Alternative *Poa* Species as Permanent and Temporary Turfgrasses in the Transition Zone

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DEDICATION

I dedicate this Thesis to my parents, Kerry and Celisa, for instilling a strong work ethic upon me that is largely responsible for making this work possible. Knowing I had their support gave me peace of mind through even the hardest of time. Also, to the love of my life, best friend, and wife Chun Hu, thank you for giving me the strength to carry on.

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ABSTRACT

As restrictions on water, fertilizer, and pesticide use increase, along with public pressure, turfgrass practitioners will need ways to meet the challenges of reduced inputs while still maintaining acceptable turf quality. Proper selection of turfgrass species and cultivars that are adapted to the climate, intended use, and level of expectation is the best and first line of defense for reduced input situations. The objective of this study was to evaluate alternative species from the bluegrass (*Poa*) genus for their performance as both permanent and temporary winter turfgrass species. In 2010 and 2011, 45 different treatments consisting of 37 different bluegrasses were established from seed in greenhouse grown plugs and transplanted into native soil in Knoxville, TN. Each treatment was evaluated monthly for percent green cover for a one year period. Bluegrasses were grouped by growth habit. In both years *P. stiriaca* Fritsch & Hayek and *P. maniototo* Petrie were in the top statistical category along with three cultivars of Kentucky bluegrass (*P. pratensis* L.) and one hybrid (*P. arachnifera* Torr. x *P. pratensis*). This indicated that there were alternative *Poa* species capable of maintaining cover similar to that of Kentucky bluegrass. A second study initiated in 2010 and repeated in 2011 examined *P. nemoralis* L. for its performance as a winter overseeding species on three bermudagrass (*Cynodon* spp.) systems; putting greens, fairways, and sports fields. *P. supina* Shrad. was tested only on a putting green, where it was found to both establish and transition too slowly, while being over competitive against the bermudagrass. *P. nemoralis* provided acceptable cover in the 2010 season and transitioned well without the use of herbicides; however, during the 2011 season this species failed to provide acceptable cover. In the fairway and sports turf studies, perennial ryegrass (*Lolium perenne* L.) and intermediate ryegrass (*L. perenne* x *L. multiflorum*

L.) maintained the highest percent green cover. *P. nemoralis* did not provide acceptable cover in either year of both studies.

INTRODUCTION

The number of grass species used as turfgrasses is relatively small in comparison to the total number of species in the Poaceae family (true grasses) that contains as many as 10,000 individual species. Many of these 10,000 species have not been tested for any kind of attributes they may possess. Turfgrass managers are constantly faced with budgetary and environmental concerns that result in the need for turfgrass species that perform under reduced input. Turfgrass breeders have worked with traditional species and successfully improved their performance to some degree in reduced input situations. Others have explored the use of native species with varying degrees of success. Although, progress has been made the demand is rising for grasses that perform under reduced input is faster than they can be developed.

The transition zone represents a unique situation where warm- and cool-season grasses can both be grown, but increased inputs are required to maintain high quality turf. A cool-season species would be most ideal because of their year round green color that does not require winter overseeding. However, cool-season grasses in the transition zone require high inputs to maintain quality turf in face of the inherent heat stress that occurs in summer.

The primary goal of the following study was to identify potential species from *Poa* with turfgrass characteristics that display an ability to tolerate heat stress. If any species are found they may contribute to the turfgrass industry by enhancing the total amount of genetic material available by developing new species or improving others ability to perform in the transition zone. This study was designed to isolate this heat stress as the primary cause of poor performance and was achieved by controlling biotic stresses such as, insects and pathogens and not allowing drought stress to occur.

Additionally, some species may be very intolerant of heat and thus may be useful in winter overseeding of bermudagrass where a natural transition is desired. Being able to allow a natural transition would reduce the inputs required by eliminating the use of herbicides that are used to transition out the overseeding species. Because of differences between different overseeding systems, studies were designed for specific overseeding trials on putting greens, fairways, and sports fields were designed to test grasses in these applications.

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CHAPTER I

LITERATURE REVIEW

Alternative species

Restrictions on water, fertilizer, and pesticide use have challenged the turf industry to develop or discover turfgrass species and cultivars capable of maintaining acceptable turfgrass quality under reduced inputs. Breeders have responded by focusing their attention on traditional turfgrass species. Turfgrass researchers have evaluated alternative species for use in turf, with some focusing strictly on native species (Mintenko et al., 2002; Salaiz, 2011; Kopec et al., 2008). Other researchers have focused on evaluating a wide array of traditional, non-traditional, and native species in specific systems, such as fairways (Watkins et al., 2010). Breeding efforts have begun with some native species with the goal of improving turf quality while keeping and improving low maintenance qualities. These species include buffalograss [*Buchloe dactyloides* (Nutt) Engelm.], prairie junegrass [*Koeleria macrantha* (Ledeb.) Schult.], and poverty oatgrass [*Danthonia spicata* (L.) P. Beauv. ex Roem. & Schult.] (Amundsen and Shearman, 2011; Watkins, 2011; Warnke and Amundsen, 2009).

Recorded experimental testing of turfgrass species and cultivars by professional organizations has been conducted for almost 100 years, starting in 1916 with the Arlington Turf Gardens (Anonymous, 1937). Variety testing, such as that done by the National Turfgrass Evaluation Program (NTEP), and many universities, provides a wealth of information on the performance of varieties within the same species and has given turfgrass breeders a way to measure the success of their breeding programs. Published research comparing species in a specific location is limited, most likely due to common knowledge of which species are best adapted to specific locations, with the common knowledge coming from simple observation and a basic understanding of plant physiology (i.e., the difference in adaptation of warm- and cool-season grasses).

Much of the research examining alternative species has been performed in particular climates such as the northern Great Plains (Mintenko et al., 2002). Many of the native species that have been studied, such as buffalograss, are not adapted to the humid, transition zone climate. No research involving the use of a non-traditional turf species has been performed in the transition zone. This is partly because many states in the transition zone, including Tennessee, have no current use restrictions on water or fertilizer. However, the need for reduced maintenance is recognized and if current trends continue, it is possible that restrictions could be put into place.

Studies examining native species have focused on species that had seed readily available. However, this is a small percentage of the approximately 10,000 species of grass. Examination of the sub-families within Poaceae (true grasses) reveals species that do not fit the criteria of a turfgrass, including the subfamily Bambusoideae, which contains the species we know as bamboo. Traditional turfgrass species come from three sub-families; the Poioideae, containing the cool-season grasses; the Panicoidae, containing warm-season species such as centipedegrass [*Eremochloa ophiuroides* (Munro) Hack] and seashore paspalum (*Paspalum vaginatum* Swartz); and the Chlorideae, containing the warm-season species bermudagrass (*Cynodon* spp.) and zoysiagrass (*Zoysia* spp.).

In the transition zone, both cool- and warm season turfgrass species can be grown successfully, but with limitations. Cool-season species are limited by their heat intolerance and warm-season species by their intolerance to freezing temperatures. Adapted cool-season grasses, like tall fescue (*Festuca arundinacea* Shreb.) are typically used in home lawns and general turf areas because they are green year-round. Adapted warm-season grasses, like bermudagrass, are favored in high use environments, such as golf courses and sports fields, where their ability to

tolerate low mowing heights, resist wear, and recover from traffic are essential. Warm-season grasses are often overseeded with cool-season species to provide green and actively growing turf during winter (Ward et al., 1974). This practice adds cost and labor to the management budget, so a cool-season permanent turf that could meet requirements for these turfgrass systems would be desirable.

Kentucky bluegrass (*Poa pratensis* L.) is suited for use on golf course tees and fairways and on sports fields in its temperate area of adaptation. Tall fescue is better adapted to a transition zone climate because of its higher tolerance to heat and deeper roots. However, tall fescue is not adapted to low mowing heights and has less recuperative ability because of its bunch type growth habit, compared to the rhizomatous growth of Kentucky bluegrass. Ideally, a cool-season turfgrass for widespread use in the transition zone would need heat tolerance, drought tolerance, a spreading growth habit, wear tolerance and rapid recovery rate, and disease resistance.

The Poa genus

The bluegrass genus (*Poa*) is comprised of as many as 575 species (Gillespie and Soreng, 2005) compared to the fescue (*Festuca*) genus, which has 360 species (Watson and Dallwitz, 1992). *Poa*, a diverse genus, occurs in a wide range of habitats (Soreng, 1990). Life forms may be annual or short- or long-lived perennials (Anton and Connor, 1995). Growth habits include bunch, stoloniferous, and rhizomatous types (Hitchcock, 1950). The bluegrasses are economically important, with many species occurring in natural grasslands worldwide, some species incorporated into improved pastures, and still others known as weeds (Anton and Connor, 1995). These species are also well known for their diversity and distribution of sex

forms. For example, forty-one of the 54 known dioecious species occur in southern South America (Anton and Connor, 1995). Diversity in breeding systems is common in the genus, with some species being highly apomictic, others highly sexual and self-incompatible, and others completely self-compatible (Huff, 2003a-b; Hurley, 2003). The genus is characterized and easily recognized by its leaf morphology that is described as having a boat-shaped leaf tip and parallel light lines down the center of the leaf (Turgeon, 2002).

Traditional Poa species

Several species of bluegrass have been utilized as turfgrasses, with Kentucky bluegrass being the most important and widely utilized of all cool-season turfgrass species (Beard, 1973). This species has become naturalized throughout the temperate regions of the world and was most likely introduced as an agronomic crop to North America (Bashaw and Funk, 1987). Movement closer to the equator is only limited by high temperatures (Hartley, 1961). Kentucky bluegrass is not only important for turf, but also as a forage grass where it is prized for its feed quality (Smith, 1981). In turfgrass systems, Kentucky bluegrass is used in everything from utility turfs to golf course tees and fairways and sports fields. The species is best adapted to cutting heights of 1.9 cm or higher (Turgeon, 2002) and thus is not suitable for putting greens. The most widespread and well known use of Kentucky bluegrass is for home lawns. It is the number one choice for lawns in the northern half of the USA (Huff, 2003a). A commonly known limitation of Kentucky bluegrass is its overall lack of drought tolerance, which necessitates the use of irrigation to maintain active growth, especially in the arid western states. In face of watering restrictions, many drought tolerance studies with this species have been conducted in the past decade (Bushman et al., 2012; Richardson et. al., 2008; Abraham et al., 2004).

A second influential *Poa* species is annual bluegrass (*Poa annua* L.). *Poa annua* is commonly regarded as a weed. It is one of the top five most widely distributed plants in the world and occurs almost everywhere man inhabits (Fenner, 1985) and one of the top 10 most studied weeds (Gardarin et al., 2009).). *Poa annua*, like many *Poa* species, is highly variable. Two life forms, with variations in between, are known to occur; an annual type (*P. annua* L. f. *annua*), and a perennial type (P. *annua* L. f. *reptans*). Although its control as a weed continues to be studied, its use as a turfgrass, particularly on putting greens, has also received attention (Huff, 1996, 1998, 2003b; White, 1994).

P. trivialis, or rough bluegrass, is another species that has had widespread use as a turfgrass. It is described as a perennial, stoloniferous species that is completely sexual in its reproduction and performs best in cool, moist environments (Hurley and Funk, 1982). Its use as a permanent turfgrass in the USA is limited because of its poor heat and drought tolerance and inability to maintain uniformity when mixed with other species (Hurley, 2003), but is recommended in northern states for shaded moist environments (Sprague, 1930). This species is used in the southern USA as a temporary cover in winter overseeding of dormant bermudagrass putting greens, where it provides a green, actively growing putting surface throughout the winter months (Sifers and Beard, 2001; Batten et al., 1980, Richardson et al., 2007).

Several other *Poa* species have been utilized as turfgrasses, but none to the same degree as the aforementioned species. Recently, improved cultivars of *P. supina* have been released in the U.S., and researchers have found this stoloniferous species to be very tolerant of traffic (Sorochan et al., 2001) and shade (Stier and Rogers, 2001). Canada bluegrass (*P. compressa* L.) has also been utilized and has generally been found to be adapted to similar climates as *P.*

pratensis. It is adapted to lower fertility soils, but generally does not have high turf quality, compared to Kentucky bluegrass (Beard, 1973).

Native Poa species

The USDA (2013) recognizes 96 species of *Poa* as being native to the USA. A large majority of these occur in western and northern regions. Of the 96 species, only about 10 have been documented in Tennessee and the surrounding transition zone states. Many of these species are categorized as endangered or rare. Also included are species, such as Kentucky bluegrass and Texas bluegrass (*P. arachnifera* Torr.), which is likely not native to Tennessee. With the exception of Texas bluegrass, Kentucky bluegrass, *P. nemoralis,* and *P. palustris*, there is no available germplasm for these native Poa species in the USDA National Plant Germplasm System (USDA, 2013).

Species that are native to a region are generally considered to be adapted to the regional climate. Turfgrasses, however, not only have to be adapted to the climate, but must also possess those characteristics that define a turfgrass. They must withstand continual defoliation from mowing, form a contiguous community, and withstand at least some traffic (Turgeon, 2002). Beard (1998) pointed out that the cool-season turfgrass species evolved under grazing pressure where close-grazing animals such as sheep (*Ovis aries* L.) and cattle (*Bos* spp.) also originated. In the USA, the American bison (*Bison bison* L.), antelope (*Antilocapra americana* Ord), and deer (*Odocoileus* spp.) would pose similar grazing pressure, however, these animals did not develop the mouth parts capable of close grazing (Beard, 1998). Buffalograss is the most successful of native grasses used as turfgrasses. The stoloniferous, warm-season species is native to the North American Great Plains (Wenger, 1943). Buffalograss is well known for its drought

tolerance and low fertility and mowing requirements, however its use in higher rainfall climates may be limited by high weed pressure and disease (Riordan and Browning, 2003).

Of all native turfgrass species, the one that may be the most attractive for the eastern transition zone states is Texas bluegrass. Texas bluegrass is a rhizomatous, dioecious species originating in Texas and Oklahoma (Read and Anderson, 2003), where high temperatures and drought conditions are common, indicating that heat and drought tolerance exist in not only this species, but also the genus as well. An undesirable trait of this species is the formation of pubescence at the base of the lemma, which makes seed harvesting and processing difficult (Read, 2001). Texas bluegrass was introduced to the southeastern USA as a forage grass, however little can be found in literature regarding its performance or use (Pittman and Read, 1998).

Poa hybrids

Interspecific hybridization as a tool for turfgrass breeding has resulted in very successful cultivars. The introduction of 'Tifgreen' (Hein, 1961) hybrid bermudagrass [*C. transvaalensis* (Burtt-Davey) × *C. dactylon* (L.) Pers.] in 1956 revolutionized the turfgrass industry in the southern USA by replacing common bermudagrass (*C. dactylon*) on putting greens with the new hybrid that had a texture and density more comparable to creeping bentgrass (*Agrostis stolonifera* L.) which was enjoyed by golfers in northern states (Robinson and Latham, 1956). Although other bermudagrass hybrids were released from this program around the same time, the most notable was 'Tifway.' (Burton, 1966) Tifway, released in 1960, was a chance hybrid that was very well suited to golf course fairways and tees (Burton, 1960). Fifty years after its release,

Tifway still rates high among modern cultivars in the National Turfgrass Evaluation Program trials (Morris, 2002).

The number of man-made interspecific hybrids is numerous with *Poa*, and a large portion of these hybrids involved the use of *P. pratensis* as one the parents. One of the earliest controlled hybrids of a *Poa* species was that of Texas bluegrass (*P. arachnifera* Torr) and Kentucky bluegrass (Vinall and Hein, 1937). Interspecific hybridizations of *Poa* species for turf, which resulted in a released cultivar, started with 'Reveille' hybrid bluegrass (Read et al., 1999). Reveille is a hybrid between Texas bluegrass and Kentucky bluegrass. The goal with this hybrid was to incorporate the heat and drought tolerance characteristics of Texas bluegrass into the higher turf quality Kentucky bluegrass. More recently, these hybrids have resulted in the release of several cultivars such as 'Thermal Blue, 'Dura Blue' and 'Longhorn' (Teuton et al., 2009; Richardson and Karcher, 2009). These hybrids were shown to be equally as suited to use as turfgrasses in comparison to tall fescue and Kentucky bluegrass (Teuton et al., 2007) and have demonstrated improved tolerance to high temperatures (Su et al., 2007). Although these hybrids have displayed enhanced heat tolerance, getting this characteristic along with drought tolerance, the desired turf quality, and economical seed production has proven difficult (Read, 2001; Merewitz et al., 2010; Abraham et al., 2004). Research specific to the transition zone has been performed. A study focusing on drought tolerance found high diversity between cultivars of hybrid bluegrasses when compared to Kentucky bluegrass and other *Poa* hybrids. At least one of the Texas hybrids ranked near top in drought tolerance, while several other Texas hybrids ranked near the bottom, indicating that hybrid status of these cultivars does not automatically confer drought tolerance (Richardson and Karcher, 2009).

Naturally-occurring hybrids have also made big impacts on the turfgrass industry. It was suggested early on that the parents of *P. annua* were *P. supina* Schrad. and *P. infirma* Kunth (Nanfeldt, 1937). Later, it was suggested that *P. trivialis* L. and *P. infirma* were the parents (Pietsch, 1989). Recently, DNA and chloroplast sequence studies verify that *P. supina* and *P. infirma* are the parents (Mao and Huff, 2012).

Interspecific hybridization with other *Poa* species has been successful, with a large portion of the crosses using Kentucky bluegrass as one of the parents (Goldman and Sims, 2005; Read, 2001; Dale et al., 1975) and hybrids have been known to occur in the wild (Clausen, 1961).

Poa breeding

As mentioned previously, the diversity of *Poa* is present in many forms. This includes sex forms, modes of reproduction, and ploidy levels. All of these characteristics must be understood before implementing breeding programs, regardless of whether the objective is inter- or intraspecific hybridizations. Sex forms in *Poa* are extremely diverse, with not only the typical monoecious and dioecious forms occurring, but also variations in between, such as gynodioeceous and gynomonoecious (Anton and Connor, 1995). In breeding, monoecious plants can be used for reciprocal crosses, where the plant can be both a maternal and paternal parent, whereas a dioecious plant can only be one or the other. In addition to sex form, the modes of reproduction are also diverse in this genus. Apomixis is common in *Poa* and has been extensively studied in Kentucky bluegrass (Kelley et al., 2009; Clausen, 1961) This mode of reproduction results in highly stable and uniform progeny, which is beneficial to breeders when a superior plant is developed, however it makes inter- and intraspecific hybridization difficult

(Huff, 2003). Fortunately, in Kentucky bluegrass, apomixis is not typically exclusive and some out-crossing can occur, with the level of apomixis or out-crossing being highly variable (Huff, 2003). Initially cultivars of Kentucky bluegrass originated as selections from old turf areas or seed fields (Pepin and Funk, 1971). Cultivar development of Kentucky bluegrass using intraspecific hybridization as a method was slow to be accepted because of many reasons relating to apomixis, however it was shown that intraspecific hybridization is a useful tool in improving Kentucky bluegrass (Pepin and Funk, 1971).

Some *Poa* species, such as *P. annua* and *P. supina*, utilize self-pollination, which results in true-breeding strains through inbreeding (Huff, 2003). Although common in agricultural crops, this mode of reproduction is not typical among turfgrasses. Like apomixis, self-fertilization is not always exclusive and out-crossing does occur. Some plants of *P.annua* have been found to outcross as much as 15%, (Ellis, 1973).

Out-crossing species are the norm for most of the other traditional turfgrasses, whether warm- or cool-season. However, there can be variations in self-incompatibility. Grasses utilizing this mode of reproduction typically rely on a foreign pollen source for fertilization. This can result in populations that contain desirable and diverse genetic combinations, however maintaining the desired combinations can be difficult because of the ease of which pollen from other sources can contaminate the material (Meyer and Watkins, 2003).

Considering that many of the species from the *Poa* genus have not been studied in depth, and knowing that many desired characteristics are present in a combination of these species, the potential exists for development of a *Poa* cultivar that meets the needs of turfgrass managers in the transition zone. This development could come in many forms; the development of a

previously unknown species, development of hybrids with traditional or other species, or through the use of biotechnology. The first step is to identify desirable characteristics in the available *Poa* germplasm.

Overseeding

Outdoor recreational activities such as golf, football, and other sports are commonly played on natural turfgrass surfaces. The management of the turfgrass is specific to the requirements of the sport played on it. These uses can be referred to as different turfgrass systems. Bermudagrass, both common [*Cynodon dactylon* (L.) Pers.] and hybrid [*C. dactylon* X *C. transvaalensis* Burtt-Davy]. is an increasingly common choice for turfgrass systems such as golf course fairways, tees, greens, and roughs (Patton, 2012), as well as athletic fields in the transition zone (Bornino, 2010). The use of hybrid bermudagrasses for golf course putting greens has historically been confined to the southern zone of the U.S. Recently, ultradwarf cultivars of hybrid bermudagrass have been released and many golf courses are choosing to convert greens from creeping bentgrass (*Agrostis stolonifera* L.) to these new cultivars (Patton, 2012; White, 2011; O'Brien and Hartwiger, 2011).

Transition Zone

The transition zone is the area of the USA between the cool humid temperate region to the north, where cool-season turfgrass species are adapted, and the southern, warm sub-tropical zone where warm-season grasses are adapted (Dunn and Diesburg, 2004). In this region, cool-season grasses often encounter significant stress from heat and warm-season grasses commonly suffer low temperature injury (Fry and Huang, 2004).

Bermudagrass

Bermudagrass is a stoloniferous and rhizomatous sod-forming grass that originated in Africa (Beard, 1973). Several species exist but *C. dactylon* and the hybrids between *C. dactylon* and *C. transvaalensis* are the most common species used for turf (Turgeon, 2002). Bermudagrass, when grown in a climate of adaptation, is well-suited to turfgrass systems such as golf courses and sports fields, where damage and wear occur and a low mowing height is dictated (Christians, 2004).

Warm-season species such as bermudagrass utilize the C4 photosynthetic pathway which is most optimal when temperatures range from 30 to 35^0C; whereas cool-season grasses (C3) photosynthesize best at air temperatures from 20 to 25^0C. These temperatures are comparable to the preferred temperatures for shoot growth, which range from 27 to 35^0C for warm-season grasses and 16 to 24^0C for cool-season (Fry and Huang, 2004). Preferential soil temperatures at which root growth is most prolific generally are a few degrees cooler than the optimum temperatures for photosynthesis and shoot growth in both warm- and cool-season species (Fry and Huang, 2004). In the transition zone, optimal temperatures occur for warm-season species, especially through summer months. However, the duration of those optimal temperatures is shorter compared to the southern regions of the U.S.

An additional factor that limits warm-season grasses is cold hardiness or freeze stress tolerance. Turfgrasses differ in the lethal temperature at which damage can occur. Some cultivars of St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], for example, have no ability to acclimate to freezing temperatures, while buffalograss can be found growing as far north as Canada (Fry and Huang, 2004). Extensive research has been conducted to test species and cultivars for their winter hardiness and acclimation to cold temperatures. One study found that there were significant differences among bermudagrass cultivars with respect to regrowth after

exposure to progressively lower temperatures. These results were correlated with levels of linoleic acid and proline and regrowth after freezing (Munshaw et al., 2006). Results such as these show that turfgrass breeders are making notable improvements in bermudagrass cold hardiness. These improvements have resulted in the use of bermudagrass farther north and have made bermudagrass a more attractive option in the transition zone.

The slowed growth that occurs during cooler periods of spring and fall and the winter dormancy period limit the use and performance of bermudagrass. During cooler periods, warm-season species experience a slowed growth rate due to reduced photosynthetic efficiency. In even colder temperatures, growth stops completely, all chlorophyll is lost from the leaf, and the grass is considered dormant. As growth slows and eventually stops, the wear tolerance and recovery of the grass from wear is diminished. One study, performed in Mississippi, showed that when traffic was applied to dormant bermudagrass the effects could be easily observed early in the study. The most notable differences occurred in spring when there were significant differences in spring green-up (Stewart et al., 2008). This decrease in wear tolerance could potentially be more pronounced in the transition zone, where temperatures are sub-optimal for a longer period of time.

