STRESS RESPONSES OF KENTUCKY BLUEGRASS VARIETIES IN MONOSTANDS AND BLENDS

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ABSTRACT

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Traditional recommendations for athletic field construction have included the blending of turfgrass varieties; however, due to recent advancements in breeding technology, single cultivars bred for generalized disease resistance, aggressive tillering, and herbicide resistance may be used in place of a blend, which was previously necessary to provide all of these characteristics. Four separate studies were initiated in East Lansing, MI on 25 September 2009 to measure the validity of using monostands instead of blends. Two studies were subjected to twelve traffic events (ten passes per week) with the Brinkman traffic simulator beginning 3 August 2010 and evaluated for various response variables. One of the studies, established on native soil, showed that the blends did not out perform all of their constituent varieties in quality, cover, and surface strength characteristics during traffic applications. In addition to these findings, a comparable experiment established on native soil but receiving 2.4 cm of high sand-based topdressing prior to traffic applications, provided similar results over the two years of data collection. Two additional studies focused on blends and monostands under *Sclerotinia homoeocarpa* (Dollar Spot) and Bispyribac-sodium (Velocity) stress. Two resistant and two susceptible varieties were chosen for blend construction. Two-year results from the dollar spot study consistently showed the resistant varieties and the blend of the two resistant varieties having fewer dollar spot infection centers and higher overall quality. Similarly, in the two-year duration, blends of the Velocity study showed tendencies of intermediate results in Normalized Difference Vegetation Index (NDVI), quality, and percent blighted tissue when compared to the resistant and sensitive varieties.

DEDICATED

To my parents, Mike and Linda Dunne
and my brothers Ben and Lane,
for their love and support
Thank you

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INTRODUCTION

Blending turfgrasses often provide advantages over single-variety stands, particularly in highly stressed situations (Beard, 1973; Turgeon, 2008; Schumann et al, 1992; Vargas, 2005; Bell, 2011). Variable environments and habitats generally more conducive to a wide range of disease and insect problems create a favorable platform for blends to succeed over monostands. In athletic fields, the tendencies for blends to compose the turf stand are undeniable considering the frequent exposure to traffic, biotic and abiotic stressors, and the lack of genetic diversity of Kentucky bluegrass (*Poa pratensis* L.). Kentucky bluegrass is a widely adaptive turfgrass species used throughout cool, humid and transitional regions of the world (Beard, 1973). However, the apomictic nature of Kentucky bluegrass has brought about changes in its use, functionality and adaptability across many situations, including but not limited to athletic fields. Prior to the introduction of 'Merion' Kentucky bluegrass in 1947, common Kentucky bluegrasses were used in low-maintenance areas but were frequent to abuse by *Helminthosporium* leaf spot caused by *Helminthosporium vagans* Dresch (Schumann et al. 1992). Currently, this disease is known separately and caused by *Dreschsler poae* (Melting-out) and *Bipolaris sorokiniana* (Leaf Spot) (Vargas, 2005). The release of 'Merion' Kentucky bluegrass provided generalized resistance to *Helminthosporium* leaf spot; however, this also brought about the onset of other devastating diseases including *Fusarium* blight (*Fusarium roseum)*, Gray leaf spot (*Piricularia grisea)*, but most importantly stripe smut (*Ustilago striiformis*). The high susceptibility of 'Merion' Kentucky bluegrass to strip smut can be directly related to the narrow gene pools and the high percentage of apomixis associated with this variety (Bruneau et al. 1992). It has been reported that 'Merion' had a level of apomixis of 96% making this variety highly uniform (Meyer 1982; Burton, 1992; Casler 2003). Although this percentage coincides with stable seed production and ultimately leading to ‘Merion’ Kentucky bluegrass’ distribution in the 1960’s, the uniformity lead to complete decimation of entire turfgrass stands by stripe smut, a cultivar specific disease (Vargas, 1980, Casler, 2003). With this in mind, there was a general lack in cultivated or improved varieties of Kentucky bluegrass at this time. Conjointly, varieties like ‘Merion’ Kentucky bluegrass were relatively unavailable, and if obtainable, were exceptionally expensive (Juska and Tyson 1955, Vargas 1980, Vargas 2005). A concept that would provide genetic diversity to a relatively uniform turf stand soon emerged, suggesting the mixing or blending of common-type Kentucky bluegrass and cultivated varieties like ‘Merion’ Kentucky bluegrass. This would introduce disease resistances to *Helminthosporium* leaf spot from ‘Merion’ and stripe smut from common-types, while reducing the cost to plant ‘Merion’ as a single-variety stand. However, blending turfgrass varieties created controversy. Madison (1971) questioned whether blending standard and dwarf varieties would prove to be an advantage due to the differing management practices required for each variety to thrive. Madison claimed that the differences in density between the varieties would cause an increase in density of the stand and would then be subject to *Helminthosporium* disease from high humidity produced within the turf canopy.

A traditional recommendation for the blending of turfgrass has been two or more varieties together with similar leaf texture, growth habit, color, shoot density and vertical growth rate in order to achieve an acceptable turfgrass stand (Beard, 1973; Vargas, 1980). Selecting varieties for use in a blend should be in accordance with the following guidelines: 1) Varieties selected have shown resistance to disease in the geographical area where the blend will be planted, 2) the varieties should be similar in appearance and competitive ability, and 3) at least one variety should be select based on adaptation to unique conditions where the blend will be planted (i.e. shade, soil pH, moisture, traffic, etc.) (Turgeon, 2008). The failure to coordinate the selection of varieties to these recommendations may reduce the efficacy of the blend over time. Vargas (2005), based on the previous research of Vargas and Turgeon (1980), suggested the inclusion of susceptible varieties of Kentucky bluegrass planted with improved varieties reduced the quality of the blend and in some instances drastically reduced the presumed percentage of stand composition of the susceptible variety to the point of elimination. Furthermore, the ecological competition that exists between turfgrass varieties or intra-specific competition, particularly aggressiveness and environmental adaptability, may also reduce the benefits of using blends (Golembiewski, 1999).

Although not available during the introduction of ‘Merion’ Kentucky bluegrass, numerous varieties have been separated in to distinct classifications used to relate these growth characteristics. Work by Rutgers University has divided Kentucky bluegrass varieties into several classifications (Park, 2005). However, blends are not necessarily advantageous because of similar growth characteristics alone. According to Funk (2000), Kentucky bluegrass provides enhanced tolerance to drought, heat, shade, close mowing, excessive wear, acid soils, salinity, as well as resistance to many of the major turfgrass diseases: all of the characteristics necessary for an ideal athletic field. However, Funk (2000) continues to suggests that the reason blends are necessary to promote all of these characteristics can be related to the lack of breeding techniques that are required to include these characteristics into a single variety. Likewise, Beard (1973) proclaims a blend cannot provide an advantage if one variety is available with superior resistance to all the noteworthy pest problems and has superior tolerance to all environmental stresses within a given habitat. As suggested by Funk, the successful development and breeding of Kentucky bluegrass varieties to exude all of the aforementioned quality characteristics relies heavily on an understanding of its apomictic reproductive system (Beard, 1973). The inhibition of the sexual process reduces a breeder's efforts to produce effective hybridizations. The development of a superior genotype within an apomictic plant results in fixed hybrid vigor, the intended goal of plant breeding programs (Casler, 2003). And since the asexual reproduction results in the production of seeds with out recombination or segregation, high levels of stability and uniformity can be achieved for seed production efforts and distribution; however, the problem lies in the sexual recombination (Casler, 2003). Kentucky bluegrass F1 hybrids segregate drastically and far exceed the parental character values, a process called transgressive segregation (Casler, 2003). Transgressive segregation develops from traditional breeding techniques and often makes interpreting quantitative genetic information difficult. Therefore, identifying a superior genotype is often a daunting task. Traditional breeding programs are responsible for varieties that, although were developed decades ago, continue to compete with novel varieties. For instance, Midnight was developed in the 1970's and continues to show standards of high quality and traffic tolerance in the most recent National Turfgrass Evaluation Program (NTEP) results (NTEP 2009, Casler 2003, Meyer 1984).

Marker-assisted selection may provide the means of developing improved varieties by giving insight into genetic changes of progeny from parental crosses. Markers such as Random Amplified Polymorphic DNA (RAPD), Restriction Fragment Length Polymorphisms (RFLP), Simple Sequence Repeats (SSR), and Amplified Fragment Length Polymorphisms (AFLP) are used in correlation to phenotypic data to locate and identify putative quantitative traits, or QTL (Quantitative Trait Loci) (Young, 2000; Huff, 2001). All of the previously mentioned markers locate polymorphisms and track the segregation of the inherited DNA sequences among the progeny of a genetic cross. This information is collected into a linkage map, which will help explain which QTL has the greatest effect on the phenotypic traits in question. The linkage map assists breeders in selecting progeny based on the desired traits segregating from the parents. These new technologies have begun to gain momentum in turfgrass breeding programs. Marker-assisted selection will lead to future consideration of mapping built from single nucleotide polymorphisms (SNPs) and unique micro-arrays designed specifically for turfgrass species.

Research conducted on blends has focused primarily on disease incidence but current research provides a unique insight into varietal composition and spatial patterns of Kentucky bluegrass varieties in blends and cost effective approaches through the addition of low-performing varieties on turfgrass quality when added to high-performing varieties. Juska and Hanson (1959) began looking at mixtures of Kentucky bluegrass, tall fescue, and colonial bentgrass for stand composition and weed competition. Interestingly, a blend of 'Merion' Kentucky bluegrass and common bluegrass was included and showed average botanical composition comparable to a stand consisting of 100% 'Merion' Kentucky bluegrass and also showing reduced bare ground percentages. Juska was inclined to prescribe a mixture of perennial species due to the susceptibility of 'Merion' to stripe smut. Funk et al. (1968) would continue the recommendation by Juska and Hanson by testing the available varieties with stripe smut as the deciding factor. The work of Juska and Hanson, and Funk generated several new research approaches including further evaluations of turf quality of blends on disease incidence, variety trials, and the eventual use of DNA fingerprinting to help explain intra-specific competition. Vargas and Turgeon (1980) showed intermediate quality ratings of turfgrass blends including resistance varieties, Merion, Nugget, and Pennstar, and susceptible varieties, Kenblue and Park, to melting-out. These results do not show improved quality of blends, but suggest a reduction of disease incidence when compared to the susceptible varieties. Furthermore, Smiley and Fowler (1986) and Fowler and Hummel (1987) proposed that the benefits of blending Kentucky bluegrass varieties were not observed under *Magnaporthe poae* (Summer Patch) and *Leptoshaeria korrae* (Necrotic Ring Spot). Continuing, Watkins et al. (1981) evaluated 60 Kentucky bluegrass varieties and 24 blends of these varieties against natural stem rust populations. Watkins presented results of the blends and the associated varieties as means for the blends and cultivars in pure stand. In this case, the blend accurately reflected a reduction in natural stem rust populations when compared to the mean of constituent varieties. (Watkins 1981). This also suggested the reduction of disease incidence with the inclusion of more than one resistant variety in the blend. Prior to the introduction of DNA fingerprinting, an accurate representation of the ecological competition between turfgrass species was limited. Only the inference of varying adaptabilities between monocultures could show the potential of a variety to a specific environment and the possible incorporation of the variety into a blend. The National Turfgrass Evaluation Program (NTEP) collects and coordinates the distribution of varieties of most turfgrass species to be evaluated for a wide range of adaptations, including heat, drought, wear and disease tolerance across several regions of the United States. Using the data compiled, improved varieties can be selected for blend construction that will provide benefits for a specific location and environment. Presently, using genetic markers has aided in evaluating competition among Kentucky bluegrass varieties. Although more research in this area would provide increased knowledge in the inter-workings of blend composition, current research reflects changes in blend constitution over time, naturally and under disease stress, spatial patterns of blends, and the effects of turf quality by introducing low- and high-performance varieties into blends. Lickfeldt et al. (2002a) used RAPD markers to track changes in blends composed of 'Blacksburg', 'Midnight', and 'Unique' Kentucky bluegrass. Lickfeldt used RAPD markers to determine spatial arrangements of Kentucky bluegrass in blends under different management practices and locations. From this, the research concluded the spatial arrangement to be randomized and not clumped, and that the management or location does not determine stand composition: Rather, the competitive advantages of the varieties determine composition. Later, Lickfeldt (2002b) used RAPD markers to determine changes over time of seeded blends of the same varieties used previously. In a three-way blend, a 33.3% blend by weight, resulted in a dramatic decrease in 'Blacksburg', and an increase in 'Midnight' from seeding to the time of the second year of sampling. In two-way blends 'Blacksburg' x 'Unique' and 'Blacksburg' x 'Midnight', 50% blends by weight, showed a decrease in 'Unique' and an increase in 'Midnight' after two years of development, respectively. Data collected shows the competition between varieties with differences in aggressiveness. However, contrary to the these findings, Golembiewski et al. (2001) demonstrated, using RAPD markers, that differing disease treatments had no ill effect on stand composition of 'Crenshaw' and 'Penncross' creeping bentgrass planted with a 50:50 ratio. Brede (2004) used molecular markers to determine the effects of varying performance varieties (low = 'Huntsville', medium = 'NuBlue', and high = 'Award') on the overall turf quality (TQ) of the blend. Brede shows through segmented regression analysis, that by adding 'Huntsville' to a high-performing variety like 'Award, the low-performing variety decreased the TQ of the high performing variety on 71% of rating dates. Likewise, adding 'NuBlue' decreased TQ of 'Award' on 60% of rating dates. Furthermore, the segmented or "pivot points" in the regression analysis were significant on 14 rating dates for 'Huntsville' suggesting that the introduction of a low-performing variety up to a 50:50 ratio did not bring down TQ and would reduce the cost of seed.

