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Competitive ability of creeping bentgrass cultivars and their potential for renovating existing putting greens through interseeding

by

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“The true joy of life is the trip. The station is only a dream. It constantly outdistances us.”

From “The Station” by Robert Hastings

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Abstract

Golf is a key industry that generates jobs, commerce, economic development, and tax revenues for communities throughout the United States. A survey conducted in Iowa showed that golf generated 769.6 million dollars in total economic output while providing over 10,000 jobs to the state. The integrity of turf swards is routinely compromised by invasion from annual bluegrass (*Poa annua* L.), and higher levels of inputs are needed to maintain acceptable quality. New cultivars of creeping bentgrass (*Agrostis stolonifera* L.) offer improved agronomic characteristics and are better able to resist invasion from annual bluegrass. The overall objective of this research was to evaluate the culture of creeping bentgrass cultivars and assess the practice of interseeding as a means of converting existing putting greens to recently developed cultivars.

Recently developed cultivars of creeping bentgrass possess finer leaf texture and more upright leaf architecture. These morphological characteristics allow for increased shoot densities. Results from our research suggest that a greater number of shoots hinders the plant's ability to recuperate from injury. Our work also demonstrated that cultivars of creeping bentgrass displayed varying lateral spread rates and stolon and internode lengths. Growth analysis revealed that low shoot density cultivars allocate more dry matter into stolons than leaves. Difference in dry matter partitioning could partially explain differences in lateral spread among cultivars of creeping bentgrass. Higher shoot density cultivars may be better suited for areas where low populations of annual bluegrass are desired. Alternatively, lower shoot density cultivars may be better suited for areas where mechanical damage is frequent and recuperative potential is important. The vegetative characteristics should be matched with desired site usage requirements for optimum performance when selecting cultivars of creeping bentgrass.

The ability of established facilities to utilize recently developed cultivars is limited as few conversion methods exist. Current renovation methods require a facility to incur significant financial loss. Interseeding has been proposed as an alternative conversion method with less financial burden. Germination studies showed that recently developed cultivars of creeping bentgrass possess greater vigor and may be better suited for interseeding compared with older cultivars. Our interseeding studies suggest that the level of maintenance and overall quality of the putting surface influence the success of conversion. Conversion through interseeding in this study was not successful when the plots were maintained under golf course conditions. Interseeding was only successful when conditions of the putting green were allowed to deteriorate below acceptable levels. The overall conditioning of the putting surface in order to permit interseeding needs to be weighed against the cost of a traditional conversion when deciding on a renovation program.

GENERAL INTRODUCTION

Golf is much more than an enjoyable pastime – it is a major industry that generates jobs, commerce, economic development, and tax revenues for communities throughout the country. A 2005 study showed that golf is a $76 billion dollar industry that generates $195 billion dollars in total economic input towards the national economy (Anonymous, 2008). In addition, a 2008 study found that the nearly 16,000 golf courses across the U.S. generated 483,649 jobs nationwide (Haydu et al., 2008). Despite this impact, the majority of the public knows little about the economic impact of the sport and the turfgrass industry. One reason for this could be the lack of published economic information characterizing the U.S. turfgrass economy.

The turfgrass industry is included under the category of “specialty crop” within the U.S. Department of Agriculture (USDA). While detailed economic information has been collected for more traditional agricultural commodities for decades, it has not been customary for economic data to be collected for the myriad of specialty crops being produced. However, vast growth in many of these specialty crop industries over the last quarter century has prompted the USDA to begin to gather data, albeit limited (Haydu et al., 2008).

To supplement governmental data, several national and state associations have initiated studies to document the economic significance of the turfgrass industry. Such data may be useful for decisions regarding resource allocation, governmental support, and regulatory actions that limit chemicals and fertilizers. In addition, growing public concern over actual and perceived environmental issues within agriculture-related fields will need to be addressed with scientific data displaying the importance of these industries.

The first such national study was published in 2002 by Golf 20/20, which is an initiative of the World Golf Foundation (Anonymous, 2002). Other turfgrass associations have followed suit with studies to demonstrate the economic impact of turfgrass at the state level. In total, economic impact studies have been conducted in 25 states. The results show the economic impact from turfgrass industries ranged from approximately 1 billion to 5 billion annually per state (Missouri Valley Turfgrass Association, 1998; Phipps, 1999; Bailey, 2000; Campbell, 2001; Howard, 2004). Golf is an important component of the turfgrass industry by accounting for a 44% share of the economic impact (Haydu et al., 2008).

Locally, the state of Iowa has the third highest number of holes per capita, which generate approximately 770 million dollars in total economic input and contributes over 10,000 jobs to the state (Chan et al., 2007). To put this in perspective, after corn and soybean production, the direct revenues generated by Iowa's golf industries exceed the income earned from the sale of all other crops in the state combined (USDA, 2006).

While these studies demonstrate the economic importance of the turfgrass industry, the positive impact of golf courses on communities relies on these facilities remaining profitable. Few turfgrass species can tolerate the intense management regimes required to maintain high value areas such as greens, tees, and fairways. Creeping bentgrass (*Agrostis stolonifera* L.) is well-suited to these locations but is routinely compromised by invasion from annual bluegrass (*Poa annua* L.). Annual bluegrass can provide an acceptable playing surface when properly maintained, but this often requires extensive chemical inputs (Grant and Rossi, 2005).

Dissertation Organization

The work in this dissertation includes both 1) scientific research and 2) creative work. The dissertation is organized into six chapters. The first chapter includes a detailed review of the literature on the dilemma turf practitioners face managing annual bluegrass, the development of creeping bentgrass for use as a turfgrass, traditional renovation procedures, the invasion process, and strategies for successful interseeding. The second chapter is a manuscript to be submitted to *HortScience* that investigates the effect of shoot density on the recuperative potential of cultivars of creeping bentgrass. The third chapter is a manuscript to be submitted to *Crop Science* that examines differences in growth rates of cultivars of creeping bentgrass and seeks to determine the underlying cause for the variation. The fourth chapter is a manuscript to be submitted to *Crop Science* that evaluates the germination characteristics among cultivars of creeping bentgrass and determines the potential for renovating existing creeping bentgrass putting greens using invasive ecology strategies. The fifth chapter is a manuscript accepted by the *Journal of Extension* discussing the use of blogs as a means of distributing quick, timely updates for professionals in the turfgrass industry. The sixth chapter is a review of the results and general conclusions drawn from the manuscripts.

Literature Review

Annual bluegrass as an inhabitant of golf course turf

Annual bluegrass is a cool-season grass found in all environments around the world associated with human activity (Warwick and Briggs, 1978). This ubiquitous species has been listed as one of the five most common plant species in the world (Fenner, 1985) and is particularly problematic on golf courses where uniformity, season-long consistency, wear tolerance and the aesthetic quality of the turf are important. Annual bluegrass generally tolerates a narrower range of environmental conditions than desirable turf species with which it competes making it more susceptible to environmental stresses and disease (Beard, 1978; Peel, 1982; Itoh et al., 1995). It also flowers heavily in the spring giving turf a yellow color and uneven texture, which are unattractive to the aesthetically oriented golf industry. Annual bluegrass creates an interesting dilemma for golf courses since most turf managers consider it a weed but are forced to manage for its survival since control of the species is so difficult. The introduction and colonization of annual bluegrass is generally regarded as an inevitable event in golf turf in climates that will support its growth. Annual bluegrass is particularly abundant on golf courses in northern temperate climates and along the coasts where temperatures are moderate and moisture abundant. Some of the most famous golf courses, such as Pebble Beach on California's Monterey Peninsula, are primarily managing annual bluegrass.

On southern golf courses annual bluegrass primarily exists as a winter annual germinating in late summer or fall, persisting through winter and producing seed before death in summer (Christians, 2007; Beard, 1973). This winter annual life history maximizes its survival under conditions of high heat and humidity. In northern climates, annual bluegrass appears to exist primarily as a perennial on golf courses. There is some debate as to whether annual biotypes also exist since well established annual bluegrass exists in all golf course environments throughout the growing season. There is speculation that annual populations appear to be perennial due to continual replacement from seed throughout the growing season (Lush, 1988).

Annual bluegrass is able to persist on golf courses for a number of reasons typical of colonizing species. The species' greatest survival characteristic is the production of large numbers of seed that remain viable for several years (Beard, 1973; Beard, 1978; Lush, 1990). The seed bank has been estimated to be as high as 210,000 seeds per square meter (Lush, 1988). Annual bluegrass will germinate whenever conditions are favorable and the constant availability of seed ensures its survival. Annual bluegrass is particularly invasive at low mowing heights such as those found on golf course greens, tees, and fairways (Christians, 2007). This unique ability to produce seed under close mowing gives annual bluegrass the ability to adapt through natural selection to a range of growing conditions created by different intensities of management. These characteristics have led some breeders to develop improved cultivars that could be produced and sold as commercial turfgrasses (Christians, 2007). However, it is unlikely that these cultivars will be able to stop wild types of annual bluegrass from invading turf swards because of the countless number of biotypes that exist.

In the golf industry where pure and genetically stable cultivars of desirable species are used in monocultures to meet specific quality-of-play standards, annual bluegrass stands out as an anomaly with its ability to assume various forms adapted to specific environments. Roundup Ready® creeping bentgrass is one possibility for controlling annual bluegrass populations on golf courses but this technology is still awaiting deregulation from the USDA and may not be available for use. Recent work has included developing improved varieties of creeping better able to withstand invasion from annual bluegrass.

The bentgrasses and advances in creeping bentgrass cultivars

The bentgrasses are made up of a group of approximately 200 species (Hitchcock, 1951) believed to have originated from Western Europe (Harlan, 1992). Only five species have been adapted for use in turfgrass: creeping bentgrass, velvet bentgrass, colonial bentgrass, dryland bentgrass, and redtop bentgrass. Of these five species, creeping bentgrass is the most widely used for sport. There are discrepancies in the literature concerning the nomenclature of this species. Early literature tends to reference creeping bentgrass as *Agrostis maritime* Lam. (Dickinson, 1930). Hitchcock (1951) referred to it as *Agrostis palustris* Huds., which he considered more stoloniferous than *Agrostis stolonifera* L. More recently, the name *Agrostis stolonifera* L. has become the accepted nomenclature for this species.

Creeping bentgrass forms a dense, uniform, fine-textured playing surface ideal for the play of golf. It is perhaps best known for its ability to form a dense, close knit canopy at mowing heights as low as 0.254 cm. It is the predominant species grown on golf course putting greens in temperate regions of the U.S. (Christians, 2007). Its use on fairways is also increasing because of its superior growth characteristics and playability (Fry and Butler, 1989; Reicher and Hardebeck, 2002). Voids and divots in creeping bentgrass swards are quickly repaired because of its aggressive lateral growth (Fagerness et al., 2000).

Bentgrass was first introduced into the U.S. during the colonial period. These bentgrasses, referred to as “south German mixed bentgrass,” were a blend of colonial bentgrass (*Agrostis capillaris* L.), velvet bentgrass (*Agrostis canina* L.), and creeping bentgrass (Duich, 1985). Over time, the mixture of grasses would segregate into patches primarily of creeping bentgrass and greens established with these mixtures displayed a mottled appearance because of variation in color, texture, and growth between the species. However, these patches or clones, presented an opportunity for the selection of improved strains and provided the foundation for future breeding programs. Desirable plants were collected from the original south German bentgrass mixtures and maintained by the United States Golf Association Green Section at the Arlington Turf Gardens in Virginia (Warnke, 2003). Some of these clones became what were known as the C series creeping bentgrasses (Duich, 1985). Metropolitan (C-51) was the first cultivar released and was eventually followed by Arlington (C-1), Cohansey (C-7), Toronto (C-15), Congressional (C-19), Collins (C-27), Washington (C-50), Old Orchard (C-52), and Dahlgreen (C-115). These vegetative cultivars provided improved uniformity and consistency but C-15 was susceptible to bacterial wilt and seeded varieties would eventually be developed. Meanwhile, collections of seed from indigenous plants of creeping bentgrass growing in tidal flatlands near Coos Bay, Oregon became known as Seaside creeping bentgrass (Duich, 1985). Seaside was the first seeded variety available other than the original south German mixed bentgrass. Seaside exhibited great variation between individual plants and lacked the vigorous growth of the C series bentgrass. As a result, most putting greens were established by vegetative means until the 1950's when the desire to expand the use of creeping bentgrass as a fairway turf led breeders to develop acceptable seeded cultivars.

A major breakthrough arrived when Dr. H.B. Musser developed the first improved seeded cultivar of creeping bentgrass, which was released in 1955 as Penncross. The seed was produced by the random crossing of three vegetatively propagated strains. Penncross provided more consistent performance than the existing vegetative strains and for decades was the only improved seeded cultivar available. Long after its release, Penncross set the standard for putting green quality and it continued to do so well into the 1990's (Shearman, 2006). Its main downfall, however, is its susceptibility to invasion from annual bluegrass.