Winter overseeding – positive benefits

One way to overcome the negative effects associated with cooler temperatures and the resulting dormancy is to overseed bermudagrass with a cool-season species. Winter overseeding is a common practice that involves seeding a cool-season species into bermudagrass and managing the resulting turf through the winter with the objective of decreasing wear (Beard and Beard, 2005) and providing an acceptable color (Ward et al., 1974). A recent study at the University of Tennessee found that when sports fields were overseeded with perennial ryegrass,

the number of traffic events the field could accommodate was doubled. The fields maintained more than 90% green cover, when compared to that of non-overseeded bermudagrass (Thoms et al., 2011).

Because bermudagrass growth slows during cool temperatures, winter annual weed pressure often increases. Overseeding cool-season species can limit competition from these weeds (Mazur and Wagner, 1987). One study, on overseeded bermudagrass putting greens, found that increasing annual bluegrass infestations were related to species/cultivars that exhibited slow establishment and low density (Batten et al., 1981). A more recent study investigated the effects of different rates of perennial ryegrass (*Lolium perenne* L.) on annual bluegrass encroachment in a bermudagrass fairway.. The authors found annual bluegrass populations at 50 plants m^{-2} when overseeding had not been performed, 10 plants m^{-2} at a seeding rate of 224 kg ha^{-1}, and at a rate of 672 kg ha^{-1}, the annual bluegrass density was reduced to one plant m^{-2}. It was also observed that annual bluegrass plants were much larger in the non-overseeded plots (Goddard et al., 2009).

Overseeding species

Research regarding winter overseeding of bermudagrass putting greens is plentiful and dates back to the late 1950's. Early research objectives were to determine the best cool-season species, the best time to overseed, and the best pre-plant sod preparation methods (Brown and Horn, 1961; Schmidt and Blaser, 1961, 1962; Gill et al., 1967). Beard (1973) summarized the results of these early studies by recommending mixtures of several species because not one species was best at all times. The species mentioned included species from *Agrostis*, *Festuca*, *Lolium*, and *Poa*. Annual ryegrass (*L. multiflorum* L.) was the standard overseeding species at the time.

In 1974, at Mississippi State University, several cool-season species were investigated for their use as winter overseeding species. Species evaluated included annual ryegrass, perennial ryegrass, creeping red (*F. rubra* var. *rubra* Gaudin) and chewings fescue [(*Festuca rubra* var. *commutata* (Thuill.) Nyman], meadow fescue (*F. elatior* L), creeping and colonial bentgrass (*A. capillaris* L.), Kentucky bluegrass, rough bluegrass, and big bluegrass (*P. ampla* Merr.), and timothy (*Phloem pretense* L). The results showed that no one species was best all the time. However, the authors suggested that when a single species is desired, perennial ryegrass is the best choice. They also recommended omitting annual ryegrass from use in the more northern areas due to its lack of frost and low temperature tolerance (Ward et al., 1974).

Similar work was conducted at Virginia Polytechnic Institute between 1969 and 1975. The research focused on perennial ryegrass alone and in mixtures. Overseeding of bermudagrass at putting green and at higher cutting heights (to simulate home lawns, golf tees, fairways, and other turf areas) were evaluated (Schmidt and Shoulders, 1980). When different cool-season species were seeded alone on a 'Tifgreen' hybrid bermudagrass putting green, the results were consistent with other research at the time in that no species performed best at all times. Perennial ryegrass, as expected, was the highest-performing species when seeded alone. Treatments where perennial ryegrass was used in mixtures also ranked highly. Rough bluegrass was considered less suitable than any other species in the study because of its lack of persistence in the spring. The excessive loss of rough bluegrass enhanced the amount of bermudagrass cover the following spring. Polystands comprised of 65% perennial ryegrass, 30% fine fescue, and 5% bentgrass were superior for overall greens use compared to monostands (Schmidt and Shoulders, 1980).

In response to the development of a number of new cultivars of perennial ryegrass, as well as other species, research was carried out during the late 1970's in Texas to investigate the

usefulness of these cultivars and species. The objective was to evaluate these cultivars and species for turf quality, ball roll characteristics, wear tolerance, and annual bluegrass encroachment (Batten et al., 1981). Perennial ryegrass ranked highest in average winter performance among all cool-season species tested. Rough bluegrass was a close second with the improved cultivar Sabre (Dickson et al., 1980) ranking the highest. Mixtures were consistently rated higher than monostands, with polystands composed of perennial ryegrass and rough bluegrass having the highest performance. Infestations of annual bluegrass were related to slow establishment and inferior turfgrass quality, with emphasis being placed on the density component of turfgrass quality (Batten et al., 1981). Perennial ryegrass cultivars and rough bluegrass were the top monostands for limiting annual bluegrass encroachment. Polystands of the two species, as expected, also performed well with the mixture 'Dixiegreen' (perennial ryegrass and chewings fescue) plus Sabre rough bluegrass performing the best (Batten et al., 1981). Perennial ryegrasses as a group had the longest ball roll distance. Older, coarse textured cultivars such as 'Linn' had significantly shorter ball roll distance. The shortest distances were found with rough bluegrass, 'Seaside' creeping bentgrass, 'Pennlawn' and 'Dawson' slender creeping red fescue [*F. rubra* ssp. *Litoralis* (G.F.W. Meyer) Auquier], and 'Jamestown' chewings fescue, Perennial ryegrass cultivars had greater relative wear tolerance, with as much as 50% more verdure remaining three days after wear stress was applied. Cultivars such as Linn displayed less wear tolerance than some of the newer cultivars. 'Penncross' creeping bentgrass, Jamestown, and Sabre had significantly higher wear tolerance than Pennlawn, 'Centurion' hard fescue (*F. longifolia* Thuill.), and 'Highlight' chewings fescue. The authors concluded that the perennial ryegrasses and the rough bluegrasses, which exhibited faster establishment, had better winter performance and less annual bluegrass encroachment. Polystands also performed better

under adverse environments and mixtures containing 80% perennial ryegrass and 20% rough bluegrass ranked the highest for turfgrass quality. Perennial ryegrasses were more wear tolerant and had longer ball roll distances than any other species tested (Batten et al., 1981).

Similar research was conducted in Florida, where turf quality, ball roll, and wear tolerance were evaluated. Only perennial and annual ryegrass was tested, with annual ryegrass considered a control. Research indicated that annual ryegrass established significantly faster than perennial ryegrass, but had a significantly lower mean quality rating across the overseeding season (Dudeck and Peacock, 1981). Annual ryegrass also had significantly higher damage estimates following traffic stress and a significantly longer ball roll distance than several of the perennial ryegrass cultivars. The authors concluded most perennial ryegrass cultivars in the trial were acceptable for overseeding based on the parameters investigated, and, although annual ryegrass had faster establishment and green speeds, its poor turf quality and wear tolerance imposed limitations on its use (Dudeck and Peacock, 1981).

By 1994, the use of rough bluegrass for putting green overseeding had become popular enough to warrant investigations of its tolerance to selected herbicides (Johnson, 1994). Perennial ryegrass continued to be the most common choice for higher cut turfs such as golf course fairways and sports turf (Richardson, 2004). Breeding efforts with perennial ryegrass resulted in several improvements, including traits associated with turf quality, such as leaf texture, color, and mowing quality (Meyer and Funk, 1989). These breeding efforts also focused on perennial ryegrass as a perennial turf in more northern climates and thus the breeding advancements resulted in cultivars that were more tolerant of environmental stresses, such as heat, drought, and disease (Meyer and Funk, 1989). This was good for situations where perennial ryegrass is desired as a perennial; however in winter overseeding situations it created a problem

because these cultivars persisted in southern climates (Horgan and Yelverton, 2001). In response to these issues, turfgrass breeders have released cultivars of intermediate ryegrass (Richardson, 2004) as an alternative to perennial ryegrass for overseeding sports and golf turfs (Schmitz, 1999).

In response to the availability of new species, research was conducted to comparing it to perennial and annual ryegrass (Richardson, 2004). Results for the two intermediate ryegrass cultivars tested, 'Froghair' and 'Transist', showed considerable variation. Froghair performed more like its annual parent and Transist performed similar to its perennial ryegrass parent. Both cultivars offered a spring transition that was earlier than perennial ryegrass but later than annual ryegrass (Richardson, 2004).

With the release of much higher density, dwarf type hybrid bermudagrasses, questions arose regarding the possibility of establishing an overseeded turf on such a dense surface. A study was conducted to compare establishment methodologies on these new bermudagrasses. Results of this study showed that smaller-seeded species such as rough bluegrass and creeping bentgrass were advantageous. However, seeding rates of rough bluegrass at 8 kg and creeping bentgrass at 2 kg 100 m^{-2}, showed a decrease in the root length of the bermudagrass base (Sifers and Beard, 2001).

Meadow fescue and tetraploid perennial ryegrass, were investigated for their usefulness for faster spring transition of bermudagrass managed under simulated fairways conditions (Richardson et al., 2007). Both species had good germination and establishment characteristics, good color and quality, and an improved spring transition over perennial ryegrass (Richardson et al., 2007). The authors also noted that rough bluegrass had the lowest seasonal quality, and that its primary use is on close cut systems such as bermudagrass greens (Richardson et al., 2007).

These results were consistent with those of the National Turfgrass Evaluation Program on-site overseeding trials; where rough bluegrass had poorer performance on fairways, compared to perennial ryegrass (Morris, 2004).

Miller et al. (2005), in fairway/athletic field trials at the University of Florida found 'LhR205' intermediate ryegrass to be one of the best at rapid establishment, with 'Gulf' annual ryegrass being the slowest. In late April and early May all grasses continued to have good cover with the exception of Gulf annual ryegrass. The two intermediate ryegrasses tested and annual ryegrass were found to have poor transition turf quality as temperatures warmed in late May (Miller et al., 2005). A putting green overseeding trial was also performed to investigate the performance where of perennial ryegrass and rough bluegrass. The rates of establishment were consistent for all treatments. Rough bluegrass entries persisted longer than the perennial ryegrass treatments with the exception of 'SRX 2NEM'. This reduced bermudagrass percentages but produced high turf quality, whereas SRX 2NEM had lower turf quality in June (Miller et al., 2005). Even though SRX 2NEM was listed in the study report as rough bluegrass it was, in fact, wood bluegrass (*Poa nemoralis* L.) (L. Brilman, personal communication, 2010).

The aforementioned studies focused primarily on the overseeding of bermudagrass putting greens, and to a lesser extent, golf course tees and fairways. Bermudagrass sports fields, especially those used for American football, deserve special attention for overseeding research because of the high traffic levels when overseeding should be performed. In the past few years, numerous research projects have addressed these needs (Thoms et al., 2011; Haselbauer et al., 2012; Trappe et al., 2012). One of these studies investigated the effect of different overseeding species, and the results concluded that perennial ryegrass was the best species (Trappe et al., 2012).

Overseeding Methods, Seeding rates, and Timing

Many of the previously mentioned research efforts considered aspects of overseeding other than species performance. These included investigations of seeding timings, seeding rates, and pre-planting sod preparation. In some of the earliest work, the effects of vertical mowing, aerification, topdressing, and seeding date were investigated (Schmidt and Blaser, 1962; Ward et al., 1974). The highest turf quality was found in treatments where vertical mowing and topdressing were used in combination, while aerification did not have positive benefits. Interestingly, in Virginia in 1962, a later seeding date of 4 October produced more winter cover than the earlier seeding date of 14 September (Schmidt and Blaser, 1962). Studies conducted in Mississippi concluded that vertical mowing had no significant effect on the number of emerged seedlings, but topdressing did significantly increase the stand density of rough bluegrass, seaside bentgrass, and mixtures of redtop bentgrass and seaside bentgrass (Ward et al., 1974). Annual ryegrass was not affected by vertical mowing and creeping red fescue was slightly reduced in 1961. In a later study, topdressing was again found to be beneficial (Ward et al., 1974). Concurrent with these studies, investigations of seeding timings yielded results indicating that overseeding 20 to 30 days before the first frost is most ideal. After evaluating seeding rates of perennial ryegrass ranging from 5.3 to 42.4 kg 100 m^{-2}, the authors concluded that a rate of 17 kg 100 m^{-2} was best (Ward et al., 1974).

Research on a 'Tifgreen' bermudagrass green evaluated the effect of seeding rate on turf quality and transition characteristics. Turf quality was positively correlated with increasing seeding rates, whereas leaf texture decreased as seeding rates increased (Mazur and Rice, 1999). Higher seeding rates did not result in faster transition in the spring and the authors concluded that

the choice of seeding rate was a compromise between turf quality, best at 150 g m^{-2} , and transition delayed at this rate (Mazur and Rice, 1999).

The release of ultradwarf bermudagrass cultivars necessitated further overseeding research. A three location study (Palm Desert, CA; Phoenix, AZ; Houston, TX) initiated in 1996, investigated the effects of rates, timing, species, and cultivation. In this study, two cultivation methods were investigated, including vertical mowing alone or vertical mowing along with the use of a plant growth regulator, trinexapac-ethyl, applied either two days before or six days after overseeding. Findings did not indicate a clear choice between the methods, but it was noted that the smaller-seeded species rough bluegrass and creeping bentgrass had more emerged seedlings (Sifers and Beard, 2001). The authors indicated that timings based on soil temperature resulted in higher success than calendar-based timings, with the optimum soil temperature range between 22 and 26^0C at 100 mm depth (Sifers and Beard, 2001). In this study, perennial ryegrass was ranked as the lowest performer at all three sites with a mixture of rough bluegrass and creeping bentgrass ranking the highest (Sifers and Beard, 2001).

Spring Transition

Although overseeding can be advantageous, the cultural practice does have some negative attributes (Horgan and Yelverton, 2001). Timing of transition is important because a transition that occurs too quickly or too early will leave voids in the turf, resulting in poor aesthetics and playability (Horgan and Yelverton, 2001). A transition that is too slow or too late will, through its cool-season plant competition, prevent the bermudagrass from making a full recovery from winter dormancy, and leave the turf in a weakened state going into the next winter's dormancy period (Askew, 2010).

In addition to the natural transition characteristics of these species, the use of chemicals as a tool to remove overseeded species has been studied and is being practiced. One of the earliest herbicides researched for this purpose was pronamide, which was found to be useful if applied at the appropriate time (Johnson, 1975). More recently, sulfonylurea herbicides like Revolver (Formasulfuron), Monument (Trifloxysulfuron-sodium) , and Manor (Metsulfuron Methyl) have been studied and found to be mostly effective but performance is dependent on temperature and not always consistent. The rate and application timing dictate how smooth the transition from cool-season to warm-season turf goes (McCauley et al., 2009). Cultural practices such as vertical mowing, aerification, and fertility have been studied as ways to facilitate spring transition without the use of chemicals. None of these cultural practices were consistently reliable when removing perennial ryegrass, and it was determined that temperature played the biggest role in the disappearance of the species (Horgan and Yelverton, 2001).

Given that there are more than 10,000 species of grasses, it is likely that several species could be developed to overseed bermudagrass that have both good turf quality during winter dormancy; while, at the same time providing a smooth spring transition that is not dependent on a chemical transition aid.

Objectives

The objectives of this project were:

1. To evaluate the performance of alternative *Poa* species as permanent turfgrasses under a general maintenance regime in the transition zone.
2. To evaluate the performance of *Poa nemoralis* and *P. supina* as temporary winter overseeding species for ultra-dwarf bermudagrass greens in the transition zone.
3. To evaluate the performance of *P. nemoralis* as a temporary winter overseeding species for bermudagrass fairways in the transition zone.
4. To evaluate the performance of *P. nemoralis* as a temporary winter overseeding species for bermudagrass sports fields under simulated football traffic in the transition zone.

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CHAPTER II

POA SPECIES AS ALTERNATIVE PERMANENT TURFGRASS SPECIES IN THE TRANSITION ZONE

Abstract

Turfgrass species that are adapted to certain regions and their intended use can have a positive benefit to the surrounding environment. The objective of this study was to evaluate *Poa* species for their potential use as permanent turfgrasses in the transition zone. In 2010 and 2011, 37 different *Poa* species (45 total treatments) were established from seed in the greenhouse and grown as plugs that were transplanted to native soil in Knoxville, TN. Plots were managed based on recommendations for Kentucky bluegrass (*P. pratensis* L.) in the transition zone. Treatment sources were from the USDA NPGS, commercially available *Poa* species, or naturalized *Poa* species collected regionally. Each treatment was evaluated for percent green cover on a monthly basis for one year. In both years, *Poa stiriaca* Fritsch & Hayek and *P. maniototo* Petrie were in the top statistical category along with the three cultivars of Kentucky bluegrass; 'Midnight Star', 'Kenblue', and a locally naturalized biotype. One hybrid, 'Armadillo' (*P. arachnifera* Torr. x *P. pratensis*) was also included. As a group stoloniferous species established faster than the bunch type and rhizomatous species. The rhizomatous species maintained the highest cover after summer and at the end of the one year trial period. As a group, the bunch type species performed poorly, but contained species that are potentially useful in overseeding systems, while others were able to maintain higher levels of cover after summer heat stress. Further research is needed to determine if these species can perform under reduced input management.

Introduction

Restrictions on water, fertilizer, and pesticide use have challenged the turf industry to develop or discover turfgrass species and cultivars capable of maintaining acceptable turfgrass

quality under reduced inputs. Turfgrass researchers have evaluated alternative species for use as turfgrasses focusing strictly on native species (Mintenko et al., 2002; Salaiz, 2011; Kopec et al., 2008). Other researchers have focused on evaluating a wide array of traditional, non-traditional, and native species in specific systems, such as fairways (Watkins et al., 2010). Breeding efforts have begun with some native species with the goal of improving turf quality while keeping and improving low maintenance qualities. These species include buffalograss [*Buchloe dactyloides* (Nutt) Engelm.], prairie junegrass [*Koeleria macrantha* (Ledeb.) Schult.], and poverty oatgrass [*Danthonia spicata* (L.) P. Beauv. ex Roem. & Schult.] (Amundsen and Shearman, 2011; Watkins, 2011; Warnke and Amundsen, 2009). Recorded experimental testing of turfgrass species and cultivars by professional organizations has been conducted for almost 100 years, starting in 1916 with the Arlington Turf Gardens (Anonymous, 1937). Variety testing, such as that done by the National Turfgrass Evaluation Program (NTEP), and many universities, provides a wealth of information on the performance of varieties within the same species.

Research examining alternative species has been performed in particular climates like the northern Great Plains (Mintenko et al., 2002). Many of the native species that have been studied, such as buffalograss, are not adapted to the humid, transition zone climate. No research involving the use of a non-traditional turf species has been performed in the transition zone. This is partly because many states in the transition zone, including Tennessee, have no current use restrictions on water or fertilizer. However, the need for reduced maintenance is recognized and if current trends continue, it is possible that restrictions could be put into place.

Studies examining native species have focused on species that had seed readily available. However, this is a small percentage of the approximately 10,000 species of grass. Examination of the sub-families within Poaceae (true grasses) reveals species that do not fit the criteria of a

turfgrass, including the subfamily Bambusoideae, which contains the species we know as bamboo. Traditional turfgrass species come from three sub-families; the Poioideae, containing the cool-season grasses; the Panicoidae, containing warm-season species such as centipedegrass [*Eremochloa ophiuroides* (Munro) Hack] and seashore paspalum (*Paspalum vaginatum* Swartz); and the Chlorideae, containing the warm-season species bermudagrass (*Cynodon* spp.) and zoysiagrass (*Zoysia* spp.).

In the transition zone, both cool- and warm-season turfgrass species can be grown successfully, but with limitations. Cool-season species are limited by their heat intolerance and warm-season species by their intolerance to freezing temperatures. Adapted cool-season grasses, like tall fescue (*Festuca arundinacea* Shreb.) are typically used in home lawns and general turf areas because they are green year-round. Adapted warm-season grasses, like bermudagrass, are favored in high use environments, such as golf courses and sports fields, where their ability to tolerate low mowing heights, resist wear, and recover from traffic are essential. Warm-season grasses are often overseeded with cool-season species to provide green and actively growing turf during winter (Ward et al., 1974). Overseeding increases cost and labor of the management budget. Therefore, a permanent cool-season species would be desirable.

Kentucky bluegrass (*Poa pratensis* L.) is suited for use on home lawns, golf course tees and fairways, and on sports fields in its temperate area of adaptation. Tall fescue is better adapted to a transition zone climate because of its higher tolerance to heat and deeper roots. However, tall fescue is not adapted to low mowing heights and has less recuperative ability because of its bunch type growth habit. Ideally, a cool-season turfgrass for widespread use in the transition zone would need heat tolerance, drought tolerance, a spreading growth habit, wear tolerance and rapid recovery rate, and disease resistance.

The Poa genus

The bluegrass genus (*Poa*) is comprised of as many as 575 species (Gillespie and Soreng, 2005) compared to the fescue genus (*Festuca*), which has 360 species (Watson and Dallwitz, 1992). *Poa*, a diverse genus, occurs in a wide range of habitats (Soreng, 1990). Life forms may be annual or short- or long-lived perennials (Anton and Connor, 1995). Growth habits include bunch, stoloniferous, and rhizomatous types (Hitchcock, 1950). The bluegrasses are economically important, with many species occurring in natural grasslands worldwide, some species incorporated into improved pastures, and still others known as weeds (Anton and Connor, 1995). These species are also well known for their diversity and distribution of sex forms. For example, forty-one of the 54 known dioecious species occur in southern South America (Anton and Connor, 1995). Diversity in breeding systems is common in the genus, with some species being highly apomictic, others highly sexual and self-incompatible, and others completely self-compatible (Huff, 2003 a-b; Hurley, 2003). The genus is characterized and easily recognized by its leaf morphology that is described as having a boat-shaped leaf tip and parallel light lines down the center of the leaf (Turgeon, 2002).

Traditional Poa species

Several species of bluegrass have been utilized as turfgrasses, with Kentucky bluegrass being the most important and widely utilized of all cool-season turfgrass species (Beard, 1973). This species has become naturalized throughout the temperate regions of the world and was most likely introduced as an agronomic crop to North America (Bashaw and Funk, 1987). Movement closer to the equator is only limited by high temperatures (Hartley, 1961). Kentucky bluegrass is not only important for turf, but also as a forage grass where it is prized for its feed quality

(Smith, 1981). In turfgrass systems, Kentucky bluegrass is used in everything from utility turfs to golf course tees and fairways and sports fields. The species is best adapted to cutting heights of 1.9 cm or higher (Turgeon, 2002) and thus is not suitable for putting greens. The most widespread and well known use of Kentucky bluegrass is for home lawns. It is the number one choice for lawns in the northern half of the USA (Huff, 2003a). A commonly known limitation of Kentucky bluegrass is its overall lack of drought tolerance, which necessitates the use of irrigation to maintain active growth, especially in the arid western states. In face of watering restrictions, many drought tolerance studies with this species have been conducted in the past decade (Bushman et al., 2012; Richardson et. al., 2008; Abraham et al., 2004).

A second influential *Poa* species is annual bluegrass (*Poa annua* L.). *Poa annua* is commonly regarded as a weed. It is one of the top five most widely distributed plants in the world and occurs almost everywhere man inhabits (Fenner, 1985) and one of the top 10 most studied weeds (Gardarin et al., 2009).). *Poa annua*, like many *Poa* species, is highly variable. Two life forms, with variations in between, are known to occur; an annual type (*P. annua* L. f. *annua*), and a perennial type (P. *annua* L. f. *reptans*). Although its control as a weed continues to be studied, its use as a turfgrass, particularly on putting greens, has also received attention (Huff, 1996, 1998, 2003b; White, 1994).

P. trivialis, or rough bluegrass, is another species that has had widespread use as a turfgrass. It is described as a perennial, stoloniferous species that is completely sexual in its reproduction and performs best in cool, moist environments (Hurley and Funk, 1982). Its use as a permanent turfgrass in the USA is limited because of its poor heat and drought tolerance and inability to maintain uniformity when mixed with other species (Hurley, 2003), but is recommended in northern states for shaded moist environments (Sprague, 1930). This species is

used in the southern USA as a temporary cover in winter overseeding of dormant bermudagrass putting greens, where it provides a green, actively growing putting surface throughout the winter months (Sifers and Beard, 2001; Batten et al., 1981, Richardson et al., 2007).

Several other *Poa* species have been utilized as turfgrasses, but none to the same degree as the aforementioned species. Recently, improved cultivars of *P. supina* have been released in the U.S., and researchers have found this stoloniferous species to be very tolerant of traffic (Sorochan et al., 2001) and shade (Stier and Rogers, 2001). Canada bluegrass (*P. compressa* L.) has also been utilized and has generally been found to be adapted to similar climates as *P. pratensis*. It is adapted to lower fertility soils, but generally does not have high turf quality, compared to Kentucky bluegrass (Beard, 1973).