With the complexity of blend construction and development, variety selection, and the continual advancements of improved varieties through traditional and molecular techniques, reverting to single-variety stands may prove beneficial. Newer varieties have increased disease resistances, wear tolerance, and protection from other abiotic and biotic stressors. For disease control, blends of Kentucky bluegrass that include resistant and susceptible varieties may increase the susceptibility of the resistant variety (Vargas et al. 1980). Vargas hypothesized that the decrease in resistance is due to the build up of inoculum surrounding the resistant variety. From a cultural practices standpoint, managing varieties under a single maintenance program will prove to be more conducive to a single variety, and due to the competitive nature of Kentucky bluegrass, the variety growing under optimal conditions may dominate the blend. With this in mind, the current benefits of using a blend in an athletic field setting are under scrutiny.

Chapter One: Effects of Traffic on Kentucky Bluegrass Varieties in Monostands and Blends on Native Soil

INTRODUCTION

Some varieties of Kentucky bluegrass grow more aggressively and have better recuperative abilities than others. Tolerant varieties to traffic have been shown to posses higher lignin content and distribution, total cell wall content, leaf width, and leaf tensile strength (Shearman *et al*., 1975; Brosnan *et al*. 2005, Carrow and Petrovic, 1992). In addition, wear tolerance in cool-season species has been linked to photosynthetic carbohydrate production, transpiration, and respiration management (Trenholm et al., 1999). Suggesting, single variety Kentucky bluegrass stands breed specifically for an aggressive growth habit and rapid recuperation rates could potentially provide a higher quality-playing surface than a blend containing traffic intolerant or slow recovering cultivars. Vargas (2005) suggests that blending improved varieties with a common Kentucky bluegrass may diminish the overall quality, or resistance to melting-out, of a 'Merion' Kentucky bluegrass stand. The same concept can be applied when considering adding a traffic intolerant variety to a blend intended for use on a high traffic area, such as an athletic field.

Wear is described as injury to a turfgrass stand from pressure, tearing, and scuffing on the turfgrass leaf tissue (Carrow and Petrovic, 1992). Turf, particularly on a high traffic area, is subject to great quantities of traffic throughout playing seasons. Although aggressive cultivars have a great effect on the wear tolerance, other factors like environment, management, and compaction greatly influence the adaptability of a turfgrass variety (Bell, 2011). Turgeon (2008) describes the limiting factor concept, developed from Liebig's law of minimums, as it applies to turfgrasses. Liebig's law of minimum states, "That if one necessary element is deficient and all others are adequate, growth will be limited by the one that is missing (Turgeon, 2008)". As the limiting factors progress, excessive soil moisture and a reduction in soil oxygen exchange greatly affect the turfgrass growth by inhibiting root respiration (Bell, 2011). On athletic fields high in silt and clay, heavy use and excessive rainfall create severe soil compaction, not to mention the physical growth reduction caused by the wear (Benson and Daniel, 1990). Furthermore, research by Kowalewski et al. (2010), although showing an increase in surface shear strength associated to turfgrass cover on native soil, showed a reduction of turfgrass cover when compared to treatments receiving subsequent topdressing applications. Applying the law of minimums to a stand composed of a blend, the reduction in growth associated with wear, compaction (oxygen), and moisture would lead to diminished quality of a single variety susceptible to any one of these conditions and also the blend as a whole. Management practices focusing on alleviating compaction, water movement and infiltration, and wear prevention may help to create a beneficial environment; however, on native soil, an aggressive Kentucky bluegrass variety with better recuperative potentials may prove as a viable monostand under high-traffic areas.

MATERIALS AND METHODS

The study was initiated on 15 September 2009 at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI, USA. Plots, 2.32-m^2 in size, of Kentucky bluegrass (*Poa pratensis* L.) varieties and blends (Table 1) were established from seed on 25 September 2009 on a Colwood-Brookston Loam/Aubbeenaubee Capac Sandy Loam (NRCS, 2009). Lebanon Country Club 13-25-12 Starter fertilizer (Lebanon Seaboard Corp., Lebanon PA) was applied at a rate of 4.88-g P_2O_5 m^{-2}. Each plot was seeded at a rate of 7.32-g m^{-2}. Prior to covering the experimental area with a 95% light transmitted germination and insect AgroFabric (A.M. Leonard, Piqua, OH) on 25 September 2009, one application of mesotrione (Tenacity)(Syngenta, Wilmington, DE) at a rate of 0.043-ml m^{-2} was applied to prevent broadleaf weeds and annual bluegrass germination. All treatments, excluding the treatments containing the variety ‘Kenblue’, were established on 25 September 2009 (Table 1). Treatments containing the variety ‘Kenblue’ were seeded on 29 September 2009. Since the germination AgroFabric was laid prior to the inclusion of these treatments, the plot areas were clearly marked until the treatments could be planted. The germination blanket was cut on three sides of the AgroFabric and pulled away from the plot area. The seed was spread using a hand shaker and sewn into the soil with a spring rake similar to the other treatments planted on 25 September 2009. The seams of AgroFabric was then stitched back together using 15.24 x 2.54 cm anchor pins.

An irrigation program was developed for the germination process of the experimental area providing 0.508-cm day^{-1} and was reduced to an as needed basis following the removal of the germination AgroFabric on 7 and 11 October 2009 for the early-seeded treatments and the

‘Kenblue’ treatments, respectively. The germination AgroFabric provided an adequate 12-day germination period for all treatments, except for ‘Barzan’ showing minimal germination. A second starter fertilizer application was applied on 11 October 2009 applied at a rate of 4.88-g P m^{-2} with a supplemental application of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2}. In 2010, applications of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2} and 42-0-0 Polyon (Harrell’s, Lakeland, Florida) at a rate of 4.88 g N m^{-2} were applied cumulating 24.4 g N m^{-2} for the year. In 2011, fertility followed the application program developed and used in the previous year. In both years of the study, twelve weekly traffic applications were initiated on 9 August 2010 and 8 August 2011. Traffic was implemented with the Brinkman Traffic Simulator and ten passes were made weekly to simulate five events, which depicts a practice field in terms of applied traffic (Cockerham et al, 1990; Vannini et al. 2007). The experimental area was mowed two times weekly at 6.35 cm and maintained throughout the two-year duration of the study. Following the completion of the traffic applications in 2010, core cultivation was performed using 2.77 cm hollow tines on 5.08 cm centers at a 5.08 cm depth. The cores were incorporated back into the soil using hand rakes to prevent contamination. Furthermore, all plots were reseeded at a 7.32-g m^{-2} rate on 6 May 2011 to properly restore plots to full turfgrass coverage and mimic an interseeded athletic field situation.

Weekly ratings of visual assessment for color, quality, and percent turfgrass cover were collected beginning 27 July 2010 and 5 August 2011. Turfgrass color and quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Percent turfgrass cover was also assessed visually. Ratings for turf shear (divoting), shear vane (pivoting), and surface hardness were taken bi-weekly throughout the duration of traffic applications for assessment of surface strength characteristics. All evaluations began with initial ratings on 27 July 2010 and 5 August 2011.

The study was established as a Randomized Complete Block Design (RCBD) with three replications. A single factor [Varieties (Table 1)] included 24 total treatments; however, for the purposes of the study, 10 treatments were compared following the analysis of all treatments in the study. Therefore, differences in least significant means were developed to compare between individual treatment means. The Proc UNIVARIATE (SAS Institute, Cary, NC) procedure was used to test the normality of homogeneity of variances and residuals. Mean separations obtained using Proc MIXED specifying all pairwise comparisons.

Table 1. List of treatments for traffic on native soil

Treatments	Sponsor
Midnight	Turf Seed Company
Right	Turf Seed Company
Prosperity	Turf Seed Company
North Star	Turf Seed Company
Moonshine	Turf Seed Company
Jump Start	Turf Seed Company
Avalanche	Turf Seed Company
PST 103-585	Turf Seed Company
PST 102-158	Turf Seed Company
PST 102-45	Turf Seed Company
Kenblue	Common-Type Standard Entry
TS Blend (25% Jump Start, 25% Avalanche, 25% Thermal Blue, 25% Moonshine)	Turf Seed Company
TS Blend (25% Right, 25% Prosperity, 25% Midnight II, 25% Moonlight SLT)	Turf Seed Company
Bar VV 0709	Barenbrug, USA
Barrister	Barenbrug, USA
Barimpala	Barenbrug, USA
Barduke	Barenbrug, USA
Barrari	Barenbrug, USA
Barzan	Barenbrug, USA
B Blend (33% Barrari, 33% Barimpala, 33% Bar VV 0709)	Barenbrug, USA
B Blend (25% Barrari, 25% Barimpala, 25% Bar VV 0709, 25% Barrister)	Barenbrug, USA
B Blend (33.3% Barrister, 33.3% Bar VV 0709, 33.3% Barrari)	Barenbrug, USA
TS Blend (33.3 % Midnight, 33.3% Prosperity, 33.3% Avalanche)	Turf Seed Company
Kenblue Blend (33.3% Midnight, 33.3% Barrister, 33.3% Kenblue)	Manufactured Blend

RESULTS AND DISCUSSION

Percent Ground Cover

All of the turf varieties included in the study (Table 1) were evaluated for percent living ground cover on a weekly basis. Statistical analysis of the twelve, weekly ratings showed significance among treatments 6 times in 2010. Pair-wise comparisons between only 7 varieties and 3 blends were included for the purpose of this study. Furthermore, provided data reflects mean ground cover following 6 weeks of traffic applications (Table 2) and 12 weeks of traffic (Table 3) in 2010. After 6 weeks of traffic, mean comparisons revealed no differences between each of the blends and the associated varieties within the blends. The varieties ‘Barrister’ and ‘Midnight’ provided a slight increase in percent ground cover to the associated blend except for the blend when the two varieties were included together. Furthermore, ‘Kenblue’, a common Kentucky bluegrass variety that was included to show the potential reduction in blend capability provided the lowest percent ground cover at 92.0% following the 6 weeks of traffic events in 2010. Following 12 weeks of traffic events, no significant differences were shown with the blend including ‘Barrister’, ‘Bar VV 0709’, and ‘Barrari’. Contrasting, differences were observed between the varieties ‘Prosperity’ and ‘Kenblue’ to their associated varieties; however the difference could not be discerned between the other two varieties included in the blend with ‘Prosperity’ and ‘Kenblue’ as monostands. Similar to 2010, statistical analysis of the twelve, weekly ratings showed significance among treatments 6 times in 2011. Mean ground cover comparisons after 6 weeks of traffic events in 2011 showed statistical differences but not necessarily biological significance between ‘Midnight’ and ‘Prosperity’ and ‘Barrister’ and the blend including ‘Barrister’, ‘Midnight’, and ‘Kenblue’ (Table 4). After 12 weeks of traffic, there were no statistical differences between the blends and the associated varieties but ‘Barrister’ did maintain a higher percent ground cover compared to the blend consisting of ‘Barrister’, ‘Midnight’, and ‘Kenblue’ (Table 5).