The passage of the Plant Variety Protection Act (PVPA) in 1970 spurred the development of many novel turfgrass cultivars (Brilman, 2005). In the late 1980's and early 1990's, many improved cultivars of creeping bentgrass such as L-93 and the Penn series cultivars (G-1, G-2, G-6, and A-1, A-2, A-4) were released (NTEP, 2004). These new cultivars offer many agronomic traits desirable on putting greens, compared to the traditional cultivars. For example, recently developed cultivars have improved disease resistance, have improved heat and drought tolerance, and are better suited to handle traffic (Bonos et al., 2001). In addition, the Penn series cultivars produce vertical shoot growth with greater shoot densities and narrower leaf blades, which has resulted in annual bluegrass invasion (Croce et al. 1998). Plant breeders have increased the shoot density by selecting for shorter internode lengths (Cattani, et al., 1996). While it is agreed that the recently developed cultivars of creeping bentgrass provide superior playing conditions and are more competitive against annual bluegrass, there are concerns over the ability of these recently developed cultivars to spread laterally. The canopy of creeping bentgrass is routinely compromised by divoting from golf clubs and by ball marks from golf balls. Injury from divots and ball marks can negatively influence the appearance and playability of creeping bentgrass swards, and divot and ball mark management programs are often an integral component of golf course management. Although creeping bentgrass is a widely used turf in temperate regions of the United States, research investigating differences in the recuperative potential among cultivars is lacking. Furthermore, an understanding of the vegetative growth characteristics would aid in selecting for improved turf characteristics in germplasm screening programs. Despite these concerns, recently developed cultivars of creeping bentgrass are viewed as superior and many turfgrass practitioners would like to utilize these improved cultivars at their facilities.

Traditional renovation and succession of plant communities

Current methods of converting turf to a new species or cultivar involve killing the area with a non-selective herbicide or soil sterilant before re-establishment. This method has proven to be reliable but requires that play be restricted from the golf course and many facilities are not able to assume the burden of significant loss in revenue. There are currently no methods for converting established turf swards to different cultivars without taking the area out of play. As a result, facilities are relegated to managing the older cultivars of creeping bentgrass that often times require larger amounts of inputs in order to maintain acceptable quality. Overseeding, interseeding, and intraseeding are alternative, less disruptive conversion methods that are used to alter the relative composition of plant communities.

The terms overseeding, interseeding, and intraseeding are commonly used interchangeably in the literature but are different procedures. Overseeding, or winter overseeding, is the introduction of seed of a cool-season (C_3) grass species into the canopy of a dormant warm-season (C_4) species (Beard, 2005). This process is used regularly in the southern regions of the United States and is often very successful because the two grass species possess distinct seasonal growth patterns. Interseeding is the introduction of seed into an established population of a different species with similar adaptation. Seeding creeping bentgrass into annual bluegrass would be an example of interseeding. Intraseeding is the introduction of seed into an established population of the same species (Beard, 2005) such as the introduction of an improved cultivar of creeping bentgrass into Penncross.

Interseeding and intraseeding have proven much more difficult because of competition from existing grasses that possess similar growth patterns (Egens, 1979).

Attempts at shifting the population of putting greens and other turf areas via interseeding have been tried in the past and there is clear disagreement between academia and industry concerning the success of this conversion technique. A number of individuals within academia contend the process is without merit (Cattani, 2001; Cattani and Nowak, 2001; Kendrick and Danneberger, 2005; Rossi, 1999; Sweeney and Danneberger, 1998; Kendrick and Danneberger, 2002; Gaussoin and Branham, 1989). Yet, many researchers from industry and turfgrass practitioners claim to find value in the practice (Brilman, 2009; Miller, 2004; Ross, 2006; Brede, 2006; Brede, 2007).

The controversy surrounding the benefit of seeding into existing turf canopies of creeping bentgrass dates back to the post World War II era when an increase in rounds left turf managers searching for a method of increasing the amount of creeping bentgrass on golf greens (Miller, 2004). During the 1920's and 1930's, seeding into existing greens was the norm before falling out of favor. The issue surfaced again in the May issue of the 1974 USGA Green Section Record that introduced the idea of topdressing as a method to improve the overall turfgrass quality of creeping bentgrass putting greens. The original program called for a mixture of sand, nutrients, and bentgrass seed to be applied every three weeks (Madison, 1974). At this time, Penncross had been released and turf practitioners were interested in utilizing it since it had improved agronomic characteristics compared to the south German mixed bentgrasses and Seaside.

The present day situation is very similar to the one faced in the past. Recently developed cultivars with improved agronomic characteristics are brought to market but the time and cost of traditional conversion practices prevents many facilities from utilizing these cultivars. Studies conducted with the hope of developing a non-disruptive method of converting established turf areas have resulted in limited success. Gaussoin and Branham (1989) were able to establish no more than 8% creeping bentgrass despite an alteration in management practices. Reicher and Hardebeck (2002) were able to convert 35% of a perennial ryegrass sward to creeping bentgrass over a three year period, while seeding into a polystand of annual bluegrass, perennial ryegrass, and Kentucky bluegrass resulted in no more than 3% creeping bentgrass. Kendrick and Danneberger (2002) and Dant et al. (2005) indicated that the effectiveness of the intraseeding techniques was quite limited unless competition from the existing turf was removed. Cattani and Nowak (2001) found that establishment of L-93 in an existing sward of Penncross was only successful when the overall condition of the existing turf was compromised to the extent that it would be unplayable.

The difficultly of establishing new cultivars is often credited to the inability of the seedlings to compete with mature plants for soil moisture and nutrients (Cattani, 2001; Cook and Ratcliff, 1984; Snaydon and Howe, 1986). Early seedling growth relies solely on seed reserves until the new plant emerges above the soil surface (Whalley, et al., 1966). Once the seed reserves are exhausted the new plant is left to compete against established plants for limited resources. Because of these challenges, establishing creeping bentgrass in an existing putting green while the turf is in play, continues to be an elusive goal of many golf course superintendents. The premise of interseeding is to introduce a desirable plant species or cultivar into an established turf sward. The goal is that over a period of time the introduced plant will become a major component of the sward. Therefore, interseeding could be viewed as a controlled invasion, and a better understanding of the invasion process could lead to strategies that improve the effectiveness of interseeding.

The invasion process

The invasion process can be divided into three phases: introduction, colonization, and naturalization (Groves, 1986; Cousens and Mortimer, 1995). The introduction phase involves the dispersal of plants into a community. Seedlings from newly introduced seed must compete with established plants and plant invasions are most likely to fail during this stage. The ‘Rules of Tens’ is an example commonly used to portray the small chance of success during the introduction phase. The rules states that only 10% of all introduced species become established and then only 10% of the established species are adapted enough to colonize and become pests (Williamson, 1996). Disturbance is a major factor during the introduction phase and often accompanies the establishment of introduced plants (Harper, 1977) along with propagule pressure. Propagule pressure describes the probability that seed will disperse and will become established, and survive in a suitable place and in sufficient numbers to maintain a species (Williamson, 1996). It takes into account the absolute number of individuals involved in any one release event and the number of release events that occur over time. Propagule pressure has been found to be an important factor influencing the persistence of introduced species (Lockwood, 2005). The colonization phase occurs when plants that were part of the founding population reproduce and increase in size and number. Plants entering the colonization phase often experience a prolonged lag time before rapid, exponential expansion is realized. The length of time spent in the lag phase and the rate of increase during exponential growth is partially dictated by environmental factors and the fitness of the introduced species (Crooks and Soule, 1999). Plants in the naturalization phase become self-perpetuating within the community. Growth in the naturalization phase slows and eventually stabilizes as niche occupancy and available resources limit the rate of spread.

The process of changing the composition of plant communities is a matter of the niche and resource requirements of the plant species and the growing conditions present in the community, or ecosystem (Danneberger, 1997). Sunlight, oxygen, and soil moisture and nutrients are examples of resources. The physical characteristics of the soil media and management practices such as mowing practices, irrigation regimes, cultivation practices, and utilization of plant protectants are examples of growing conditions. Each species within a community will have its own niche. The niche would be the range of resources and conditions that each of these plants needs to grow and reproduce. Invasive plants tend to be highly plastic and are able to adapt to a wide range of environmental conditions resulting in a rather large niche. However, when another competing species is introduced, the availability of resources can be dramatically altered. These conditions describe the realized niche, or the range of resources and conditions needed for a plant species to survive when competition is present. Two species will coexist only if there is enough differentiation in their requirements for resources and conditions. Annual bluegrass commonly coexists with creeping bentgrass on golf courses. However, if adequate differentiation is not present, one species will be driven from the habitat.

Turfgrass practitioners will often alter management practices in order to alter the environment and grant a competitive advantage to the newly establishing seedlings. One method of reducing the competitiveness from the existing turf is through a stress event. A myriad of cultural factors designed to harm the existing turf and provide a competitive advantage to the seedlings is often employed. Varying irrigation (Cattani, 2001; Gaussoin and Branham, 1989) and fertility regimes (Eggens and Wright, 1985), scalping the existing canopy (Kendrick and Danneberger, 2002), applying mechanical disruption, (Engelke and Kenworthy, 2001) and applying plant growth regulators (Gaussoin and Branham, 1989; Bowman, 1997) have all been utilized in past studies. While some of these cultural practices have shown promise, applying too much stress may result in unrecoverable damage to the turf, and the area will need to be taken out of play in order to allow time for recovery. Successful conversion therefore, depends on a multitude of factors.

The principles of invasion ecology create an interesting dilemma for turf practitioners attempting to change the composition of established turf swards. The attraction of interseeding is the idea of establishing a new species or cultivar without a stoppage in play and loss in revenue. Past research demonstrates the success of seedlings sown into established plant communities increases as the level of disruption increases (Caruso, 1970). However, the level of disruption necessary for interseeding to be successful would likely disrupt the uniformity of the putting green and may not be tolerated by the clientele. A loss of play and a reduction in revenue would negate the benefit of interseeding.

Strategies for successful interseeding

While many techniques and strategies have been used to introduce seed into existing turf canopies, few have proven successful. More recently, Henry et al. (2005) investigated the effects of seeding date and interseeding cultivar on the establishment of creeping bentgrass into an annual bluegrass putting green. Their results suggested mid-summer seeding dates resulted in the greatest conversion and that recently released cultivars of creeping bentgrass are better suited for interseeding compared with traditional cultivars such as Penncross. Interseeding Penn A-4 and L-93 creeping bentgrass during the mid-summer months resulted in a 72% conversion over 12 months of annual bluegrass to creeping bentgrass. Interseeding these same cultivars during the fall months provided at best 17% conversion and interseeding Penncross mid-summer resulted in a 14% conversion. These results indicate that the time of seeding and the cultivar used are key factors influencing the success of interseeding.

Although fall is considered the best time of year to establish cool-season turfgrass species, it could be the worst time for interseeding, especially when annual bluegrass is a component of the turf sward. Annual bluegrass produces large amounts of seed during the fall season, and it will colonize disturbed areas given the opportunity (Kaminski and Dernoeden, 2002; Murphy, 1999). In contrast, annual bluegrass tends to be less competitive during the warm summer months. Brede (1982) found that the growth of annual bluegrass nearly stops during the summer months when day lengths are at their maximum. In addition, Beard (1978) reported a substantial drop in the germination of annual bluegrass when soil temperatures exceeded 27° F. It is also possible that the limited success of conversion in past studies could be partially attributed to the use of Penncross. Cultivars of creeping bentgrass could vary in their germination characteristics and choosing cultivars with greater seedling vigor might increase the success of conversion. In addition, research has demonstrated that recently developed cultivars of creeping bentgrass are more competitive against annual bluegrass due to greater shoot densities (Beard, 2001).

Another strategy to increase the success of interseeding is to increase the seeding rate. The interseeding research conducted by Henry et al. (2005) utilized a seeding rate of 73 kg ha^{-1}, which is higher than normal. Christians (2007) recommends seeding rates of 12-49 kg ha^{-1} for creeping bentgrass. Kraft et al. (2004) reported greater success with above average seeding rates when renovating a perennial ryegrass fairway to Kentucky bluegrass (*Poa pratensis* L.), and Bigelow and Chalmers (1995) found that above average seeding rates increased the number of seedlings when interseeding into a mixed sward of creeping bentgrass and annual bluegrass. However, Madison (1966) and Rossi and Millett (1996) found that high seeding rates of creeping bentgrass result in immature plants that are susceptible to disease and death. While increasing seeding rates could have detrimental effects on the development and survival of seedlings, Minner et al. (2008) reported seeding at above average rates was beneficial when trying to establish turf cover when traffic is present.

Our overall research objectives are to 1) identify cultivars of creeping bentgrass that possess superior recuperative potential, 2) examine differences in establishment rates among cultivars and determine the factors associated with differential growth rates, 3) identify cultivars that possess superior germination characteristics, and 4) evaluate the effectiveness of renovating an existing creeping bentgrass putting green through interseeding.

Literature Cited

Anonymous. 2002. The golf economy report. Available at http://www.golf2020.com/Reports/2020_GER_F.pdf (verified 28 Mar. 2011). Arlington, Virginia: SRI International.

Anonymous. 2008. The 2005 Golf Economy Report. Available at http://www.golf2020.com/CurrentNews/EconomicImpact_2005GolfEconomyReport_3.pdf (verified 10 Jan. 2011). Arlington, Virginia: SRI International.

Bailey, A. 2000. Virginia turfgrass industry. Virginia Agricultural Statistics Service, Richmond, VA.

Bonos, S.A., K.A. Plumley, W.A. Meyer, J.A. Murphy, B.B. Clarke, W.K. Dickson, J.B. Clark, and D.A. Smith. 2001. Performance of bentgrass cultivars and selections in New Jersey turf trials. p. 1-21. *In* A.B. Gould (ed.) Rutgers turfgrass proceedings. Vol. 33. Rutgers Ctr. Turfgrass Sci, New Brunswick, N.J.

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J.B. 1978. Annual bluegrass (*Poa annua* L.): Description, adaptation, culture and control. Available at http://archive.lib.msu.edu/DMC/turfgrass/PDF/rr352.pdf (verified 28 Apr. 2010). Michigan State University, Agr. Exp. Stn., East Lansing, MI.