Native Poa species

The USDA (2013) recognizes 96 species of *Poa* as being native to the USA. A large majority of these occur in western and northern regions. Of the 96 species, only about 10 have been documented in Tennessee and the surrounding transition zone states. Many of these species are categorized as endangered or rare. Also included are species, such as Kentucky bluegrass and Texas bluegrass (*P. arachnifera* Torr.), which is likely not native to Tennessee. With the exception of Texas bluegrass, Kentucky bluegrass, *P. nemoralis,* and *P. palustris*, there is no available germplasm for these native Poa species in the USDA National Plant Germplasm System (USDA, 2013).

Species that are native to a region are generally considered to be adapted to the regional climate. Turfgrasses, however, not only have to be adapted to the climate, but must also possess those characteristics that define a turfgrass. They must withstand continual defoliation from

mowing, form a contiguous community, and withstand at least some traffic (Turgeon, 2002). Beard (1998) pointed out that the cool-season turfgrass species evolved under grazing pressure where close-grazing animals such as sheep (*Ovis aries* L.) and cattle (*Bos* spp.) also originated. In the USA, the American bison (*Bison bison* L.), antelope (*Antilocapra americana* Ord), and deer (*Odocoileus* spp.) would pose similar grazing pressure, however, these animals did not develop the mouth parts capable of close grazing (Beard, 1998). Buffalograss is the most successful of native grasses used as turfgrasses. The stoloniferous, warm-season species is native to the North American Great Plains (Wenger, 1943). Buffalograss is well known for its drought tolerance and low fertility and mowing requirements, however its use in higher rainfall climates may be limited by high weed pressure and disease (Riordan and Browning, 2003).

Of all native turfgrass species, the one that may be the most attractive for the eastern transition zone states is Texas bluegrass. Texas bluegrass is a rhizomatous, dioecious species originating in Texas and Oklahoma (Read and Anderson, 2003), where high temperatures and drought conditions are common, indicating that heat and drought tolerance exist in not only this species, but also the genus as well. An undesirable trait of this species is the formation of pubescence at the base of the lemma, which makes seed harvesting and processing difficult (Read, 2001). Texas bluegrass was introduced to the southeastern USA as a forage grass, however little can be found in literature regarding its performance or use (Pittman and Read, 1998).

Poa hybrids

Interspecific hybridization as a tool for turfgrass breeding has resulted in very successful cultivars. The introduction of 'Tifgreen' (Hein, 1961) hybrid bermudagrass [*C. transvaalensis*

(Burtt-Davey) × *C. dactylon* (L.) Pers.] in 1956 revolutionized the turfgrass industry in the southern USA by replacing common bermudagrass (*C. dactylon*) on putting greens with the new hybrid that had a texture and density more comparable to creeping bentgrass (*Agrostis stolonifera* L.) which was enjoyed by golfers in northern states (Robinson and Latham, 1956). Although other bermudagrass hybrids were released from this program around the same time, the most notable was 'Tifway.' (Burton, 1966) Tifway, released in 1960, was a chance hybrid that was very well suited to golf course fairways and tees (Burton, 1960). Fifty years after its release, Tifway still rates high among modern cultivars in the National Turfgrass Evaluation Program trials (Morris, 2002).

The number of man-made interspecific hybrids is numerous with *Poa*, and a large portion of these hybrids involved the use of *P. pratensis* as one the parents. One of the earliest controlled hybrids of a *Poa* species was that of Texas bluegrass (*P. arachnifera* Torr) and Kentucky bluegrass (Vinall and Hein, 1937). Interspecific hybridizations of *Poa* species for turf, which resulted in a released cultivar, started with 'Reveille' hybrid bluegrass (Read et al., 1999). Reveille is a hybrid between Texas bluegrass and Kentucky bluegrass. The goal with this hybrid was to incorporate the heat and drought tolerance characteristics of Texas bluegrass into the higher turf quality Kentucky bluegrass. More recently, these hybrids have resulted in the release of several cultivars such as 'Thermal Blue, 'Dura Blue' and 'Longhorn' (Teuton et al., 2009; Richardson and Karcher, 2009). These hybrids were shown to be equally as suited to use as turfgrasses in comparison to tall fescue and Kentucky bluegrass (Teuton et al., 2007) and have demonstrated improved tolerance to high temperatures (Su et al., 2007). Although these hybrids have displayed enhanced heat tolerance, getting this characteristic along with drought tolerance, the desired turf quality, and economical seed production has proven difficult (Read, 2001;

Merewitz et al., 2010; Abraham et al., 2004). Research specific to the transition zone has been performed. A study focusing on drought tolerance found high diversity between cultivars of hybrid bluegrasses when compared to Kentucky bluegrass and other *Poa* hybrids. At least one of the Texas hybrids ranked near top in drought tolerance, while several other Texas hybrids ranked near the bottom, indicating that hybrid status of these cultivars does not automatically confer drought tolerance (Richardson and Karcher, 2009).

Naturally-occurring hybrids have also made big impacts on the turfgrass industry. It was suggested early on that the parents of *P. annua* were *P. supina* Schrad. and *P. infirma* Kunth (Nanfeldt, 1937). Recently, DNA and chloroplast sequence studies confirmed that *P. supina* and *P. infirma* are the parents (Mao and Huff, 2012).

Interspecific hybridization with other *Poa* species has been successful, with a large portion of the crosses using Kentucky bluegrass as one of the parents (Goldman and Sims, 2005; Read, 2001; Dale et al., 1975) and hybrids have been known to occur in the wild (Clausen, 1961).

Poa breeding

As mentioned previously, the diversity of *Poa* is present in many forms. This includes sex forms, modes of reproduction, and ploidy levels. All of these characteristics must be understood before implementing breeding programs, regardless of whether the objective is inter- or intraspecific hybridizations. Sex forms in *Poa* are extremely diverse, with not only the typical monoecious and dioecious forms occurring, but also variations in between, such as gynodioeceous and gynomonoecious (Anton and Connor, 1995). In breeding, monoecious plants can be used for reciprocal crosses, where the plant can be both a maternal and paternal parent,

whereas a dioecious plant can only be one or the other. In addition to sex form, the modes of reproduction are also diverse in this genus. Apomixis is common in *Poa* and has been extensively studied in Kentucky bluegrass (Kelley et al., 2009; Clausen, 1961) This mode of reproduction results in highly stable and uniform progeny, which is beneficial to breeders when a superior plant is developed, however it makes inter- and intraspecific hybridization difficult (Huff, 2003a). Fortunately, in Kentucky bluegrass, apomixis is not typically exclusive and some out-crossing can occur, with the level of apomixis or out-crossing being highly variable (Huff, 2003a). Initially cultivars of Kentucky bluegrass originated as selections from old turf areas or seed fields (Pepin and Funk, 1971). Cultivar development of Kentucky bluegrass using intraspecific hybridization as a method was slow to be accepted because of many reasons relating to apomixis, however it was shown that intraspecific hybridization is a useful tool in improving Kentucky bluegrass (Pepin and Funk, 1971).

Some *Poa* species, such as *P. annua* and *P. supina*, utilize self-pollination, which results in true-breeding strains through inbreeding (Huff, 2003b). Although common in agricultural crops, this mode of reproduction is not typical among turfgrasses. Like apomixis, self-fertilization is not always exclusive and out-crossing does occur. Some plants of *P.annua* have been found to outcross as much as 15%, (Ellis, 1973).

Out-crossing species are the norm for most of the other traditional turfgrasses, whether warm- or cool-season. However, there can be variations in self-incompatibility. Grasses utilizing this mode of reproduction typically rely on a foreign pollen source for fertilization. This can result in populations that contain desirable and diverse genetic combinations, however maintaining the desired combinations can be difficult because of the ease of which pollen from other sources can contaminate the material (Meyer and Watkins, 2003).

Considering that many of the species from the *Poa* genus have not been studied in depth, and knowing that many desired characteristics are present in a combination of these species, the potential exists for development of a *Poa* cultivar that meets the needs of turfgrass managers in the transition zone. This development could come in many forms; the development of a previously unknown species, development of hybrids with traditional or other species, or through the use of biotechnology. The first step is to identify desirable characteristics in the available *Poa* germplasm.

Selecting species from habitats that have a climate similar to the eastern U.S. transition zone may result in species that perform better than species from dissimilar climates. Climate classifications show that there are other regions in the world that share the same Cfa climate designation as the eastern U.S. transition zone (Köppen, 1900). The Cfa climate occurs in the mid-latitude regions of the eastern side of my most continents. Included is the south eastern U.S.,south eastern South America, south eastern Australia, New Zealand, and south east china. The Cfa climate designation is described as warm temperate, fully humid, with hot summers.

Materials and Methods

A two-year study was initiated on 16 August 2010 and repeated on 15 August 2011. It began with the selection and acquirement of various *Poa* species (Table 2.1). The USDA National Plant Germplasm System has nearly 100 different species of *Poa* available, with nearly 300 species listed in their system (USDA, 2013). Resources available for this study restricted the number of species that could be evaluated. Species were chosen based on their original collection location, with the preferred location being those with a Köppen climate designation of

Cfa. Additional species were chosen from climates from other designations for comparison. Locally adapted bio-types of *Poa* species were collected and utilized, as well as commercially available cultivars of *Poa* species. Two cultivars of *P. pratensis* were chosen. 'Kenblue' was chosen because it is commonly included in variety trials and is considered a standard common type Kentucky bluegrass (Bonos et al., 2000). A second variety, 'Midnight Star' is a high-performing variety for the transition zone (C. Rose-Fricker, personal communication, 2009). A commercially available hybrid of Texas x Kentucky bluegrass, 'Armadillo', was included.

Seeds (Table 2.1) were sown in plug flats, with each plug measuring 4.4 cm x 4.4 cm, and filled with Fafard no. 2 growing medium (Sun Gro Horticulture Canada Ltd., Agawam, MA) on 16 August 2010 and 15 August 2011. A total of 24 plugs were seeded for each of the 45 treatments. Greenhouse conditions were maintained throughout the six week growing period with daily temperatures averaging 24º C. The number of seeds sown in each plug varied and was dependent upon the germination rate of each treatment, with the target of achieving 10 plants per plug. Plugs with more than 10 seedlings were thinned. Irrigation was applied as needed to maintain conditions favorable for germination. A 12-55-6 fertilizer was applied at 2.5 g N m^{-2} at seeding. Three weeks after seeding, a 20-20-20 fertilizer was applied at 5 g N m^{-2}. Plants were trimmed to 7.6 cm height as needed.

Prior to field planting, the soil was tilled to a 15 cm depth and then leveled. A soil fumigant, dazomet (Basamid® G) (Certis USA L.L.C. Columbia, MD), was applied at 53.7 g m^{-2} and watered in. Polyethylene sheeting was used to cover the site for three days, after which the covers were removed and an additional week was allowed to let the Basamid dissipate from the soil before planting.

At six weeks after seeding (1 October 2010 and 3 October 2011), plants were transplanted to the field at the East Tennessee Research and Education Center, Knoxville, on a Sequatchie silt loam soil (fine-loamy, siliceous, semi active, thermic Humic Hapludult). Plot size was 66 cm x 81 cm, arranged in a randomized complete block design with four replications. Six plugs were planted on 15 cm centers, arranged in a two × three pattern within the center of the plot. A 5 cm diameter plugging tool was used to cut holes in the soil for the plugs. After placing the plug in the soil, the remaining space around the plug was backfilled with native soil from the plugging operation.

A 10-10-10 fertilizer was applied at 5 g N m^{-2} at planting, followed by a 5 g N m^{-2} of the same analysis applied on 1 November 2010 and 30 October 2011. The following spring a 24-6-12 fertilizer, with 50% of the nitrogen in a slow release form, was applied on 15 March and 2 May 2011 and 15 March and 1 May 2012. Mowing was initiated one week after planting at a cutting height of 7.6 cm weekly during active growth. Irrigation was applied as needed to prevent moisture stress. Fungal pathogens and insects were controlled preventatively using rotations of broad spectrum, long residual products with rates based on label recommendations. Percent green turf cover was evaluated using digital image analysis (DIA), using previously described methods (Richardson et al., 2001). DIA was initiated each year at one month after field planting and continued on monthly intervals for a one year period resulting in 12 rating dates beginning in November and ending in October of each year.

Both years and months differed and were therefore analyzed and reported separately. Species were grouped by their observed growth habit in the field as bunch type, rhizomatous, or stoloniferous. These groups were analyzed as a fixed effect along with each individual species.

Results

When grouped by growth habit, differences were observed between groups, between years, and between dates within years (Table 2.2). The two seasons were comparable at the November and December rating dates, with all groups increasing in cover (Figure 2.1 A-B). Notable differences were observed between December and January of the two seasons. In 2010-2011, the rate of increase slowed and little cover was gained (Figure 2.1 A). The 2011-2012 season was different, with a considerable increase in cover for all growth habit groups in January (Figure 2.1 B). Between January and February in 2010-2011, a slight increase was observed with the stoloniferous group. Whereas, the rhizomatous and bunch type groups showed a slight decrease in cover (Figure 2.1 A). During the 2011-2012 season the bunch type group remained the same. Whereas the stoloniferous and rhizomatous group had gains in cover, with the stoloniferous group showing the highest gain (Figure 2.1 B).

Stoloniferous species were consistently advantageous by the first rating date, occurring in November, having 3-4% more green cover than the bunch type and rhizomatous species (Figure 2.1 A-B). This trend continued through March of both years, with increasing separation between the stoloniferous species in comparison to the rhizomatous species and bunch types (Figure 2.1 A-B). In April through July of the 2010-2011 season, the stoloniferous species did not differ from the rhizomatous species (Figure 2.1 A). From August through final rating date of the 2010-2011 season, the rhizomatous group had significantly more cover than the bunch type and stoloniferous groups , which did not differ from each other (Figure 2.1 A). During the 2011-2012 season, the stoloniferous species maintained significantly higher cover than the bunch and rhizomatous types from the first rating date in November through the final rating date in October (Figure 2.1 B). During the period from January until October, the rhizomatous group was

intermediate, having higher cover than the bunch types but lower cover than the stoloniferous types (Figure 2.1 B)**.**

The rhizomatous group contained Kentucky bluegrass, which is known to have the ability to maintain cover in the transition zone when properly managed. Within the three treatments of this species, Midnight Star and a local naturalized species designated "GC" both had 16 occurrences in the top category (Tables 2.3-2.4). However, GC was the most consistent having an eight months in the top category, in comparison to Midnight Star which had eleven in the first season and only five the next (Table 2.3-2.4). Kenblue only occurred in the top statistical category a total of nine times for both seasons (Table 2.3-2.4). Armadillo, a hybrid between Texas bluegrass and Kentucky bluegrass, performed similar to the Kentucky bluegrass cultivars, having seven and eight months in the top category in the 2010-2011 and 2011-2012 seasons respectively (Tables 2.3-2.4). Canada bluegrass (*P. compressa* L.) also performed well, occurring in the top group nine times in the first season and 6 times in the second season (Tables 2.3-2.4). *P. maniototo* had a higher number of occurrences in the top statistical category than any of the Kentucky bluegrass cultivars with a total of 17 (Table 2.3-2.4). *P. stiriaca* had the highest number of occurrences in the top statistical category with 12 in the first season and 10 in the second. All other rhizomatous species tested never made the top category for any month of either year (Tables 2.3-2.4).

In the stoloniferous group, an experimental *P. trivialis* cultivar CR-91 had the highest number of occurrences with nine in the first season and seven in the second (Tables 2.3-2.4). *P. supina* had fewer occurrences, with six and eight months in the top categories, respectively. All other stoloniferous cultivars and species did occur in the top category at some point, however the

number of occurrences were inconsistent between years. Included in these species was one of the unknown *Poa* species with USDA accession number PI 16171 (Tables 2.3-2.4).

In the bunch type group, *P. annua* and *P. longifolia* consistently performed well. *P. annua* was in the top statistical category for five and six months out of 12 during the 2010-2011 and 2011-2012 seasons respectively (Tables 2.3-2.4). This species was consistent between seasons, always occurring in the top statistical category in November, but not in January and February, and returned to top statistical category in March through June. In the first season, *P. annua* again returned to the top statistical category on the final rating date in October 2011. Similarly, *P. longifolia* was in the top statistical group for five months in both seasons. In the first season, this species was best in December through March and again in August (Table 2.3). In the second season it was best in November through March. In both seasons, *P. longifolia* had significantly higher cover than all other bunch type species (Tables 2.3-2.4). *P. flexuosa* had fewer instances in the top category, but was consistent between years, having four months in the top category (Tables 2.3-2.4). However, in the first season this occurred in April through July, and in July through October in the second season. *P. alpina* had the same total number of occurrences in the top category, but was inconsistent between years, having two months in the top category in the first season and six months in the second season. Other species had fewer instances in the top category, and were inconsistent between seasons (Table 2.3-2.4).

When means across all treatments for each month and year were examined the highest cover was found in April of the 2010-2011 season, and March of 2011-2012 (Tables 2.3-2.4). The lowest cover was found in September in 2010-2011 and August in 2011-2012 (Tables 2.3-2.4). In September of the 2010-2011 in the rhizomatous group, the Kentucky bluegrass

treatments GC and Midnight Star, the Texas x Kentucky--hybrid Armadillo, and *P. stiriaca* were in the top statistical group and significantly higher than any treatments in the bunch type and stoloniferous groups, maintaining greater than 74% green cover (Table 2.3).). In the stoloniferous category the highest cover achieved was 15.9% and 15.6% for *P. trivialis* CR-91 and Supranova *P. supina*, respectively (Table 2.3). The only two bunch types in the top statistical category were *P. gilgiana* and *P. lanigera* with 39 and 32% green cover, respectively (Table 2.3) In August of 2011-2012, *P. flexuosa* stood alone in the top statistical category among the bunch types at 74% green cover (Table 2.4).

In the rhizomatous group, all *P. pratensis* cultivars, the -Texas x Kentucky hybrid, *P. stiriaca,* and *P. maniototo* were all in the top category with a minimum of 88% green cover, which was statistically higher than *P. flexuosa* in the bunch type group (Table 2.4). In the stoloniferous group *P. supina*, CCC and CR-91 *P. trivialis* were in the top category and not different from the rhizomatous group, with a minimum of 86% green cover for *P. trivialis* CR-91. That was not different from the bunch type *P. flexuosa*, while the other stoloniferous treatments were significantly different (Table 2.4).

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Discussion

The differing gains of cover for the period between December and January are best explained by temperatures during these times (Figure 2.2). December 2010 and January 2011 both had below normal monthly average temperatures in comparison to December 2011 and January 2012, which had above average temperatures (Figure 2.2). Both years were consistent, in that the stoloniferous group showed significantly higher cover during the first few months following establishment, indicating that the species as a group established quickly and were able

to provide more cover going into winter (Table 2.2). It is important to realize that this group was only represented by two species, one *P. supina* cultivar and three *P. trivialis* entries representing locally naturalized and experimental types (Table 2.1). *P. supina* is described as having a good establishment rate (Beard and Beard, 2005), however it not as fast as perennial ryegrass (*Lolium perenne* L.) (Sorochan and Rogers, 2001). *P. trivialis* is described as having a rapid establishment rate (Beard and Beard, 2005), but it does not establish as rapidly as perennial ryegrass (Goatley and Philley, 1998). No literature could be found comparing the establishment rates of *P. supina* and *P. trivialis*. At the first rating date of November in both seasons there was no significant difference between *P. supina* and CR-91 *P. trivialis*, suggesting that these two species are comparable in establishment rate.

The use of *P. supina* in the transition zone has not been tested to the author's knowledge. It has been suggested that it should be used only in areas north of the transitions zone (Stier, 1998). The results of this study show that it was only able to maintain an acceptable level of cover in one out of the two summers tested. *P. trivialis* also only maintained cover in the same summer as *P. supina*, suggesting the heat tolerance is similar and is a limitation to the use of these species in the transition zone. The reason both these species were able to maintain cover in one year and not the other is best explained by summer temperatures and the subsequent growing degree day accumulations (Figure 2.3-2.4). The average monthly temperatures were higher in the summer of 2011 during July through the final rating date in October, in comparison to normal and the summer of 2012. Summer temperatures in2012 were above normal in June and July, but below normal for the remaining rating dates (Figure 2.2). Additionally, growing degree accumulations at a base temperature of 18.3 C° indicated that the summer of 2011 accumulated 149 more growing degrees than the summer of 2012 (Figure 2.3). Preliminary data from 2009-

2010 (Appendix A) support this because many species were reduced to 0%, including all of the stoloniferous species. However, preventative fungicide and insecticide applications were not made to the preliminary trial, therefore it is possible that biotic stresses were a factor. During the summer of 2010, 151 more growing degree days were accumulated than the summer of 2011(data not shown). Based on this, only one of three summers were cool enough for *P. trivialis* and *P. supina* to maintain an acceptable level of cover. In theory this data could be used to establish a southern boundary for these species by finding locations that have lower temperatures in summer than the summer of the 2012 in Knoxville, TN.

When hybrids are counted as different species, the rhizomatous group was represented by 10 entries (Table 2.1). This group, as a whole, was intermediate between the stoloniferous and bunch type groups (Figure 2.1 A-B), with the exception of the late summer and early fall of the first season, when the rhizomatous group was superior to the other groups (Figure 2.1 A). The increased performance of the rhizomatous species as a whole in the summer of 2011 suggests that these species are better adapted to the high temperature stress that occurs in summer. However, this was not observed in the summer of 2012 when the stoloniferous group maintained higher cover than both the rhizomatous and bunch type groups. This is explained by temperatures and subsequent growing degree accumulations that were observed over the two summers (Figures 2.2-2.3). This difference in temperature indicated that the cooler temperatures during the summer of 2012 were less stressful and all groups maintained higher levels of cover in comparison to the previous year.

In the aforementioned preliminary trial (Appendix A) during an even hotter summer, the majority of the species that maintained cover were rhizomatous, including species that were not Kentucky or Texas x Kentucky bluegrass hybrids. This further supported results that showed that

the rhizomatous group had higher heat tolerance, based on its ability to maintain cover during high temperature stress. The rhizomatous group also contained the highest number of commercially available cultivars that included two cultivars of Kentucky bluegrass and one cultivar of a Kentucky-Texas hybrid. This may have been advantageous to these groups because two of the cultivars, Midnight Star Kentucky bluegrass and Armadillo Texas x Kentucky hybrid, were either bred for tolerance to heat or previously performed well in trials in the transition zone. However, there were several rhizomatous species that performed poorly, such as *P. nervosa* and *P. spp*. PI 368993.

There were two unique species in the rhizomatous group that performed as well or better than Kentucky bluegrasses and their hybrids. *P. maniototo,* a species collected in New Zealand in 1957, had more total occurrences (17) in the top statistical category than Midnight Star Kentucky bluegrass (16). *P. stiriaca* had a total of 23 total occurrences in the two trial years. Further testing of these species will need to be conducted to further verify their usefulness as turfgrasses.

The bunch type group, as a whole, performed poorly in comparison to the other growth habits. This was explained by their inability to fill in the large gaps that resulted from the spaced planting method. This group contained the largest number of entries with 28 different species representing the group. In this group, *P. longifolia* stood out with its rapid establishment and high cover through winter, suggesting it may be useful as a temporary winter turf. *P. annua* was a second species with this potential, however its potential use would not be recommended for winter overseeding because of its prolific seed production and weed status that could cause un-wanted infestations. *P. flexuosa* deserved merit because of its performance in 2010-2012 and 2011-2012, having four occurrences in the top statistical category in both years during mid-

summer through early fall. In the preliminary trial, however, this species appeared dead by June and there was no evidence of regrowth in the fall.

Although all stoloniferous species and most of the bunch types died, there were two bunch type species that survived the summer of 2010 in the aforementioned preliminary trial (Appendix A). *P. sierbiana* and *P. lanigera* were two bunch types that survived, but their cover was very low in comparison to the rhizomatous group, suggesting that these bunch types also had heat tolerance (Appendix A). These species also survived through 2010-2011 and 2011-2012 trials. *P. lanigera* occurred in the top statistical group four times in 2010-2011 and once in 2011-2012, occurring in mid- or late-summer. *P. sierbiana* was in the top statistical category three times in 2010-2012 and none in 2011-2012, again the occurrences typically occurred in the summer. This further suggested heat tolerance was present in these species; however this was masked when a cooler summer allowed other species to maintain cover that would normally be lost in summer.