Quality

All of the turf varieties included in the study were evaluated for visual turfgrass quality on a weekly basis. Statistical analysis of the twelve, weekly ratings showed significance among treatments 8 times in 2010. Pair-wise comparisons between only 7 varieties and 3 blends were included for the purpose of this study. Furthermore, provided data reflects turfgrass quality following 6-weeks (Table 2) and 12 weeks of traffic applications (Table 3) in 2010. After 6-weeks of traffic, differences were only noticed among the blend containing ‘Midnight’, ‘Avalanche’, and ‘Prosperity’. The variety ‘Midnight’ produced quality less than the variety ‘Prosperity’; however, ‘Midnight’ did not significantly differ from ‘Avalanche’ and the blend. After 12-weeks of traffic, ‘Prosperity’ had a significantly lower quality than ‘Avalanche’, ‘Midnight’, and the blend containing the three varieties. Similar to the 6-week quality ratings, there were no differences in the blends containing ‘Barrister’, ‘Bar VV 0709’ and ‘Barrari and the blend containing ‘Midnight’, ‘Barrister’, and ‘Kenblue’. Data collection in 2011 revealed significance among treatments 8 times, similar to 2010. Six-week traffic data showed no significance among all blends and their associated varieties (Table 4). The absence of differences was also reflected following 12-weeks of traffic events (Table 5). The variety ‘Barrister’ had a higher turfgrass quality rating than the blend containing ‘Barrister’, ‘Midnight’, and ‘Kenblue’, although not significant.

Table 2. Mean comparisons of treatments following 6-weeks of traffic on native soil in 2010, obtained 17 September at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	97.3 a†	6.7 a	85.0 a	16.7 a	59.7 a
Bar VV 0709	96.3 a	7.3 a	88.3 a	13.0 a	60.7 a
Barrari	96.3 a	7.0 a	83.7 a	14.7 a	59.0 a
*Blend	96.7 a	7.3 a	85.0 a	16.0 a	52.7 a
Midnight	97.0 a	6.3 b	83.3 ab	16.7 a	60.3 a
Avalanche	94.0 a	6.7 ab	80.3 ab	15.3 a	59.7 a
Prosperity	94.7 a	7.0 a	72.7 b	15.0 a	54.3 a
Blend	94.7 a	6.7 ab	90.3 a	16.7 a	61.7 a
Midnight	97.0 a	6.3 a	83.3 ab	16.7 a	60.3 a
Barrister	97.3 a	6.7 a	85.0 ab	16.7 a	59.7 a
Kenblue	92.0 a	6.3 a	81.7 b	14.0 a	54.7 a
Blend	99.0 a	6.7 a	92.0 a	14.0 a	57.0 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 3. Mean comparisons of treatments following 12-weeks of traffic on native soil in 2010, , obtained 12 November at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	68.3 a†	4.7 a	84.5 a	18.7 a	103.0 a
Bar VV 0709	75.0 a	5.0 a	82.3 a	21.0 a	109.0 a
Barrari	70.0 a	5.3 a	71.0 a	19.3 a	100.0 a
*Blend	71.7 a	5.0 a	86.0 a	21.3 a	91.0 a
Midnight	61.7 ab	4.7 ab	73.7 a	18.7 a	92.0 a
Avalanche	62.3 ab	5.0 a	77.0 a	19.0 a	105.0 a
Prosperity	50.0 b	4.0 b	75.7 a	18.0 a	94.0 a
Blend	70.0 a	5.3 a	84.0 a	17.3 a	96.0 a
Midnight	61.7 a	4.7 a	73.7 a	18.7 a	92.0 a
Barrister	68.3 a	4.7 a	84.5 a	18.7 a	103.0 a
Kenblue	48.3 b	4.3 a	86.7 a	19.0 a	104.0 a
Blend	61.7 a	4.3 a	79.0 a	17.3 a	104.0 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 4. Mean comparisons of treatments following 6-weeks of traffic on native soil in 2011, obtained 21 September at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	99.0 a†	7.0 a	68.0 a	14.0 b	61.0 a
Bar VV 0709	99.0 a	7.3 a	67.0 a	14.0 b	57.3 a
Barrari	99.3 a	7.7 a	70.7 a	15.3 ab	51.0 a
*Blend	99.0 a	7.0 a	71.0 a	16.7 a	55.3 a
Midnight	95.0 b	7.0 a	65.0 a	14.0 a	56.0 a
Avalanche	98.0 ab	6.7 a	65.3 a	15.3 a	59.3 a
Prosperity	98.3 a	6.7 a	56.3 a	14.3 a	51.3 a
Blend	97.0 ab	6.7 a	62.3 a	14.7 a	54.3 a
Midnight	95.0 b	7.0 a	65.0 a	14.0 ab	56.0 a
Barrister	99.0 a	7.0 a	68.0 a	14.0 ab	61.0 a
Kenblue	95.0 b	6.3 a	68.0 a	12.7 b	55.0 a
Blend	95.3 b	6.3 a	66.7 a	15.0 a	54.3 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 5. Mean comparisons of treatments following 12-weeks of traffic on native soil in 2011, obtained 2 November at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	82.0 a†	5.7 a	70.7 a	14.7 a	63.7 a
Bar VV 0709	81.0 a	5.7 a	74.0 a	14.3 a	63.7 a
Barrari	80.3 a	5.7 a	74.7 a	15.7 a	63.0 a
*Blend	81.0 a	5.7 a	78.7 a	14.3 a	63.0 a
Midnight	76.0 a	5.0 a	69.7 a	14.3 a	61.7 a
Avalanche	74.0 a	5.0 a	63.3 a	14.7 a	63.7 a
Prosperity	77.0 a	5.0 a	66.0 a	14.3 a	61.7 a
Blend	79.0 a	5.3 a	66.7 a	15.7 a	65.3 a
Midnight	76.0 a	5.0 a	69.7 a	14.3 a	61.7 a
Barrister	82.0 a	5.7 a	70.7 a	14.7 a	63.7 a
Kenblue	75.3 a	5.0 a	68.3 a	15.3 a	62.3 a
Blend	76.0 a	5.0 a	70.7 a	15.0 a	64.7 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Surface Strength Characteristics

Surface strength characteristics were taken to evaluate the surface performance of the field during consistent applications of traffic and to potentially assess the playability of a field during a traffic event at a particular point of a 12-week season. In 2010, evaluations of surface strength characteristics were taken every 3-weeks succeeding initial ratings on 30 July 2010. The turf shear tester ratings for 18 October 2010 were not available due to necessary maintenance on the equipment. In 2010, analysis of turf shear tester ratings reflected significance on half of the rating dates. Six-week traffic events revealed differences in resistance to divoting among blends containing 'Midnight', 'Avalanche', and 'Prosperity' and 'Midnight', 'Barrister', and 'Kenblue'. The varieties 'Prosperity' and 'Kenblue' produced turf shear tester ratings lower than their respective blends. Following 12-weeks of traffic events there were no significant differences between the blends and their constituent varieties. Analysis of shear vane data showed significance among treatment means only initially on 30 July 2010 and produced no significant differences between blends and their associated varieties following 6-weeks and 12-weeks of traffic events. Similarly, Clegg hammer data, or surface hardness, did not show significance throughout the 12-weeks of traffic applications in 2010 (Table 2 and 3).

In 2011, evaluations of surface strength characteristics were taken biweekly after the initial ratings on 5 August. Analysis of turf shear tester ratings produced one rating date showing significance; however, differences among the blends and the associated varieties were not observed. Shear vane data analysis revealed significance 2-times throughout the traffic applications, initially on 5 August and on 21 September 2011. The blend containing 'Barrister', 'Bar VV 0709', and 'Barrari' was significantly higher than 'Barrister' and 'Bar VV 0709' but not 'Barrari'. Furthermore, the blend containing 'Midnight', 'Barrister', and 'Kenblue', ‘Barrister’ alone, and ‘Midnight’ alone were significantly greater than ‘Kenblue’ as a monostand. Lastly, Clegg hammer data analysis showed significance after 4-weeks of traffic simulation. The data did not show significance among the blends and the varieties contained with in the blends Tables 4 and 5).

CONCLUSIONS

The analysis of the native soil data in 2010 and 2011 produced a consistent occurrence following 6-weeks and 12-weeks of traffic events with the Brinkman traffic simulator. The blends did not outperform all of the monostands of the associated varieties within the blends in percent turfgrass ground cover, turfgrass quality, Turf Shear Tester ratings, shear vane ratings, and Clegg hammer ratings. Furthermore, traffic simulation on native soil reflected the ability of the individual varieties to compete against the continual traffic applications and the potential for increased compaction and a reduction of oxygen available for respiration. That is, this experiment showed how the varieties would react in unfavorable growing conditions as suggested by law of minimums previously suggested. Varieties showing poor adaptability to these conditions were ‘Kenblue’ and ‘Prosperity’. ‘Kenblue’, a common-type Kentucky bluegrass variety with low tolerance to traffic (NTEP), represents a variety that would not commonly be included among improved varieties like ‘Barrister’ and ‘Midnight’. However, even when ‘Kenblue’ produced a reduction in turfgrass cover and Turf Shear Tester in 2010, the effects with in the blend were not observed. This suggests that the other varieties included may have compensated for the susceptibility. Likewise in 2010, ‘Prosperity’ also showed a significant reduction in turfgrass cover, quality, and Turf Shear Tester but did not have an ill effect on the blend as shown by the blend compared to the other varieties included, ‘Midnight’ and ‘Avalanche’. The development of these varieties within the blend could have been offsetting producing a lower percentage of ‘Prosperity’ with in the turf stand initially. Therefore, a reduction of ‘Prosperity’ with in the blend may not have been substantial.

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Chapter Two: Effects of Traffic on Kentucky Bluegrass Varieties in Monostands and Blends with High-Sand Based Topdressing Applications Over Native Soil

INTRODUCTION

Sand topdressing on an athletic field will provide a number of advantages. Higher sand content will reduce the compaction in a high trafficked area, prevent an accumulation of thatch, and improve drainage or water movement through the root zone of the turf (Vavrek, 1993). Recent research conducted by Kowalewski et al. (2010) and Miller (2008) has shown that sand topdressing can improve the wear tolerance, turfgrass cover, density and surface strength, of a variety of turfgrass stands, including Kentucky bluegrass. Further research conducted by Kowalewski et al. (2011) shows sand topdressing to provide improved surface drainage and decreases in surface water runoff; all important factors for providing a dry, stable playing surface. With this in mind, Kentucky bluegrass varieties with more aggressive tillering will tend to accept more frequent and heavier topdressing programs and will provide a better, more uniform playing surface than blends containing cultivars with a weak or slow growth habit.

Areas that receive excessive use and intense traffic often include soil modifications to reduce the effects of wear and ultimately compaction on native soils high in silt and clay. On athletic fields, the inclusion of sand topdressing programs has become a increasingly used management practice and soil amendment. The relatively high macropore volume and low inclusion of silt and clay allows for the inherent ability to maintain air movement, water infiltration, and resistance to compaction, making this amendment desired in an athletic field setting (Bingaman and Kohnski, 1970, Henderson et al., 2005, Carrow and Petrovic, 1992). Research by Samaranayake et al. (2008), suggested wear on creeping bentgrass (*Agrostis palustris*) and velvet bentgrass (*Agrostis canina*) caused more damage than the resulting soil compaction. This study was performed on a sandy loam soil and offers inference into the importance of sand as a soil modification. With this in mind, the reliability placed on selecting wear tolerant species is more beneficial than alleviating poor soil conditions when sand topdressing or sand as a soil modification is used. The additions of wear intolerant varieties of Kentucky bluegrass into a blend may result in more aggressive varieties leaning out the number of varieties originally included in the blend. Therefore, aggressively growing-wear tolerant varieties may provide evidence to the single-variety plantings for athletic field use.