Beard, J.B. and H. Beard. 2005. Beard's turfgrass encyclopedia for golf courses, grounds, lawns, sports fields. East Lansing, MI: Michigan State University Press.

Beard, J.B., P. Croce, M. Mocioni, A. De Luca, and M. Volterrani. 2001. The competitive ability of thirteen *Agrostis stolonifera* cultivars to annual bluegrass. Int. Turfgrass Soc. Res. J. 9:828-831.

Bigelow, C.A. and D.R. Chalmers. 1995. Interseeding establishment of creeping bentgrass [*Agrostis stolonifera* var. *paustris* ‘Southshore’ (Huds.) Faw.] into an annual bluegrass (*Poa annua* L.) turfgrass system. p. 1-5. *In* Va. Tech Turfgrass and Hort. Field Days and Va. Turf and Landscape Conf. and Trade Show Proc. Va. Polytechnic Inst. and State Univ. and Va. Turfgrass Council, Blackburg, VA.

Bonos, S.A., K.A. Plumley, W.A. Meyer, J.A. Murphy, B.B. Clarke, W.K. Dickson, J.B. Clark, and D.A. Smith. 2001. Performance of bentgrass cultivars and selections in New Jersey turf trials. p. 1-21. *In* A.B. Gould (ed.) Rutgers turfgrass proceedings. vol. 33. Rutgers Ctr. Turfgrass Sci, New Brunswick, N.J.

Bowman, D.C. 1997. Determining best management practices to convert a putting green from penncross to a new variety. 1997 USGA Turfgrass and Environ. Res. Summary.

Brede, A.D. 1982. Interaction of three turfgrass species. Ph.D. diss. Pennsylvania State Univ, University Park.

Brede, A.D. 2007. Alpha and T-1 creeping bentgrass, new cultivars for golf. HortScience. 42:1301-1302.

Brede, A.D. 2006. Four tips to interseed bentgrass into poa annua. Available at http://www.golfdom.com/plants/poa-annua/four-tips-interseed-bentgrass-poa-annua (verified 18 June 2010). Turfgrass Trends.

Brilman, L.A. 2005. Turfgrass breeding in the United States: Public and private, cool and warm season. Int. Turf. Soc. Res. J. 10:508-514.

Brilman, L.A. 2009. Bentgrass conversion – It can work! Available at http://www.sroseed.com/IdeasInPlay/PDF_articles/Bent_conv_SR.pdf (verified 10 Nov. 2010). Ideas In Play, Seed Research of Oregon.

Campbell, G.E. 2001. The Illinois green industry: Economic impact, structure, and characteristics. Dep. of Natural Res. and Environ. Sci. Series 2001-01. Univ. of Illinois, Champaign, IL.

Caruso, J.L. 1970. Early seedling survival of *Melilotus* in bluegrass sod. Ecology. 51:553-554.

Cattani, D.J., Miller, P.R., and Smith, S.R., Jr. 1996. Relationship of shoot morphology between seedlings and established turf in creeping bentgrass. Can. J. Plant Sci. 76:283-289.

Cattani, D.J. and J.N. Nowak. 2001. Interseeding in creeping bentgrass: A viable option or wishful thinking? Golf Course Manage. 69:49-54.

Cattani, D.J. 2001. Effect of turf competition on creeping bentgrass seedling establishment. Int. Turfgrass Soc. Res. J. 9:850-854.

Chan, N., J. Chase, K. Johnston, J. Ozawa, P. Ryan, and Y. Ophelia. 2007. The Iowa Golf Economy 2006. Available at http://www.iowagcsa.org/pdfformat/economicimpactreport.pdf (verified 10 Jan. 2011). Arlington, Virginia: SRI International.

Christians, N.E. 2007. Fundamentals of turfgrass management. 3rd ed. John Wiley & Sons, Hoboken, NJ.

Cook, S.J., and D. Ratcliff. 1984. A study of the effects of root and shoot competition on the growth of green panic (*Panicum maximum* var. *trichoglume*) seedlings in an existing grassland using root exclusion tubes. J. Appl. Ecol. 21:971-982.

Cousens, R. and M. Mortimer. 1995. Dynamics of Weed Populations. Cambridge University Press, New York.

Croce, P., M. Mocioni, and J.B. Beard. 1998. *Agrostis* cultivar characterizations for closely mowed putting greens in a Mediterranean climate. p. 668-678. *In* M.R. Farrally and A.J. Cochran (ed.) Science and golf III. Proc. 3rd World Sci. Congr. Golf, St. Andrews, U.K.

Crooks, J. and M.E. Soule. 1999. Lag times in population explosions of invasive species: Causes and implications. p. 103-125. *In* O.T. Sandlund, P.J. Schei, and A. Viken (ed.) Invasive species and biodiversity management. Kluwer Academic, Dordrecht, Netherlands.

Danneberger, K. 1997. Coming to terms with turfgrass ecology. Golf Course Manage. 65:56-59.

Dant L.A. 2005. Timing of Roundup® application critical when converting golf course turf to Roundup Ready® creeping bentgrass. Inter. Turf. Soc. Res. J. 10:333-338.

Duich, J.M. 1985. The bent grasses. Weeds Trees and Turf. January. p. 72-78. Harcourt Brace Jovanovick Publ., New York.

Dickinson, L.S. 1930. The Lawn. Orange Judd Publishing Company, Inc., New York, NY.

Eggens, J.L. 1979. The response of some Kentucky bluegrass cultivars to competitive stress from annual bluegrass. Can. J. Plant Sci. 59:1123-1128.

Eggens, J.L. and C.P.M. Wright. 1985. Nitrogen effects on monostands and polystands of annual bluegrass and creeping bentgrass. HortScience. 20:109-110.

Engelke, M.C. and K.E. Kenworthy. 2001. Interseeding: A new approach. Available at http://www.golfdom.com/turfgrass-maintenance/seed/interseeding-a-new-approach (verified 18 June 2010). Turfgrass Trends.

Fagerness, M.J., F.H. Yelverton, J. Isgrigg, III, and R.J. Cooper. 2000. Plant growth regulators and mowing height affect ball roll and quality of creeping bentgrass putting greens. HortScience. 35:755–759.

Fenner, M. 1985. Seed Ecology. Chapman and Hall, New York, NY.

Fry, J.D. and J.D. Butler. 1989. Annual bluegrass and creeping bentgrass evapotranspiration rates. HortScience. 24:269-271.

Gaussoin, R.E., and B.E. Branham. 1989. Influence of cultural factors on species dominance in a mixed stand of annual bluegrass/creeping bentgrass. Crop Sci. 29:480-484.

Grant, J., and F. Rossi. 2005. Evaluation of turf management systems with reduced chemical pesticide inputs. Turfgrass Environ. Res. Summ. p. 50.

Groves, R.J. 1986. Invasion of Mediterranean ecosystems by weeds. p. 129-145. *In* B. Dell, S.J.M. Hopkins, and B.B. Lamont (ed.) Resilience in Mediterranean-Type Ecosystems. Junk, Dordrecht, Netherlands.

Harlan, J.R. 1992. Crops and Man, 2nd ed. American Soc. of Agron., Madison, WI.

Harper, J.L. 1977. The population biology of plants. Academic, London.

Haydu, J.J. A.W. Hodges, and C.R. Hall. 2008. Estimating the Economic Impact of the U.S. Golf Course Industry: Challenges and Solutions. HortScience. 43:759-763.

Henry, G.M., S.E. Hart, and J.A. Murphy. 2005. Overseeding bentgrass species into existing stands of annual bluegrass. HortScience. 40:468-470.

Hitchcock, 1951. Manual of the Grasses of the United States. USDA Misc. Publ. 200. U.S. Gov. Print. Office, Washington, DC.

Howard, C.A. 2004. New York turfgrass survey. New York Agricultural Statistics Services, Albany, NY.

Itoh, M., H. Kobayashi and K. Ueki. 1995. Variation in morphology, reproductive allocation and propagule production of *Poa annua* L. in arable lands. Weed Research, Japan 40: 279-286.

Kaminski, J.A. and P.H. Dernoeden. 2002. Seasonal germination of annual bluegrass in Maryland. Agron. Abstr. 123-013 (CD Rom).

Kendrick, D. and K. Danneberger. 2005. Intraseeding to convert creeping bentgrass putting greens to new cultivars. Golf Course Manage. 73:143-146.

Kendrick, D.K. and T.K. Dannegerger. 2002. Lack of competitive success of an intraseeded creeping bentgrass cultivar into an established putting green. Crop Sci. 42:1615-1620.

Kraft, R.W., S.J. Keeley, and K. Su. 2004. Conversion of fairway-height perennial ryegrass turf to Kentucky bluegrass without nonselective herbicides. Agron. J. 96:576-579.

Lockwood, J.L., P. Cassey, and T. Backburn. 2005. The role of propagule pressure in explaining species invasions. Trends in Ecology and Evolution. 20:223-228.

Lush, Mary. 1990. Biology of *Poa annua* - the secret of success. New Zealand Turf Manage. J. p. 5-7.

Lush, W.M. 1988. Biology of *Poa annua* in a temperate zone golf putting green. II. The seed bank. J. of Appl. Ecol. 25:989-997.

Madison, J.H. 1966. Optimum rates of seeding turfgrasses. Agron. J. 58:441-443.

Madison, J.H., J.L. Paul, and W.B. Davis. 1974. Consider a new management program for greens. U.S. Golf Assn. Green Section Record. May. 12:16-18.

Miller, L. 2004. Intraseeding/Interseeding: What’s the hullabaloo? On Course 58:13-17.

Miltner, E.D., G.K. Stahnke, G.J. Rinehart, and P.A. Backman. 2005. Seeding of creeping bluegrass into existing golf course putting greens. HortScience. 40:457-459.

Minner, D.D., and F.J. Valverde, R.M. Pirtle. 2008. Seeding rates that maximize turf cover when sown during traffic. p. 57-62. *In* J.C. Stier et al. (ed.) Proceedings of the Second International Conference on Turfgrass Science and Management for Sports Fields. Proc. 2nd Int. Conf. on Turfgrass, Beijing, China. 24-29 June. 2007.

Missouri Valley Turfgrass Association. 1998. Missouri turfgrass economic impact survey. MVTA, Columbia, MO.

Murphy, J.A., J.A. Honig, and T.J. Lawson. 1999. Seeding date and bentgrass cultivar effects on annual bluegrass invasion. Agron. Abstr. 91:140.

NTEP. 2004. National Bentgrass Putting Green Trial–2003. NTEP No. 04-1. USDA-ARS, Beltsville, MD.

Peel, C.H. 1982. A review of the biology of Poa annua L. with special reference to sports turf. J. Sports Turf Res. Inst. 58:28-40.

Phipps, M.G. 1999. North Carolina turfgrass survey. North Carolina Agricultural Statistics Service, Dep. Of Agric. And Consumer Services, Raleigh.

Reicher, Z.J. and G.A. Hardebeck. 2002. Overseeding strategies for converting golf course fairways to creeping bentgrass. HortScience. 37:508-510.

Ross, K.J. 2006. On the fence (Turfgrass management). Available at http://www.golfcourseindustry.com/Article.aspx?article_id=71688 (verified 16 September 2010). Golf Course Industry Magazine.

Rossi, F.S. and S.M. Millett. 1996. Long-term consequences of seeding bentgrasses at high rates. Golf Course Manage. 10:49-52.

Rossi, F.S. 1999. Interseeding bentgrasses into established turf: You can't just plant new grass over old and expect improved putting greens. Golf Course Manage. 67:53-56.

Shearman, R.C. 2006. Fifty years of splendor in the grass. Crop Sci. 46:2218-2229.

Snaydon, R.W., and C.D. Howe. 1986. Root and shoot competition between established ryegrass and invading grass seedlings. J. Appl. Ecol. 23:667-674.

Sweeney, P. and K. Danneberger. 1998. Introducing a new creeping bentgrass cultivar through interseeding: Does it work? U.S. Golf Assn. Green Sect. Record 36(5).

USDA, National Agricultural Statistics Service. 2006. Cash farm income by commodities, Iowa. 2006 Agricultural Statistics Bulletin, p.114.

Warnke, Scott. 2003. Creeping bentgrass. p. 175-185. Casler, M.D. and R.R. Duncan. (ed.) *In* Turfgrass Biology, Genetics, and Breeding. John Wiley and Sons, Inc., Hoboken, New Jersey.

Warwick, S.I. and D. Briggs. 1978. The genecology of lawn weeds: I. Population differentiation in *Poa annua* L. in a mosaic environment of bowling green lawns and flower beds. New Phytologist. 81:711-723.

Whalley, R.B.D., C.M. McKell, and L.R. Green. 1966. Seedling vigor and the non-photosynthetic stage of seedling growth in grasses. Crop Sci. 6:147-150.

Williamson, M. 1996. Biological invasions. Chapman and Hall, London.