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Appendix A

Tables

Table 2.1. Poa species evaluated for turfgrass potential in 2010-2012 in Knoxville, TN

Species	Identifier	Origin	Year	Growth habit
Poa alpina	PI 540425	Alaska	1990	Bunch
P. alsodes	FHSP	Tennessee	2009	Bunch
P. annua	CWA	Washington	2009	Bunch
P. arachXdusenii	PI 659610	Texas	1997	Rhizomatous
P. arachnifera	IHH	NA	NA	Rhizomatous
P. arida	PI 578806	Kansas	1963	Rhizomatous
P. candamoana	PI 47850	Peru	1983	Bunch
P. chaixi	PI 659624	Germany	2006	Bunch
P. cita	W6 22519	New Zealand	2000	Bunch
P. colensoi	W6 22527	New Zealand	2000	Bunch
P. compressa	CC	Tennessee	2007	Rhizomatous
P. dusenii	PI 598733	Argentina	1993	Bunch
P. flexuosa	W6 25683	Greenland	2003	Bunch
P. gilgiana	PI 478581	Peru	1981	Bunch
P. hybrida	PI 249765	Greece	1958	Bunch
P. iridifolia	PI 154882	Uruguay	1946	Bunch
P. lanigera	PI 477105	Uruguay	1980	Bunch
P. ligulata	PI 517033	Morocco	1983	Bunch
P. lindsayi	PI 237163	New Zealand	1957	Bunch
P. longifolia	PI 380991	Iran	1973	Bunch
P. maniototo	PI 237164	New Zealand	1957	Rhizomatous
P. nemoralis	PI 442544	Belgium	1979	Bunch
P. nervosa	PI 232352	Wyoming	1955	Rhizomatous
P. ochroleuca	PI 168621	Austaralia	1948	Bunch
P. palustris	PI 274644	Poland	1961	Bunch
P. pratensis	GC	Tennessee	2007	Rhizomatous
P. pratensis	Kenblue	NA	NA	Rhizomatous
P. pratensis	Midnight Star	NA	NA	Rhizomatous
P. archnifera x pratensis	Armadillo	NA	NA	Rhizomatous
P. secunda	PI 578850	Washington	1961	Bunch
P. sierbiana	PI 282383	Australia	1962	Bunch
P. sterilis	PI 283963	Australia	1962	Bunch
P. stiriaca	PI 283964	Poland	1962	Rhizomatous
P. supina	Supranova	NA	NA	Stoloniferous
P. trivialis	CR-91	NA	NA	Stoloniferous
P. trivialis	WSGC	Tennessee	NA	Stoloniferous
P. trivialis	CCC	Tennessee	NA	Stoloniferous
P. spp.	W6 13033	China	1993	Bunch

Table 2.1. Continued.

Species	Identifier	Origin	Year	Growth habit
P. spp.	PI 204265	Argentina	1952	Bunch
P. spp.	PI 368993	Chile	1965	Rhizomatous
P. spp	PI 598605	Kazakhstan	1992	Bunch
P. spp.	PI 619511	Turkey	1994	Bunch
P. spp.	PI 632504	Bulgaria	1996	Bunch
P. spp.	PI 655177	Agrentina	1996	Bunch

Table 2.2. ANOVA table for growth habit groups and entries for percent green cover over a one year period in Knoxville, TN.

Trial year	Source	df	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2010-2011	Group	2	***	***	***	***	***	*	***	***	***	***	***	***
	Entries (Group)	42	***	***	***	***	***	***	***	***	***	**	***	***
2011-2012	Group	2	***	***	***	***	***	***	***	***	***	***	***	***
	Entries (Group)	42	***	***	***	***	***	***	***	***	***	***	***	***

*, **, ***, significant at the 0.05, 0.01, and 0.001 probability levels

Table 2.3. Effect of growth habit and entries on percent green cover over a one year period in 2010-2011 in Knoxville, TN.

Growth	Entry	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Bunch	*Poa alpina*	18	43	38	29	82	86	86	88	70	19	6	14
	P. alsodes	9	24	29	26	67	80	71	69	60	16	11	15
	P. annua	24	49	51	50	84	96	94	70	32	6	3	10
	P. candamoana	5	14	11	14	49	60	54	51	39	14	17	21
	P. chaixi	10	23	25	28	68	73	68	61	43	13	7	7
	P. cita	12	29	29	28	80	76	69	63	51	23	13	15
	P. colensoi	4	17	17	19	65	78	72	63	49	13	7	12
	P. dusenii	5	22	24	26	65	68	55	47	39	15	6	14
	P. flexuosa	17	39	42	37	78	87	90	86	63	16	11	22
	P. gilgiana	12	25	18	18	63	78	73	74	69	18	39	53
	P. hybrida	9	20	20	24	64	57	40	28	26	23	3	7
	P. iridifolia	15	35	39	34	69	84	86	75	58	19	7	15
	P. lanigera	13	36	43	45	78	85	65	64	56	47	32	58
	P. ligulata	13	44	52	46	87	84	52	46	45	9	8	13
	P. lindsayi	11	29	29	27	70	69	66	51	46	15	12	18
	P. longifolia	17	52	61	63	87	59	51	44	40	18	9	20
	P. nemoralis	10	31	36	38	82	89	62	45	40	11	11	15
	P. ochroleuca	9	27	28	31	81	85	56	50	43	17	12	23
	P. palustris	13	38	41	38	82	88	82	81	71	20	13	25
	P. secunda	12	40	50	51	85	72	62	47	53	25	4	13
	P. sierbiana	12	40	45	51	80	79	73	69	57	19	9	26
	P. sterilis	14	39	46	44	87	88	62	38	44	29	9	15
	P. spp. PI 13033	12	27	24	24	63	67	71	52	49	22	8	11
	P. sp.p PI 204265	9	27	30	31	78	62	50	37	33	12	10	9
	P. spp. PI 598605	28	51	52	42	85	89	76	43	35	13	7	9
	P. spp. PI 619511	19	50	55	50	91	56	36	25	29	2	4	5
	P. spp. PI 632504	16	46	50	46	86	85	53	50	58	15	17	32
	P. spp. PI 655177	7	24	25	24	67	76	82	67	45	23	9	17

Table 2.3.Continued.

Growth	Entry	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Rhizomatous	*P. arachnifera×dusenii*	7	23	27	27	73	74	53	41	36	31	18	37
	P.arachnifera	9	27	31	31	68	67	60	59	53	29	33	64
	P. arida	11	27	29	27	76	82	64	67	63	26	19	39
	P. compressa	16	44	50	44	87	97	92	77	89	50	41	43
	P. maniototo	15	37	41	39	81	92	87	95	84	75	71	93
	P. nervosa	11	29	32	27	77	63	53	45	40	18	8	12
	P. prat GC	15	40	45	42	81	73	80	93	90	71	87	96
	P.prat KB	12	41	46	37	79	80	80	87	82	57	61	83
	P. prat MS	15	46	51	47	82	91	86	95	87	62	74	88
	P. arachnifera x pratenis	14	42	47	43	77	81	82	92	81	72	82	91
	P. stiriaca	15	50	56	62	90	99	95	97	90	73	79	98
	P. spp. PI 368993	11	36	42	45	81	70	64	61	54	12	12	19
Stoloniferous	*P. supina*	27	48	45	46	87	97	96	95	87	28	16	17
	P. trivialis CCC	6	27	33	46	89	62	55	40	47	18	8	15
	P. trivialis WS	8	27	33	34	85	89	84	83	76	12	5	8
	P. trivialis CR	25	58	61	58	89	89	93	78	87	25	16	21
	P. spp. PI 16171	19	52	59	55	87	64	69	53	45	12	8	10
LSD		3	7	8	10	11	14	19	21	24	29	14	15

Table 2.4. Effect of growth habit and entries on percent green cover over a one year period in 2011-2012 in Knoxville, TN.

Growth	Entry	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Bunch	Poa alpina	20	37	40	29	62	75	64	77	77	45	54	74
	P. alsodes	10	9	16	3	11	35	43	41	46	41	48	66
	P. annua	25	43	58	65	88	92	87	78	60	36	44	92
	P. candamoana	11	22	37	33	37	34	32	12	12	9	21	43
	P. chaixi	12	26	32	33	55	47	36	34	31	22	34	47
	P. cita	15	32	60	67	76	23	10	1	1	2	4	22
	P. colensoi	12	23	39	38	51	23	8	8	7	6	11	32
	P. dusenii	6	17	21	18	26	15	7	5	4	3	10	23
	P. flexuosa	18	36	47	44	70	84	47	63	74	74	77	92
	P. gilgiana	21	33	46	45	48	40	53	12	22	1	11	12
	P. hybrida	15	26	39	48	65	19	22	2	1	1	9	4
	P. iridifolia	15	30	39	32	41	59	28	48	28	27	29	46
	P. lanigera	14	33	55	68	77	54	19	24	36	39	66	75
	P. ligulata	13	32	49	54	56	37	6	2	1	1	5	12
	P. lindsayi	13	24	27	22	33	39	25	37	14	13	22	44
	P. longifolia	28	48	83	90	86	9	12	19	21	36	47	72
	P. nemoralis	14	35	57	61	75	66	20	4	6	5	12	20
	P. ochroleuca	13	34	60	63	79	69	13	10	6	7	21	44
	P. palustris	21	45	60	60	77	55	53	52	59	60	68	80
	P. secunda	17	33	62	72	78	20	11	1	1	2	5	17
	P. sierbiana	17	35	61	69	63	16	11	8	11	16	41	56
	P. sterilis	18	40	63	68	70	64	13	20	26	37	51	78
	P. spp. PI 13033	9	20	24	18	33	45	42	45	46	36	51	71
	P. sp.p PI 204265	9	22	33	36	44	15	12	10	12	9	15	42
	P. spp. PI 598605	17	33	40	28	48	53	23	28	11	7	21	32
	P. spp. PI 619511	9	26	37	47	72	5	4	0	0	1	2	3
	P. spp. PI 632504	15	37	58	66	84	47	9	21	14	33	56	76
	P. spp. PI 655177	9	20	33	21	36	55	28	34	30	32	38	68

Table 2.4. Continued

Growth	Entry	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Rhizomatous	P. arachnifera×dusenii	12	22	32	31	48	33	22	14	19	25	42	63
	P.arachnifera	14	29	48	57	69	44	30	30	41	34	67	88
	P. arida	13	27	39	41	65	43	35	35	43	43	70	87
	P. compressa	19	40	60	68	86	95	60	51	54	71	54	96
	P. maniototo	19	38	43	44	73	89	89	95	99	95	92	98
	P. nervosa	14	28	44	40	55	5	12	3	2	2	11	24
	P. prat GC	21	38	60	66	78	55	58	77	96	92	89	94
	P.prat KB	12	29	49	46	68	53	50	78	95	90	92	94
	P. prat MS	10	25	47	42	63	80	66	89	97	95	91	96
	P. arachnifera x *pratensis*	15	37	61	66	83	67	63	85	97	88	89	95
	P. stiriaca	15	38	61	72	91	94	85	82	91	93	93	98
	P. spp. PI 368993	9	23	37	50	58	13	10	6	8	12	28	50
Stoloniferous	*P. supina*	20	36	47	50	86	98	91	91	98	96	89	99
	P. trivialis CCC	22	48	84	95	98	42	45	70	83	90	88	98
	P. trivialis WS	7	17	33	48	79	88	76	78	73	68	63	92
	P. trivialis CR	21	44	74	83	92	93	78	92	81	86	69	93
	P. spp. PI 16171	20	41	72	79	90	58	46	78	78	72	68	83
LSD		3	5	9	8	9	9	9	9	12	12	14	16

Appendix B

Figures

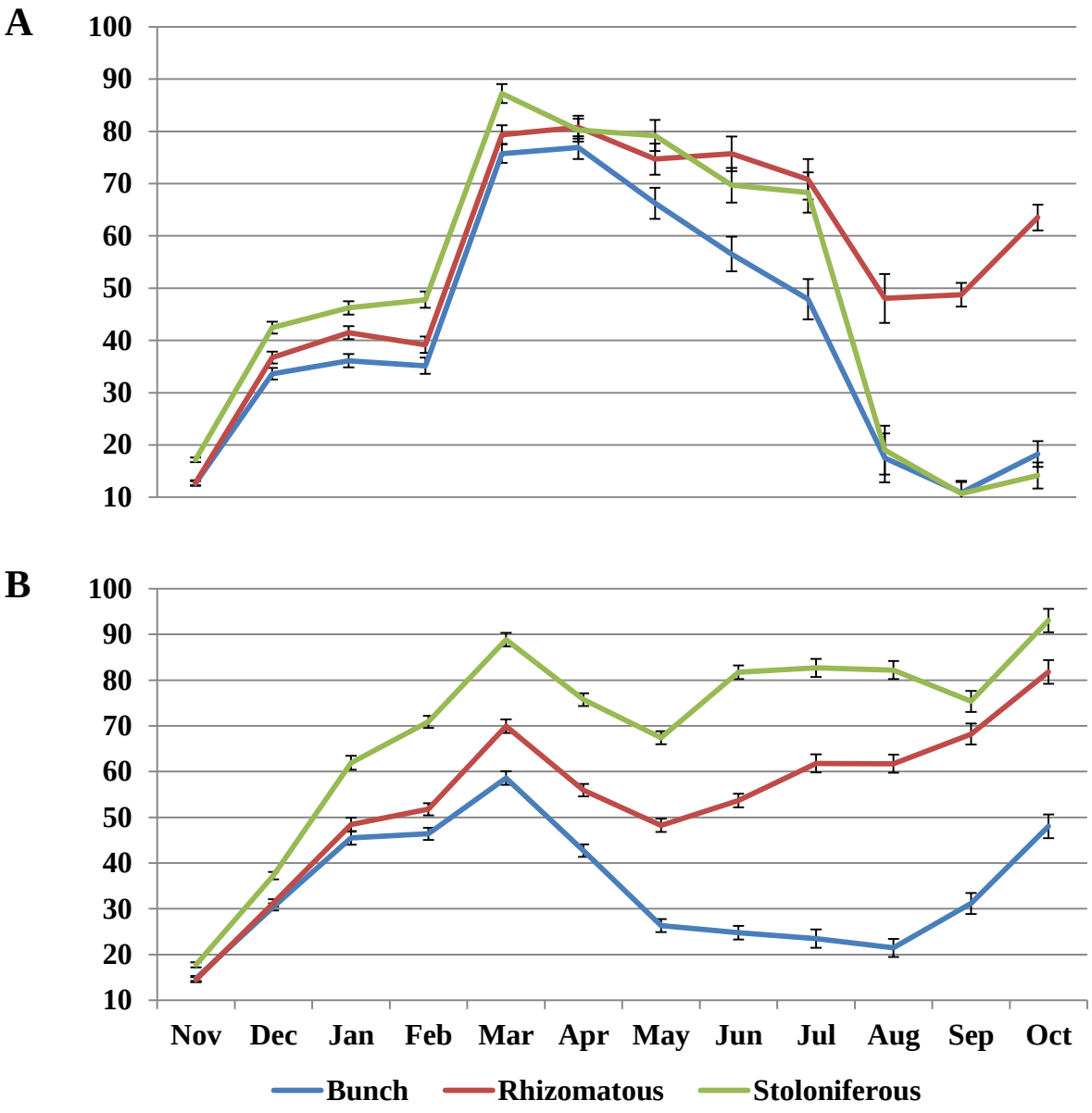


Figure 2.1. Percent green cover of growth habit groups over a one year period during 2010-2010 (A) and 2011-2012 (B) in Knoxville, TN.
†Error bars represent $LSD_{(0.05)}$.

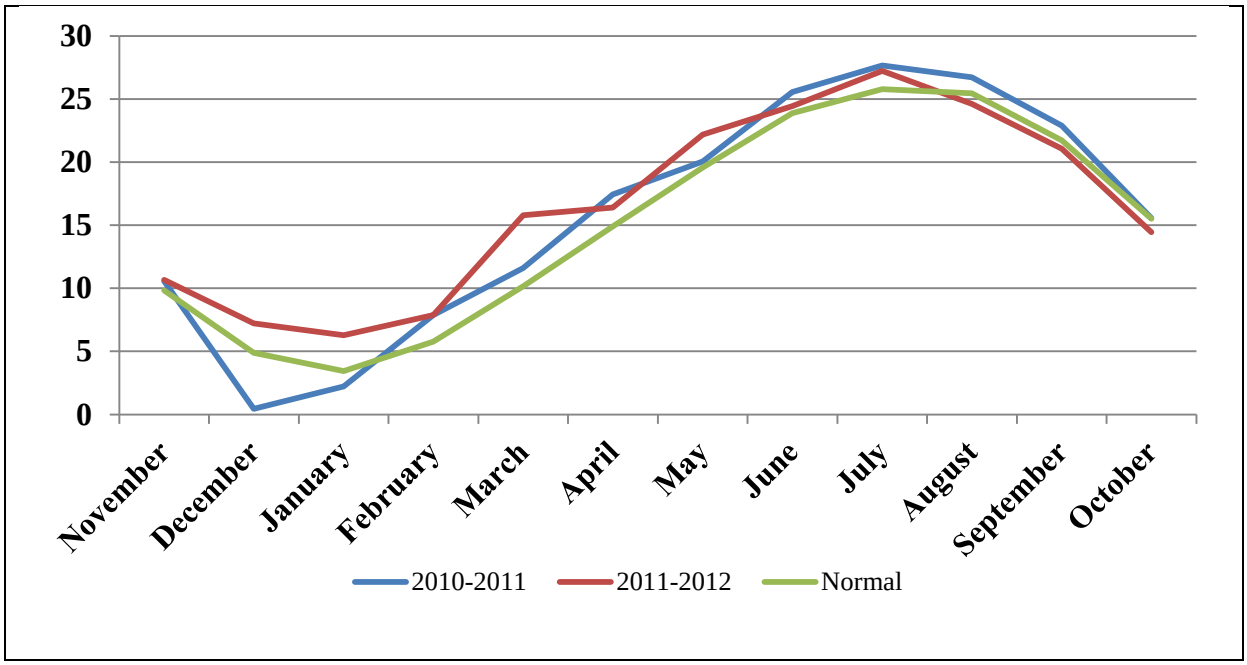


Figure 2.2. Monthly average air temperatures with a 29 year normal for comparison in Knoxville, TN.
†Data courtesy of NOAA

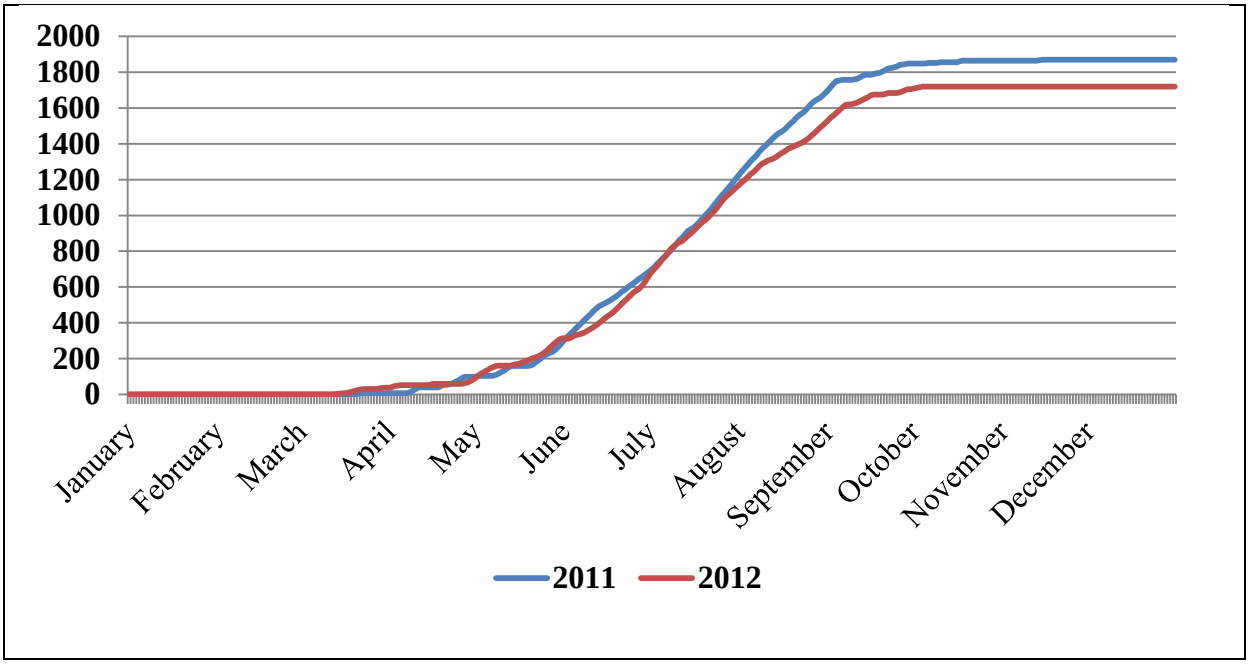


Figure 2.3. Growing degree day accumulations at a base temperature of 18.3 C° in Knoxville, TN.
†Data adopted from the East Tennessee Research and Education Center in Knoxville, TN.

CHAPTER III

POA SPECIES AS TEMPORARY WINTER OVERSEEDING SPECIES IN THE TRANSITION ZONE

Abstract

Pesticide restrictions are increasing and necessitate the need to explore alternative pest control options. Bermudagrass (*Cynodon* spp.) is commonly overseeded with a cool-season turfgrass species to provide a green and actively growing surface during winter dormancy. Unfortunately, species used for overseeding persist longer than is ideal in spring, warranting the use of herbicides to remove them. The objective of this study was to investigate the use of *P. nemoralis* L. and *P. supina* Schrad. as winter overseeding species on bermudagrass putting greens, fairways, and sports turfs in the transition zone and to compare their performance to traditional overseeding grasses. The effects of using herbicides to aid the transition were also examined. Treatments were planted and managed according to standard overseeding practices. Percent green cover was monitored throughout the trial and grid counts were used to assess species composition of plots during the spring transition period. On the putting green, *P. supina* was slower to establish and had unacceptable natural transition characteristics. *P. nemoralis* exhibited acceptable cover on the putting green during the first year, but not the second with good transition in the first year. Rough bluegrass (*P. trivialis* L) and perennial ryegrass (*Lolium perenne* L.) provided acceptable cover both years, but poor natural transition. On the fairway and sports turf studies, perennial ryegrass and intermediate ryegrass (*L. perenne* X *L. multiflorum* Authority) provided the best cover, while perennial ryegrass had a less desirable natural transition than intermediate ryegrass. *P. nemoralis* failed to provide acceptable cover for both years. *P. supina* was not evaluated in these two trials. Herbicide use improved transition characteristics in all trials.

Introduction

The use of bermudagrass (*Cynodon* spp.) on golf courses and sports fields continues to move northward in the transition zone (Patton, 2012; O'Brien and Hartwiger, 2011). This is due to advancements made by breeders in improving cold hardiness, as well as the positive attributes of bermudagrass: heat, drought, and wear tolerance; excellent recuperative potential and pest resistance. Bermudagrass unfortunately, experiences long winter dormancy in the transition zone. This dormancy results in diminished wear tolerance and recovery (Stewart et al., 2008) and increased susceptibility to winter annual weed invasion (Goddard et al., 2009). To combat the negative effects of winter dormancy, bermudagrass is often overseeded with a cool-season turfgrass to provide a green, actively growing surface (Ward et al., 1974). The cool-season species selected is an important decision and is specific to the application. Annual ryegrass (*Lolium multiflorum* Lam.) was once the standard for overseeding. However, as new species and varieties have been tested, annual ryegrass is no longer recommended, and perennial ryegrass (*L. perenne* L.) is the new standard (Ward et al., 1974; Schmidt and Shoulders, 1980).

Unfortunately winter overseeding comes with negative effects. The most notable is the persistence of the cool-season species into the spring and early summer (Horgan and Yelverton, 2001). This persistence leads to competition against the bermudagrass and may inhibit its full potential (Askew, 2010). In response to the persistence of overseeded species, two things happened. First, herbicides were recommended for the removal of the overseeding species (Horgan and Yelverton 2001). Second, new species were developed and evaluated for overseeding. These species included intermediate ryegrass (*L. perenne* × *L. multiflorum*), meadow fescue (*Festuca pratensis* Huds.), and tetraploid perennial ryegrass (*L. perenne* L.). This work found improved transition characteristics for these species in fairway and sports turf

settings. (Richardson, 2004;Richardson et al., 2007; Summerford et al., 2009; Trappe et al., 2012).

