.6 a	8.5 ab	8.6 ab	7.9 abc

Pyrenees	Tufted hairgrass	9.0 a	8.7 a	7.7 abc	7.7 bc
Gator	Perennial ryegrass	4.5 bc	3.3 d	2.2 d	1.6 e
North Dakota	Prairie junegrass	4.8 b	3.7 d	3.8 d	2.7 de
Plantation	Tall fescue	8.9 a	7.4 ab	5.9 c	3.7 d

*Spec=Species

[x]Sethoxydim was applied at rates of 0.0, 1.315, 2.630, and 5.26 $L\cdot ha^{-1}$ (control, 0.5x, 1.0x, and 2.0x rate respectively). Methylated seed oil at 2.15 $L\cdot ha^{-1}$ was used with all rates except the control rate.

[y]Individual plant quality ratings were taken using a visual 1 to 9 scale with 9 indicating optimum individual plant quality (absence of discoloration and decline), 6 indicating minimum acceptable plant quality (some discoloration and decline), and 1 indicating plant death (complete discoloration and plant death).

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

Table 2.6. Cool-season visual turfgrass quality ratings in response to sethoxydim herbicide treatments at 2 and 5 WAT of the September 17th, 2009 spray date (Trial 4).

Cultivar or Selection	**Spec***	**2009 Cool-Season Turfgrass Ratings**			
		Spray Date: September 17th, 2009 (Trial 4)			
		2 WAT			
		Treatment^{xy}			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	7.4 ab^{z}	4.9 d	5.8 c	4.6 de
Baron	Kentucky bluegrass	6.3 bc	5.5 cd	5.6 c	4.1 de
Broadway	Kentucky bluegrass	7.9 ab	7.6 abc	6.5 bc	6.1 bcd
Kenblue	Kentucky bluegrass	8.7 a	7.5 abcd	8.5 a	7.0 abc
Washington	Kentucky bluegrass	8.8 a	8.7 a	8.5 a	7.5 ab
Celestial	Strong creeping red fescue	9.0 a	9.0 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	8.1 ab	8.9 a	8.8 a
Intrigue	Chewing's fescue	9.0 a	9.0 a	9.0 a	9.0 a
Minotaur	Hard fescue	8.7 a	9.0 a	9.0 a	9.0 a
SR6000	Tufted hairgrass	7.4 ab	7.7 abc	7.8 ab	7.9 ab
Germany	Tufted hairgrass	9.0 a	9.0 a	9.0 a	9.0 a
Pyrenees	Tufted hairgrass	8.9 a	8.9 a	9.0 a	9.0 a
Gator	Perennial ryegrass	7.1 abc	5.6 bcd	5.6 c	3.7 e

North Dakota	Prairie junegrass	5.1 c	5.3 cd	5.8 c	4.6 cde
Plantation	Tall fescue	9.0 a	9.0 a	9.0 a	9.0 a
Cultivar or Selection	**Spec***	**2009 Cool-Season Turfgrass Ratings (Continued)**			
		Spray Date: September 17th, 2009 (Trial 4)			
		5 WAT			
		Treatment^{xy}			
		C	**0.5x**	**1.0x**	**2.0x**
Award	Kentucky bluegrass	4.4 bc^{z}	2.7 de	3.1 de	2.3 e
Baron	Kentucky bluegrass	2.7 c	2.5 e	2.6 e	2.2 e
Broadway	Kentucky bluegrass	4.5 bc	3.3 cde	2.6 e	2.3 e
Kenblue	Kentucky bluegrass	5.5 b	4.0 cde	3.8 de	3.6 de
Washington	Kentucky bluegrass	5.8 b	5.2 bc	4.6 cd	3.2 e
Celestial	Strong creeping red fescue	8.9 a	8.9 a	9.0 a	9.0 a
Common	Sheep fescue	9.0 a	8.2 a	8.8 a	8.6 a
Intrigue	Chewing’s fescue	9.0 a	9.0 a	9.0 a	9.0 a
Minotaur	Hard fescue	9.0 a	8.8 a	8.9 a	9.0 a
SR6000	Tufted hairgrass	5.8 b	6.9 ab	5.9 bc	6.1bc
Germany	Tufted hairgrass	8.6 a	8.3 a	8.4 a	7.9 ab

Pyrenees	Tufted hairgrass	8.7 a	8.7 a	8.8 a	8.4 a
Gator	Perennial ryegrass	5.6 b	4.8 bcd	4.1 de	2.2 e
North Dakota	Prairie junegrass	4.4 bc	3.9 cde	4.3 d	3.7 de
Plantation	Tall fescue	8.8 a	7.8 a	6.3 b	5.2 cd

*Spec=Species

[x]Sethoxydim was applied at rates of 0.0, 1.315, 2.630, and 5.26 $L \cdot ha^{-1}$ (control, 0.5x, 1.0x, and 2.0x rate respectively). Methylated seed oil at 2.15 $L \cdot ha^{-1}$ was used with all rates except the control rate.

[y]Individual plant quality ratings were taken using a visual 1 to 9 scale with 9 indicating optimum individual plant quality (absence of discoloration and decline), 6 indicating minimum acceptable plant quality (some discoloration and decline), and 1 indicating plant death (complete discoloration and plant death).

[z]Means in the same column followed by the same letters are not significantly different according to Tukey's (HSD) test at the $P \leq 0.05$ level.

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