EFFECTS OF SHOOT DENSITY ON THE RECUPERATIVE POTENTIAL OF CREEPING BENTGRASS CULTIVARS

A paper to be submitted to *HortScience*

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Abstract. Recently developed cultivars of creeping bentgrass (*Agrostis stolonifera* L.) possess higher shoot densities. The increased shoot densities allow these cultivars to better resist invasion from annual bluegrass, but few data exist regarding differences in the recuperative potential among cultivars of creeping bentgrass. Our objective was to determine the effects of shoot density on the recuperative potential among cultivars of creeping bentgrass. The recuperative potentials of twenty three cultivars of creeping bentgrass and a single cultivar of colonial bentgrass (*Agrostis capillaris* L.) were evaluated in 2009 and 2010 by creating simulated divots and allowing the cultivars to recover from stolon growth. The cultivars were maintained under conditions designed to mimic a golf course fairway. Divot recovery was evaluated semiweekly by using digital image analysis techniques. In 2009, all cultivars had divot recovery rates statistically similar to 'Penncross' although improved cultivars did exhibit greater shoot densities. In 2010, the cultivars SR

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1150, T-1 and Kingpin had divot recovery rates significantly lower than ‘Penncross’. Shoot density was inversely proportional to divot recovery rate, suggesting that a greater number of shoots may hinder the ability to recuperate from injury. Stability analysis indicated that ‘Alpha’, ‘Crenshaw’, ‘LS-44’, ‘Penn A-4’, ‘Penncross’, ‘Pennlinks II’, ‘Putter’ and ‘Southshore’ exhibited consistent, above average lateral spread across the two years in this study. The increased shoot density of newer cultivars may slow the recuperative potential of creeping bentgrass and should be considered when selecting cultivars for specific use areas such as green, tees, and fairways.

Introduction

Creeping bentgrass creates a dense, high-quality playing surface and is commonly used for intensely managed turf areas on golf courses (Beard, 1973). Its popularity is partially due to its aggressive lateral growth from stolons, which allows this species to partially recuperate in areas continuously subject to wear and divoting. Traditional plant breeding has led to the development and release of many cultivars that possess enhanced turfgrass characteristics. Recently developed cultivars of creeping bentgrass have superior agronomic characteristics, have increased resistance to diseases, and are more tolerant of low mowing heights, traffic, and variation in temperatures (Bonos et al., 2001). In addition, newer cultivars of creeping bentgrass possess more vertical shoot growth and narrower leaf blades compared to cultivars such as Penncross. The changes in the architectural and morphological characteristics have resulted in cultivars of creeping bentgrass with increased shoot densities (Sweeney et al., 2001).

Higher shoot densities help impede invasion from annual bluegrass (Beard et al. 2001; Croce et al. 1998), which is an inevitable component of intensely managed turfgrass areas. New cultivars of creeping bentgrass with increased shoot densities have been produced by selection to shorten the length of the internodes (Cattani et al., 1996). Research conducted by Sweeney et al. (2001) demonstrated that more recently developed cultivars of creeping bentgrass possessed up to 27% greater shoot density compared with older cultivars. While many believe the recently developed cultivars of creeping bentgrass create an improved playing surface, there are questions about the ability of these high-density cultivars to spread laterally. Walker et al. (2003) demonstrated that ‘Penncross’ recovered significantly faster from divot injury than ‘L-93’.

Cultivar selection tends to focus on various turf characteristics such as quality, color, leaf texture, density, and tolerance to various abiotic and biotic factors (Morris, 2010). Managing injury from divots is important in order to maintain maximum turfgrass cover and uniform playing conditions. Data for recuperative potential among cultivars of creeping bentgrass would allow for cultivars to be chosen based upon site specific requirements such as greens, tees, and fairways. Although it is generally agreed that creeping bentgrass possesses aggressive recuperative potential, minimal research has focused on differences I this trait among cultivars of creeping bentgrass.

This lack of comparative data among cultivars may partially be due to the subjectivity and time necessary for data collection. The National Turfgrass Evaluation Program (NTEP) coordinates national cultivar testing for creeping bentgrass and other turfgrass species. The NTEP evaluates establishment visually on a percentage cover basis. Because of the subjective nature of visual ratings, the data are often highly variable and subtle differences are difficult to identify due to the high variances (Murphy et al., 1995). The line-intersect method is another common method of quantifying percentage cover. This method involves placing a grid over the entire plot or a portion of the plot and counting the number or type of plant found at each intersection on the grid (Kershaw, 1973; Laycock and Canaway, 1980). Although the line-intersect method has proven to be an effective procedure in turfgrass research, the time and labor required of this procedure can limit its usefulness. More recently, digital image analysis (DIA) has been shown to be an effective and accurate method of obtaining objective, reproducible measures of turfgrass cover (Richardson et al., 2001).

Digital image analysis has been used as a research tool to obtain a variety of data across agricultural disciplines including turfgrass. Because of the quantitative and reproducible nature of turfgrass coverage measurements using DIA, establishment rates can be modeled more effectively to develop growth analysis curves, which can then be used to predict rate of establishment or the number of days to reach a specified coverage. Digital image analysis has been effectively used in a range of turfgrass establishment studies, including establishment from seed (Shaver et al., 2006), sprigs (Schnell et al., 2009), and vegetative plugs (Patton et al., 2007). In addition, researchers have used DIA to demonstrate differences in recuperative potential between cultivars of bermudagrass (Karcher et al., 2005a; Trappe et al., 2009) and zoysiagrass (Karcher et al., 2005b; Patton et al., 2007; Trappe et al., 2009). The objectives of our research were to determine the relationship between shoot density and the recuperative potential among cultivars of creeping bentgrass.

Materials and Methods

The study was conducted at the Iowa State University Horticulture Research Station near Gilbert, IA. Divot injury was simulated on 3 June 2009 and 1 June 2010 by removing a single core of turf and soil (10.8 cm diameter by 10 cm) from established plots of 23 commercially available cultivars of creeping bentgrass and a single cultivar of colonial bentgrass (Table 1) and backfilling with native soil. ‘Penncross’ served as the control and the remaining cultivars represented recently developed cultivars of creeping bentgrass. Soil type was a Nicollet clay-loam (fine-loamy, mixed, mesic-Aquic Hapludolls) with 19 kg ha^{-1} P, 95.2 kg ha^{-1} K, 3.6% organic matter, and a pH of 7.5. A weather station located onsite measured daily air temperatures and precipitation (Fig. 1).

Plots measured 1.5 by 1.5 m and were arranged as a randomized complete block with three replications. The same plots were used in both years of the study but different areas of the plot were evaluated in each year to ensure that divot injury in 2009 did not affect recovery in 2010. Maintenance was designed to simulate golf course fairway conditions with mowing performed two or three times weekly at 1.27 cm, irrigation applied to prevent drought stress, and applications of a soluble fertilizer (18N-0P-19.9K) every 14 d supplied 12.2 kg ha^{-1} N and 13.7 kg ha^{-1} K. Chlorothalonil [tetrachloroisophthalonitrile] and boscalid [3-pyridinecarboxamide, 2-chloro-N-(4’-chloro(1,1’-biphenyl)-2-yl] were applied at 8.1 and 0.4 kg a.i. ha^{-1}, respectively, on 23 June, 18 Aug., and 16 Sept. each year to manage dollar spot occurrence.

Digital images of each plot were taken semiweekly with a Fuji FinePix F10 camera in order to evaluate data by using digital image analysis (DIA). Data were collected starting the day of injury and continued until full recovery or until disease occurrence interfered with the

DIA analysis. The camera was mounted on a tripod to produce a consistent height (1.2 m) between the lens and soil surface. A black, rubber mat with an opening the size of the original divot was placed around each divot and the interior of the mat was analyzed for percentage green cover. Percentage cover was determined through DIA by using Sigma ScanPro (Systat, Software, Richmond, CA). The hue range was set from 47 to 107 and the saturation from 10 to 100 in order to avoid overestimation of green plant tissue as described by Patton et al. (2007). A calibration image with an object of known area was obtained during each data collection event and was used to convert data from selected pixels to percentage recovery that had occurred based on the size of the original divot. To determine the percentage divot recovery for each cultivar, the data were fit to the linear model [Divot Recovery = R x DAI], where R is the percentage recovery and DAI is the number of days after divot injury. Two cores (1.9 cm diameter) from each plot were collected in June 2009 and 2010 and stored at -20° C for evaluation of shoot density. Shoot density was determined by counting the number of live tillers in each core (Skogley and Sawyer, 1992).

Data were analyzed using PROC REG, PROC GLM, and PROC MIXED (SAS institute, Cary, NC). Means were separated by using Fisher's protected least significant difference (LSD) at $\alpha = 0.05$. Analysis of variance revealed a significant year × cultivar interaction ($p = 0.0375$). Graphical representation of the interaction displayed a change in order among many of the cultivars. Therefore, the data were analyzed using two methods. First, the data are presented separately for 2009 and 2010. Second, a stability analysis was performed in order to investigate the consistency of the 24 cultivars across the two growing seasons. The objective of stability analysis is to identify cultivars that perform consistently across a range of environmental conditions. Several statistical methods have been suggested and utilized to study the adaptation and stability of cultivars to varying environmental conditions (Lin et al., 1986). Here, we used the method proposed by Francis and Kannenberg (1978) that uses the coefficient of variation (CV) of each cultivar as a measure of stability. A cultivar with the dependent variable mean above average and a below average CV was considered stable.

Results and Discussion

Variation in divot recovery rate and shoot density. We observed differences in divot recovery among the 24 cultivars in 2010 ($p = 0.0309$) but not in 2009 ($p = 0.4063$). In 2009, all cultivars had divot recovery rates similar to 'Penncross'. Differences were detected in shoot density counts [tillers/dm^2] among the cultivars ($p = 0.0011$) (Table 2). The cultivar 007 had the greatest shoot density among cultivars and nearly 30% greater than the mean value of 1422 tillers/dm^2. The cultivars T-1, SR 1150, Alpha, Kingpin, and Declaration all had shoot density counts similar to '007'. In addition, orthogonal polynomial contrasts indicated differences in shoot density between 'Penncross' and all other cultivars ($p = 0.0192$). Among cultivars, 007, Declaration, Kingpin, Alpha, SR 1150, T-1, Bengal, MacKenzie, Tyee, and Penn G-6 had shoot density 27 to 57% greater than 'Penncross'. Despite differences among cultivars in shoot density, no correlation was found between shoot density and divot recovery rates in 2009 (Fig 2b).

In 2010, divot recovery [percentage d^{-1}] ranged from 1.32 to 2.71 with a mean of 2.15. The most rapidly recovering cultivar (Putter) exhibited a divot recovery rate 105% greater than the slowest recovering cultivar (Kingpin). The cultivars SR 1150, T-1, and Kingpin had divot recovery rates 52 to 86% slower than 'Penncross'. Three of the five cultivars with the greatest divot recovery rates also had the lowest shoot densities. Despite not observing differences in shoot density in 2010 ($p = 0.1433$) regression analysis revealed an inverse relationship between shoot density and divot recovery rate ($r^2 = 0.10$, $p = < 0.0074$) (Fig. 2a).

Past research demonstrates that cultivars of creeping bentgrass differ in turfgrass quality characteristics in addition to resistance to abiotic and biotic stresses (Morris, 2010). Our results indicate that cultivars of creeping bentgrass also can differ in their recuperative potential. Schmitz et al. (2005) demonstrated a difference in divot recovery rate between 'Seaside II' and five other cultivars of creeping bentgrass but noted that differences between cultivars were small. While we were able to demonstrate significant differences in 2010, cultivars could not be separated in 2009. In addition, the difference in magnitude between divot recovery rates between 2009 and 2010 along with the year × cultivar interaction indicate that the rate of divot recovery is greatly influenced by environmental conditions. The general trend of greater divot recovery rate values in 2010 compared to 2009 are likely due to differences in temperature and rainfall between the two growing seasons (Fig. 1). With the exception of a spike in air temperatures during the latter half of June 2009, temperatures were below average. This is in contrast to 2010 in which June and July saw record amounts of rainfall and experienced above average temperatures.

Differences in shoot density among cultivars of creeping bentgrass were also observed in our study in 2009 (Table 2). Recently developed cultivars of creeping bentgrass consistently produced shoot densities > 1500 tillers/dm^2 and orthogonal polynomial contrasts showed a difference between 'Penncross' and all other cultivars. These results are similar to those of Sweeney et al. (2001) who also demonstrated a difference in shoot density between improved cultivars and ‘Penncross’ during the summer months. Our findings also revealed an inverse relationship between shoot density and divot recovery rate (Fig. 2a) in 2010, indicating that cultivars with lower shoot densities are able to recovery quicker from divots compared with cultivars with greater shoot densities. The cultivar T-1 had the second slowest divot recovery rate and the second highest shoot density whereas ‘Putter’ had the highest divot recovery rate and second lowest shoot density (Table 3). These results are consistent with the findings of Walker et al. (2003) who demonstrated cultivar effects in divot recovery rate between ‘L-93’ and ‘Penncross’ creeping bentgrass. The lack of correlation between these two variables in 2009 could be partially explained by the narrow range in divot recovery rate values among cultivars.

Stability among cultivars. Clearly, the divot recovery rate and shoot density of creeping bentgrass cultivars was strongly influenced by environmental conditions. Making cultivar recommendations can be challenging when cultivar × environment interactions exist because the phenotypic response is not the same for all genotypes. Some cultivars included in this study appear to be better adapted to the cooler temperatures and moderate rainfall experienced during 2009, whereas others were better adapted to the above average temperatures and rainfall experienced during 2010. Because environmental conditions are variable even within specific geographic regions, an evaluation of the ability of the cultivars to produce consistent results is desirable. Cultivar CV across growing seasons was used to distinguish stable and un-stable cultivars (Francis and Kannenberg, 1978). The procedure divided the cultivars into four groups (Fig 3., Fig. 4). A cultivar having a low CV and high dependent variable value was considered stable. Based upon these criteria, the cultivars Alpha, Crenshaw, LS-44, Penn A-4, Penncross, Pennlinks II, Putter and Southshore all displayed above average divot recovery rates and below average CV values (Fig. 3). These results indicate that these cultivars exhibited the capability for aggressive lateral spread across the two growing seasons experienced during this experiment. The cultivars Century, Crystal Bluelinks, Imperial, MacKenzie, and Penn G-6 also exhibited above average divot recovery rates but possessed CV values that were above the mean. Therefore, while these cultivars possessed above average divot recovery rates, their performance was strongly influenced by varying environmental conditions.