MATERIALS AND METHODS

The study was initiated on 15 September 2009 at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI, USA. Plots, 2.32-m^2 in size, of Kentucky bluegrass (Poa pratensis L.) varieties and blends (Table 6) were established from seed on 25 September 2009 on a Colwood-Brookston Loam/Aubbeenaubee Capac Sandy Loam (NRCS, 2009). Lebanon Country Club 13-25-12 Starter fertilizer (Lebanon Seaboard Corp., Lebanon PA) was applied at a rate of 4.88-g P m^{-2}. Each plot was seeded at a rate of 7.32-g m^{-2}. Prior to covering the experimental area with a 95% light transmitted germination and insect AgroFabric (A.M. Leonard, Piqua, OH) on 25 September 2009, one application of mesotrione (Tenacity)(Syngenta, Wilmington, DE) at a rate of 0.043-ml m^{-2} was applied to prevent broadleaf weeds and annual bluegrass germination. All treatments, excluding the treatments containing variety 'Kenblue', were established on 25 September 2009 (Table 6). Treatments containing the variety 'Kenblue' were seeded on 29 September 2009. Since the germination AgroFabric was laid prior to the inclusion of these treatments, the plot areas were clearly marked until the treatments could be planted. The germination blanket was cut on three sides of the AgroFabric and pulled away from the plot area. The seed was spread using a hand shaker and sewn into the soil with a spring rake similar to the other treatments planted on 25 September 2009. The seams of AgroFabric was then stitched back together using 15.24 x 2.54 cm anchor pins.

An irrigation program was developed for the germination process of the experimental area providing 0.508-cm day^{-1} and was reduced to an as needed basis following the removal of the germination AgroFabric on 7 and 11 October 2009 for the early-seeded treatments and the

‘Kenblue’ treatments, respectively. The germination AgroFabric provided an adequate 12-day germination period for all treatments, except for ‘Barzan’ showing minimal germination. A second starter fertilizer application was applied on 11 October 2009 applied at a rate of 4.88-g P m^{-2} with a supplemental application of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2}. In 2010, applications of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2} and 42-0-0 Polyon (Harrell’s, Lakeland, Florida) at a rate of 4.88 g N m^{-2} were applied cumulating 24.4 g N m^{-2} for the year. In 2011, fertility followed the application program developed and used in the previous year. Four weekly applications of a well-graded, high-sand-content topdressing were initiated on 10 June 2010 and 15 June 2011 to provide 2.54-cm and 5.08-cm, respectively. The applications would be similar to topdressing applications on an athletic field and would provide improved infiltration, shoot density, and surface shear strength (Kowalewski et al. 2010). The root-zone mixture used as the sand topdressing, (90.0% sand, 7.0% silt, and 3.0% clay) developed for athletic field construction (ASTM International, 2006; Henderson et al. 2005), was applied at a 0.635-cm depth to achieve the aforementioned depths for each year.

During the two years of the study, twelve weekly traffic applications were initiated on 9 August 2010 and 8 August 2011. Traffic was implemented with the Brinkman Traffic Simulator and ten passes were made weekly to simulate five events, which depicts a practice field in terms of applied traffic (Cockerham et al. 1990; Vannini et al. 2007). The experimental area was mowed two times weekly at 6.35 cm and maintained throughout the two-year duration of the study. Following the completion of the traffic applications in 2010, core cultivation was performed using 2.77 cm hollow tines on 5.08 cm centers at a 5.08 depth. The cores were incorporated back into the soil using hand rakes to prevent contamination. Furthermore, all plots were reseeded at a 7.32-g m^{-2} rate on 6 May 2011 to properly restore plots to full turfgrass coverage and mimic an interseeded athletic field situation.

Weekly ratings of visual assessment for color, quality, and percent turfgrass cover were collected beginning 27 July 2010 and 5 August 2011. Turfgrass color and quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Percent turfgrass cover was also assessed visually. Ratings for turf shear (divoting), shear vane (pivoting) and surface hardness were taken bi-weekly throughout the duration of traffic applications for assessment of surface strength characteristics. All evaluations began with initial ratings on 27 July 2010 and 5 August 2011.

The study was established as a Randomized Complete Block Design (RCBD) with three replications. A single factor [Varieties (Table 6)] included 24 total treatments; however, for the purposes of the study, 10 treatments were compared following the analysis of all treatments in the study. Therefore, differences in least significant means were developed to compare between individual treatments. The Proc UNIVARIATE (SAS Institute, Cary, NC) procedure was used to test the normality of homogeneity of variances and residuals. Mean separations obtained using Proc MIXED specifying all pair-wise comparisons.

Table 6. List of treatments for traffic on topdressing over native soil

Treatments	Sponsor
Midnight	Turf Seed Company
Right	Turf Seed Company
Prosperity	Turf Seed Company
North Star	Turf Seed Company
Moonshine	Turf Seed Company
Jump Start	Turf Seed Company
Avalanche	Turf Seed Company
PST 103-585	Turf Seed Company
PST 102-158	Turf Seed Company
PST 102-45	Turf Seed Company
Kenblue	Common-Type Standard Entry
TS Blend (25% Jump Start, 25% Avalanche, 25% Thermal Blue, 25% Moonshine)	Turf Seed Company
TS Blend (25% Right, 25% Prosperity, 25% Midnight II, 25% Moonlight SLT)	Turf Seed Company
Bar VV 0709	Barenbrug, USA
Barrister	Barenbrug, USA
Barimpala	Barenbrug, USA
Barduke	Barenbrug, USA
Barrari	Barenbrug, USA
Barzan	Barenbrug, USA
B Blend (33% Barrari, 33% Barimpala, 33% Bar VV 0709)	Barenbrug, USA
B Blend (25% Barrari, 25% Barimpala, 25% Bar VV 0709, 25% Barrister)	Barenbrug, USA
B Blend (33.3% Barrister, 33.3% Bar VV 0709, 33.3% Barrari)	Barenbrug, USA
TS Blend (33.3 % Midnight, 33.3% Prosperity, 33.3% Avalanche)	Turf Seed Company
Kenblue Blend (33.3% Midnight, 33.3% Barrister, 33.3% Kenblue)	Manufactured Blend

RESULTS AND DISCUSSION

Percent Ground Cover

All of the turf varieties included in the study (Table 6) were evaluated for percent living ground cover on a weekly basis. Statistical analysis of the twelve, weekly ratings showed significance among treatments 10 times in 2010. Pair-wise comparisons between only 7 varieties and 3 blends were included for the purpose of this study. Therefore, provided data reflects mean ground cover following 6 weeks of traffic applications (Table 7) and 12 weeks of traffic (Table 8) in 2010. After 6 weeks of traffic, mean comparisons revealed differences between monostands of 'Midnight', 'Barrister', and 'Kenblue' and the blend containing these varieties. Although not biologically significant, 'Kenblue' produced turfgrass ground cover lower than 'Midnight' alone, 'Barrister' alone, and the blend. Following 12-weeks of traffic applications, several differences were observed. The variety 'Prosperity' had significant reduction in turfgrass cover compared to 'Midnight', 'Avalanche' and the blend containing these varieties. Furthermore, the blend containing 'Barrister', 'Bar VV 0709', and 'Barrari' and 'Barrister' alone showed significant reduction in turfgrass ground cover compared to 'Bar VV 0709'. Statistical analysis of the twelve, weekly ratings showed significance among treatments 5 times in 2011. Again, pair-wise comparisons between only 7 varieties and 3 blends were included for the purpose of this study. Following 6-weeks of traffic applications, no difference among treatment means were observed (Table 9). Mean ground cover comparisons after 12-weeks of traffic events in 2011 produced significance among the blend containing the varieties 'Midnight', 'Avalanche', and 'Prosperity' and the blend containing 'Midnight', 'Barrister', and 'Kenblue' (Table 10). The variety 'Prosperity' showed a significant reduction in percent ground cover compared to 'Midnight' and the blend, but not 'Avalanche'. Furthermore, the variety 'Kenblue' in monostand had a significant reduction in turfgrass ground cover compared to 'Midnight' alone, 'Barrister' alone, and the blend containing the varieties.

Quality

All of the turf varieties included in the study were evaluated for turfgrass quality on a weekly basis. Statistical analysis of the twelve, weekly ratings showed significance among treatments 11 times in 2010. Pair-wise comparisons between only 7 varieties and 3 blends were included for the purpose of this study. Therefore, provided data reflects turfgrass quality following 6-weeks (Table 7) and 12 weeks of traffic applications (Table 8) in 2010. After 6-weeks of traffic, although the treatment means were significant, the blends that were evaluated did not significantly differ than the associated varieties. Following 12-weeks of traffic applications, several differences were observed. The variety 'Avalanche' had a significantly higher turfgrass quality rating compared to 'Prosperity'; however, 'Midnight' and the blend containing 'Midnight', 'Avalanche', and 'Prosperity', did not significantly differ to either 'Avalanche' or 'Prosperity'. Furthermore, the variety 'Bar VV 0709' was significantly greater than the blend containing 'Barrister', 'Bar VV 0709', and 'Barrari' in turfgrass quality. Although not significant, 'Barrari' had greater turfgrass quality than the associated blend and all treatments were significantly greater than 'Barrister' in monostand. Data collection in 2011 revealed significance among treatments 5 times, greatly reduced from 2010. After six-weeks of traffic applications, there were no significant differences among the evaluated blends and their associated varieties (Table 9). Similar to the 6-week ratings, there were no differences between the evaluated blends and their constituent varieties (Table 10).

Table 7. Mean comparisons of treatments following 6-weeks of traffic on topdressing over native soil in 2010, obtained 17 September at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	99.7 a†	8.0 a	73.7 a	11.3 a	51.0 a
Bar VV 0709	99.3 a	8.3 a	74.3 a	11.3 a	51.0 a
Barrari	98.0 a	8.0 a	72.3 a	10.3 a	59.0 a
*Blend	99.0 a	7.7 a	71.7 a	9.7 a	51.0 a
Midnight	100.0 a	8.3 a	75.0 a	10.0 a	49.0 a
Avalanche	99.3 a	8.0 a	68.3 a	11.0 a	51.0 a
Prosperity	100.0 a	8.0 a	70.0 a	9.7 a	50.0 a
Blend	99.7 a	8.0 a	70.0 a	10.7 a	54.0 a
Midnight	100.0 a	8.3 a	75.0 a	10.0 a	49.0 a
Barrister	99.7 a	8.0 a	73.7 a	11.3 a	51.0 a
Kenblue	97.0 b	7.3 a	70.3 a	9.3 a	51.0 a
Blend	99.0 a	8.0 a	67.0 a	11.7 a	48.0 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 8. Mean comparisons of treatments following 12-weeks of traffic on topdressing over native soil in 2010, obtained 12 November at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	56.7 b†	4.0 c	52.3 a	10.3 b	78.0 a
Bar VV 0709	90.0 a	6.7 a	46.0 a	14.7 a	80.0 a
Barrari	87.3 ab	6.3 ab	49.0 a	11.3 b	87.0 a
*Blend	71.7 b	5.3 b	55.0 a	11.0 b	75.7 a
Midnight	58.3 a	4.3 ab	49.7 a	9.7 a	83.0 a
Avalanche	75.7 a	5.3 a	50.3 a	9.7 a	77.7 a
Prosperity	48.3 b	4.0 b	53.3 a	8.0 a	82.0 a
Blend	70.0 a	5.0 ab	52.7 a	8.7 a	74.3 a
Midnight	58.3 a	4.3 a	49.7 a	9.7 a	83.0 a
Barrister	56.7 a	4.0 a	52.3 a	10.3 a	78.0 a
Kenblue	72.7 a	5.0 a	49.3 a	9.3 a	89.7 a
Blend	68.3 a	5.0 a	51.7 a	9.0 a	73.0 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 9. Mean comparisons of treatments following 6-weeks of traffic on topdressing over native soil in 2011, obtained 21 September at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	100.0 a†	7.7 a	52.3 a	12.7 a	53.7 a
Bar VV 0709	99.3 a	7.7 a	46.0 a	14.3 a	53.7 a
Barrari	99.7 a	8.0 a	49.0 a	12.3 a	50.3 a
*Blend	99.3 a	7.7 a	55.0 a	12.3 a	53.0 a
Midnight	100.0 a	8.3 a	49.7 a	11.3 a	57.3 a
Avalanche	100.0 a	8.3 a	50.3 a	13.7 a	57.3 a
Prosperity	99.3 a	8.0 a	53.3 a	11.0 a	51.7 a
Blend	100.0 a	7.7 a	52.7 a	12.3 a	51.7 a
Midnight	100.0 a	8.3 a	49.7 a	11.3 a	57.3 a
Barrister	100.0 a	7.7 a	52.3 a	12.7 a	53.7 a
Kenblue	98.0 a	7.7 a	49.3 a	12.7 a	55.0 a
Blend	100.0 a	8.0 a	51.7 a	12.3 a	55.0 a