Early research investigated several cool-species for use in overseeding greens including annual ryegrass, perennial ryegrass, creeping red (*Festuca. rubra* var. *rubra*) and chewings fescue (*F. rubra* var. *commutata*), meadow fescue (*F. elatior*), creeping (*Agrostis stolonifera*) and colonial bentgrass (*A. capillaris*), Kentucky bluegrass (*P. pratensis*), rough bluegrass (P. *trivialis*), big bluegrass (*P. ampla*), and Timothy (*Phloem pretense*) (Ward et al., 1974). Later research found perennial ryegrass and rough bluegrass to be the best choice for greens (Batten et al., 1981). Recently it has been recommended that smaller seeded species such as creeping bentgrass or rough bluegrass, with emphasis on the latter, be used in place of perennial ryegrass (Sifers and Beard, 2001). Rough bluegrass demonstrated early and abrupt transitions that resulted in poor ratings (Ward et al., 1974; Schmidt and Shoulders, 1980). However, later studies indicated that it persisted longer than other species (Sifers and Beard, 2001; Richardson et al., 2007). This indicated that breeding efforts aimed at improving disease and heat tolerance have resulted in increased persistence of rough bluegrass, similar to perennial ryegrass.

The only known instance of a new overseeding species being tested for putting greens in the past two decades is in overseeding trials conducted in Florida in 2004 and 2005. In these trials, an experimental variety designated 'SRX 2NEM' was mistakenly reported as *P. trivialis* (Miller et al., 2005) However, the species was actually *Poa nemoralis* L (Brilman, personal communication, 2010). SRX 2NEM performed similar to *P. trivialis* with the exception of poorer quality ratings in early summer. This suggests an abrupt transition (Miller et al., 2005). Data from trials at the University of Tennessee show that a USDA accession of *P. nemoralis*, without

competition, dies in late spring or early summer with the onset of higher temperatures when mown at 7.6 cm (Data not shown or published).

P. nemoralis is an erect bunch type grass tolerant of shade and cold. However, seed availability is poor and expensive (Brede, 2000). It is native to Eurasia and is naturalized in North and South America and Australasia (USDA, 2013). It is suitable for shaded lawns (Huff, 2001). *P. nemoralis* was shown to have low tolerance to atmospheric drought (Carroll, 1943). Other literature regarding the performance of this species in turf or forage systems is extremely limited.

A second species that may be useful for overseeding greens is *P. supina* Schrad. *P. supina* is described as a stoloniferous sod-forming grass with good shade and traffic tolerance (Stier and Rogers, 2001). Supina bluegrass is native to the alpine regions of Europe and has been shown to be very competitive with other species. When seeded with Kentucky bluegrass or overseeded into existing stands of perennial ryegrass in northern US states and Canada, it was found to be the predominant species after a few years (Sorochan et al., 2001; Dodson et al., 2012). To our knowledge the heat tolerance of this species has not been investigated. However the recommendation is that its use should only occur in areas north of the transition zone (Stier, 1998). Supina bluegrass has been reported to be used on putting greens in Europe. This indicates that it is adapted to low mowing heights (Sorochan and Rogers, 2000). Additionally, data from current trials suggest that it can persist into mid-summer at a 7.6 mm mowing height with no competition (data not shown or published).

P. nemoralis and *P. supina* both have characteristics that warrant further investigation of their usefulness in winter overseeding. The objective of this study was to investigate the use of *P.*

nemoralis and *P. supina* as overseeding species on putting greens, fairways, and sports turfs in the transition zone.

Materials and Methods

Three winter overseeding studies were conducted at the East Tennessee Research and Education Center, Knoxville (35º54'N, 83º57'W). The studies were conducted on three bermudagrass stands: 'TifEagle' (Hanna and Elsner, 1999) ultradwarf hybrid bermudagrass [*C. transvaalensis* (Burtt-Davey) × *C. dactylon* (L.) Pers.] putting green, 'Riviera' common bermudagrass [*C. dactylon* (L.) Pers.] fairway, and 'Tifway' hybrid bermudagrass [C. transvaalensis (Burtt-Davey) × C. dactylon (L.) Pers.] trafficked sports turf. All studies were established on a Sequatchie silt loam soil (fine-loamy, siliceous, semi active, thermic Humic Hapludult). Plot sizes were 1.2 m × 1.2 m and arranged in a randomized complete block experimental design with four replications. Prior to spring transition, treatment design was a replication within blocks, At spring transition, the treatment design changed to a two factor (species and transition type) factorial. The species factor included a non-overseeded control and varied depending on the specific study (Table 3.1). The transition factor was either trifloxysulfuron-sodium (Monument® 75WG) or natural transition.

Prior to seeding the treatments, the bermudagrass surface was prepared by vertical mowing in two directions. After seeding, the trials were top-dressed with 3 mm of sand. The bermudagrass stands were irrigated two to three times each day to promote germination. After germination, the studies were irrigated as needed to prevent drought stress. For the second year, all studies were moved to an adjacent area that had not been previously overseeded.

Seeding rates were based on previous literature and were specific to the turfgrass system (Miller et al., 2005) (Table 1). Pure live seed was calculated using the official seed analysis results provided on the label. The seed was stored at 4^{o}C throughout the duration of the study. Germination tests were performed in December of each year.

The second factor involving the two transition types included the application of trifloxysulfuron-sodium (TS) and natural transition (NT). The TS was applied at the maximum label rate of 29 g a.i. ha^{-1} on 6 May 2011 and 2 May 2012, using a 4-nozzle boom with a 1 m effective width and 8002 nozzles calibrated to deliver 13 L 100 m^{-2}. A non-ionic surfactant was included at 0.25% v/v. For the NT treatments, transition was allowed to occur naturally.

Ultradwarf TifEagle Putting Green

The putting greens were seeded 30 September 2010 and 22 September 2011. The species treatment consisted of a non-overseeded control, *P. nemoralis* 'SRX 2NEM', *P. trivialis* 'Quasar', *P. supina* 'Supranova', and *L. perenne* Champion GQ, which was a blend of 50% 'Zoom' 40% 'SRX 4600' and 10% 'Racer 2'.

Mowing was withheld for two weeks after seeding then initiated at a cutting height of 10 mm, Mowing was gradually lowered over a four week period to 3.5 mm with a 6 day per week mowing frequency during active growth. Turf stands were fertilized at a rate of 5 g N m^{-2} with a complete fertilizer (10-2-20) per growing month.

Riviera Fairway

The fairway trial was seeded 28 September 2010 and 23 September 2011. Species treatments consisted of *L. multiflorum* 'Gulf', *L. perenne* × *L. multiflorum* 'Transcend', *L. perenne* Champion GQ blend, *P. trivialis* 'Quasar', and *Poa nemoralis* 'SRX 2NEM'. Mowing

was withheld for one week after seeding then resumed at a cutting height of 16 mm at a three day per week frequency during periods of active growth. The fairway stand was fertilized at a rate of 5 g N m^{-2} with an incomplete fertilizer (46-0-0) per growing month.

Tifway Sports Turf

Species, species seeding date, and all other cultural practices were identical to the aforementioned fairway study. Mowing height was 22 mm at a frequency of three days per week. Simulated football traffic was applied using the Cady Traffic Simulator (Henderson et al., 2005). For both years, beginning two weeks after seeding (WAS) 10 simulated football games were applied over a four week period.

Data Collection

Percent green turf cover was evaluated quantitatively using digital image analysis (DIA) according to the methods of Richardson et al., (2001). In each year, DIA was initiated at two weeks after seeding (WAS), was performed weekly during active growth, and ceased at eight weeks after transition (WAT). At four and eight WAT, species composition was measured by identifying the species growing at each of the 100 intersects created by a 1 m^2 grid as either bermudagrass or overseeded species. The total count for each species was then totaled for each plot.

All data were analyzed using mixed model ANOVA in the SAS system 9.2 (Statistical Analysis Software, Cary, NC). In the pre-transition phase of the study, the second factor (TS) had not been applied, so every treatment occurred in every block twice. Therefore, data were analyzed with a treatment design of replications within blocks. Percent green cover values from the pre-transition phase of the study were used to calculate area under the percent green cover

curve (AUPGCC) similar to the methods used by Campbell and Madden (1991) to calculate area under the disease progress curve (AUDPC). AUPGCC is expressed as the percent green cover × day and describes percent green cover throughout the overseeding season (October – May). In the pre-transition phase, years were different for all three turfgrass systems. Thus the years are presented separately. DIA post-transition and grid counts were analyzed as a factorial treatment design and years were different for all three systems and thus presented separately. Dates differed and are presented separately to display differences among the species and transition type factors at different timings.

In-house germination tests conducted both years showed a significant interaction between treatment and years and thus the interactions are reported. However, seeding rates remained the same for both seasons. The *P. nemoralis* seed had a drop in germination of 24.3% in 2011 compared to results from 2010. *P. supina* had a 28.2% increase in germination in 2011 (Table 3.1) The wood bluegrass seed was five years old when it was acquired in the summer of 2010 and its drop in germination is consistent with the information provided by the supplier (Brilman, personal communication, 2010). The increase in germination of *P. supina* may be explained by use of a newer lot of seed for 2011 in comparison to the previous year's seed, which was approximately three years old. The seed germination of all other treatments did not differ significantly between years, including the *L. perenne* blend that was also replaced with a new lot for the 2011 season.

Results and Discussion

Putting Green

Percent green cover through the overseeding season

the2010 trial compared to the 2011 trial (Table 3.2). This is explained by the above average temperatures occurring through winter and early spring of 2012 compared to the 2010 to 2011 season when temperatures were below normal in December and January (Figure 3.7). However, the percent green cover contribution of treatments was reduced in the second season (Table 3.2). Previous research indicated that the optimum soil temperatures for overseeding are between 22 and 26^0C (Batten et al., 1980). Soil temperatures at the time of seeding were slightly below optimum at 21.7^0C in 2010 and optimum at 23.7^0C in 2011 (Figure 3.8) However, the AUPGCC data shows that cover was higher in 2010 compared to 2011 (Table 3.2). Monthly averages for air temperature showed that September and October of both years were similar (Figure 3.7). Daily average air temperatures showed that during the first week after seeding temperatures were 13 to 2^0 C higher in 2011 than for the same period during 2010 (Figure 3.9). Additionally, an afternoon thunderstorm occurred just after seeding in 2011. The precipitation was heavy enough to cause the seeds to float and be deposited on top of the canopy resulting in less seed to soil contact. The irrigation cycles were identical between the two years; however, considering the poor seed to soil contact and higher air temperatures, it is likely that many seeds did not imbibe enough moisture for germination and establishment and thus led to lower cover values for the seeded treatments during 2011 through 2012. Compounding this was the health and quality of the bermudagrass stand. During the growing season of 2010, the maintenance of

the green was minimal and resulted in a poor surface quality at the time of seeding. During 2011, the greens management was more intense and resulted in a denser and higher quality surface at the time of seeding in 2011. This increased level of quality and density may have posed more competition against the developing seedlings, resulting in a poorer stand.

In both seasons, *P. trivialis* ranked highest with the exception of the 2011 trial year, when *L. perenne* ranked the same as *P. trivialis* (Table 3.2). This was consistent with previous studies where *L. perenne* and *P. trivialis* were found to be the best species for overseeding bermudagrass putting greens when compared to other species (Batten et al., 1981). *P. supina* ranked higher than *L. perenne* in the 2010 trial, but not in the 2011 trial. In 2010 *P. nemoralis* was not different than either supina bluegrass or *L. perenne* indicating that *P. nemoralis* was able to provide a sufficient cover. However, *P. nemoralis* was not different from the control in the 2011 trial. This could be explained by the drop in germination that was observed with these two treatments. In addition, a lack of competiveness against actively growing bermudagrass may have contributed to reduced establishment for all treatments.

Grid Counts Post TS Application

Results were similar for both years at 4 WAT. *P. trivialis*, *P. supina*, and *L. perenne* all had lower percentages of bermudagrass counts than the non-overseeded control and *P. nemoralis*, when allowed to transition naturally (Fig. 3.1 and 3.2). This was surprising because in the 2010 trial, the amount of cover provided by *P. nemoralis* was similar to *L. perenne* and *P. supina*. This indicated that *P. nemoralis* did not present as much competition against the bermudagrass compared to the other treatments. *P. supina* had the lowest bermudagrass plant counts in both years; however, it was only significantly different in 2012. The results remained

the same at eight WAT in both years with *P. supina* having significantly lower bermudagrass counts than *P. trivialis* and *L. perenne*. This indicated that supina bluegrass was a strong competitor against bermudagrass during this time of year. This was consistent with findings showing that *P. supina* was able to dominate mixed stands even when seeded at ratiosof 10:90 with Kentucky bluegrass (Sorochan et al., 2001).

When TS was applied, all treatments responded similarly and were not different from the non-overseeded control or *P. nemoralis*, with NT (Figures 3.1-2). This showed that applications of an herbicide such as TS were an effective way to remove overseeded species from bermudagrass and thus remove competition.. Another exception was supina bluegrass in 2012 at four WAT. Similar to perennial ryegrass in 2011, supina bluegrass was found to have a lower percentage of bermudagrass compared to all other treatments with TS applied and the non-overseeded control and wood bluegrass with NT, respectively. However, supina bluegrass was different from perennial ryegrass in that supina bluegrass was found in grid counts at 19% even though TS had been applied, indicating that TS was not as effective on this species in comparison to other grasses tested and, in turn, competed with the bermudagrass.

Percent Green Cover Post TS Application

In an ideal spring transition, the overseeded species would gradually decline while the bermudagrass fills in, resulting in no cover loss. However, abrupt transitions can occur, leaving voids in the turf that reduce turfgrass cover during a natural transition or after herbicide applications. When allowed to transition naturally, the species treatments in the 2010 trial showed no difference in percent green cover at two WAT cover or in subsequent weeks (Table 3.3). When treated with TS at two WAT, *P. trivialis* had the significantly lowest cover of 63.2%.

L. perenne dropped to 82.6%, but was not different than the other species receiving the TS treatment which ranged from 89.3 to 95.9% green cover (Table 3.3). In the second year trial, *P. trivialis* again had the lowest cover rating at two WAT at 59% cover. *L. perenne,* at 66% cover, was not different from either *P. trivialis* or *P. supina* at 71% cover when treated with NT. This trend continued into and ended at three WAT with *P. trivialis* and *L. perenne* having less cover than all other treatments. At six WAT rough bluegrass and supina bluegrass, when allowed a natural transition, had lower cover ratings than all other treatment combinations. This trend was still apparent, especially with *P. supina*, at the last rating date eight WAT. This data showed that *L. perenne* and especially *P. trivialis* could cause unacceptable reductions in cover when an herbicide is used to facilitate transition. In this study, the highest label rate of TS was used in early May. Lower rates and a later application date have resulted in a more gradual transition (McCauley et al., 2009).

Fairway

Percent Green Cover Throughout the Overseeding Season

Similar to the aforementioned putting green study, the non-overseeded control showed an increase in AUPGCC values that was explained by warmer winter temperatures during the 2011 through 2012 season (Table 3.4). This increase was also observed in all treatments including *P. nemoralis*, which was better than the control in both years but was still not at an acceptable level (Table 3.4). *L. perenne* and *L. perenne* × *L. multiflorum* were consistently the best performers. *P. trivialis* rated better than *L. multiflorum*. In the second year, *L. perenne* had higher cover ratings than *L. perenne* × *L. multiflorum*, which rated higher than *P. trivialis* and *L. multiflorum* (Table

3.4) Similar results have been found with comparisons of *L. perenne* and *L. perenne* × *L. multiflorum* (Richardson et al., 2007; Richardson, 2004) However, the performance of *P. trivialis* in the first year trial was not consistent with previous research that found *P. trivialis* to be inferior to *L. perenne* in fairways. The performance of *P. trivialis was* consistent with previous research the second year (Richardson et al., 2007; Morris, 2004).

Grid Counts Post TS Application

L. perenne × *L. multiflorum* and *L. perenne* ,regardless of transition type, and *P. trivialis* with NT resulted in significantly lower bermudagrass percentagesat 4 WAT. Specifically, *L. perenne* × *L. multiflorum* and *P. trivialis* had the lowest percentages of bermudagrass, followed by *L. perenne*. In the second year, *P. trivialis* alone had the lowest percentage of bermudagrass, followed by *L. perenne* and, finally, *L. perenne* × *L. multiflorum*. During the 2010 trial, significant differences were still found at eight WAT, with *P. trivialis* having the lowest bermudagrass percentages, followed by *L. perenne*. *L. perenne* × *L. multiflorum* was not statistically different fromany other treatment. In the second year, no significant differences were found at the 8WAT rating (Figure 3.4). In both years and on both rating dates the use of TS resulted in no significant difference among treatments receiving that application. This indicated that it was an effective tool for removing all species tested and resulted in an increased amount of bermudagrass in the plots.

Percent Green Cover Post TS Application

In both years at two WAT, *L. multiflorum*, *L. perenne*× *L. multiflorum*, and *P. trivialis* had significantly lower percent green cover after application of TS. However, in 2012, *L. multiflorum* and *L. perenne*× *L. multiflorum*, when allowed NT, also displayed a drop in cover

indicating a sudden natural transition. This trend continued at three WAT and was joined by *P. trivialis* with NT and *L. perenne* with TS. *L. perenne*× *L. multiflorum* and *P. trivialis* continued to show lower green cover at six WAT. By eight WAT, *P. trivialis* with NT had the lowest cover, however percent green cover only ranged from 95.2 to 98.7%.

Sports Turf

Percent Green Cover Throughout The Overseeding Season

Similar to the green and fairway studies, the sports turf study also showed an increase in AUPGCC values of the non-overseeded controls in the second year of the study. This result was explained by above average temperatures in the winter of 2011-2012 (Table 3.5). With the exception of the control and *P. nemoralis*, the AUPGCC values were similar between the two years. *L. perenne* and *L. perenne* ×*L. multiflorum* both had the highest AUPGCC values and were not different from one another in either year. *P. nemoralis* was not better than the control in either year. Therefore it was not suitable for this application. *L. multiflorum* and *P. trivialis* had lower values than *L. perenne* ×*L. multiflorum* and *L. perenne* in both years. *L. multiflorum* and *P. trivialis* were not significantly different in the second year; however *L. multiflorum* was better than *P. trivialis* in the first year. This suggested that both of these species, especially *P. trivialis*, were not suited to this application. These results, aside from *P. trivialis*, were similar to Trappe et al. (2012), where *L. perenne* was found to have the highest coverage in two out of three years when subjected to the equivalent of six National Football League games.

Grid Counts Post TS Application

At four WAT in 2011, *L. perenne, L. perenne* × *L. multiflorum,* and *P. trivialis* all had lower bermudagrass percentages than other treatments and were not different from one another

when allowed to transition naturally. At eight WAT, *L. perenne* and *P. trivialis* still had lower bermudagrass percentages than all other treatments and were not different from one another. In 2012, *L. perenne* with NT had the significantly lowest bermudagrass percentage. *P. trivialis* with NT had more bermudagrass than *L. perenne* but not as much as *L. perenne* × *L. multiflorum* with NT, or *L. perenne* with TS. *P. nemoralis* with TS had more bermudagrass coverage but not as high as the non-overseeded controls. In 2012 at eight WAT, no significant differences were found among treatments, with the exception of *L. perenne* at four WAT in 2012. At this point TS was successful in removing the overseeded species and resulted in increased bermudagrass percentages.

Percent Green Cover Post TS Application

In the first year at 2 WAT, *L. perenne* × *L. multiflorum* with TS had the lowest green cover rating at 82% (Table 3.7). *L. perenne* was not different at 86% cover. *P. trivialis* and *L. multiflorum* were not significantly different than *L. perenne* but were better than *L. perenne* × *L. multiflorum*. When a NT was allowed, *P. trivialis* had the highest cover at 99%, and was not different from any other NT treatment, except *L. multiflorum* at 89%. There was no significant difference amongany treatments in subsequent weeks in the first year. In the second year at two WAT *L. perenne* × *L. multiflorum* with TS had the lowest cover at 59%. *L. multiflorum* had slightly more cover at 62.5%, but not different than *L. perenne* × *L. multiflorum.* *L. multiflorum* with NT also had low cover at 66%, suggesting transition was naturally occurring. *L. perenne* with NT had the highest cover at 96.5% and was significantly different from all other treatments, with the exception of *P. trivialis* with NT at 93%. At 3 WAT, *L. perenne* × *L. multiflorum* with TS continued to have the significantly lowest cover at 59%. *L. multiflorum* with NT and TS, *L. perenne* × *L. multiflorum* with NT, and P. trivialis with TS also had low cover values, but

different from *L. perenne* × *L. multiflorum* with TS. This suggested that natural transition was occurring for the NT treatments. *L. perenne* with TS stood alone at 80% cover. All other treatments with higher cover than *L. perenne* with TS were significantly higher and not different from each other. At 6 WAT, *P. trivialis* with NT had the lowest cover at 62%, but was not different from *L. perenne* × *L. multiflorum* with NT at 71%. *L. multiflorum* with NT also had low cover at 82% and was not different from *L. perenne* × *L. multiflorum.* All other treatments had higher cover but were not different from *L. multiflorum* with NT. By 8 WAT there were no significant differences among treatments (Figure 3.7).

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Appendix C

Tables

Table 3.1 Treatments, seeding rates specific to the study, and percent germination of seeds planted in overseeding trials in 2010 and 2011 in Knoxville, TN.

		Seeding rates[†]		Germination[‡]	
Species	**Cultivar**	**Greens**	**Fairway & Sports**	**2010**	**2011**
		----------g m^{-2}----------		--------%--------	
Lolium multiflorum	**Gulf**	**--**	**68**	**96**	**97**
L. perenne* × *L. multiflorum	**Transcend**	**--**	**63**	**96**	**96**
L. perenne	**Champion GQ[§]**	**146**	**44**	**89**	**94**
Poa nemoralis	**SRX 2NEM**	**54**	**15**	**63**	**39**
P. supina	**Supranova**	**39**	**--**	**50**	**78**
P. trivialis	**Quasar**	**39**	**10**	**91**	**95**
				LSD (0.05) 10.3	

[†] Seeding rates adopted from previous literature with pure live seed calculations using the label analysis.
[‡] Germination refers to results from in house tests conducted in the December following establishment in both years.
[§] Champion GQ refers to a blend of perennial ryegrass cultivars consisting of; 50% 'Zoom', 40% 'SR 4600', and 10% 'Racer 2'

Table 3.2. Effects of overseeded species on percent green cover throughout the overseeding season displayed as area under the percent green cover curve (AUPGCC) on a 'TifEagle' bermudagrass putting green in Knoxville, TN.

Treatments[†]	AUPGCC	
	2010	2011
Control[‡]	4262	6264
Poa nemoralis	15900	6603
P. trivialis	17594	11864
P. supina	16392	10093
Lolium perenne	14996	12654
LSD (0.05)	443	425

[†] **Cultivars consisted of 'SRX 2NEM'** ***Poa nemoralis,*** **'Quasar'** ***P. trivialis,*** **'Supranova'** ***P. supina,*** **and Champion GQ blend** ***Lolium perenne.***

[‡] **Control was represented as non-overseeded bermudagrass.**

Table 3.3 Effect of overseeding species by transition type on percent green cover on a 'TifEagle' putting green during the spring transition period in Knoxville, TN.