The cultivars 007, Alpha, Declaration, Kingpin, L-93, SR 1150, and T-1 all displayed above average shoot densities and below average CV values (Fig. 4). The cultivars Bengal, LS-44, and Mackenzie all possessed CV values below the mean but their shoot densities ranked close to the mean. The cultivars Tyee and Independence also exhibited above average shoot densities values but possessed CV values that were above the mean. ‘Alpha’ was the only cultivar to exhibit recuperative potential and shoot densities above the mean and CV values below the mean.

The results of this research indicate that cultivars of creeping bentgrass can differ in recuperative potential and differences are influenced by environmental conditions. Our data indicate that the greater shoot densities of recently developed cultivars of creeping bentgrass may hinder their recuperative potential compared with lower shoot density cultivars. This trade-off between recuperative potential and shoot density needs to be considered when selecting cultivars for specific use areas. Higher shoot density cultivars may be better suited for areas where lower populations of annual bluegrass are desired. Alternately, lower shoot density cultivars may be better suited for areas where damage from divoting is severe and recovery is important.

Literature Cited

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J.B., P. Croce, M. Mocioni, A. De Luca, and M. Volterrani. 2001. The competitive ability of thirteen *Agrostis stolonifera* cultivars to annual bluegrass. Intl. Turfgrass Soc. Res. J. 9:828-831.

Bonos, S.A., K.A. Plumley, W.A. Meyer, J.A. Murphy, B.B. Clarke, W.K. Dickson, J.B. Clark, and D.A. Smith. 2001. Performance of bentgrass cultivars and selections in New Jersey turf trials, p. 1-21. In: A.B. Gould (eds.). Rutgers turfgrass proceedings. Vol. 33. Rutgers Ctr. Turfgrass Sci, New Brunswick, N.J.

Cattani, D.J., Miller, P.R., and Smith, S.R., Jr. 1996. Relationship of shoot morphology between seedlings and established turf in creeping bentgrass. Can. J. Plant Sci. 76:283-289.

Croce, P.M. Mocioni, and J.B. Beard. 1998. *Agrostis* cultivar characterizations for closely mowed putting greens in a Mediterranean climate, p. 668-678. In: M.R. Farrally and A.J. Cochran (eds.). Science and golf III. Proc. 3rd World Sci. Congr. Golf, St. Andrews, U.K.

Francis, T.R. and L.W. Kannenberg. 1978. Yield stability studies in short-season maize 1. A descriptive method for grouping genotypes. Can. J. Plant Sci. 58:1029-1034.

Karcher, D.E., M.D. Richardson, J.W. Landreth, and J.H. McCalla, Jr. 2005a. Recovery of bermudagrass varieties from divot injury. Appl. Turfgrass Sci. 13 Jan. 2011. <http://www.plantmanagementnetwork.org/pub/ats/research/2005/divot/>.

Karcher, D.E., M.D. Richardson, J.W. Landreth, and J.H. McCalla, Jr. 2005b. Recovery of zoysiagrass varieties from divot injury. Appl. Turfgrass Sci. 13 Jan. 2011. <http://www.plantmanagementnetwork.org/pub/ats/research/2005/zoysia/>.

Kershaw, K.A. 1973. Quantitative and dynamic plant ecology. 2nd ed. Am Elsevier Publishing Co., New York.

Laycock, R.W., and P.M. Canaway. 1980. An optical point quadrat frame for the estimation of cover in closely-mown turf. J. Sports Turf Res. Inst. 56:91–92.

Lin, C.S., M.R. Binns, and L.P. Lefkovitch. 1986. Stability analysis: Where do we stand? Crop Sci. 26:894-900.

Morris, K.N. 2010. A guide to NTEP turfgrass ratings. Natl. Turfgrass Evaluation Program. USDA-ARS, Beltsville, MD. 28 Apr. 2011. <http://www.ntep.org/reports/ratings.htm#seedlvig>.

Murphy, W.M., J.P. Silman, and A.D.M. Barreto. 1995. A comparison of quadrat, capacitance meter, HFRO sward stick, and rising plate for estimating herbage mass in a smooth-stalked, meadow-grass dominant white clover sward. J. Brit. Grass. Soc. 50:452-455.

Patton, A.J., J.J. Volenec, and Z.J. Reicher. 2007. Stolon growth and dry matter partitioning explain differences in zoysiagrass establishment rates. Crop Sci. 47:1237-1245.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Schmitz, S.J., T.B. Voigt, B.E. Branham, and T.W. Fermanian. 2005. Optimizing divot recovery. Golf Course Manage. 73:82-86.

Schnell, R. W., D. M. Vietor, R. H. White, T. L. Provin, and C. L. Munster. 2009. Effects of composted biosolids and nitrogen on turfgrass establishment, sod properties, and nutrient export at harvest. HortScience. 44:1746-1750.

Shaver, B. R., M. D. Richardson, J. H. McCalla, D. E. Karcher, and P. J. Berger. 2006.

Dormant seeding bermudagrass cultivars in a transition-zone environment. Crop Sci. 46: 1787-1792.

Skogley, C.R. and C.D. Sawyer. 1992. Field research, p. 589-614. In: D.V. Waddington, R.N. Carrow, and R.C. Sherman. (eds.). Turfgrass Amer. Soc. of Agron., Madison, WI.

Sweeney, P., K. Danneberger, and D. Wang. 2001. Root weight, nonstructural carbohydrate content, and shoot density of high-density creeping bentgrass cultivars. HortScience. 36:368-370.

Trappe, J., A. Patton, D. Karcher, and M. Richardson. 2009. Differences exist in the divot recovery among bermudagrass and zoysiagrass cultivars. Arkansas Turfgrass Report 2008, Ark. Ag. Exp. Sta. Res. Ser. 568:141-144.

Walker, K. S., C. A. Bigelow, and G. A. Hardeback. 2003. Creeping bentgrass fairway divot recovery as affected by irrigation frequency, cultivar and divot mixture seed additions: 2003. Annu. Rep., Purdue Univ. Turfgrass Sci. Program. p. 41-45.

Figure 1. Maximum and minimum daily temperature and monthly rainfall during 2009 and 2010 at the Iowa State University Horticulture Research Station.

Figure 2. Shoot density influences percentage divot recovery in (A) 2010 but not in (B) 2009. Regression equation for (A), $y = 3.27 + -0.0008$. Significant at the $p < 0.01$ level (**) or not significant (NS).

Figure 3. Divot recovery rate versus coefficient of variation for 24 cultivars of creeping bentgrass. Values are averaged over 2009 and 2010 growing seasons.

Figure 4. Shoot density versus coefficient of variation for 24 cultivars of creeping bentgrass. Values are averaged over 2009 and 2010 growing seasons.

Table 1. Cultivar, year, developer, and seed source for 24 cultivars of creeping bentgrass.

Cultivar[Z]	**Year**[Y]	**Accession Developers**	**Seed Source**
Penncross	1955	Pennsylvania State University	Tee-2-Green
Putter	1989	University of Washington, Jacklin Seed Division J.R. Simplot, and Medalist America	Jacklin Seed Division J.R. Simplot
Southshore	1992	Rutgers University and Loft's Seed, Inc.	Jacklin Seed Division J.R. Simplot
Crenshaw	1993	Texas A&M University, University of Arizona, and Loft's Seed, Inc.	ProSeeds Marketing
L-93	1995	Rutgers University and Loft's Seed, Inc.	Jacklin Seed Division J.R. Simplot
Penn A-4	1995	Pennsylvania State University	Tee-2-Green
Penn G-6	1995	Pennsylvania State University	Tee-2-Green
Century	1998	Texas Agricultural Experiment Station	ProSeeds Marketing
Imperial	1998	Texas Agricultural Experiment Station	ProSeeds Marketing
Alister[X]	2002	Pure Seed Testing, Inc.	Tee-2-Green
Bengal	2002	Barenbrug Holland BV	Barenbrug USA
Independence	2002	Lebanon Seaboard Company and Rutgers University	Lebanon Seaboard Company
LS-44	2003	Blue Moon Farms	Links Seed
Alpha	2004	Jacklin Seed Division J.R. Simplot	Jacklin Seed Division J.R. Simplot
Memorial	2004	Rutgers University and The Scotts Company	The Scotts Company
Pennlinks II	2004	Pure Seed Testing, Inc.	Tee-2-Green
T-1	2004	Jacklin Seed Division J.R. Simplot	Jacklin Seed Division J.R. Simplot
Declaration	2005	Lebanon Seaboard Company and Rutgers University	Lebanon Seaboard Company
007	2006	Rutgers University and R.H. Hurley	Seed Research of Oregon
Kingpin	2006	Rutgers University	ProSeeds Marketing
MacKenzie	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
SR 1150	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
Tyee	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
Crystal Bluelinks	2007	Pure Seed Testing, Inc.	Tee-2-Green

[Z] Cultivars sorted according to date released

[Y] Year released or made available to public

[X] Colonial bentgrass cultivar

Table 2. Creeping bentgrass divot recovery and shoot density by cultivar for 2009 growing season.

Cultivar[Z]	**Divot recovery**[Y]	**Shoot density**
	percentage d^{-1}	dm^2
Imperial	2.02	1416
Penn G-6	1.89	1485
007	1.87	1836
Crystal Bluelinks	1.86	1392
Alister[X]	1.86	1181
SR 1150	1.82	1602
Southshore	1.80	1088
L-93	1.80	1400
Century	1.79	1392
Penncross	1.78	1170
Memorial	1.75	1181
MacKenzie	1.74	1509
Penn A-4	1.71	1252
Tyee	1.71	1509
Putter	1.70	1263
LS-44	1.69	1380
Pennlinks II	1.68	1298
Declaration	1.68	1660
Crenshaw	1.68	1380
Bengal	1.66	1521
Alpha	1.66	1602
T-1	1.63	1556
Kingpin	1.59	1614
Independence	1.58	1439
Mean	1.75	1422
$LSD_{0.05}$[W]	NS	302**

[Z] Cultivars sorted according to divot recovery.

[Y] Data were collected semiweekly and were fit to the linear model [Divot Recovery = R x DAI], where R is the rate of increase and DAI is the number of days after divot injury.

[X] Colonial bentgrass cultivar.

[W] NS, *, ** Nonsignificant, and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 3. Creeping bentgrass divot recovery and shoot density by cultivar for 2010 growing season.

Cultivar[Z]	**Divot recovery**[Y]	**Shoot density**
	percentage d^{-1}	dm^2
Putte	2.71	1170
Crenshaw	2.62	1333
Alpha	2.57	1532
Penncross	2.46	1181
Pennlinks II	2.42	1170
Penn G-6	2.41	1275
LS-44	2.39	1438
MacKenzie	2.36	1298
Southshore	2.34	1252
Century	2.33	1345
Penn A-4	2.32	1474
Independence	2.28	1544
Imperial	2.24	1392
Crystal Bluelinks	2.18	1287
Bengal	2.03	1275
Alister[X]	2.03	1380
Declaration	2.01	1521
Memorial	1.98	1286
007	1.87	1509
L-93	1.84	1591
Tyee	1.71	1532
SR 1150	1.62	1532
T-1	1.50	1579
Kingpin	1.32	1369
Mean	2.15	1386
$LSD_{0.05}$[W]	0.81*	NS

[Z] Cultivars sorted according to divot recovery.

[Y] Data were collected semiweekly and were fit to the linear model [Divot Recovery = R x DAI], where R is the rate of increase and DAI is the number of days after divot injury.

[X] Colonial bentgrass cultivar.