* Blends comprised of three associated varieties located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 10. Mean comparisons of treatments following 12-weeks of traffic on topdressing over native soil in 2011, obtained 2 November at HTRC, East Lansing, MI

Treatment	Percent Ground Cover	Quality ‡	Turf Shear Tester (Nm)	Shear Vane (Nm)	Clegg Hammer (Gmax)
Barrister	88.3 a[†]	6.3 a	46.0 a	11.7 a	55.7 a
Bar VV 0709	90.0 a	6.7 a	56.3 a	11.0 a	57.7 a
Barrari	91.7 a	6.7 a	44.0 a	12.3 a	57.7 a
[*]Blend	91.3 a	7.0 a	45.3 a	11.0 a	59.7 a
Midnight	90.0 a	6.7 a	42.7 a	10.7 a	59.3 a
Avalanche	86.0 ab	6.3 a	44.7 a	11.7 a	60.7 a
Prosperity	81.7 b	5.7 a	41.7 a	9.7 a	55.3 a
Blend	89.0 a	6.7 a	45.3 a	10.0 a	52.7 a
Midnight	90.0 a	6.7 a	42.7 a	10.7 a	59.3 a
Barrister	88.3 a	6.3 a	46.0 a	11.7 a	55.7 a
Kenblue	81.7 b	6.0 a	49.0 a	9.7 a	55.3 a
Blend	88.3 a	6.3 a	44.3 a	11.3 a	58.0 a

* Blends comprised of three constituents located directly above treatment

† Means in same column and blend grouping followed by the same letter are not significantly different according to (p=0.05)

‡ Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Surface Strength Characteristics

Surface strength characteristics were taken to evaluate the surface performance of the field during consistent applications of traffic and to potentially assess the playability of a field during a traffic event at a particular point of a 12-week season. In 2010, similar to the study on native soil, evaluations of surface strength characteristics were taken every 3-weeks succeeding initial ratings on 30 July 2010. The turf shear tester ratings for 18 October 2010 were not available due to necessary maintenance on the equipment. In 2010, analysis of Turf Shear Tester ratings reflected significance on only one of the rating dates. Six-week traffic events revealed no differences in resistance to divoting among blends and their associated varieties (Table 7). Following 12-weeks of traffic applications, analysis of treatment means showed significance but there were no observed differences between the blends and their constituent varieties evaluated for this study (Table 8). Analysis of shear vane data, showed significance among treatment means on 4 rating dates in 2010. Although the analysis of treatments means showed significant differences, there were no differences among the blends and the associated varieties following 6-weeks of traffic applications. Contrasting, the analysis of treatment means after 12-weeks of traffic applications did reveal differences in resistance to pivoting. The variety ‘Bar VV 0709’ was significantly higher in the shear vane ratings than the blend containing ‘Barrister’, ‘Bar VV 0709’, and ‘Barrari’, ‘Barrister’ alone, and ‘Barrari’ alone. Surface hardness evaluations, did not show significance throughout the 12-weeks of traffic applications in 2010.

In 2011, evaluations of surface strength characteristics were taken biweekly after the initial ratings on 5 August. Analysis of turf shear tester ratings produced one rating date showing significance; however, differences among the blends and the associated varieties were not observed. Shear vane data analysis revealed significance 2-times throughout the traffic applications, on 23 August and on 26 October 2011. On these rating dates, the blends did not outperform all of their associated varieties. Furthermore, there were no significant differences between treatment means after 6-weeks and 12-weeks of traffic applications (Tables 9 and 10). Analysis of Clegg hammer data showed significance on only one rating day in 2011. Although significant, the blends did not out perform all of the associated varieties in monostands. Furthermore, after 6-weeks and 12-weeks of simulated traffic, there were no difference between the blends and the associated varieties.

CONCLUSIONS

Topdressing provides numerous advantages to a turfgrass stand including wear tolerance, resistance to compaction, increased infiltration and surface drainage, and overall turfgrass cover (Kowalewski et al, 2011; Vavrek, 1993; Miller, 2008). Although the studies cannot be compared, the topdressing did provide higher turfgrass ground cover percentages, turfgrass quality, and a reduction in surface hardness than the native soil alone. Similar to the native soil, a consistent occurrence following 6-week and 12-week traffic applications emerged. The blends did not outperform the monostands of the associated varieties of the blends in percent turfgrass ground cover, turfgrass quality, and surface strength characteristics. In fact, after 12-weeks of traffic applications, the variety 'Bar VV 0709' had significantly higher percent turfgrass ground cover, turfgrass quality, and resistance to pivoting than the blend containing 'Barrister', 'Bar VV 0709', and 'Barrari'. The variety 'Barrister' had drastic reduction in percent turfgrass ground cover and turfgrass quality after the 6-weeks of traffic applications, which may have had a direct effect on the performance of the blend. In addition, 'Prosperity' had a lower percent turfgrass ground cover and quality after 12-weeks of traffic in 2010 and both 'Prosperity' and 'Kenblue' had significantly less percent turfgrass cover in 2011. Since 'Barrister' was also included in the blend with 'Kenblue', and the resulting 'Kenblue' did not affect the blend including 'Midnight', 'Barrister', and 'Kenblue' then suggesting 'Barrister' had a direct affect on the blend including 'Barrister', 'Bar VV 0709', and 'Barrari' seems accurate, although the reduction in performance of 'Barrister' and 'Kenblue' happened in separate years. If anything this should suggest the importance of using a blend: the ability of one variety covering for another seems inevitable. With this being said, using a monostand of a high performing improved variety does show advantages.

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Chapter Three: Evaluation of *Sclerotinia homoeocarpa* (Dollar Spot)Pressure on Kentucky Bluegrass Varieties in Monostands and Blends

INTRODUCTION

One of the purposes of planting a blend instead of a single cultivar in an athletic field setting is to protect against a major disease causing severe deterioration of the entire turf stand (Vargas *et al*., 1980). Traditionally, a blend of two or more improved Kentucky bluegrass cultivars was necessary to prevent diseases such as melting out, and stripe smut from completely desiccating a stand. But improved varieties, with multiple disease resistance, may suggest otherwise. Turfgrass' have two types of resistance, specific (vertical) and generalized (horizontal). Specific resistance is characterized by a variety having resistance to a specific race of the pathogen and is associated with pathogens lacking a sexual reproductive stage. Generalized resistance is characterized by a variety having resistance to all existing races for a particular pathogen and is not limited by sexual or asexual reproduction, which provides durable resistance (Vargas, 2005). Common Kentucky bluegrass was severely susceptible to melting out. The identification and development of Merion Kentucky bluegrass is a traditional example of horizontal resistance because Merion maintained resistance across all races for nearly 50 years (Vargas, 2005). Although Merion has generalized resistance against melting out, it does not have resistance against stripe smut, a variety specific disease (Vargas et al, 1980). Therefore, breeding efforts have strived to incorporate specific resistance genes, most likely pyramided, to maintain resistance. However, as more and more Kentucky bluegrass cultivars are breed for resistance to these particular diseases, other diseases, such as *Ophinosphaerlla korrae* (necrotic ring spot), *Magnaporthe poae (s*ummer patch), and *Sclerotinia homoeocarpa* (dollar spot), become prevalent, suggesting that blends may still be necessary for broad-spectrum disease resistance.

Dollar spot, caused by *Sclerotinia homoeocarpa*, is a fungal pathogen that has been gaining momentum in recent years. The disease is characterized by necrotic lesions on turfgrass leaf blades and result in sunken areas in the turf ranging from the size of a quarter to the size of a silver dollar (Vargas, 2005). Individual spots may coalesce and destroy the turf in large, distinct areas (Vargas, 2005). Mainly transplanting mycelium of an infected area by mowers and other maintenance equipment can help circulate the pathogen and dollar spot can become prevalent across an entire turf stand, if the appropriate management is not taken. Presumably, blends provide greater disease resistance than monostands and recent data suggests that this can be the case across several turfgrass species. Golembiewski et al. (2001) suggested planting Crenshaw and Penncross together, a 50:50 blend by weight, provided a reduction of dollar spot incidence and the development of the disease than the susceptible variety (Crenshaw) alone. Green and Burpee (1997), showed there was a decrease in the progression of Rhizoctonia blight, caused by *Rhizoctonia solani* Kuhn, on blends of tall fescue (*Festuca arundinecea* Schreb.) when proportions of the resistant varieties were increased. Furthermore, Vargas and Turgeon (1980) reported intermediate resistance of blends of ‘Merion’ and common-type Kentucky bluegrass to melting-out (*Drechslera poae* Drech.) and Fusarium blight (*Fusarium roseum*). Abernathy et al. (2001) showed that two- and three-way blends of ‘Penn A-4’, ‘Crenshaw’, ‘L-93’, ‘Mariner’, and ‘Penncross’ creeping bentgrass, when compared to monostands, indicated that the level of activity of dollar spot was a compromise between resistance levels of individual cultivars. All of these suggest that there is an improved sense of resistance associated with using a blend; however, the resistance is shown only when being compared to the susceptible variety alone. The advancements in breeding, traditional and molecular, since the introduction of ‘Merion’ Kentucky bluegrass as the first cultivated variety have been integral in producing the vast majority of varieties that include a wide-range of disease resistances. The prevalence of the dollar spot disease on athletic fields is potentially reduced by recurring traffic; therefore, selecting varieties with resistance to diseases common to the location will provide relevance to using monostands instead of blends.

MATERIALS AND METHODS

The study was initiated on 15 September 2009 at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI, USA. Kentucky bluegrass varieties with known resistance and susceptibility were selected (NTEP 2009) Plots, 4.64-m^2 in size, of the Kentucky bluegrass (Poa pratensis L.) varieties and blends (Table 11) were established from seed on 25 September 2009 on a Colwood-Brookston Loam/Aubbeenaubee Capac Sandy Loam (NRCS, 2009). Lebanon Country Club 13-25-12 Starter fertilizer (Lebanon Seaboard Corp., Lebanon PA) was applied at a rate of 4.88-g P m^{-2}. Each plot was seeded at a rate of 7.32-g m^{-2}. Prior to covering the experimental area with a 95% light transmitted germination and insect AgroFabric (A.M. Leonard, Piqua, OH), one application of mesotrione (Tenacity)(Syngenta, Wilmington, DE) at a rate of 0.043-ml m^{-2} was applied to prevent broadleaf weeds and annual bluegrass germination.

An irrigation program was developed for the germination process of the experimental area providing 0.508-cm day^{-1} and was reduced to an as needed basis following the removal of the germination AgroFabric on 7 October 2009. The germination AgroFabric provided an adequate 12-day germination period for all treatments. A second starter fertilizer application was applied on 11 October 2009 applied at a rate of 4.88-g P m^{-2} with a supplemental application of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2}. In 2010, applications of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2} and 42-0-0 Polyon

(Harrell's, Lakeland, Florida) at a rate of 4.88 g N m^{-2} were applied accumulating 14.6 g N m^{-2} for the year. In 2011, fertility followed the application program developed and used in the previous year. The experimental area was inoculated with a sand-cornmeal based inoculum of *Sclerotinia homoeocarpa* vegetative compatibility group (VCG)-B (Table 11) on 17 June 2010 and again on 7 July 2011. Fertilizer applications were halted following the inoculation of the experimental area to encourage disease development and persistence on nutrient deprived turf. Irrigation was also stopped to further influence dollar spot disease incidence.