		2010				2011			
		Weeks into transition period							
Transition[†]	Species	2	3	6	8	2	3	6	8
NT	Control[‡]	98.4	99.0	99.0	99.9	94.6	96.3	97.1	92.5
	Poa nemoralis[§]	99.8	99.5	96.5	99.6	95.8	96.3	97.4	93.2
	P. trivialis	99.2	99.3	88.9	98.4	95.4	96.1	77.3	84.9
	P. supina	99.1	98.5	98.9	99.6	99.0	94.9	77.1	77.6
	Lolium perenne	99.7	99.7	99.1	99.7	95.7	91.6	89.1	88.6
TS	Control	89.9	93.7	98.2	99.2	96.3	96.3	97.9	92.7
	P. nemoralis	89.3	86.1	98.8	99.6	92.8	94.0	97.2	87.9
	P. trivialis	63.2	76.1	94.3	98.7	58.8	74.8	96.4	92.1
	P. supina	95.9	93.0	96.9	99.1	70.8	90.7	95.0	91.4
	L. perenne	82.6	85.5	95.5	99.5	66.2	71.2	91.5	85.2
	LSD (0.05)	13.7	13.2	7.8	1.6	7.9	5.5	10.8	7.9

[†] **Transition types were either natural transition (NT) or herbicide transition with trifloxysulfuron-sodium (TS) applied at 29 g a.i. ha^{-1} on 6 May 2011 and 2 May 2012.**

[‡] **Control was represented as non-overseeded bermudagrass.**

[§] **Cultivars consisted of 'SRX 2NEM' *Poa nemoralis*, 'Quasar' *P. trivialis,* 'Supranova' *P. supina,* and Champion GQ blend *Lolium perenne.***

Table 3.4. Effects of overseeded species on percent green cover throughout the overseeding season displayed as area under the percent green cover curve (AUPGCC) on a 'Riviera' bermudagrass fairway in Knoxville, TN.

Treatments[†]	AUPGCC	
	2010	2011
Control[‡]	5634	10987
Lolium multiflorum	10492	14526
L. perenne × *L. multiflorum*	13046	15733
L. perenne	12497	16329
Poa trivialis	11785	14835
P. nemoralis	8564	11795
LSD (0.05)	1005	571

[†] Cultivars consisted of 'Gulf' *L. multiflorum*, 'Transcend' *L. perenne* × *L. multiflorum*, Champion GQ *L. perenne*, 'Quasar' *Poa trivialis*, and SRX 2NEM *P. nemoralis*.

[‡] Control was represented as non-overseeded bermudagrass.

Table 3.5. Effect of overseeding species by transition type on percent green cover on a 'Riviera' fairway during the spring transition period in Knoxville, TN.

		2010				2011			
		Weeks into transition period							
Transition[†]	Species	2	3	6	8	2	3	6	8
NT	Control[‡]	90.7	94.0	99.3	98.1	91.5	89.2	90.8	98.3
	Lolium multiflorum	87.0	91.8	99.2	98.3	66.6	65.8	90.0	98.7
	L. perenne × *L. multiflorum*	94.8	94.5	97.2	95.1	78.7	60.5	83.3	96.9
	L. perenne	98.0	98.0	98.8	96.0	95.6	90.6	91.0	98.3
	Poa trivialis	98.4	98.4	89.3	89.2	89.7	73.9	85.4	95.2
	P. nemoralis	94.3	94.3	99.3	98.0	90.0	84.5	92.3	98.2
TS	Control	83.3	88.3	98.1	98.1	91.5	91.4	90.9	97.7
	Lolium multiflorum	73.0	86.9	98.4	98.4	58.2	74.3	91.8	97.9
	L. perenne × *L. multiflorum*	75.0	79.6	97.4	97.4	58.4	63.3	91.2	98.1
	L. perenne	91.8	90.4	98.2	98.2	83.9	75.5	86.0	98.6
	Poa trivialis	74.2	77.1	98.1	98.1	63.5	57.5	82.5	98.4
	P. nemoralis	85.9	91.2	98.5	98.5	83.9	83.5	93.8	98.4
	LSD (0.05)	13.7	13.2	7.8	1.6	7.9	5.5	10.8	7.9

[†] **Transition types were either natural transition (NT) or herbicide transition with trifloxysulfuron-sodium (TS) applied at 29 g a.i. ha^{-1} on 6 May 2011 and 2 May 2012.**

[‡] **Control was represented as non-overseeded bermudagrass.**

[§] **Cultivars consisted of 'SRX 2NEM'** ***Poa nemoralis,*** **'Quasar'** ***P. trivialis,*** **'Supranova'** ***P. supina,*** **and Champion GQ blend** ***Lolium perenne.***

Table 3.6. Effects of overseeded species on percent green cover throughout the overseeding season displayed as area under the percent green cover curve (AUPGCC) on a 'Tifway' bermudagrass sports turf with traffic in Knoxville, TN.

Treatments[†]	percent green cover	
	2010	2011
Control[‡]	6624	8940
Lolium multiflorum	11891	11084
L. perenne × *L. multiflorum*	13899	13587
L. perenne	13660	14170
Poa trivialis	9073	10896
P. nemoralis	7364	9042
LSD (0.05)	826	594

[†] Cultivars consisted of 'Gulf' *L. multiflorum*, 'Transcend' *L. perenne* × *L. multiflorum*, 'Champion GQ' *L. perenne*, 'Quasar' *Poa trivialis*, and SRX 2NEM *P. nemoralis.*

[‡] Control was represented as non-overseeded bermudagrass.

[§] 10 simulated football games were applied over a month period beginning two weeks after seeding with the Cady traffic simulator.

Table 3.7 Effect of overseeding species by transition type on percent green cover on a 'Tifway' sports turf with traffic[¶] during the spring transition period in Knoxville, TN.

		2010				2011			
		Weeks into transition period							
Transition[†]	Species	2	3	6	8	2	3	6	8
NT	Control[‡]	95.4	99.6	97.7	99.5	86.5	88.2	88.5	95.9
	Lolium multiflorum	91.5	99.7	94.8	99.7	66.1	67.5	82.0	89.4
	L. perenne × *L. multiflorum*	93.8	99.3	97.7	99.7	78.0	65.7	70.9	76.8
	L. perenne	95.9	99.5	98.4	99.6	96.5	92.7	90.1	87.5
	Poa trivialis	99.1	99.6	94.3	99.7	93.3	89.0	62.2	70.8
	P. nemoralis	94.2	99.6	98.3	99.6	84.9	88.9	85.4	93.6
TS	Control	94.2	99.7	97.4	99.7	81.9	88.6	90.1	95.0
	Lolium multiflorum	89.2	99.8	96.3	99.6	62.5	69.1	88.1	94.7
	L. perenne × *L. multiflorum*	81.7	99.6	98.8	99.6	59.1	53.8	86.1	92.1
	L. perenne	85.6	99.7	98.9	99.4	90.2	80.1	86.5	89.1
	Poa trivialis	87.9	99.7	98.1	99.6	77.4	66.4	83.4	93.1
	P. nemoralis	95.4	99.8	96.7	99.6	83.9	86.8	90.5	96.8
	LSD (0.05)	5.4	0.3	3.2	0.2	6.3	6.5	11.4	11.7

[†] **Transition types were either natural transition (NT) or herbicide transition with trifloxysulfuron-sodium (TS) applied at 29 g a.i. ha^{-1} on 6 May 2011 and 2 May 2012.**

[‡] **Control was represented as non-overseeded bermudagrass.**

[§] **Cultivars consisted of 'SRX 2NEM'** ***Poa nemoralis,*** **'Quasar'** ***P. trivialis,*** **'Supranova'** ***P. supina,*** **and Champion GQ blend** ***Lolium perenne.***

[¶] **10 simulated football games were applied over a month period beginning two weeks after seeding with the Cady traffic simulator.**

Appendix D

Figures

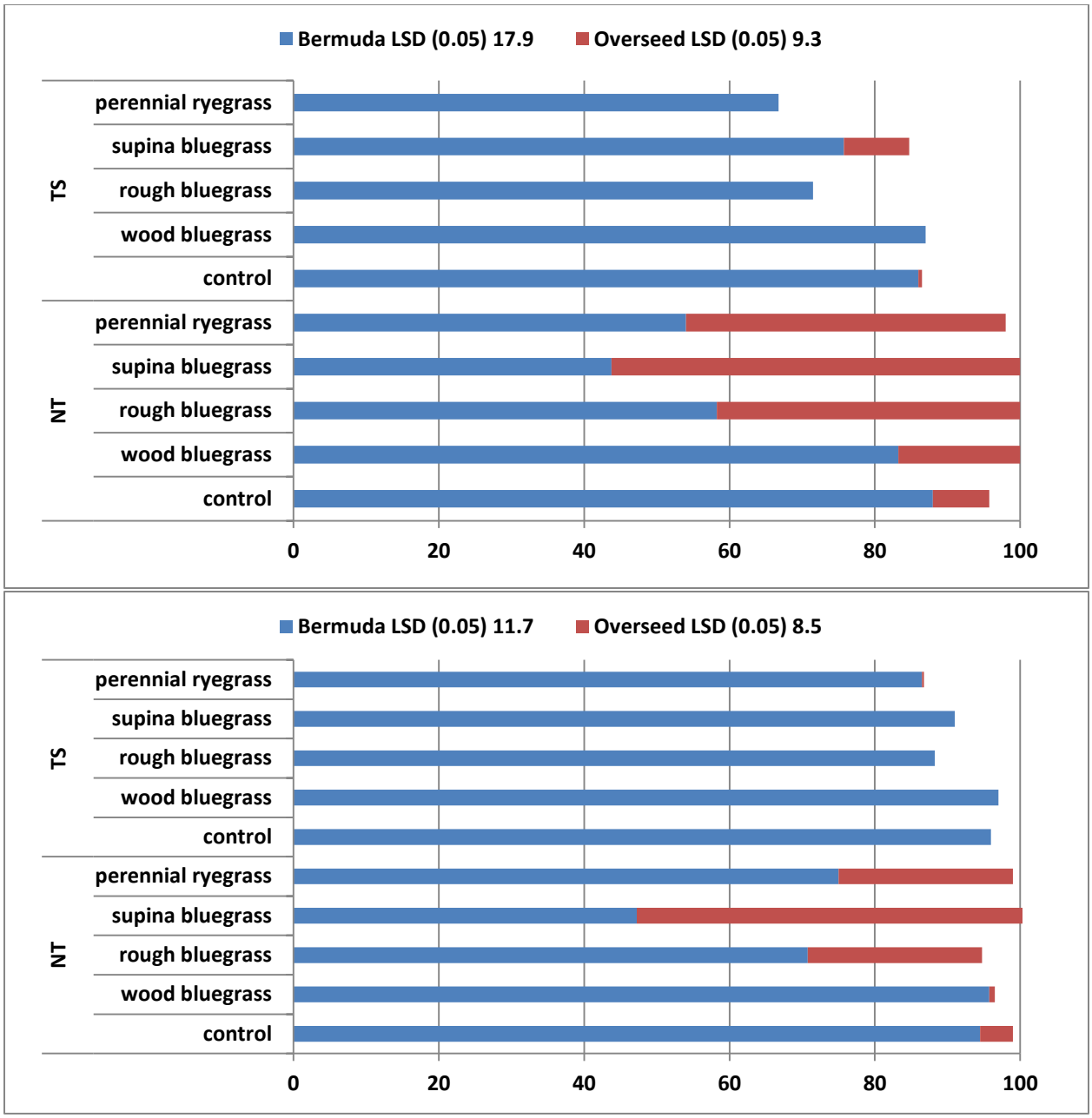


Fig. 3.1. Percent composition of bermudagrass and overseeded species by transition type on a 'TifEagle' putting green at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 6 May 2011. NT represents natural transition and TS represents an herbicide transition with trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

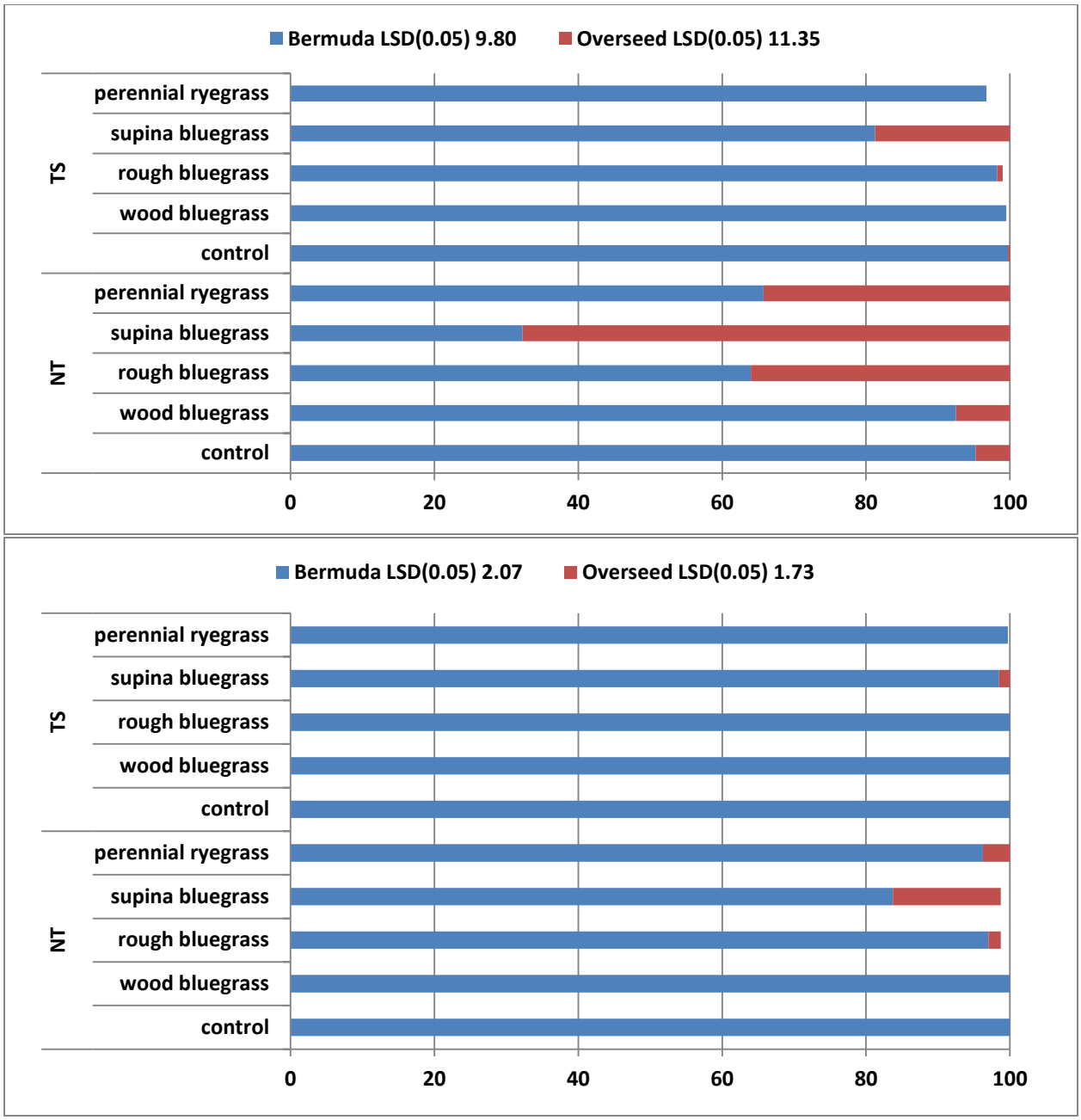


Fig. 3.2. Percent composition of bermudagrass and overseeded species by transition type on a 'TifEagle' putting green at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 2 May 2012. NT represents a natural transition and TS represents an herbicide transition with trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

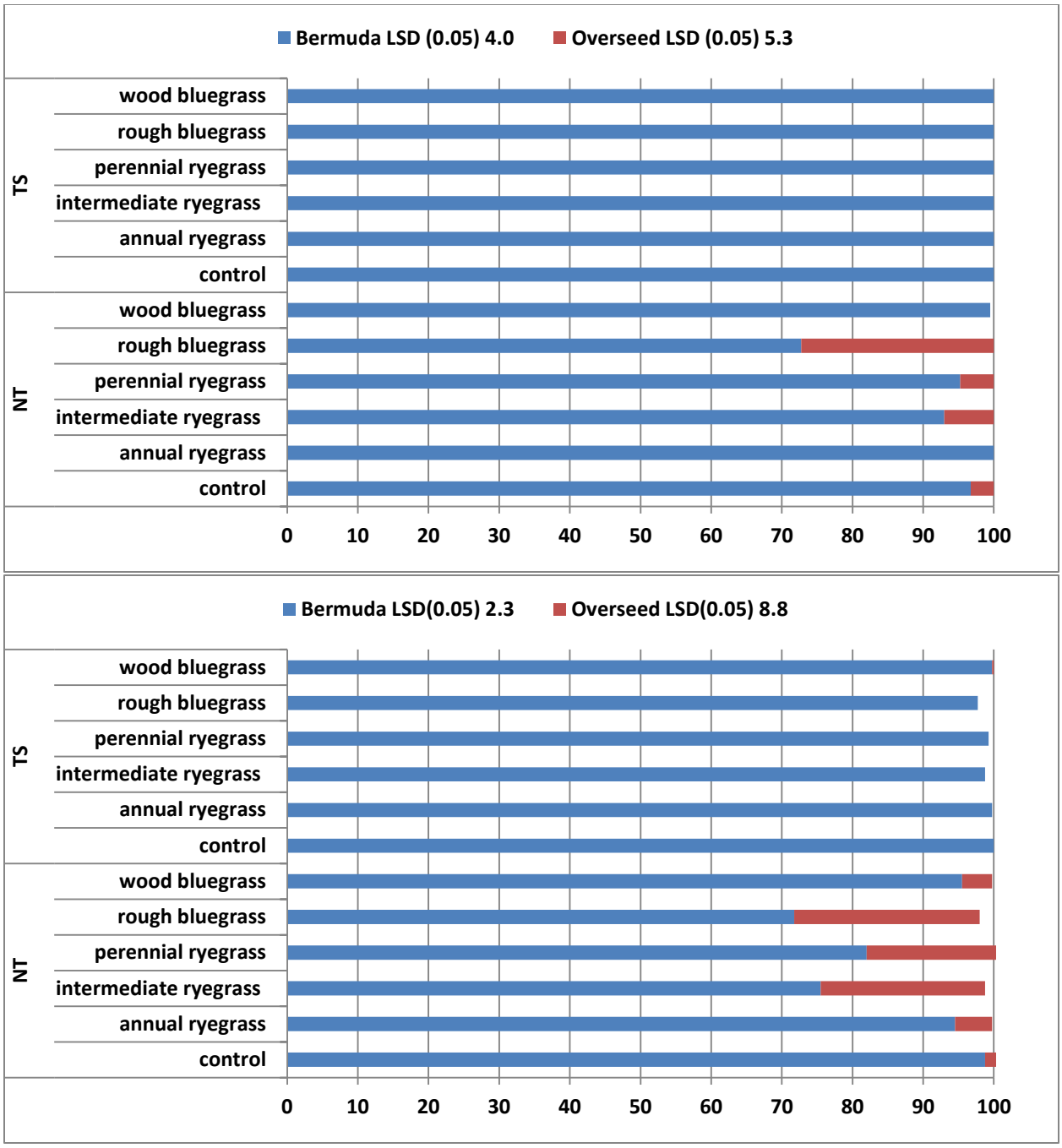


Fig. 3.3. Percent composition of bermudagrass and overseeded species by transition type on a 'Riviera' fairway at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 6 May 2011. NT represents a natural transition and TS represents an herbicide transition with trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

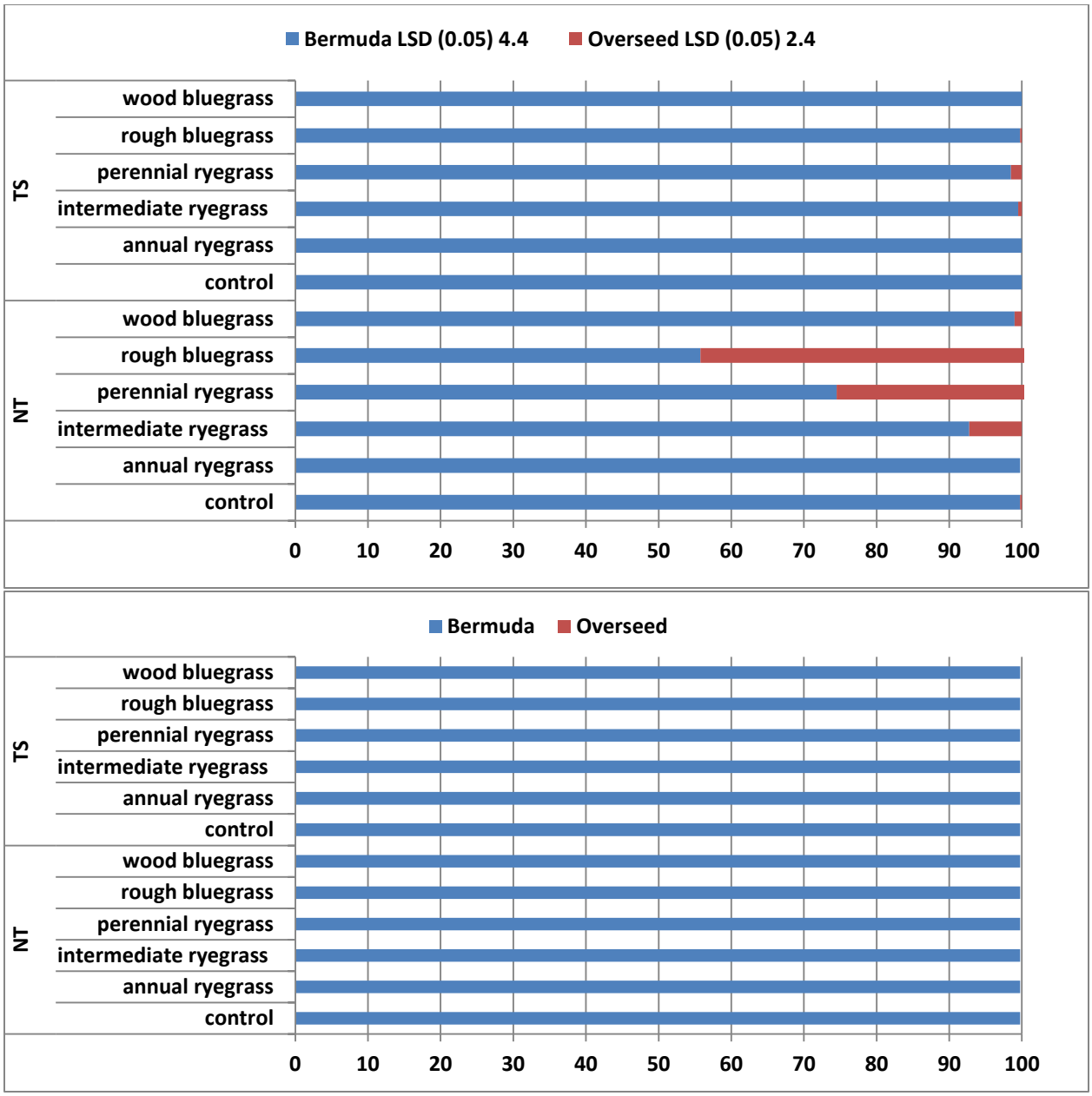


Fig. 3.4. Percent composition of bermudagrass and overseeded species by transition type on a 'Riviera' fairway at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 2 May 2012. NT represents a natural transition and TS represents an herbicide transition with Trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