[W] NS, *, ** Nonsignificant, and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

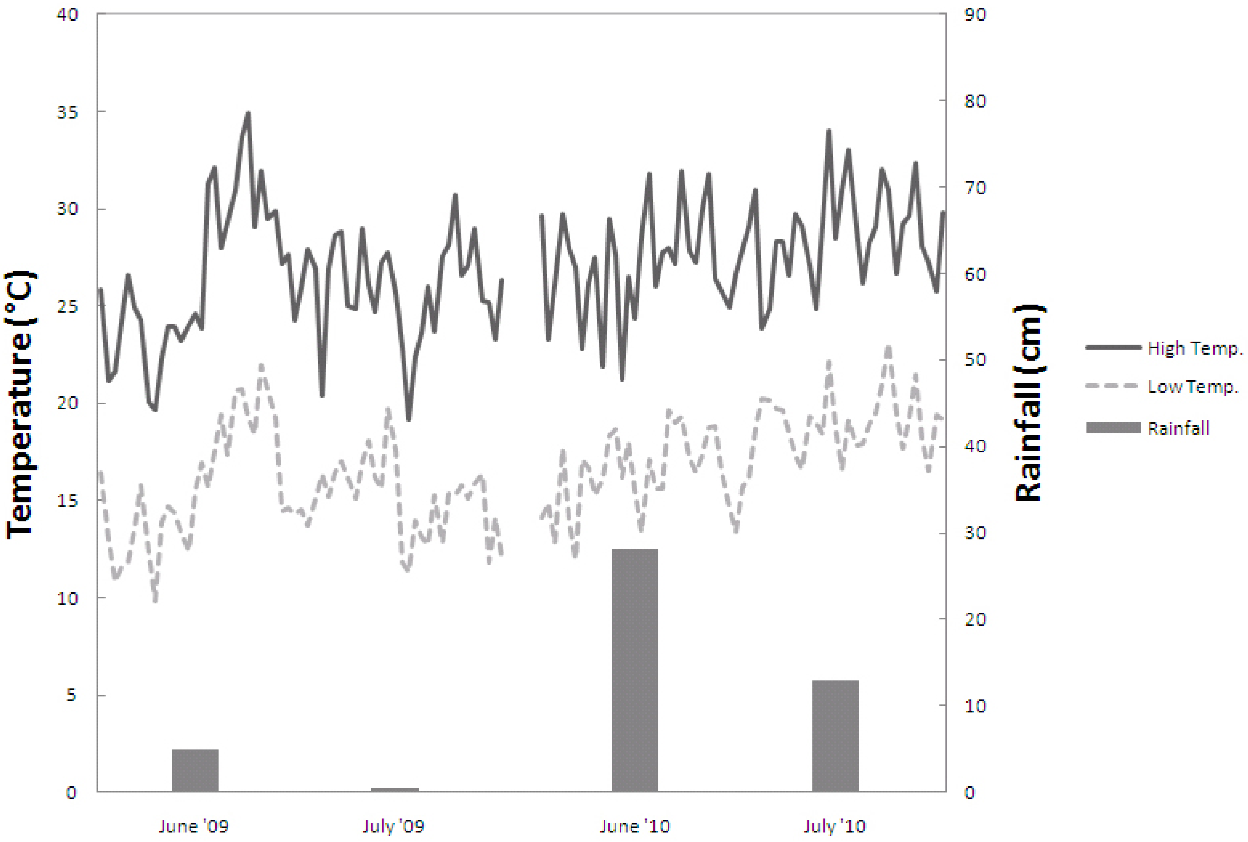
Temperature (°C)
40
35
30
25
20
15
10
5
0
Rainfall (cm)
90
80
70
60
50
40
30
20
10
0
June '09
July '09
June '10
July '10
High Temp.
Low Temp.
Rainfall

Fig. 1.

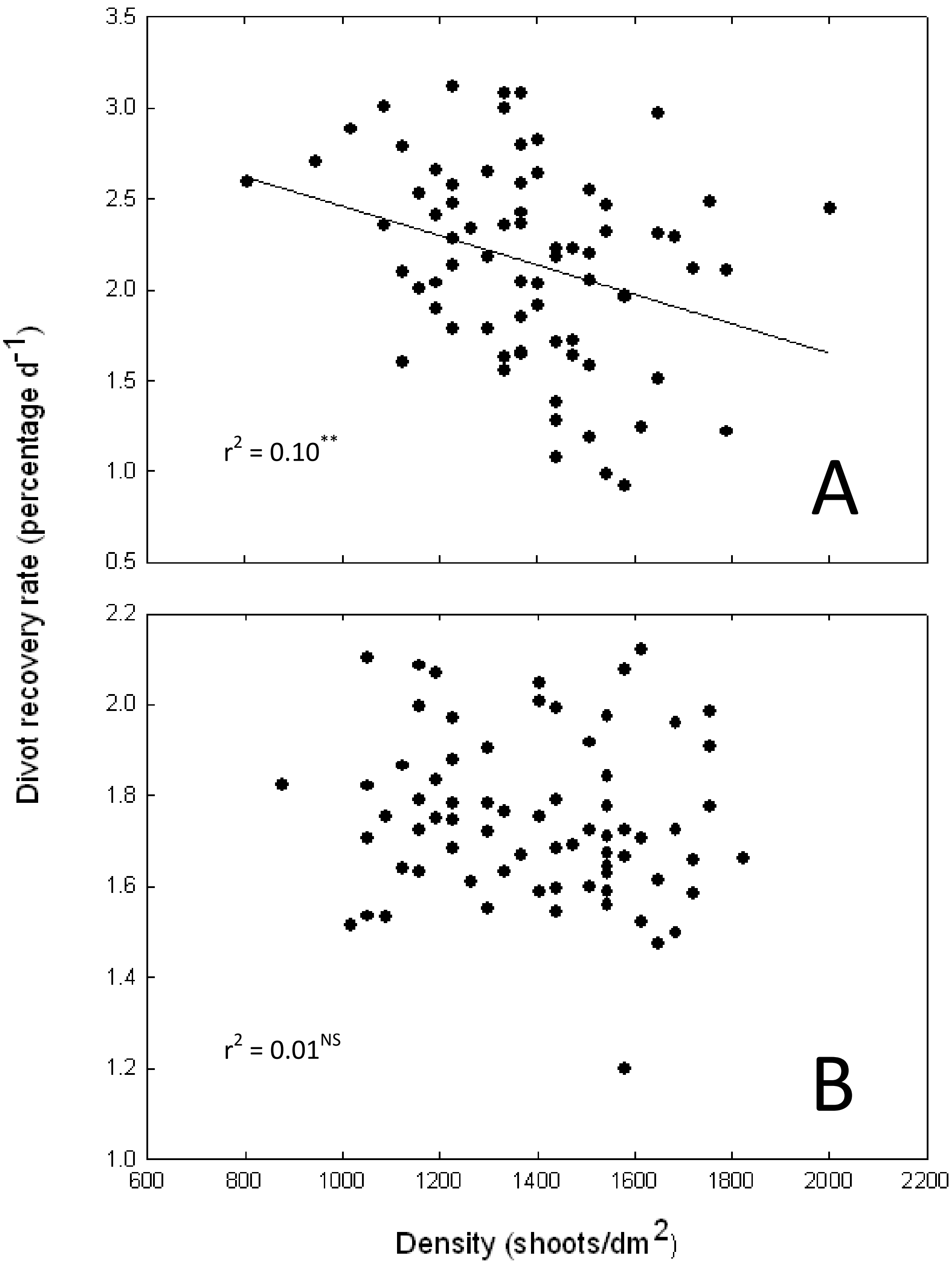
Divot recovery rate (percentage d^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
$r^2 = 0.10^{**}$
A
2.2
2.0
1.8
1.6
1.4
1.2
1.0
$r^2 = 0.01^{NS}$
B
600
800
1000
1200
1400
1600
1800
2000
2200
Density (shoots/dm^2)

Fig. 2.

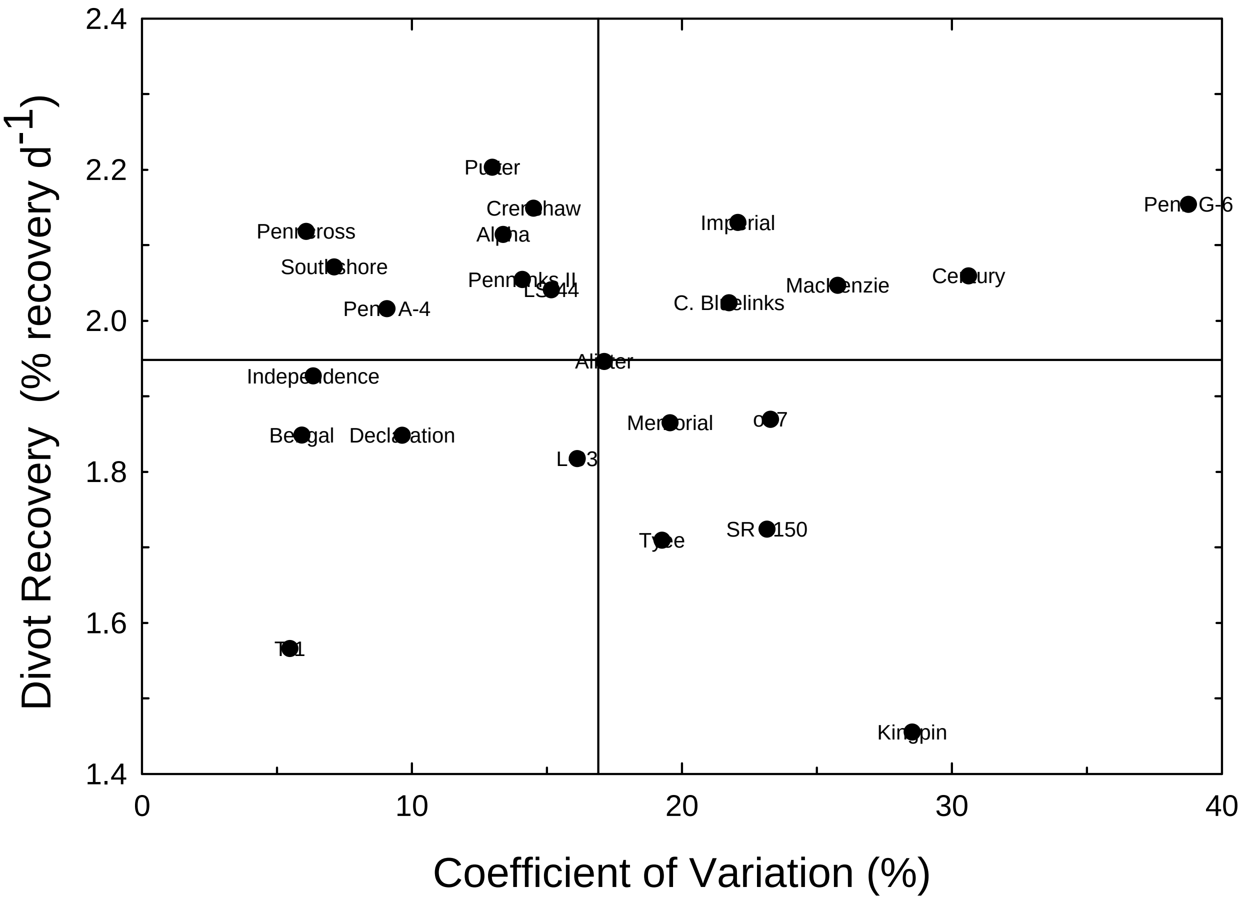
Putter
Crenshaw
Alpha
Penncross
Southshore
Pennlinks II
LS-44
Penn A-4
Imperial
Penn G-6
Century
Mackenzie
C. Bluelinks
Allister
Independence
Bengal
Declaration
L-93
Memorial
007
Tyee
SR 1150
T-1
Kingpin
2.4
2.2
2.0
1.8
1.6
1.4
0
10
20
30
40
Divot Recovery (% recovery d^{-1})
Coefficient of Variation (%)

Fig. 3.

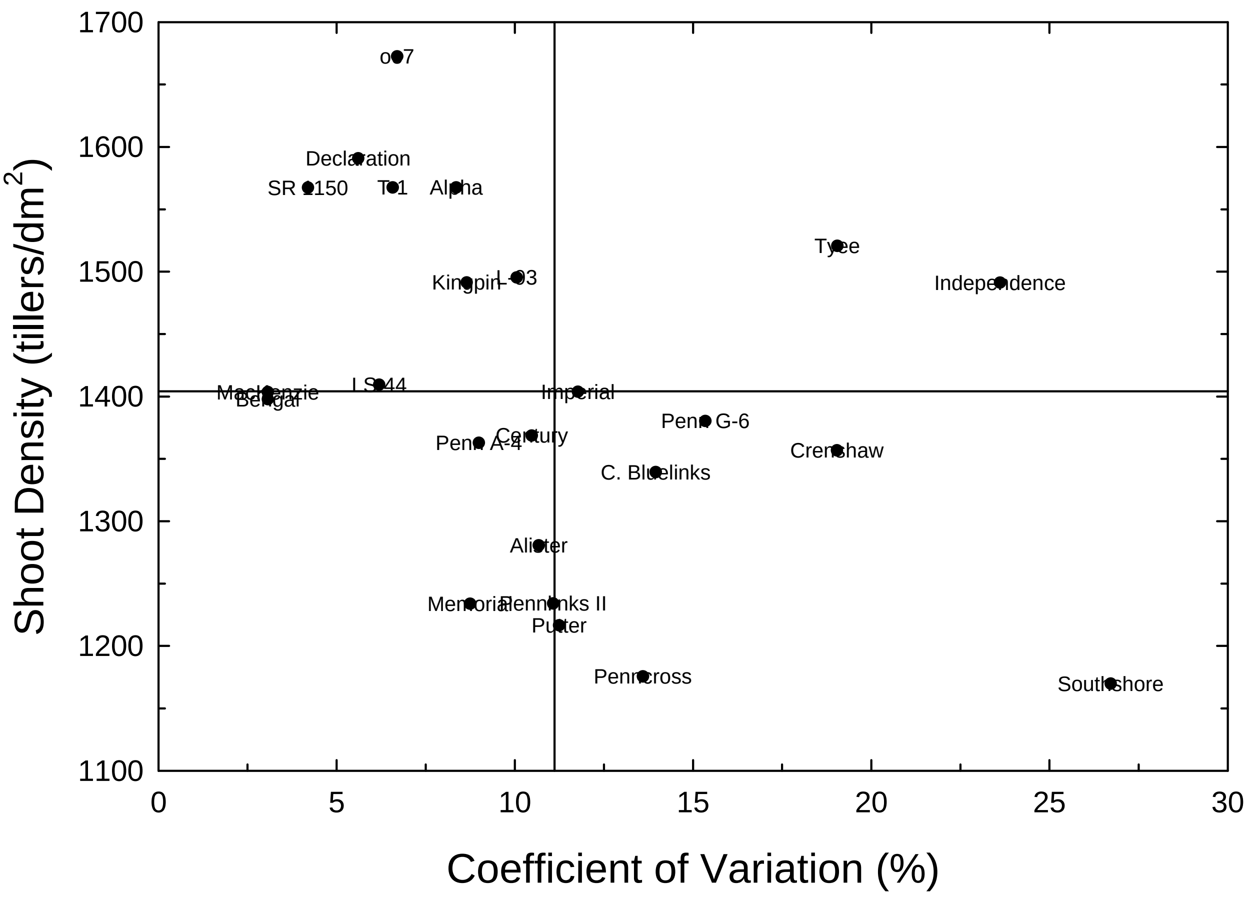
Shoot Density (tillers/dm^2)
Coefficient of Variation (%)
1700
1600
1500
1400
1300
1200
1100
0
5
10
15
20
25
30
o07
Declaration
SR 1150
T-1
Alpha
Tyee
Kingpin
L-93
Independence
LS-44
Mackenzie
Bengal
Imperial
Penn G-6
Century
Penn A-4
Crenshaw
C. Bluelinks
Alister
Memorial
Pennlinks II
Putter
Penncross
Southshore

Fig. 4.