Weekly ratings of visual assessment for quality, dollar spot lesion counts, and percent dollar spot infected area were collected beginning 19 July 2010 and 25 July 2011. Turfgrass quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Dollar spot infection centers were counted individually and percent dollar spot infected area was assessed visually.

The study was analyzed as a Completely Randomized Design (CRD) with three replications. A single factor [Varieties (Table 11)] included 14 total treatments and were examined using Proc UNIVARIATE procedure to test the normality of homogeneity of variances and residuals. Means separations were determined from selected analysis of Fisher's least significant difference at a 0.05 level of probability.

In 2010, a second study to examine the effects of dollar spot on the same treatments (Table 11) was established on 15.24-cm of a well-graded, high-sand-content root-zone mix [90.0% sand, 7.0% silt, and 3.0% clay (ASTM 2006, Henderson et al. 2005)]. The study was initiated on 29 September 2010 and adhered to the same protocol for establishment as the previous study. As with the previous study, prior to covering the experimental area with a 95% light transmitted germination and insect AgroFabric (A.M. Leonard, Piqua, OH), one application of mesotrione (Tenacity)(Syngenta, Wilmington, DE) at a rate of 1.9-ml m^{-2} was applied to prevent broadleaf weeds and annual bluegrass germination. Weekly ratings of visual assessment for quality, dollar spot lesion counts, and percent dollar spot infected area were collected beginning 25 July 2011 following the inoculation on 7 July 2011. Turfgrass quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Dollar spot infection centers were counted individually and percent dollar spot infected area was assessed visually. The study was analyzed as a Randomized Complete Block Design (CRD) with three replications. The single factor was examined using Proc UNIVARIATE procedure to test the normality of homogeneity of variances and residuals. Means separations were determined from selected analysis of Fisher's least significant difference at a 0.05 level of probability.

Table 11. List of treatments for Kentucky bluegrass monostands and blends under dollar spot pressure

Treatments
Barrister [B]
Midnight [T]
North Star [S1]
Barrari [S2]
B + T
B + S1
B + S2
T + S1
T + S2
B + T + S1
B + T + S2
B + S1 + S2
T + S1 + S2
B + T + S1 + S2

RESULTS AND DISCUSSION

Quality

Following inoculation of the study, all treatments (Table 11) were evaluated for turfgrass quality across 7 rating dates. Analysis of turfgrass quality revealed significant differences among the treatment means 2 times, 21 Aug and 6 September 2010. Mean comparisons on 6 September 2010 show the resistant varieties, ‘Barrister’ and ‘Midnight’ having greater turfgrass quality than the susceptible varieties, ‘North Star’ and ‘Barrari’; however, ‘Midnight’ was significantly better in quality than ‘Barrister’ and the susceptible varieties (Table 12). Of the blends that were created, the blend of the two resistant varieties (B + T) and the blend of the two resistant varieties with ‘North Star’ (B + T + S1) were significantly greater than the resistant variety ‘Barrister’ but no differences between these blends and the resistant variety ‘Midnight’. Two *Poa annua* (annual bluegrass) ratings were taken 17 May and 11 June 2010. Although not significant among treatments, the ‘Barrister’ treatment had a greater percent *Poa annua* than all other treatments for both rating dates. The resistant variety ‘Midnight’ was significantly greater in turfgrass quality than 80% of the blends created. In 2011, analysis for turfgrass quality produced significance 2-times, on 7 September and 18 September. Mean separation on 18 September 2011 showed the resistant varieties ‘Barrister’ and ‘Midnight’ statistically greater in turfgrass quality than the susceptible varieties ‘North Star’ and ‘Barrari’ (Table 13). The resistant variety ‘Barrister’ was statistically greater than only one blend composed of ‘Barrister’ and the susceptible variety ‘Barrari’ (B + S2). The resistant variety ‘Midnight’ was statistically greater in turfgrass quality than 3 of the created blends, ‘Barrister’ and ‘Barrari’ (B + S2), ‘Barrister’, ‘Midnight’ and ‘North Star’ (B + T + S1), and ‘Midnight’, ‘North Star’ and ‘Barrari’ (T + S1 +

Table 12. Mean separation of Kentucky bluegrass monostands and blends for quality, dollar spot infection centers, and percent dollar spot infected turfgrass cover on 6 September 2010 at HTRC, East Lansing, MI

Treatments	Quality†	Dollar Spot Infection Centers	Percent Dollar Spot Infected Turfgrass Cover
Barrister [B]	7.3	48.0	8.3
Midnight [T]	8.0	33.0	6.0
North Star [S1]	7.0	85.0	14.0
Barrari [S2]	7.0	78.0	12.0
B + T	8.0	31.0	5.0
B + S1	7.0	53.0	9.3
B + S2	7.3	40.0	9.0
T + S1	7.3	56.0	9.0
T + S2	7.0	69.0	11.3
B + T + S1	8.0	38.0	6.5
B + T + S2	7.3	39.0	5.7
B + S1 + S2	7.0	80.0	13.5
T + S1 + S2	7.0	72.0	12.7
B + T + S1 + S2	7.3	68.0	11.0
LSD (0.05)	0.6	31.4	5.5

† Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 13. Mean separation of Kentucky bluegrass monostands and blends for quality, dollar spot infection centers, and percent dollar spot infected turfgrass cover on 18 September 2011 at HTRC, East Lansing, MI

Treatments	Quality†	Dollar Spot Infection Centers	Percent Dollar Spot Infected Turfgrass Cover
Barrister [B]	8.0	25.3	3.0
Midnight [T]	8.3	24.7	3.7
North Star [S1]	7.0	62.0	10.3
Barrari [S2]	6.7	86.0	13.7
B + T	8.0	34.0	4.3
B + S1	8.3	26.0	3.7
B + S2	7.3	67.3	9.7
T + S1	8.0	37.0	4.7
T + S2	8.0	35.0	4.7
B + T + S1	8.0	40.3	5.7
B + T + S2	7.7	29.0	3.7
B + S1 + S2	8.0	34.3	5.3
T + S1 + S2	7.7	33.7	5.0
B + T + S1 + S2	8.0	39.7	5.3
LSD (0.05)	0.6	24.7	3.8

† Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 14. Mean separation of Kentucky bluegrass monostands and blends for quality, dollar spot infection centers, and percent dollar spot infected turfgrass cover on high, sand-based rootzone on 15 September 2011, at HTRC, East Lansing, MI

Treatments	Quality†	Dollar Spot Infection Centers	Percent Dollar Spot Infected Turfgrass Cover
Barrister [B]	8.0	14.0	3.0
Midnight [T]	8.0	10.0	1.7
North Star [S1]	6.7	44.0	8.0
Barrari [S2]	6.7	49.0	9.3
B + T	8.0	8.0	1.7
B + S1	7.3	16.0	3.0
B + S2	7.0	40.0	7.7
T + S1	7.0	34.0	5.7
T + S2	8.0	17.0	2.7
B + T + S1	7.7	28.3	5.0
B + T + S2	8.0	24.7	4.0
B + S1 + S2	7.3	32.0	5.3
T + S1 + S2	7.7	27.3	4.7
B + T + S1 + S2	7.7	25.0	4.7
LSD (0.05)	1.0	15.3	3.5

† Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

S2). Also in 2011, analysis for the replicated study on 6-inches of high, sand-based rootzone mix produced significance among 3 of the rating dates, 18 August, 30 August, and 15 September 2011. Again, mean separation on 15 September 2011 showed both of the resistant varieties having greater turfgrass quality than the two susceptible varieties (Table 14). In this instance, the two resistant varieties were greater in turfgrass quality than two blends, 'Barrister' and 'Barrari' (B + S2), and 'Midnight' and 'North Star' (T + S1). In all years and studies, the top-performing blend was consistently the blend of the two resistant varieties.

Dollar Spot Infection Centers

Similar to turfgrass quality, counts for dollar spot infection centers per plot were recorded following the inoculation of the study. In 2010, analysis of the dollar spot infection centers count was significant on only one of the rating dates, 6 September 2010. Mean separation on 6 September revealed significant differences between the both resistant varieties, 'Barrister' and 'Midnight' to one susceptible variety, 'North Star' (Table 12). Furthermore, the variety 'Midnight' was also statistically lower in dollar spot infection centers than the other susceptible variety, 'Barrari'. Of the blends that were created, 'Barrister' was only significantly lower in dollar spot infection centers than one blend, 'Barrister', 'North Star', and 'Barrari' (B + S1 + S2). On the other hand, 'Midnight' produced fewer dollar spot infection centers than 4 of the created blends including the 4-way blend, 'Midnight', 'North Star', and 'Barrari' (T + S1 + S20, 'Barrister', 'North Star', and 'Barrari' (B + S1 + S2), and 'Midnight' and 'Barrari' (T + S2). In 2011, analysis of dollar spot infection centers produced significant ratings on 7 September and 18 September. Mean separation on 18 September 2011 showed the resistant varieties significantly lower in infection centers when compared to the susceptible varieties (Table 13).

Furthermore, the resistant varieties were only statistically lower in infection centers to a single blend created with ‘Barrister’ and ‘Barrari’ (B + S2). Also in 2011, analysis of the replicated study on high, sand-based rootzone mix produced significant mean separation on 23 August and 15 September. Data collected on 15 September 2011 continued to show the resistant varieties lower in dollar spot infection centers compared to the susceptible varieties in monostands (Table 14). The variety ‘Barrister’ produced significantly lower infection centers than the blend containing ‘Midnight’ and ‘North Star’ (T + S1), the blend with ‘Barrister’ and ‘Barrari’ (B + S2), and also the blend with ‘Barrister’, ‘North Star’, and ‘Barrari’ (B + S1 + S2). The variety ‘Midnight’ showed significantly reduced dollar spot infection centers compared to 50% of the blends that were created.

Percent Dollar Spot Infected Turfgrass

Percentages for dollar spot infection centers per plot were recorded following the inoculation of the study. In 2010, analysis of percent dollar spot infected turfgrass cover was significant on three of the rating dates, 19 July, 6 September, and 17 September. Mean separation on 6 September revealed significant differences between ‘Midnight’ and both susceptible varieties, but ‘Barrister’ was only lower in percent dollar spot infected turfgrass cover than ‘North Star’ (Table 12). The variety ‘Barrister’ was not statistically greater in percent dollar spot infected turfgrass cover. The blend ‘Barrister’, ‘North Star’, and ‘Barrari’ (B + S1 + S2), and the blend ‘Midnight’, ‘North Star’, and ‘Barrari’ (T + S1 + S2), were greater in percent infected turfgrass cover than ‘Midnight’, in monostand. In 2011, analysis of dollar spot infected turfgrass cover produced significant ratings on 30 August, 7 September and 18 September. Mean separation on 18 September 2011 showed the resistant varieties significantly lower in infected turfgrass cover when compared to the susceptible varieties (Table 13). Furthermore, the resistant varieties were only statistically lower in infection centers to a single blend created with 'Barrister' and 'Barrari' (B + S2). Also in 2011, analysis of the replicated study on high, sand-based rootzone mix produced significant mean separation on 23 August and 15 September. Data collected on 15 September 2011 continued to show the resistant varieties lower in dollar spot infected turfgrass cover compared to the susceptible varieties in monostands (Table 14). The variety 'Barrister' produced significantly lower infected turfgrass cover than the blend containing 'Barrister' and 'Barrari' (B + S2). The variety 'Midnight' showed significantly reduced dollar spot infection centers compared to 30% of the blends that were created.