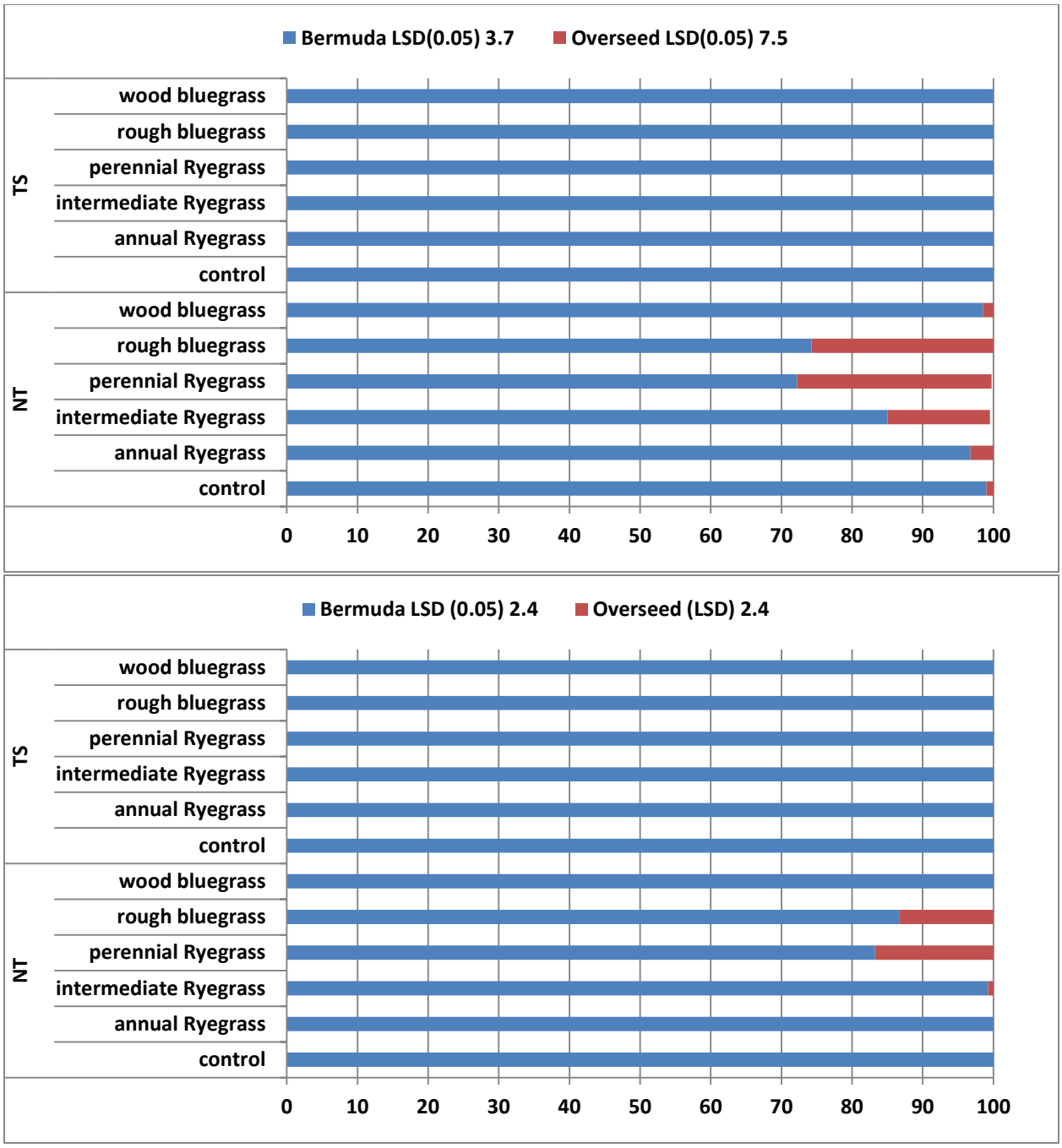


Fig. 3.5. Percent composition of bermudagrass and overseeded species by transition type on a 'Tifway' sports turf with traffic at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 6 May 2011. NT represents a natural transition and TS represents an herbicide transition with trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

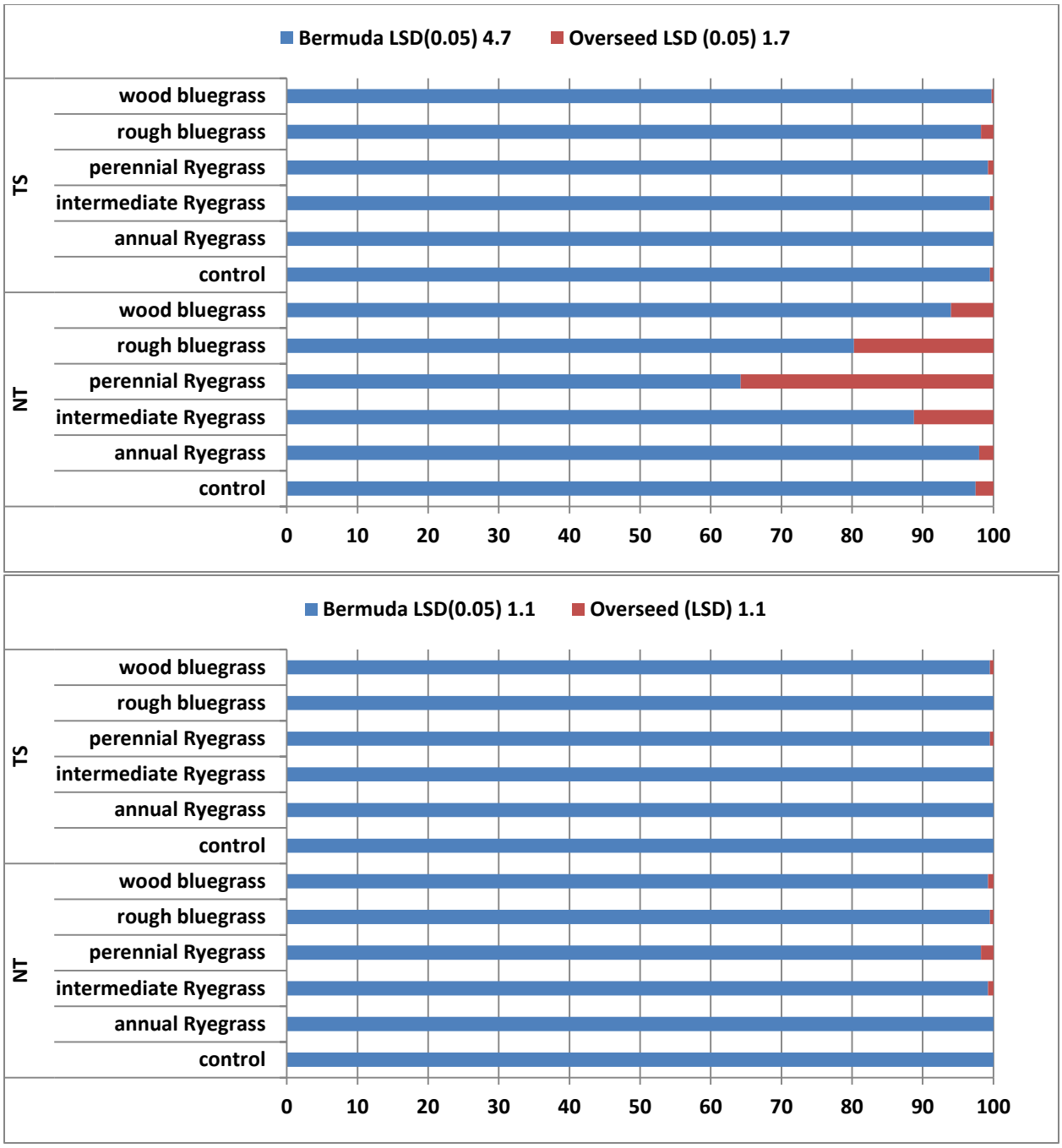


Fig. 3.6. Percent composition of bermudagrass and overseeded species by transition type on a 'Tifway' sports turf with traffic at four (top) and eight (bottom) weeks after the beginning of spring transition occurring on 2 May 2012. NT represents a natural transition and TS represents an herbicide transition with trifloxysulfuron-sodium applied 29 g a.i. ha^{-1}.

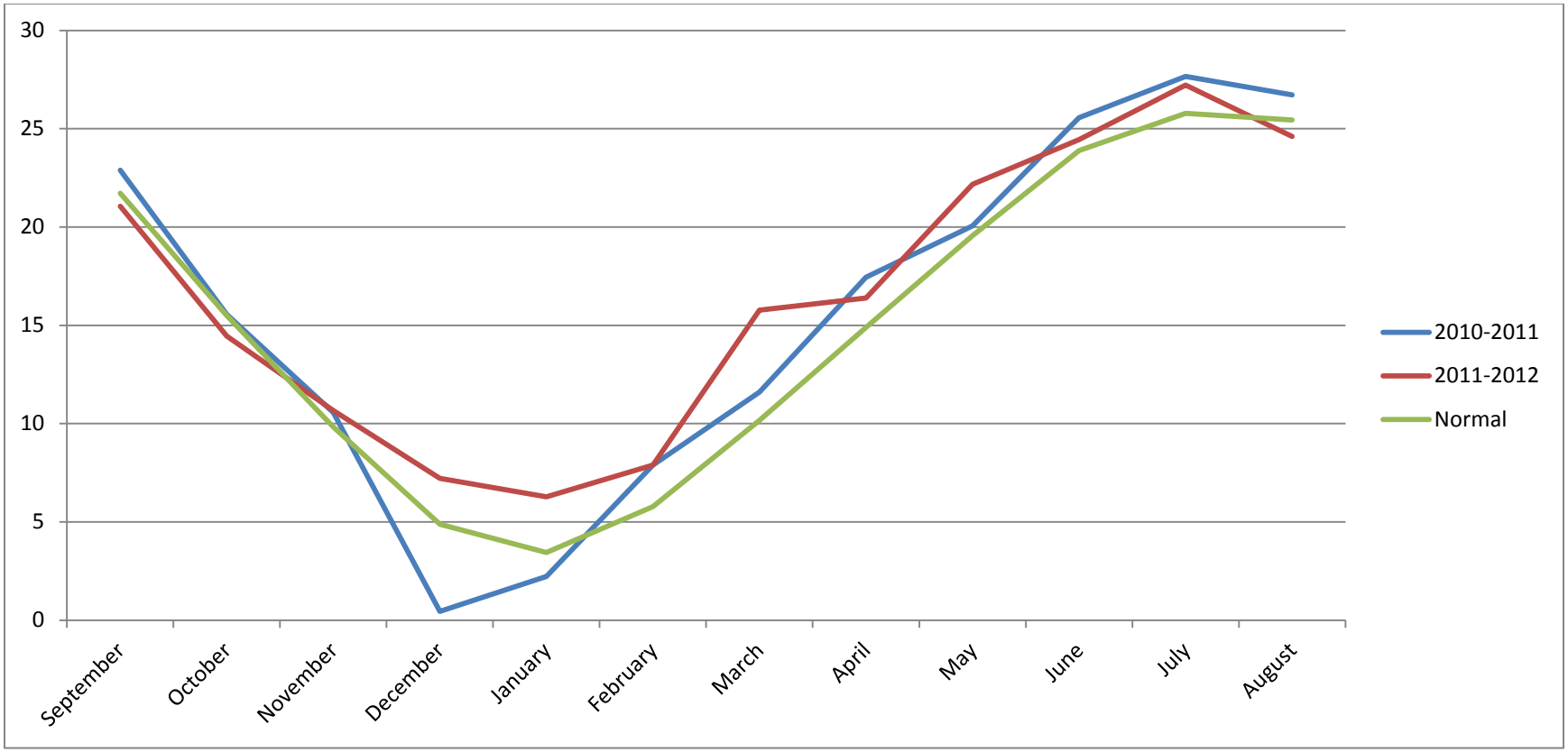


Fig. 3.7. Monthly average air temperatures for Knoxville, TN in 2010-2011 and 2011-2012 with a 29 year normal for comparison.
[†]Data courtesy of NOAA.

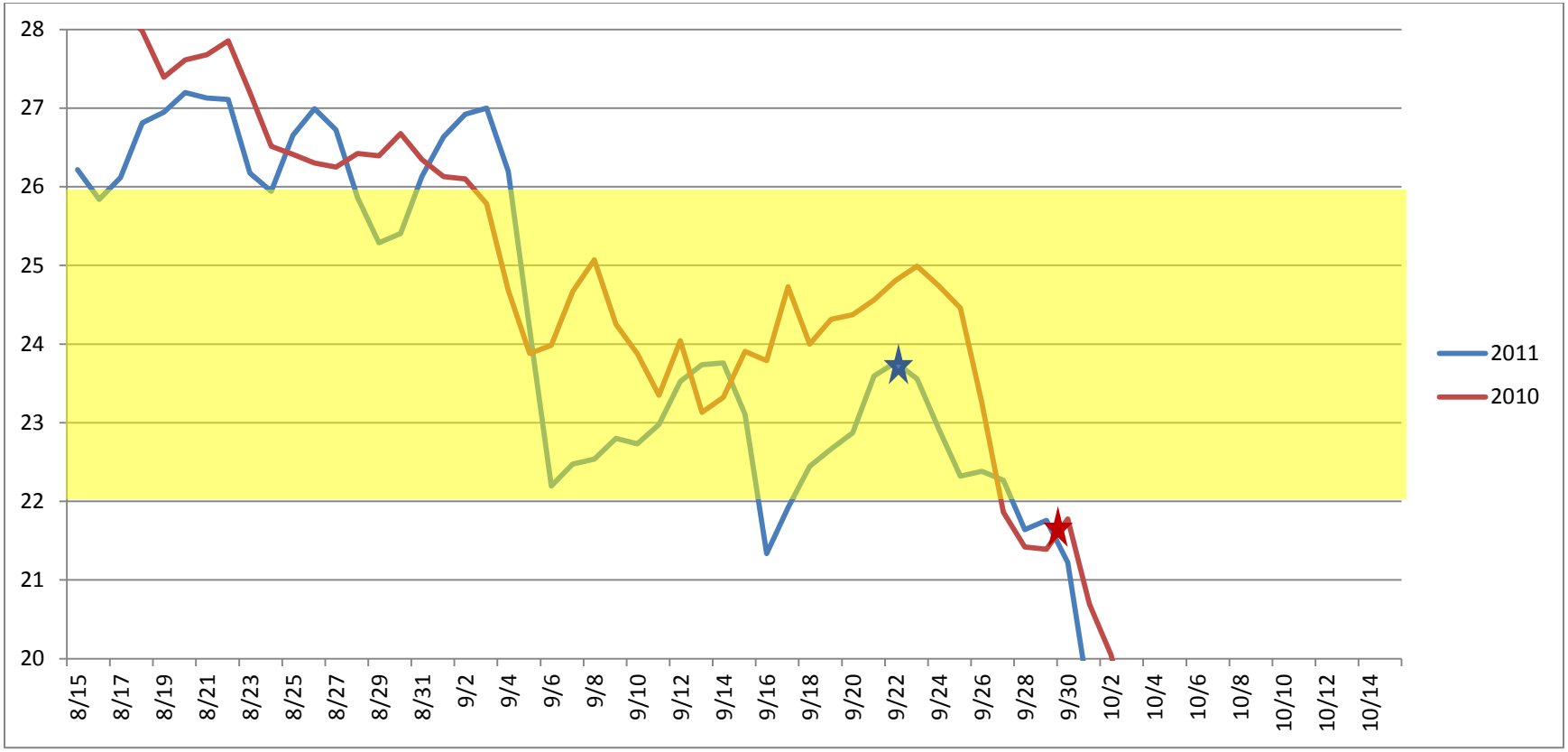


Figure 3.8. Daily soil temperature at the East Tennessee Research and Education Center in fall of 2010 and 2011.

†Highlighted area indicates optimum soil temperatures for overseeding (Batten et al., 1981)

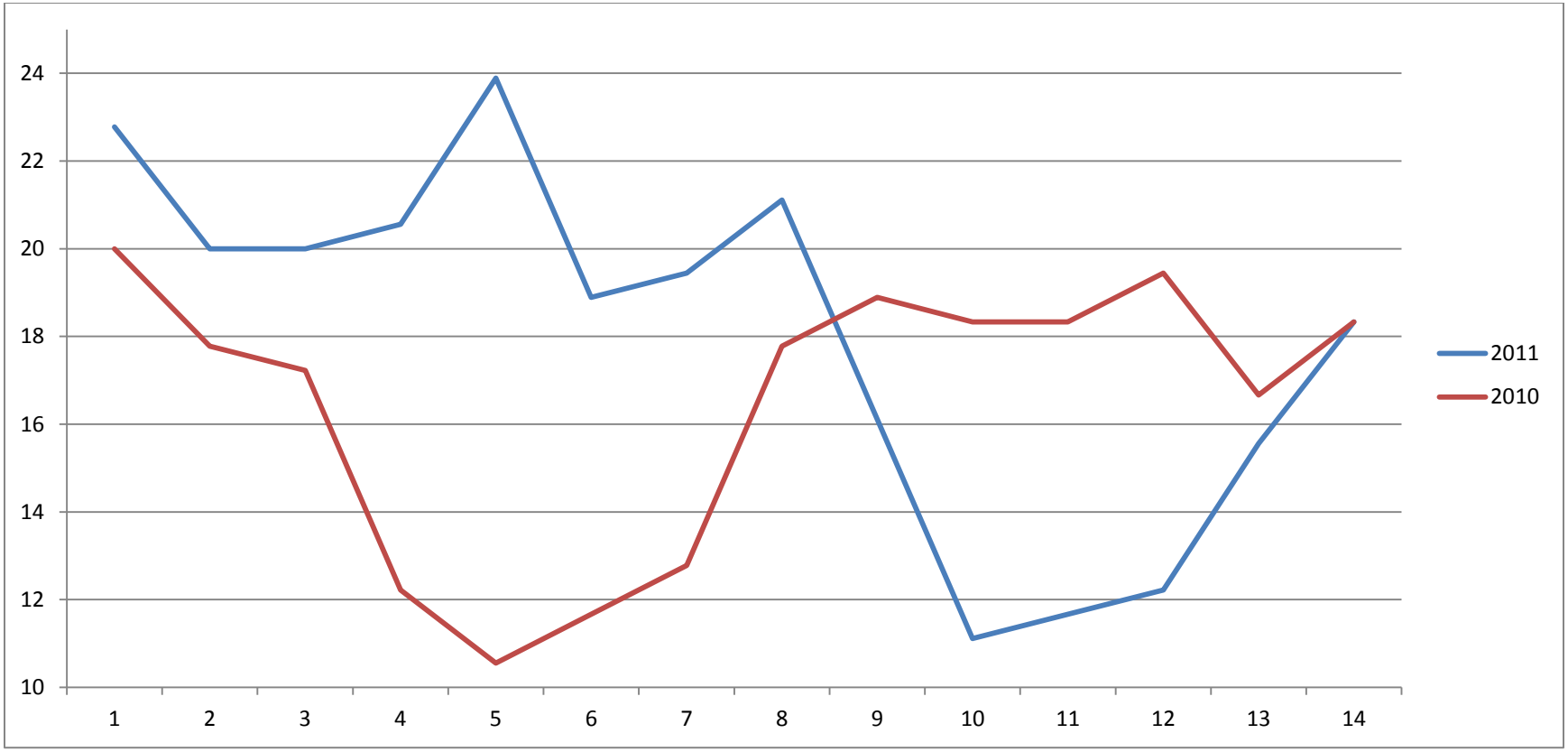


Figure 3.9. Daily average air temperatures at seeding and two weeks after at the East Tennessee Research and Education Center, Knoxville.

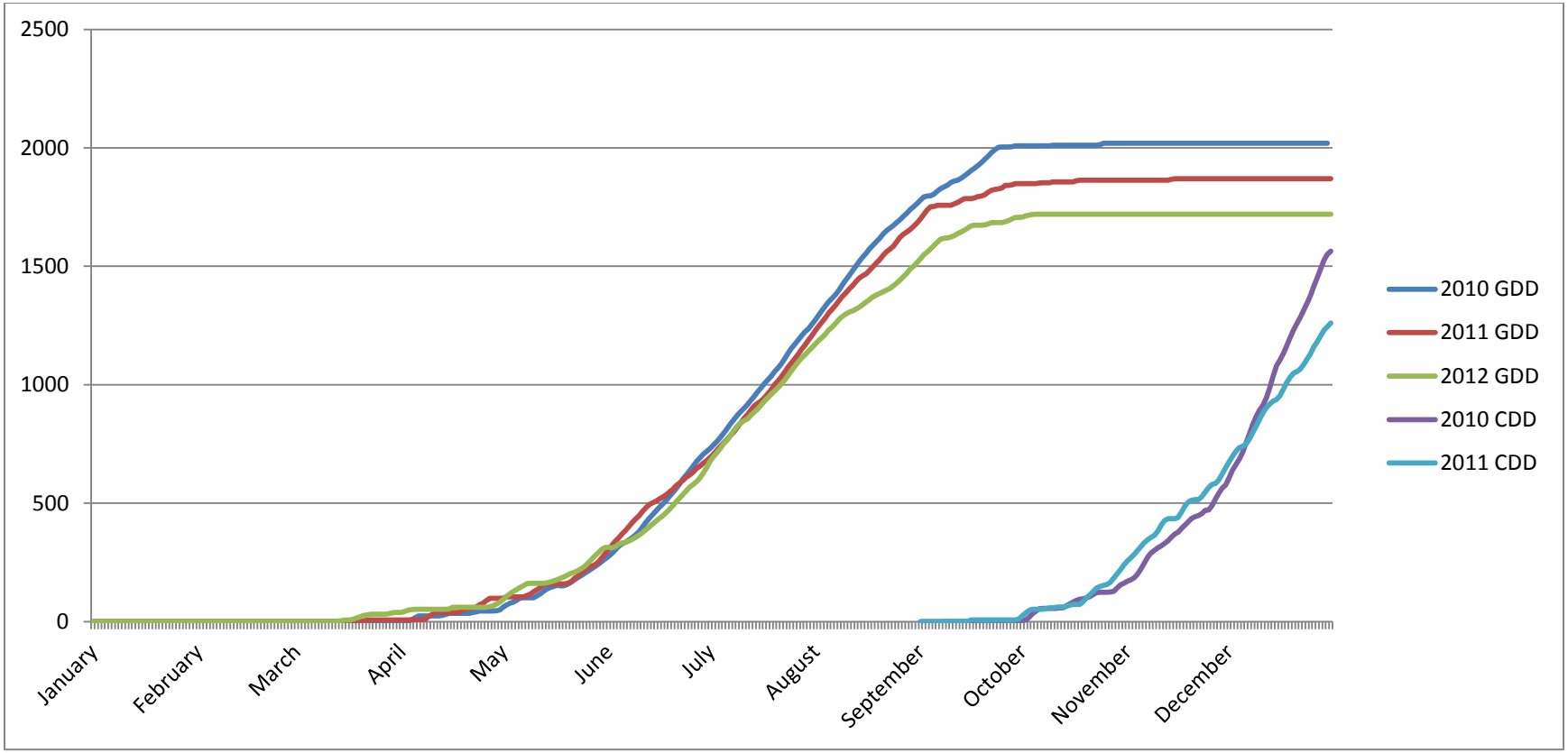


Figure 3.10. Growing and cooling degree day accumulations at a base of 18.3°C.

†Data calculated from the East Tennessee Research and Education Center weather station, Knoxville.

Appendix E

Preliminary Species Evaluation Data

Materials and Methods

A preliminary study was initiated on 29 July 2009 to evaluate alternative *Poa* species for turf in the transition zone. This study began with the selection and acquisition of various *Poa* species from the USDA National Plant Germplasm System (NPGS). These were chosen based on their original collection location, with the preferred location being those with a Köppen climate classification of Cfa. The Cfa climate classification represents a warm temperate, fully humid, hot summer climate similar to that of the eastern USA transition zone. Several USDA accessions were obtained from areas with this climate and additional species were selected to represent other climates. Additionally, locally adapted bio-types of *Poa* species were collected and utilized, as well as commercially available cultivars of *Poa* species, for a total of 40 entries.

Seeds were sown in flats with Fafard No. 2 growing medium (Sun Gro Horticulture Canada Ltd., Agawam, MA) on 29 September 2009. One month after seeding, individual seedlings were transplanted to plug flats with each plug measuring 4.4 cm x 4.4 cm. and filled with Fafard No. 2 growing medium. Each plug was planted with one plant from one seed. Greenhouse conditions were maintained throughout the six week growing period with daily temperatures averaging 24º C. Irrigation was applied as needed to maintain conditions favorable for germination and growth. A 12-55-6 fertilizer was applied at 2.5 g N m^{-2} at seeding. One month after seeding and after transplanting to plug flats, a 20-20-20 fertilizer was applied at 5 g N m^{-2}. Plants were trimmed to a 7.6 cm height weekly.

Prior to field planting, the soil was tilled to a 15 cm depth and then leveled. A soil fumigant, dazomet (Basamid® G) (Certis USA L.L.C. Columbia, MD), was then applied at 53.7 g m^{-2} and watered in. Polyethylene sheeting was used to cover the site for three days, after which

the covers were removed and an additional week was allowed to let the Basamid dissipate from the soil before planting.

At eight weeks (1 October 2009) after seeding, plants were transplanted to the field at the East Tennessee Research and Education Center, Knoxville, on a Sequatchie silt loam soil (fine-loamy, siliceous, semi active, thermic Humic Hapludult). Plots were 66 cm x81 cm and arranged in a randomized complete block design with three replications. Six plugs (plants) were planted on 15 cm centers arranged in a two × three pattern within the center of the plot. A 5 cm diameter plugging tool was used to cut holes in the soil for the plugs. After placing the plug in the soil, the remaining space around the plug was backfilled with native soil from the plugging operation.