LATERAL SPREAD AND DRY MATTER PARTITIONING OF CREEPING BENTGRASS CULTIVARS

A paper to be submitted to *Crop Science*

Marcus A. Jones[1,2] and Nick E. Christians[2]

ABSTRACT

Several creeping bentgrass (*Agrostis stolonifera* L.) cultivars are available that possess varying vegetative characteristics. A better understanding of the vegetative growth among creeping bentgrass cultivars is essential to its culture and would aid breeders in selecting for improved turf characteristics in germplasm screening programs. Our objectives were to identify differences in establishment rates among cultivars of creeping bentgrass and to determine the factors associated with differing growth rates by using growth analysis techniques. Spaced plantings of twenty-four cultivars of creeping bentgrass were evaluated for stolon characteristics and lateral spread. Two cultivars with differing lateral spread were used for further growth analysis in a growth chamber. Cultivars of creeping bentgrass displayed varying lateral spread, and stolon and internode lengths. 'Penncross' exhibited greater lateral spread and longer internodes compared with improved cultivars. 'Bengal' had

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the slowest lateral spread and the shortest mean stolon and internode length. Internode and stolon length were positively correlated as were internode length and establishment rate indicating, that cultivars with long internodes also possess fast establishment rates and longer stolons. Growth analysis indicated that Penncross and Bengal produce similar amounts of dry matter but Penncross allocates more dry matter into stolons than leaves. Variation in dry matter partitioning could partially explain differences in lateral spread among cultivars of creeping bentgrass. The vegetative characteristics should be matched with desired site usage requirements for optimum performance when selecting cultivars of creeping bentgrass.

INTRODUCTION

Creeping bentgrass is a cool-season, perennial grass species that is primarily adapted to the cool-humid region of the United States (Beard, 1973). It is the most tolerant cool-season turf of continuous, close mowing and established creeping bentgrass spreads vegetatively by vigorous stoloniferous growth (Kik and Joenje, 1990). Creeping bentgrass is well suited to areas receiving traffic and wear because of its aggressive stoloniferous growth and ability to form a dense, uniform playing surface due in part to a high tiller density.

The stolons help create surface structure while providing a means for recuperative potential. Stolon development and internode elongation also increase plant dry weight through the addition of cellulose and lignin (Esau, 1977). Various cell wall components, including lignin and cellulose, have proven to be good indicators of turfgrass wear tolerance (Shearman and Beard, 1975). Similarly, tiller density is an important shoot morphological characteristic that has been positively related to wear stress recovery (Hawes and Decker, 1977) and potential wear stress resistance in turf (Lush, 1990).

Cultivars of creeping bentgrass have undergone many improvements since the south German mixed bentgrasses. The first major breakthrough came in the mid 1950s when H.B. Musser released Penncross creeping bentgrass (Hein, 1958). The passage of the plant variety protection act in 1970 spurred on the development and release of a host of improved turfgrass cultivars (Brilman, 2005). The most recently developed cultivars of creeping bentgrass tend to possess more upright growth, finer textured leaf blades and increased tiller densities compared with Penncross and are more tolerant of traffic and heat and drought stress (Croce et al., 1993; Sifers and Beard, 1997; Toubakaris and McCarty, 2000). Cattani et al. (1996) demonstrated that the increase in tiller density was accomplished by shortening the length of the internodes. A benefit of more tillers per unit area is greater resistance to invasion from annual bluegrass (Croce et al., 1998). However, some researchers and turf practitioners believe the proliferation in the number of tillers and resulting shorter internodes may decrease the lateral spread of creeping bentgrass, and there are conflicting data in the literature regarding this matter (Cattani et al., 1996; Cattani, 1999). Cultivars of creeping bentgrass are reported to vary in their internode lengths (Cattani et al. 1996) but there is no study quantifying differences in lateral spread rates between cultivars.

Although creeping bentgrass is commonly used on golf course putting greens, tees, and fairways, the types of damage experienced for these areas differ. Voids are common on tee boxes and landing areas within fairways due to severe divoting from golf clubs. Many turf practitioners allocate considerable time and effort to maximize turf cover on these areas. Golf course putting greens experience concentrated traffic and damage from ball marks. A reduction in turfgrass density on putting greens can hasten invasion from annual bluegrass and compromise the surface uniformity and playability. Annual bluegrass can become a major component of turf swards (Harivandi, et al., 2005) and greater inputs are required to maintain acceptable playing conditions during stress periods (Turgeon, 1996). Because the types of damage vary between areas within a golf course the characteristics of the turf should also differ. An understanding of the vegetative growth among creeping bentgrass cultivars is essential to its culture and would aid breeders in selecting for improved turf characteristics in germplasm screening programs. A growth analysis of creeping bentgrass could also help explain differences in vegetative growth characteristics.

Growth analysis is a quantitative method used to describe and interpret the performance of whole plant systems by using weights, areas, and volumes (Hunt, 2003). These measurements are used to obtain indices of plant growth such as crop growth rate (CGR), relative growth rate (RGR) , unit leaf rate (ULR), leaf area ratio (LAR), specific leaf area (SLA), leaf weight ratio (LWR), stem weight ratio (SWR), and root weight ratio (RWR). Crop growth rate is the simplest index of plant growth and measures the rate of change in size. Relative growth rate expresses growth in terms of total dry weight and allows for a more equitable comparison compared with CGR where initial plant size is not accounted for. Unit leaf rate measures the efficiency at which plant leaves accumulate dry matter. Leaf area ratio is a morphological index that measures the leafiness of a plant. In practice, LAR uses the leaf area of a plant to compare photosynthesis against respiration. Specific leaf area compares the area of leaves on a plant to total leaf dry weight per plant. Indices comprised of ratios such as LWR, SWR, and RWR attempt to illustrate the partitioning of dry matter into these plant parts. A review of these indices and formula is available from Patton et al. (2007).

The objectives of this research were to identify differences in establishment rates among creeping bentgrass cultivars and to determine the factors associated with differing growth rates by using growth analysis techniques.

MATERIALS AND METHODS

Establishment rate

Twenty-three commercially available cultivars of creeping bentgrass and a single cultivar of colonial bentgrass were removed from established plots as plugs (10.8 cm diameter by 10 cm) on 3 June 2009 and 1 June 2010 (Table 1). Each plug was transplanted into the center of a single 1.0 by 1.0 m plot. Field plots were located at the Iowa State University Horticulture Research Station near Gilbert, IA. Soil type was a Nicollet clay-loam (fine-loamy, mixed, mesic-Aquic Hapludolls) with 70 kg ha^{-1} P, 530 kg ha^{-1} K, 3.7% organic matter, and a pH of 8.0. Plots were arranged in a lattice design with five treatments per incomplete block, five incomplete blocks per replication, and four replications for a total of 100 experimental units. Penncross served as a control and was replicated twice in order to achieve a 5 by 5 by 4 balanced lattice design with 25 treatments. The remaining 23 cultivars were considered improved cultivars. Each year prior to transplant, field plots were fumigated with dazomet (Tetrahydro-3,5,-dimethyl-2H-1,3,5-thiadiazine-2-thione) at 488 kg ha^{-1} in order to minimize weed competition. Weeds that appeared during the study were manually removed. Plugs were irrigated daily for the first month to encourage establishment and as needed to prevent drought stress thereafter. Stolons reaching the plot borders were redirected inside the plot using sod staples.

Digital images of each plot were taken at 15, 30, 45, 60, 75, 90, and 105 days after planting (DAP) with a Fuji FinePix F10 camera. The camera was mounted on a monopod to produce a consistent height (1.2 m) between the lens and soil surface. Percentage cover was determined by using digital image analysis (DIA) (Sigma Scan Pro, Systat, Software, Richmond, CA). Digital image analysis has been shown to be an effective and accurate method to obtain objective measures of percentage turfgrass cover (Richardson, 2001). The hue range was set from 47 to 107 and the saturation from 10 to 100 in order to avoid overestimation of green plant tissue as described by Patten et al. (2007). A calibration image with an object of known area was also obtained during each data collection event and was used to convert data from selected pixels to percentage cover (cm^2).

Data collections of percentage cover concluded at 105 DAP due to weed pressure and because some cultivars of creeping bentgrass were nearing complete establishment within the plot. The data were fit to the linear model [Coverage = (R x DAP) + I], where R is the rate of increase, DAP is days after plugging, and I was equal to the natural logarithm of 93.5 cm^2, which was the starting coverage of all cultivars. Internode lengths were obtained with a dial caliper 120 DAP by measuring the length of the fourth internode from the terminus on three randomly chosen stolons. Measurements were recorded using the ridge of tissue left by the sheath attachment to determine the internode termini. Data were analyzed using the PROC REG, PROC LATTICE, PROC GLM, and PROC PLOT functions (SAS Institute, Cary, NC). Means were separated using Fisher’s protected least significant difference (LSD) at $\alpha = 0.05$.

Growth Analysis

Based upon preliminary results from the field trials, a fast-growing and a slow-growing cultivar were chosen for further growth analysis. The experiment was conducted twice from 1 November 2009 to 1 May 2010. A 1- to 2-cm segment of stolon containing a single node and leaf and root tissues from each cultivar were planted in sand filled trays with individual wells measuring 3.8 cm in diam. Forty-eight samples were collected for each cultivar, for a total of 96 experimental units. Plants were fertilized daily with half-strength Hoagland's solution and allowed to establish in the greenhouse for 6 wk before being transferred to a growth chamber (Percival Scientific, Perry, IA) set at 25°C with a 14-h photoperiod and fluorescent light supplying an average of 650 μmol m^{-2} s^{-1} photosynthetically active radiation. Eight plants of each cultivar were harvested at 0, 7, 14, and 21 d after being transferred to the growth chamber. The leaves, roots, and the remaining portion of the plant, which mainly consisted of plant stems, were separated. The leaves were collected and weighed before being placed on non-reflective, black fabric. Digital images were recorded and DIA was used to quantify the leaf area by using the same procedure as described in the establishment rate study. Root and stem tissues were oven dried for 72 h at 68°C and weighed. Roots were combusted in a muffle furnace (Fisher Scientific, Waltham, MA) and root weights were calculated as the difference in dry weight before and after combustion.

Values for CGR, RGR, ULR, LAR, SLA, LWR, SWR, and RWR were calculated using formulae described by Patton et al. (2007) and verified by using the spreadsheet tool from Hunt et al. (2002). Data were analyzed using the PROC GLM procedure of SAS. Plant growth indices were separated by using Fisher's protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Statistical analysis

Plotting the data revealed an exponential growth response so coverage values were transformed by using the natural logarithm, and establishment rates were determined by using linear regression. The function provided a good fit of the data, with r^2 values all ≥ 0.98. Error variances for dependent variables were homogeneous for the establishment rate and growth analysis experiments so data were combined over the two years for analysis.

Lateral spread

Cultivars of creeping bentgrass displayed different coverage, lateral spread, and stolon and internode lengths. Overall, Penncross exhibited a greater capability to cover, faster lateral spread, and longer internodes compared with improved cultivars (Table 2). Penncross displayed coverage 21 and 25% greater coverage compared with improved cultivars 30 and 105 DAP, respectively. In addition, the lateral spread for Penncross was 7% faster compared with improved cultivars and its internode length was 16% greater (Table 2).

Differences in coverage among cultivars of creeping bentgrass first appeared 30 DAP and were observed at each data collection thereafter. Variation in coverage before 30 DAP was minimal and was likely the result of stolons being severed during harvest and transplant. Stolon elongation in our study commenced at approximately 20 DAP each year. Values of coverage for 30 and 105 DAP are presented as a summary of the data. Coverage ranged from 253 to 391 cm^2 at 30 DAP, and 4282 to 9237 cm^2 at 105 DAP (Table 3). One of the

Penncross entries possessed the greatest coverage 30 DAP. Penncross is considered an industry standard due to its widespread use by turfgrass practitioners and researchers since its introduction in the mid 1950s. The cultivars ‘Imperial’, ‘Crenshaw’, ‘SR 1150’, ‘Penn G-6’, ‘Putter’, and ‘Kingpin’ all had coverage values similar to Penncross. These same cultivars along with ‘L-93’, ‘Southshore’, ‘Tyee’, ‘MacKenzie’, ‘Century’, and ‘Alpha’ also had the greatest coverage 105 DAP. The cultivar Bengal had coverage 30 DAP that was less than the mean of 320 cm^2 and also had the smallest coverage 105 DAP. The top Penncross entry had coverage values 55 and 110% greater than Bengal at 30 and 105 DAP, respectively. Rankings for coverage 30 and 105 DAP closely reflected lateral spread rates among the cultivars.