CONCLUSIONS

After reviewing the data collected across the two years of the study and also incorporating the replicated study on high, sand-based rootzone mix, evidence suggests that the blends, in most cases, were amid the ratings for the resistant varieties, 'Barrister' and 'Midnight', and the susceptible varieties, 'North Star' and 'Barrari'. The blends that did not necessarily follow suit included 'Barrister', 'Midnight', and 'North Star' (B + T + S1), 'Barrister', 'Midnight', and 'Barrari' (B + T + S2), and also the blend of the two resistant varieties together, were among the top-performing blends, consistently. Blends including higher percentages of the susceptible varieties often exhibited higher dollar spot infection centers, percent infected turfgrass cover, and in turn, lower turfgrass quality. These findings were congruent with the original findings of blend construction by Vargas and Turgeon (1980) that showed lower disease ratings for melting out, Fusarium blight, and stripe smut when including a resistant and susceptible variety together compared to the susceptible variety in a monostand. Furthermore, by planting resistant varieties in monostands, the ability of inoculum to build-up and eventually reduce the efficacy of the resistant variety to oppose *Sclerotinia homoeocarpa* pathogenicity is not present because susceptible varieties are not included. Therefore, the incompatibility associated with the resistant variety to the pathogen may prolong life of the turf stand. Since it is not known if the dollar spot resistance in these Kentucky bluegrass varieties is specific (vertical) or generalized (horizontal) it is difficult to know whether the resistance will last. However, based on this study the resistance appears to be similar to generalized resistance to melting-out in Kentucky bluegrass (Vargas 1980). If this is the case, the cultivars should retain their resistance to dollar spot with reduced chances of a new strain of the pathogen developing that could overcome the resistance. This evidence is strongly supported by the duration of dollar spot resistance in ‘Midnight’ Kentucky bluegrass since the release of the variety decades ago.

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Chapter Four: Evaluation of Bispyribac-sodium (Velocity) applications on Kentucky Bluegrass Varieties in Monostands and Blends

INTRODUCTION

Improved varieties of Kentucky bluegrass selected for Velocity tolerance may provide field managers with another means to suppress annual bluegrass (*Poa annua* L.) invasion. Because of Kentucky bluegrass's genetic similarities to annual bluegrass, it is the most sensitive turfgrass species to Bispyribac-sodium (Velocity) applications for annual bluegrass control. Therefore, consecutive applications of Velocity to a blend containing one or more varieties that are susceptible to the herbicide could be a critical error.

Although found in every continent of the world as a cultivated turfgrass for performance turf, annual bluegrass is typically classified as a weed. Annual bluegrass can become the dominant turf under irrigated, closely mowed, intensely fertilized turfgrass conditions which are apparent on most golf courses and athletic fields (Beard, 1973). In the field, annual bluegrass attracts attention because of the dissimilar light green coloration and the great contrast between varieties of Kentucky bluegrass' dark green appearance. The eradication of annual bluegrass from a Kentucky bluegrass stand has proven to be a daunting task due to the adaptability of the turfgrass. Annual bluegrass tolerates compacted soils, full sun, shade and close mowing heights and also exists as biotypes ranging between short-lived annuals to long-lived perennials (Gibeault, 1972; Slavens, 2010). These characteristics and the adaptability make annual bluegrass extremely competitive.

Chemical controls, although limited in number, have developed to combat annual bluegrass invasion in Kentucky bluegrass. Research by Reicher et al. (2011), studied the fall application of mesotrione (Tenacity) on annual bluegrass control in Kentucky bluegrass.

Researchers showed in some of the experiments that span the 6-years of the study, that greater than 80% control of annual bluegrass could be achieved; however, inconsistencies across all of the studies were observed and marginal control was obtained depending on location and year. The use of mesotrione for control of annual bluegrass in Kentucky bluegrass seems promising but not overly impressive. The low sensitivity of Kentucky bluegrass to mesotrione makes the herbicide intriguing. Contrary to mesotrione, ethofumesate (Prograss) has shown minimal control to no control of annual bluegrass at rates ≤10.2 kg ha^{-1}, and at high rates of 20.2 kg ha^{-1} up to 62% control was observed (Meyer and Branham, 2006). However injury associated with Kentucky bluegrass varied by variety. 'Moonlight' and 'America' never showed injury associated with ethofumesate applications; However, 'North Star', and 'Total Eclipse' showed severe damage. Like ethofumesate, Kentucky bluegrass sensitivity to Bispyribac-sodium (Velocity) is more drastic than mesotrione (Lycan and Hart, 2005). Bispyribac-sodium, an ALS (acetolactate synthase) inhibiting herbicide, has been used to control annual bluegrass in creeping bentgrass putting greens (McCullough and Hart, 2008, 2010; Lycan and Hart, 2006; Park et al. 2002). McCullough and Hart (2010) observed 90% control of annual bluegrass with acceptable creeping bentgrass discoloration after 8-weeks following 24.6 g ha^{-1} regimen. Furthermore, McCullough and Hart (2008) used spray adjuvants to increase the efficacy and reduce the amount of Bispyribac-sodium used. Spraying with crop oil concentrate, nonionic surfactant and methylated seed oil increased foliar absorption of bispyribac-sodium 45, 46, and 75%, respectively. Studies by Lycan and Hart (2005, 2006) assessed the severity of bispyribac-sodium applications across several turfgrass species. Single applications ranging from 37 to 296 g ha^{-1} were applied to Kentucky bluegrass (Poa pratensis), perennial ryegrass (Lolium perenne

L.), tall fescue (Festuca arundinacea [L.] Schreb.), and chewings fine fescue (Festuca rubra L. subsp. Commutata Gaud.) and evaluated for injury. Kentucky bluegrass was least tolerant to bispyribac-sodium with up to 28% injury at the highest rate. Injury on the other species was determined to be more chlorotic with Kentucky bluegrass experiencing severe stunting and thinning. Kentucky bluegrass also had the most minimal, incomplete recover of the four turfgrass species evaluated. Lycan and Hart (2006) investigated the responses of creeping bentgrass (Agrostis palustris), annual bluegrass (Poa annua L.), Kentucky bluegrass (Poa pratensis L.), and rough bluegrass (Poa trivialis L.) to foliar, soil, and foliar plus soil applied bispyribac-sodium absorption and translocation. The study exhibited an intermediate absorption and translocation of ^{14}C-bispyribac in Kentucky bluegrass compared to creeping bentgrass (tolerant) and annual or rough bluegrass (sensitive) contributing to the greater tolerance of creeping bentgrass to bispyribac-sodium. This also suggests that Kentucky bluegrass shows slightly better tolerance to bispyribac-sodium than annual bluegrass and varying tolerances among Kentucky bluegrass varieties may attribute to using bispyribac-sodium for removal of annual bluegrass in Kentucky bluegrass. Shortell et al. (2008) assessed 55 varieties of Kentucky bluegrass for bispyribac-sodium tolerance. Injury during the two year evaluation of the varieties showed injury ranging between 8% and 93% 8 weeks following the initial treatment. Shortell et al. (2008) indicates the potential for the development of varieties with improved bispyribac-sodium tolerance.

MATERIALS AND METHODS

The study was initiated on 15 September 2009 at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI, USA. Kentucky bluegrass varieties were selected based on sensitivity to Bispyribac-sodium applications. Plots, 4.64-m^2 in size, of the Kentucky bluegrass (Poa pratensis L.) varieties and blends (Table 15) were established from seed on 25 September 2009 on a Colwood-Brookston Loam/Aubbeenaubee Capac Sandy Loam (NRCS, 2009). Lebanon Country Club 13-25-12 Starter fertilizer (Lebanon Seaboard Corp., Lebanon PA) was applied at a rate of 4.88-g P m^{-2}. Each plot was seeded at a rate of 7.32-g m^{-2}. Prior to covering the experimental area with a 95% light transmitted germination and insect AgroFabric (A.M. Leonard, Piqua, OH), one application of mesotrione (Tenacity)(Syngenta, Wilmington, DE) at a rate of 1.9-ml m^{-2} was applied to prevent broadleaf weeds and annual bluegrass germination.

An irrigation program was developed for the germination process of the experimental area providing 0.508-cm day^{-1} and was reduced to an as needed basis following the removal of the germination AgroFabric on 7 October 2009. The germination AgroFabric provided an adequate 12-day germination period for all treatments, except treatments including 'Barzan' as previously noted in experiments 1 and 2 (Table 15). A second starter fertilizer application was applied on 11 October 2009 applied at a rate of 4.88-g P m^{-2} with a supplemental application of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2}. In 2010, applications of 46-0-0 Urea (The Andersons, Inc., Maumee, Ohio) at a rate of 2.44-g N m^{-2} and

42-0-0 Polyon (Harrell's, Lakeland, Florida) at a rate of 4.88 g N m^{-2} were applied cumulating 19.5-g N m^{-2} for the year. Four applications of Bispyribac-sodium [17 DG Formulation (Valent, inc. Walnut Creek, CA) at a rate of 37.1 g ha^{-1} were applied over a two-week period beginning 15 June 2010.

Weekly ratings of visual assessment for quality and percent blighted tissue were collected beginning on the initial application date, 15 June 2010. Turfgrass quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Percent blighted tissue was assessed visually as a percent of injured turf over the plot area. Also, Normalized Difference Vegetation Index (NDVI) ratings were taken weekly with the Field Scout TCM 500 turf color meter (Spectrum Technologies, Inc. Plainfield, IL).

The study was analyzed as a Completely Randomized Design (CRD) with three replications. A single factor [Varieties (Table 15)] included 14 total treatments and 42 total plots were examined using Proc UNIVARIATE procedure to test the normality of homogeneity of variances and residuals. Due to the exclusion of treatments including 'Barzan', contrasts for mean separation were obtained using Proc MIXED of the remaining treatments.

In 2010, a second study to examine the effects of Bispyribac-sodium on the same treatments (Figure 15), were established on 15.24-cm of a well-graded, high-sand-content root-zone mix [90.0% sand, 7.0% silt, and 3.0% clay (ASTM 2006, Henderson et al. 2005)]. The study was initiated on 29 September 2010 and adhered to the same protocol for establishment as the previous study. Plot sizes were reduced to 1.67-m^2. The variety 'Barzan' was replaced with 'Barrister' and also included in all blends associated with 'Barzan'. Weekly ratings of visual assessment for quality and percent blighted tissue were collected beginning on the initial

Table 15. List of treatments for Kentucky bluegrass monostands and blends under bispyribac-sodium stress

Treatments (2010)	Treatments (2011)
Barzan [B]	Barrister [B]
Moonshine [T]	Moonshine [T]
North Star [S1]	North Star [S1]
Avalanche [S2]	Avalanche [S2]
B + T	B + T
B + S1	B + S1
B + S2	B + S2
T + S1	T + S1
T + S2	T + S2
B + T + S1	B + T + S1
B + T + S2	B + T + S2
B + S1 + S2	B + S1 + S2
T + S1 + S2	T + S1 + S2
B + T + S1 + S2	B + T + S1 + S2

application date. Again, four applications of Bispyribac-sodium [17 DG Formulation (Valent, inc. Walnut Creek, CA) at a rate of 37.1 g ha^{-1} were applied over a two-week period beginning 30 August 2011. Turfgrass quality were rated using a 1-9 scale, with 1 being inferior, 9 being superior and 6 being acceptable (NTEP, 2009). Percent blighted tissue was assessed visually as a percent of injured turf over the plot area. Also, Normalized Difference Vegetation Index (NDVI) ratings were taken weekly with the Field Scout TCM 500 turf color meter (Spectrum Technologies, Inc. Plainfield, IL). The study was analyzed as a Randomized Complete Block Design (CRD) with three replications. The single factor was examined using Proc UNIVARIATE procedure to test the normality of homogeneity of variances and residuals. Means separations were determined using Proc GLM from selected analysis of Fisher's least significant difference at a 0.05 level of probability.