A 10-10-10 fertilizer was applied at 5 g N m^{-2} at seeding, followed by a second 5 g N m^{-2} of the same analysis applied one month after planting on 1 November 2009. The following year a 24-6-12 analysis with 50% of the nitrogen in a slow release form was applied on 15 March 2010 and 2 May 2010. Mowing was initiated one week after planting at a weekly cutting height of 7.6 cm when actively growing. Irrigation was applied as needed to prevent moisture stress. No pesticides were applied.

Percent green turf cover was evaluated using digital image analysis (DIA) according to previously described methods (Richardson et al., 2001). DIA was initiated at one month after field planting and continued at monthly intervals for one year, resulting in 12 rating dates, beginning in November and ending in October. Interactions were present for treatment and date, therefore dates are presented separately. Treatments were grouped based on their observed growth habit in the field. Both groups and treatments were analyzed as fixed effects with treatments nested within groups.

Results and Discussion

Bluegrasses with stoloniferous growth habits were advantageous from the first rating date in November until June, when cover rapidly began to decline for all growth habits (TablesA.2, Fig. A.1). By July, the cover of the stoloniferous group dropped below the rhizomatous group and was not different from the bunch types. Both the stoloniferous and bunch type species remained at or near 0% cover throughout the remainder of the trial. The rhizomatous group was advantageous through the summer and was the only group that gained significant cover in the successive rating months after July.

The highest performing bunch type was *Poa annua*, which occurred in the top statistical category nine times during the season. This species was best from November through June and again in October. During July-August there was virtually no cover, indicating that the species was dead. The rebound in cover in October was explained by the germination of seedlings that were ripe in spring. Other notable bunch types would include *P. erinacea*, which was in the top statistical group five times in the period from November through March. Although *P. lanigera* and *P. sierbiana* dropped to a low level of cover over summer, they did survive better than other bunch types, indicating that they had heat tolerance.

The stoloniferous group was only represented by two species; *P. supina* and *P. trivialis*. The *P. trivialis* entries gained more cover than *P. supina* in late fall and winter of 2009. *P. trivialis* 'CCC' had significantly higher cover than all others in January and February. *P. supina* maintained cover later into the summer, suggesting it has higher heat tolerance.

The rhizomatous group was represented by 10 species. Two of these species, *P. compressa* and *P. stiriaca*, were both in the top statistical category in the group seven times, which occurred consecutively from the first rating date in November through May. A locally

naturalized entry of Kentucky bluegrass also performed well over all, occurring in the top statistical group six times. However in August, ‘Thermal Blue’ Texas x Kentucky hybrid and ‘Midnight Star’ and ‘Kenblue’ Kentucky bluegrass were in the top statistical category. This continued into the successive months with *P. maniototo* joining the group in September.

In summary, the results of this trial indicated that many of the entries were unsuitable for the transition zone because of their inability to persist in the summer. This suggested that these species should be investigated for their performance in overseeding trials and thus a two-year research project was designed. This data also led to even more species being trialed in a similar fashion to the above mentioned trial. However, the new study utilized preventative applications of fungicides and insecticides in an attempt to minimize biotic stresses that may have played a big factor in the aforementioned preliminary data and helped to evaluate loss in turf cover related to heat stress. The small plots and spaced planting method made it difficult to differentiate damage from fungal pathogens and insects. From a permanent turf standpoint, *P. maniototo* showed promise for use as a turfgrass.

Tables

Table E.1. Species, cultivars, accessions, experimental designation and growth habits of treatments planted in October, 2009 in Knoxville, TN.

Species	Identifier	Growth habit
Poa alpina	**PI 540425**	**Bunch**
P. annua	**WCGC'**	**Stoloniferous**
P. annua'	**CWA**	**Bunch**
P. arachnifera	**W6 17703**	**Rhizomatous**
P. arctica	**PI 236901**	**Rhizomatous**
P. arida	**PI 578806**	**Rhizomatous**
P. chaixii	**W6 28274**	**Bunch**
P. cita	**W6 22519**	**Bunch**
P. colensoi	**W6 22527**	**Bunch**
P. compressa	**CC**	**Rhizomatous**
P. dusenii	**PI 598733**	**Bunch**
P. flexuosa	**W6 25683**	**Bunch**
P. erinacea	**PI 204263**	**Bunch**
P. gilgiana	**PI 478581**	**Bunch**
P. hybrida	**PI 249765**	**Bunch**
P. iridifolia	**PI 154882**	**Bunch**
P. lanigera	**PI 477105**	**Bunch**
P. lanuginosa	**PI 269649**	**Bunch**
P. ligularis	**PI 284255**	**Bunch**
P. ligulata	**PI 517033**	**Bunch**
P. lindsayi	**PI 237163**	**Bunch**
P. longifolia	**PI 380991**	**Bunch**
P. marcantha	**W6 26828**	**Bunch**
P. maniototo	**PI 237164**	**Rhizomatous**
P. nemoralis	**PI 442544**	**Bunch**
P. nervosa	**PI 232352**	**Rhizomatous**
P. palustris	**PI 274644**	**Bunch**
P. pratensis	**GC**	**Rhizomatous**
P. pratensis	**Kenblue**	**Rhizomatous**
P. pratensis	**Midnight Star**	**Rhizomatous**
P. arachnifera x P. pratensis	**Thermal Blue**	**Rhizomatous**
P. arachnifera x P. pratensis	**Armadillo**	**Rhizomatous**
P. poecila	**W6 13851**	**Bunch**
P. psilolepis	**W6 23610**	**Bunch**

Table E.1. Continued

Species	Identifier	Growth habit
P. secunda	**PI 578850**	**Bunch**
P. sieberiana	**PI 282383**	**Bunch**
P. stiriaca	**PI 283964**	**Rhizomatous**
P. supina	**Supranova**	**Stoloniferous**
P. trivialis	**CR-91**	**Stoloniferous**
P. trivialis	**CCC**	**Stoloniferous**

Figures

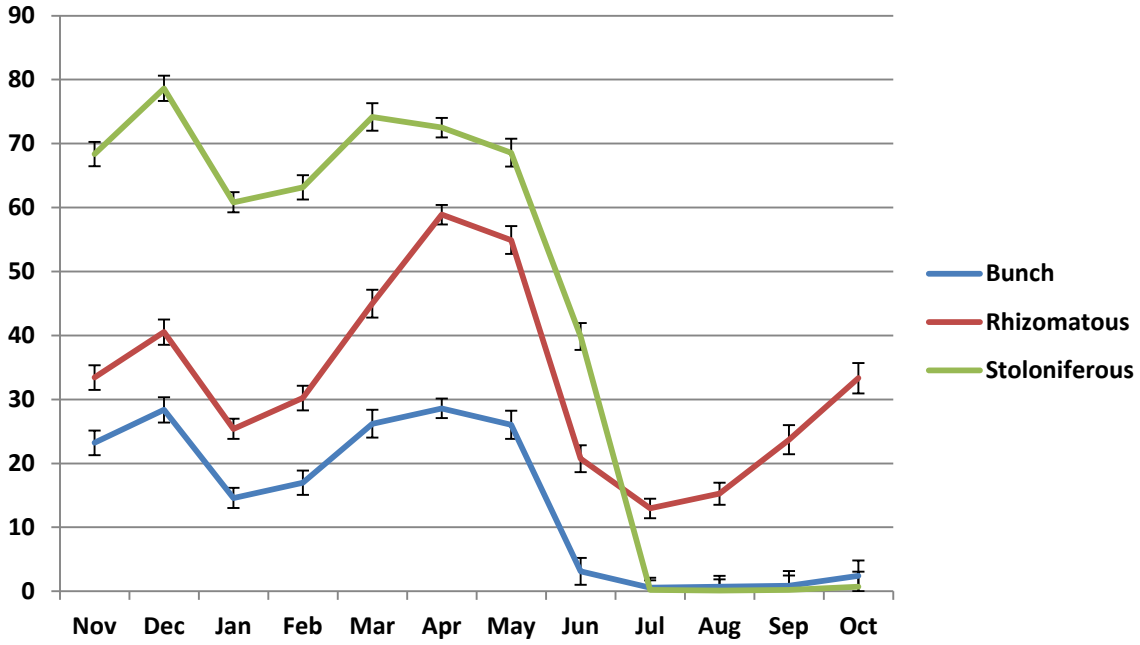


Figure E-1. Percent green cover of growth habit groups over a one year period in 2009-2010 at Knoxville, TN.
†Error bars represent LSD(0.05).

Appendix F

Greenhouse hybridizations

Materials and Methods

In June 2009, 20 different USDA accessions of Texas bluegrass were seeded into a peat based medium. After germination, 10 seedlings were selected from each of the 20 accessions and transplanted into individual pots. In August of 2009, accessions of several other *Poa* species were seeded. Seedlings were transplanted into pots with as many as three seedlings planted per pot. Pots of Texas bluegrass and all other species were maintained under greenhouse conditions until pots were moved outside for natural vernalization in November 2009. These pots remained outside until early February 2010, when one plant from each of the 20 Texas bluegrass accessions were moved back into the greenhouse under a 14-hour day length and an average daily temperature of 24°C. This continued for each subsequent week until all 10 plants of each accession were brought into the greenhouse. During the fifth week, all other species were brought in to the greenhouse. The dioecious Texas bluegrass plants were monitored daily during maturity and plants identified as males were discarded. Plants identified as females were retained for hybridization attempts. The maternal female Texas bluegrass plants were paired with other species suspected of reaching anthesis at the same time. A total of three different paternal species were paired with the Texas bluegrass females, including *P.* dusenii, *P. arida*, and *P. sierbiana*. Single immature inflorescences of the aforementioned species were covered with dialysis tubing, along with the inflorescence of the Texas bluegrass plant, which was situated below the intended paternal species. This resulted in one attempted cross for each paternal species. After anthesis and maturation, seeds of the maternal Texas bluegrass plants were harvested and stored at 4°C for 3 months, after which time they were sown in the greenhouse.

Results and Discussion

Of the three attempted hybrids, only one produced seed that germinated. For the two that had no progeny, this may be explained by an incompatibility mechanism such as differing numbers of chromosomes, Additionally, this indicated that the dialysis tubing was successful in preventing fertilization by foreign pollen sources. The paternal species that resulted in the successful hybrid was *P. dusenii*. The approximately 100 plants produced from this one panicle appeared uniform and healthy, and were included as treatments in the research trial described in Chapter II where these plants were tested as a single entry in the trial. An additional plant was kept in the greenhouse for further evaluation, along with samples of the parent plants that were of the same age. Visual observations of the plant showed that it was intermediate between the two parent species. The hybrid plant had a leaf texture that was in between those of the two parent species (Figure B.3)

During 2010 through 2012, data were collected on percent green cover in a two-year trial initiated in 2010, where several species of *Poa* were evaluated. Percent green cover comparisons of the hybrid with its maternal and paternal species, as well Kentucky bluegrass and a Texas-Kentucky hybrid. Although comparisons were made with the parent species, it is important to realize that these were not the actual plants used as parents of the hybrid and these data were only a general comparison (Figure B.1). These data showed that the hybrid was typically intermediate between the two parent species, and did not perform as well as the Kentucky bluegrass and the Kentucky Texas hybrid. The 2010-2011 trial was allowed to grow to maturity and produce seed in the summer of 2012. Mature plant heights were measured and no significant differences were found in height between the maternal Texas bluegrass and the hybrid. The hybrid was significantly taller than its paternal species (Figure B.2).

Figures

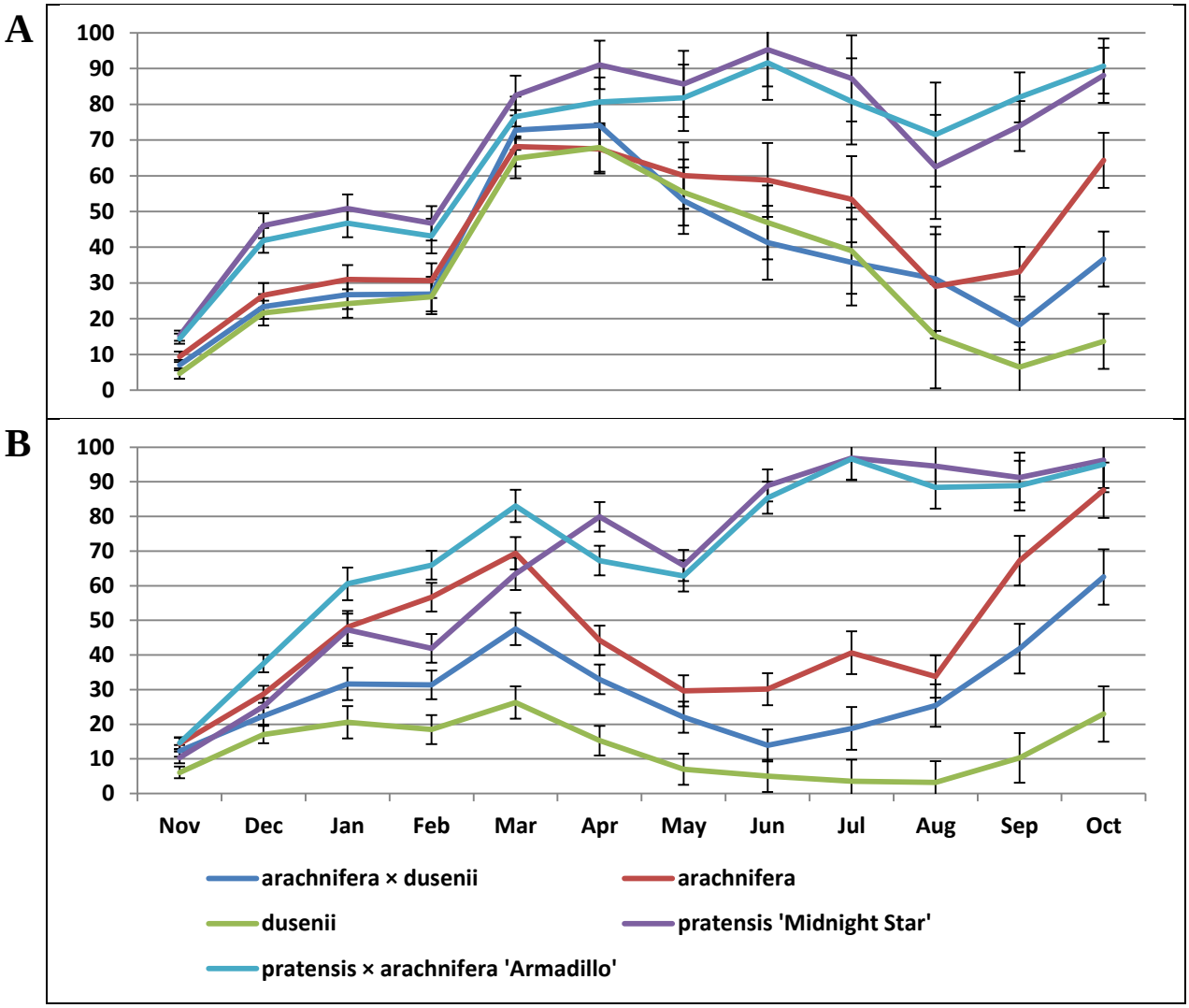


Figure F.1. Percent green cover of selected species and cultivars in comparison to the hybrid P. arachnifera × dusenii in 2010-2011 (A) and 2011-2012 (B)
†The *P. arachnifera* and *P. dusenii* represented the species and were not the actual parent plants.

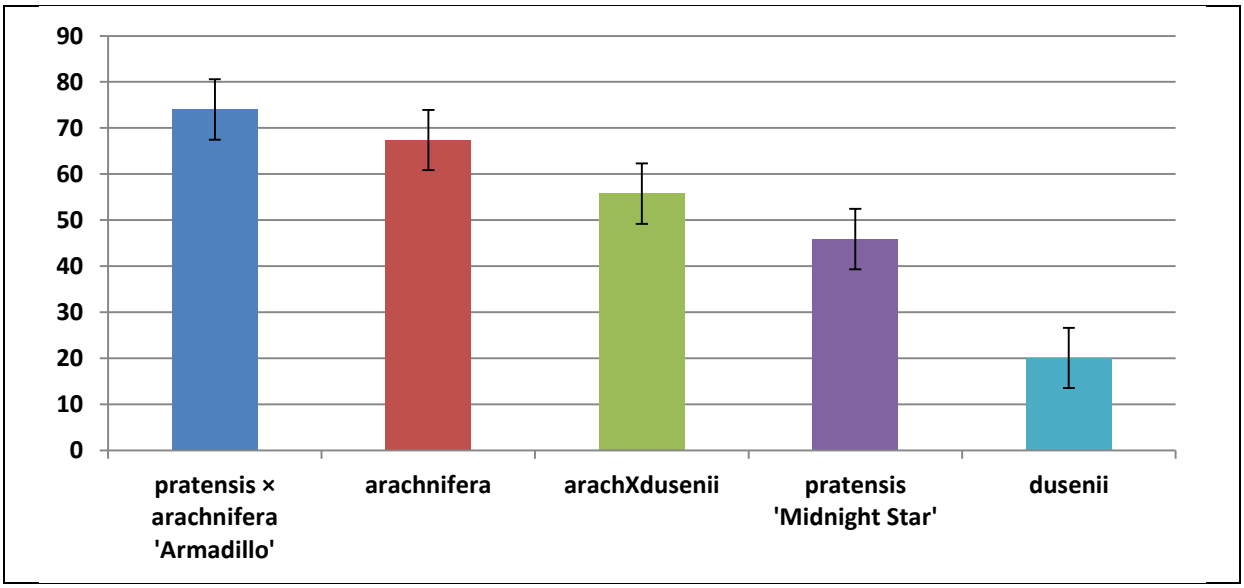


Figure F.2. Mature height in cm of selected species and cultivars in comparison to the hybrid P. *arachnifera* × *dusenii*.

†*P. arachnifera* and *P. dusenii* represented these species and were not the actual parents of the hybrid.



Figure F.3. *P. arachnifera* left, *P. arachnifera* × *P. dusenii* center, and *P. dusenii* right.
†The plants of *P. arachnifera* and *P. dusenii* represent the species and were not the actual parents used in the cross.

Appendix G

Un-mown characteristics

As part of the preliminary trial described in Appendix A, an additional trial was planted adjacent to that trial that differed only in that no mowing was performed. This trial was performed to study characteristics of these grasses when left un-mown. The characteristics measured included; maturity dates recorded as the first day of the year when flowers were visible; mature height, which was measured as height from the ground to top of 12 randomly sampled flowering culms; the number of flowering culms per plot; and the dried biomass in grams per plot (Table C.1.)

Tables

Table E.1. Un-mown characteristics of *Poa* species and cultivars in 2010 in Knoxville, TN.

Species/Cultivar	Identifier	Biomass	Height	Culms	Maturity
		g plot^{-1}	cm	# plot^{-1}	day
P. alpina	PI 540425	20	15	ND	112
P. trivialis	WSGC	138	61	782	132
P. annua	CWA	27	28	ND	48
P. arachnifera	W6 17703	77	57	57	115
P. arctica	PI 236901	42	19	ND	103
P. arida	PI 578806	87	63	298	120
P. chaixii	W6 28274	25	58	2	124
P. cita	W6 22519	353	83	22	145
P. colensoi	W6 22527	28	39	22	111
P. compressa	CC	171	51	902	153
P. dusenii	PI 598733	13	34	39	102
P. flexuosa	W6 25683	19	39	70	139
P. erinacea	PI 204263	263	ND	367	157
P. gilgiana	PI 478581	167	73	12	139
P. hybrida	PI 249765	95	87	15	140
P. iridifolia	PI 154882	38	22	427	140
P. lanigera	PI 477105	238	74	229	124
P. lanuginosa	PI 269649	17	ND	40	124
P. ligularis	PI 284255	12	22	40	107
P. ligulata	PI 517033	75	42	182	121
P. lindsayi	PI 237163	ND	ND	ND	ND
P. longifolia	PI 380991	95	62	265	126
P. marcantha	W6 26828	17	28	ND	ND
P. maniototo	PI 237164	113	50	389	124
P. nemoralis	PI 442544	256	66	1012	116
P. nervosa	PI 232352	102	22	496	97
P. palustris	PI 274644	122	72	153	ND
P. pratensis	GC	220	73	570	119
P. pratensis	KenBlue	180	75	407	119
P. pratensis	Midnight Star	78	42	476	124
P. pratensis X arachnifera	Thermal Blue	140	53	492	122
P. pratensis X arachnifera	Armadillo	243	75	664	119
P. poecila	W6 13851	ND	ND	ND	ND
P. psilolepis	W6 23610	55	65	110	139
P. secunda	PI 578850	301	77	488	124
P. sieberiana	PI 282383	477	96	356	141
P. stiriaca	PI 283964	218	60	936	153

P. supina	**Supranova**	**9**	**29**	**ND**	**71**

Table E.1. Continued

Species/Cultivar	Identifier	Biomass	Height	Culms	Maturity
P. trivialis	**CR-91**	**102**	**47**	**968**	**131**
P. trivialis	**CCC**	**200**	**31**	**737**	**103**
$LSD_{(0.05)}$		**68**	**9**	**142**	**16**

Conclusions

These studies confirm that there are other *Poa* species that perform similarly or better than the traditional turfgrass *Poa* species in the transition zone under typical turfgrass management. Where a permanent perennial turf is desired the rhizomatous species as a group are the best choice because of their ability to maintain more percent green cover in summer in comparison to the stoloniferous and bunch type groups. Within the rhizomatous group the *P. pratensis* entries performed well as expected. However, *P. stiriaca* and *P. maniototo*, two species that have not previously been tested in turfgrass application, are two species that perfomed as well or in some cases better than *P. pratensis.* Further research is needed to test these species under differing climates, uses, and management styles to further determine their applicability as turfgrasses.

The stoloniferous group, representing *P. trivialis* and *P. supina*, as a whole displayed the fastest establishment. However, in hot summers these species tend to lose green cover and eventually complete death occurs. *P. trivialis* is used for winter overseeding of bermudagrass where it is treated as an annual. The results of this trial indicate differences among the entries of *P. trivialis* that suggest variation in the spring transition can be expected. Specifically, improved cultivars maintained green cover later into the summer and can behave as a perennial, whereas a wild type is more likely lose cover earlier and behave as an annual. *P. supina* performed similar to the improved types of *P. trivialis*.

The bunch type group as a whole performed poorly in comparison to the rhizomatous and stoloniferous groups. However, it is important to realize that these species were at a disadvantage

in comparison to the other growth habits that have the ability to spread and fill in a given area and thus produce more green cover. In terms of a permanent turf *P. lanigera* and *P. sierbiana* showed the most promise by maintaining more green cover though the summer than the other bunch type entries. Further testing with these species planted in a higher density, either vegetatively or seeded, is warranted. *Poa annua* established and performed well until early to mid-summer. This indicates a potential use of this species as a temporary turf for winter overseeding of bermudagrass. However, this species is not recommended because of invasive potential and prolific seed production. *P. longifolia* is second species that displayed characteristics that indicate potential usefulness as a overseeding species because of its rapid establishment and high cover during winter.

In terms of *Poa* species, for temporary turfs used for winter overseeding of bermudagrass, *P. trivialis* and *Lolium perenne* are the best choice for putting greens. However, it is recommended that both of this species be removed via herbicides. *P. supina* and *P.nemoralis* were also tested. *P. supina* was found to be too aggressive and resulted in low percentages of bermudagrass well into the summer that resulted in poor performance in summer regardless of natural or chemical transition. *P. nemoralis* displayed acceptable cover in one year but not the other. In the year it provided cover the natural transition was superior to all other treatments except the non-overseeded control. However, due to the inconsistencies with this species it is not recommended.

On fairways and sports fields *L. perenne* and *L.perenne* × *L. multiflorum* provided the highest cover throughout the winter season. *L. perenne*, when treated with a herbicide, provided the best transition characteristics and is therefore recommended for these applications. *P. nemoralis* did not provide an acceptable level of cover.

Vita

Lucas Freshour was born in Greeneville, TN on July 21, 1980. He grew up in Greeneville and the surrounding area and attended high school at Chuckey-Doak High School, graduating in 1998. After graduation he entered the work force, working in various different manufacturing facilities. After becoming interested in the turfgrass field he enrolled at Walters State Community College and completed an Associate of Applied Science degree in Turfgrass Science in the spring of 2005. He then went on to pursue his Bachelors of Science with a concentration in Turfgrass management, which he completed in the fall of 2008. In spring of 2009 Lucas accepted a graduate research position under the direction of John Sorochan. Upon graduation Lucas plans to work in industry in position he accepted with the Scotts company.