RESULTS AND DISCUSSION

Quality

Following the initial applications of bispyribac-sodium on 15 June 2010 and 30 August 2011, weekly ratings were taken on turfgrass quality. In 2010, analysis of treatment means produced significance 6 times occurring on 29 June, 2 July, 6 July, 12 July, 19 July and 23 July. However, only 5 treatments were analyzed due to an unanticipated poor germination of the variety ‘Barzan’. Therefore, all treatments including the variety ‘Barzan’ were not included in the analysis of 2010 rating dates. Mean separation on 12 July showed drastic differences between the remaining bispyribac-sodium tolerant variety ‘Moonshine’, the sensitive varieties ‘North Star’ and ‘Avalanche’ and the blends created between the three varieties (Table 16). The variety ‘Moonshine’ showed the highest quality rating and was statistically greater than all other treatments. Of the sensitive varieties ‘North Star’ was statistically greater than ‘Avalanche’ in monostands. Of the blends that were created between the three varieties, all were statistically greater in quality than ‘Avalanche’ alone and no differences were observed between the blends and ‘North Star’. The top-performing blend included ‘Moonshine’ and ‘North Star’ (T + S1), which was an expected result. Analysis in 2011, after the study was replicated on high, sand-based rootzone mix and ‘Barzan’ replaced with ‘Barrister’ as a bispyribac-sodium tolerant variety, treatment means revealed significance on only one of the rating dates occurring on 21 September. Mean separation on 21 September produced significant differences between the tolerant varieties ‘Barrister’ and ‘Moonshine’ and the sensitive varieties ‘North Star’ and ‘Avalanche’ (Table 17). Furthermore, both tolerant varieties were greater in turfgrass quality than all blends except the four-way blend.

Table 16. Mean separation of Kentucky bluegrass monostands and blends for quality, Normalized Difference Vegetation Index and percent blighted tissue under bispyribac-sodium stress on 12 July 2010 at HTRC, East Lansing, MI

Treatments	Quality†	Normalized Difference Vegetation Index	Percent Blighted Tissue
Midnight [T]	8.0	0.697	3.0
North Star [S1]	6.0	0.656	21.0
Barrari [S2]	5.0	0.607	36.7
T + S1	7.0	0.689	10.0
T + S2	6.0	0.667	16.7
T + S1 + S2	5.7	0.656	15.7
LSD (0.05)	0.4	0.050	9.9

† Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Table 17. Mean separation of Kentucky bluegrass monostands and blends for quality, Normalized Difference Vegetation Index and percent blighted tissue under bispyribac-sodium stress on 21 September 2011 at HTRC, East Lansing, MI

Treatments	Quality†	Normalized Difference Vegetation Index	Percent Blighted Tissue
Barrister [B]	8.3	0.700	4.0
Moonshine [T]	8.3	0.686	3.0
North Star [S1]	5.3	0.611	31.7
Avalanche [S2]	5.3	0.630	26.6
B + T	7.7	0.666	6.7
B + S1	7.0	0.668	11.7
B + S2	7.0	0.667	12.7
T + S1	6.3	0.650	18.3
T + S2	7.0	0.638	16.0
B + T + S1	7.3	0.673	9.3
B + T + S2	7.0	0.653	8.3
B + S1 + S2	6.3	0.650	17.3
T + S1 + S2	6.3	0.640	19.3
B + T + S1 + S2	7.3	0.674	9.0
LSD (0.05)	1.3	0.031	12.5

† Quality: 1= Poor, 5 = Acceptable, and 9 = Excellent

Normalized Difference Vegetation Index

Following the initial applications of bispyribac-sodium on 15 June 2010 and 30 August 2011, weekly ratings were taken on Normalized Difference Vegetation Index (NDVI). In 2010, analysis of treatment means produced significance 5 times occurring on 29 June, 2 July, 6 July, 12 July and 19 July. However, only 5 treatments were analyzed due to an unanticipated poor germination of the variety ‘Barzan’. On 12 July 2010, the tolerant variety ‘Moonshine’ was only statistically greater in NDVI compared to the sensitive variety ‘Avalanche’. Additionally, there were no differences between ‘Moonshine’ and the created blends; however, the 3-way blend was not statistically different than the sensitive variety ‘Avalanche’ (Table 16). In 2011, analysis of the treatment means from the replicated study on high, sand-based rootzone mix with ‘Barzan’ replaced with ‘Barrister’ as a bispyribac-sodium tolerant variety provided significance on 2 of the ratings dates, happening on 15 September and 21 September. Treatment means on 21 September showed the tolerant varieties having higher NDVI ratings than the sensitive varieties (Table 17). The varieties ‘Barrister’ and ‘Moonshine’ in monostands showed higher NDVI ratings than 70% and 50% of the blends, respectively. ‘Moonshine’ proved to be significantly indifferent to the ‘Barrister’ and ‘Moonshine’ (B + T) blend and ‘Barrister’ and ‘Avalanche’ (B + S2) Blend.

Percent Blighted Turfgrass Tissue Cover

Weekly percent blighted turfgrass tissue cover was also taken weekly following the initial application of bispyribac-sodium on 15 June 2010 and 30 August 2011. In 2010, analysis of treatment means for percent blighted turfgrass tissue showed significance 6 times, occurring on 29 June, 2 July, 6 July, 12 July, 19 July and 23 July. Similar to turfgrass quality and NDVI, analysis of percent blighted turfgrass tissue cover excluded all treatments including the variety

‘Barzan’. Mean separation of percent blighted turfgrass tissue cover yielded significant differences between the tolerant variety ‘Moonshine’ and the sensitive varieties ‘North Star’ and ‘Avalanche’ (Table 16). Furthermore, ‘Avalanche’ had significantly greater percent blighted tissue cover compared to ‘North Star’. When measured against the created blends, ‘Moonshine’ was statistically lower in percent blighted turfgrass tissue cover than the blend ‘Moonshine’ and ‘Avalanche’ (T + S2) and the 3-way blend but not the blend ‘Moonshine’ and ‘North Star’. This is justified by the decrease in percent blighted tissue cover of the variety ‘North Star’ from ‘Avalanche’ in monostands. In 2011, analysis of percent blighted turfgrass tissue cover exposed only one rating date with significance among treatment means on 21 September. To reiterate, changes were made between 2010 and 2011 to the study to include ‘Barrister’ instead of ‘Barzan’ and was established on high, sand-based rootzone mix. On 21 September 2011, the trend continued with both tolerant varieties having a significant reduction in percent blighted tissue cover when compared to the sensitive varieties in monostands (Table 17). The variety ‘Barrister’ produced lower percentages of blighted tissue cover than the blend containing ‘Moonshine’ and ‘North Star’ (T + S1), the blend with ‘Barrister’, ‘North Star’ and, ‘Avalanche’ (B + S1 + S2), and the blend including ‘Moonshine’, ‘North Star’, and ‘Avalanche’ (T + S1 + S2). In addition to these blends, the variety ‘Moonshine’ provided lower percent blighted tissue cover compared to the blend ‘Moonshine’ and ‘Avalanche’ (T + S2), also.

CONCLUSIONS

With bispyribac-sodium providing another means for Poa annua (annual bluegrass) suppression, varieties that are tolerant to the herbicide will provide a weed free field. Research by Shortell et al. (2008) has provided ranges in sensitivities of Kentucky bluegrass varieties to bispyribac-sodium applications. The inclusion of one or more of the varieties least tolerant to consecutive applications of bispyribac-sodium may prove detrimental as shown by this research. Although changes from the 2010 to the 2011 in design and set-up may have changed the study entirely, strong evidence regarding the plausibility of using monostands or blends of all tolerant varieties for continual applications of bispyribac-sodium are conclusive. In both years of the study, regardless if on native soil or a high, sand-based rootzone mix, the tolerant varieties were higher in turfgrass quality and NDVI and lower in percent blighted tissue cover than the sensitive varieties in monostand. In addition, 'Moonshine' and 'Barrister', although not always significant, were higher in turfgrass quality and NDVI and lower in percent blighted tissue cover than all blends that were created. Similar to the dollar spot, the blends that were created were always intermediate in turfgrass quality, NDVI and percent blighted tissue cover as compared to the tolerant and sensitive varieties in monostands. Furthermore, differences in turfgrass quality, NDVI and percent blighted tissue cover between the two tolerant varieties, 'Moonshine' and 'Barrister' (2011 only), and the sensitive varieties, 'North Star' and 'Avalanche', in monostands provided a predictor for the performance of each blend. For instance, the combination of 'Moonshine' and 'North Star' (T + S1) was higher in turfgrass quality, NDVI, and lower in percent blighted tissue cover compared to the blend between 'Moonshine' and 'Avalanche' (T + S2), provided that 'North Star' was greater in performance under these ratings than 'Avalanche'. The same held true in 2011; however, the role of 'Avalanche' in blends on the sand-based system was more beneficial in this year compared to ‘North Star’. Lastly, 3-way blends consisting of higher percentages of sensitive varieties, generally had lower turfgrass quality, NDVI ratings, and higher percent blighted tissue cover compared to all other blends, which suggests the importance of using tolerant varieties to bispyribac-sodium if the herbicide is to be used as a means to suppress annual bluegrass invasion in athletic field situations.

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THESIS CONCLUSION

Evaluation of the Kentucky bluegrass varieties in monostands and blends under traffic, dollar spot, and bispyribac-sodium stress has presented plausibility of using monostands of improved varieties to replace blends. In both traffic studies, results suggest that using varieties with increased traffic tolerance, recuperative potential, and aggressiveness showed, in some cases, to have increases in percent ground cover, quality, and surface strength characteristics compared to a blend where the variety was included ('Bar VV 0709'). Likewise, monostands of resistant varieties under dollar spot and bispyribac-sodium stress provided an increase in turfgrass quality, a reduction in dollar spot infection centers, and a reduction in percent blighted turfgrass tissue when compared to blends created from resistant and susceptible varieties. Having said this, the use of these improved varieties in monostands may be limited to highly maintained turfgrass stands. The safety blanket associated with diversity of disease resistances and growth characteristics among Kentucky bluegrass varieties in a blend may allow low maintenance municipalities to maintain turfgrass cover and quality without the potential threat of complete decimation by a variety specific disease, like stripe smut. Furthermore, a blend consisting of varieties tolerant to bispyribac-sodium will still provide field managers a means to suppress annual bluegrass.

The evolution of monostands has already begun. Now and in the immediate future, the use of herbicide tolerant varieties of turfgrass species, particularly glyphosate tolerant, will require monostands. Nandula et al. (2008) began screening varieties of Italian ryegrass (*Lolium multiflorum*) populations for glyphosate tolerances. In their investigations, varieties 'Tribbett' and 'Fratesi' showed a threefold increase based on dose required to cause a 50% reduction in plant growth when compared to a glyphosate susceptible variety, 'Elizabeth'. Hart et al. (2005), through a recurrent selection-breeding program, identified glyphosate tolerance in 'Aurora Gold', a variety of hard fescue. The experiment showed single rate applications of 0.6 to 0.8 kg ha^{-1} could be applied to 'Aurora Gold' with minimal injury or stand thinning. Furthermore, multiple applications of glyphosate at 0.4 to 0.6 kg ha^{-1} showed similar reduced injury. Hart described the hard fescue variety 'Aurora Gold' as an ideal variety for golf course roughs, vineyards, orchards, and landscapes and would incorporate glyphosate into a weed management program.

Breeding programs are attempting to generate herbicide tolerance into turfgrass; however, the use of genetically modified (GM) turfgrass could be the next breakthrough in monostand implementation. The ecological impacts of GM turfgrasses, biosafety, gene flow and intellectual property (IP) rights, remains a concern; in spite of this, genetic engineering for herbicide resistance would provide complete protection from products such as glyphosate and other herbicides for grasses (Spillane et al., 2004). The creation of glyphosate resistant creeping bentgrass is both encouraging due to the potential in weed management programs yet imposes negative ecological impacts. Reichman et al. (2006) showed transgene flow of transgenic herbicide-resistant creeping bentgrass (*Agrostis stolonifera* L.) to compatible wild species, which could establish and resist direct applications of glyphosate. The problem with most turfgrass species is the ability to cross-pollinate. However, Kentucky bluegrass reproduces asexually by apomixis. The fixed hybrid vigor and low recombination potential associated with an apomictic plant may limit gene flow and increase potential to develop transgenic varieties for commercial release (Spillane et al., 2004). Johnson et al. (2006) showed an overall hybrid frequency of 0.048% and hybrid frequency at 0-m distance of 0.53% of Kentucky bluegrass hybrids when measuring pollen mediated gene flow of intra- and inter-specific turfgrass species. Johnson suggests that apomixis in receptor plants and pollen competition most likely reduced the number of hybrids; however, gene flow did occur but at low frequencies and over short distances. The use of Kentucky bluegrass to include genetic modifications due to its asexual nature may produce advanced hybrids with increased disease and herbicide resistances and would demand further investigation into the potential of monostands.

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