Lateral spread [$\log_e$ (coverage) d^{-1}] differed among cultivars, and values ranged from 0.0355 to 0.0434 with a mean of 0.0402 (Table 3). Differences in lateral spread have also been found among cultivars of tall fescue and zoysiagrass (St. John et al., 2009; Patton et al., 2007). One of the entries of Penncross had the fastest lateral spread rate and Bengal had the slowest. All cultivars had lateral spread rates similar to Penncross except ‘T-1’, ‘Declaration’, ‘Memorial’, ‘Independence’, ‘Alister’, ‘LS-44’, and Bengal. Cultivars of creeping bentgrass also differed in their mean stolon and internode lengths (Table 3). These results are similar to earlier findings from Cattani et al. (1996), who reported differences in stolon and internode lengths between 15 cultivars of creeping bentgrass.

Penncross and Bengal had the longest and shortest mean stolon length 45 DAP and longest and shortest mean internode length 120 DAP, respectively. Although the two entries of Penncross had longer internodes compared with improved cultivars, there was no difference in stolon length (Table 2). These results were likely influenced by the mean stolon length being measured 45 DAP and discrepancies may have been greater later in the study. Mean stolon length 45 DAP ranged from 28.3 to 38.1 cm and mean internode length 120 DAP ranged from 2.46 to 3.57 cm (Table 3). The cultivars Century, '007', Declaration, Memorial, Independence, Alister, LS-44, and Bengal had the shortest mean stolon and internode lengths. Internode and stolon length were positively correlated ($r^2 = 0.074$, $p < 0.0001$) with cultivars having long internodes also displaying long mean stolon length. Cattani (1999) also reported a correlation between internode and stolon length between 'Emerald' and 'UM-67-10', the parental germplasm of '18th Green'. With the exception of Century and 007, these remaining cultivars also exhibited the slowest lateral spread (Table 3). The difference in lateral spread could be partially influenced by the variation in morphological characteristics among cultivars. Research has shown that recently developed cultivars of creeping bentgrass have more shoots per unit area (Sweeney et al., 2001; Cattani and Clark, 1991). Additional reports indicate that the increase in tillers is likely the result of shortening the length of the internodes, which creates a more compact plant (Cattani et al., 1996). Established creeping bentgrass primarily spreads vegetatively by stolon production and internode elongation. Regression analysis revealed a positive relationship between lateral spread and internode length ($r^2 = 0.089$, $p < 0.0001$), suggesting that cultivars with longer internodes had a greater capability for lateral spread. With the exception of Century, 'Pennlinks II', and 007, the cultivars that had the fastest lateral spread all had internodes greater than 3 cm. Although these findings do not indicate a direct relationship between the two variables, this trend indicates that planting cultivars of creeping bentgrass with longer internodes could hasten lateral spread rates. The plugs of creeping bentgrass were not mowed during this study. Mowing has been found to reduce the lateral spread of turfgrasses in other studies (Patton and Reicher, 2006). While mowing could influence cultivars differently, our findings agree with Walker et al. (2003), who demonstrated that Penncross was able to recover quicker from divot injury compared with a recently developed high-density cultivar L-93.

Growth Analysis

The cultivars Penncross and Bengal were chosen to represent a fast and slow-growing cultivar of creeping bentgrass for further growth analysis. Differences were observed between the two cultivars for CGR, LWR, and SWR (Table 4). Penncross had a CGR 63% greater than Bengal. This large disparity between the two cultivars is likely the result of the CGR not accounting for the difference in initial size between the two cultivars. In contrast, when differences in initial size are adjusted for, the RGR values indicate that Penncross and Bengal have similar growth rates.

Dry matter production (ULR), LAR and SLA were similar for both cultivars. Plants with lower CGR values tend to have higher LAR and SLA (Patton et al., 2007). Larger LAR and SLA values are characteristics of plants that have more leaves, with the individual leaves being thinner. Individual leaf blades of improved cultivars of creeping bentgrass such as Bengal tend to be narrower than those of Penncross (Croce et al., 1998). The LAR and SLA values for Bengal are larger compared with Penncross but the disparity is not large enough for the values to be different. Although ULR was the same for both cultivars, LWR and SWR values reveal that dry matter was partitioned differently between species. Bengal allocated 20% more dry weight into leaves (LWR) compared with Penncross. In contrast, Penncross invests 8% more of its dry weight into stolons (SWR). Both species dedicate a similar amount of dry weight to root production. The difference in dry matter partitioning could partially account for the greater establishment rate of Penncross compared with Bengal. Previous work has demonstrated that a high density creeping bentgrass allowed for an increase in tiller development at an earlier stage in development compared with a low density bentgrass (Cattani, 1999). Variation in dry matter partitioning and plant development could have implications for plant growth. Results of this growth analysis indicate that cultivars with faster establishment rates tend to allocate more dry matter to stem (stolon) production than to leaves. These findings agree with the results from our field work, which demonstrated that faster establishing cultivars produced longer stolons and longer internodes compared with slower establishing cultivars.

These studies investigated differences in lateral spread among cultivars of creeping bentgrass and sought to reveal factors associated with growth between a fast and slow-growing cultivar. Our results indicate that cultivars of creeping bentgrass possess varying establishment rates and that Penncross had a greater capability for lateral spread than recently developed cultivars. Positive relationships were found between internode and stolon length and between internode length and lateral spread. These findings indicate that internode length is an important morphological characteristic influencing the lateral spread of creeping bentgrass cultivars. Furthermore, the observed variation in lateral spread could result from differences in dry matter partitioning among cultivars. Because creeping bentgrass is often used in areas subject to heavy traffic and wear, differences in lateral spread would be of great interest to turfgrass practitioners who are trying to maximize turfgrass cover. While our data indicate that Penncross is superior to recently developed cultivars with respect to lateral spread, its main disadvantage is its potential for invasion by annual bluegrass, an inevitable inhabitant of intensely managed turf (Christians, 2007). Tiller density is also an important shoot morphological characteristic in creeping bentgrass that plays an important role in traffic tolerance and turf recovery (Hawes, and Decker, 1977; Lush, 1990). Research has shown that tiller density also affects the success of creeping bentgrass competing with annual bluegrass (Beard et al., 2001) but shoot density is negatively related to internode length (Cattani, 1999). Therefore, both morphological traits should be considered, and selection of creeping bentgrass cultivars should be based on site specific requirements. Cultivars with characteristics conferring greater traffic tolerance may be better suited for high traffic areas such as putting greens. Cultivars with greater abilities for lateral spread may be better suited for areas subject to frequent divoting such as tee boxes and fairways.

LITERATURE CITED

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hal, Englewood Cliffs, NJ.

Beard, J.B., P. Croce, M. Mocioni, A. De Luca, and M. Volterrani. 2001. The comparative competitive ability of thirteen *Agrostis stolonifera* cultivars to *Poa annua*. Int. Turfgrass Soc. Res. J. 9:828-831.

Brilman, L.A. 2005. Turfgrass breeding in the United States: Public and private, cool and warm season. Int. Turfgrass Soc. Res. J. 10:508-514.

Cattani, D.J. 1999. Early plant development in ‘Emerald’ and ‘UM67-10’ creeping bentgrass. Crop Sci. 39:754-762.

Cattani, D.J., P.R. Miller, and S.R. Smith, Jr. 1996. Relationship of shoot morphology between seedlings and established turf in creeping bentgrass. Can. J. Plant Sci. 76:283-289.

Cattani, D.J. and K.W. Clark. 1991. Influence of wear-stress on turfgrass growth components and visual density ratings. Can. J. Plan Sci. 71:305-308.

Christians, N.E. 2007. Fundamentals of turfgrass management. 3rd ed. John Wiley & Sons, Hoboken, NJ.

Croce, P., M. Mocioni, and J.B. Beard. 1998. *Agrostis* cultivar characterization for closely mowed putting greens in a Mediterranean climate. p. 668-678. *In* M.R. Farrally and A.J. Cochran (ed.) Science and golf III. Proc. 3rd World Sci. Congr. Golf, St. Andrews, U.K.

Croce, P., M. Mocioni, V.M. Pich, and J.B. Beard. 1993. Comparitive dollar spot susceptibilities of 17 bentgrass (*Agrostis* spp.) cultivars under putting green conditions. Final Res. Rep. No. 201. Green Section, Federazione Italiana Golf, Rome.

Esau, K. 1977. Anatomy of seed plants. 2nd ed. John Wiley and Sons, Inc., New York.

Harivandi, M.A., W.B. Hagan, and K.N. Morris. 2005. Evaluating bentgrasses for quality, speed, thatch development and annual bluegrass invasion. Int. Turfgrass Soc. Proc., p. 60-61.

Hawes, D.T. and Decker, A.M. 1977. Healing potential of creeping bentgrass as affected by nitrogen and soil temperature. Agron. J. 69:212-214.

Hein, M.A. 1958. Registration of varieties of strains of grasses. Bentgrasses: Penncross Creeping (Reg. No. 1) Agron. J. 50:399.

Hunt, R. 2003. Growth analysis, individual plants. *In* B. Thomas et al. (ed.) Encyclopedia of applied plant sciences. Academic Press, London.

Hunt, R., D.R. Causton, B. Shipley, and A.P. Askew. 2002. A modern tool for classical plant growth analysis. Ann. Bot. (London) 90:485-488.

Kik, C.J. van Adnel, and W. Joenje. 1990. Life-history variation in ecologically contrasting populations of *Agrostis stolonifera*. J. Ecol. 78:962-973.

Lush, W.M. 1990. Turf growth and performance evaluation based on turf biomass and tiller density. Agron. J. 82:505-511.

Patton, A.J., J.J. Volenec, and Z.J. Reicher. 2007. Stolon growth and dry matter partitioning explain differences in zoysiagrass establishment rates. Crop Sci. 47:1237-1245.

Patton, A.J., and Z.J. Reicher. 2006. Mowing height impacts establishment rate of zoysiagrass cultivars. *In* 2006 annual report. Purdue Univ. Turfgrass Sci. Program, Dep. Of Agron., Purdue Univ., West Lafayette, IN.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884-1888.

Shearman, R.C., and J.B. Beard. 1975. Turfgrass wear tolerance mechanisms. II. Effects of cell wall constituents on turfgrass wear tolerance. Agron. J. 67:211-215.

Sifers, S.I., and J.B. Beard. 1997. Seasonal shoot and root morphology – Growth characterizations of 12 bentgrass (*Agrostis* spp.) cultivars under close mowing. Res. Rep. No. 306. Int. Sports Turf Inst., College Station, TX.

St. John, R., J. Fry, D. Bremer, and S. Keeley. 2009. Establishment rates and lateral spread of *Festuca arundinacea* cultivars. Inter. Turfgrass Soc. Res. J. 11:481-487.

Sweeney, P., K. Danneberger, and D. Wang. 2001. Root weight, nonstructural carbohydrate content, and shoot density of high-density creeping bentgrass cultivars. HortScience. 36:368-370.

Toubakaris, M., and B. McCarty. 2000. Heat stress separates old and new bentgrasses. Golf Course Manage. 68(7):49-53.

Turgeon, A.J. 1996. Turfgrass management. Prentice Hall, upper Saddle River, NJ.

Walker, K. S., C. A. Bigelow, and G. A. Hardeback. 2003. Creeping bentgrass fairway divot recovery as affected by irrigation frequency, cultivar and divot mixture seed additions: 2003. Annu. Rep. Purdue Univ. Turfgrass Sci. Progr. p. 41-45.

Table 1. Cultivar, year, developer, and seed source for 24 cultivars of creeping bentgrass.

Cultivar[†]	**Year**[‡]	**Accession Developers**	**Seed Source**
Penncross	1955	Pennsylvania State University	Tee-2-Green
Putter	1989	University of Washington, Jacklin Seed Division J.R. Simplot, and Medalist America	Jacklin Seed Division J.R. Simplot
Southshore	1992	Rutgers University and Loft's Seed, Inc.	Jacklin Seed Division J.R. Simplot
Crenshaw	1993	Texas A&M University, University of Arizona, and Loft's Seed, Inc.	ProSeeds Marketing
L-93	1995	Rutgers University and Loft's Seed, Inc.	Jacklin Seed Division J.R. Simplot
Penn A-4	1995	Pennsylvania State University	Tee-2-Green
Penn G-6	1995	Pennsylvania State University	Tee-2-Green
Century	1998	Texas Agricultural Experiment Station	ProSeeds Marketing
Imperial	1998	Texas Agricultural Experiment Station	ProSeeds Marketing
Alister[§]	2002	Pure Seed Testing, Inc.	Tee-2-Green
Bengal	2002	Barenbrug Holland BV	Barenbrug USA
Independence	2002	Lebanon Seaboard Company and Rutgers University	Lebanon Seaboard Company
LS-44	2003	Blue Moon Farms	Links Seed
Alpha	2004	Jacklin Seed Division J.R. Simplot	Jacklin Seed Division J.R. Simplot
Memorial	2004	Rutgers University and The Scotts Company	The Scotts Company
Pennlinks II	2004	Pure Seed Testing, Inc.	Tee-2-Green
T-1	2004	Jacklin Seed Division J.R. Simplot	Jacklin Seed Division J.R. Simplot
Declaration	2005	Lebanon Seaboard Company and Rutgers University	Lebanon Seaboard Company
007	2006	Rutgers University and R.H. Hurley	Seed Research of Oregon
Kingpin	2006	Rutgers University	ProSeeds Marketing
MacKenzie	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
SR 1150	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
Tyee	2006	Rutgers University and Seed Research of Oregon	Seed Research of Oregon
Crystal Bluelinks	2007	Pure Seed Testing, Inc.	Tee-2-Green

† Cultivars sorted according to date released

‡ Year released or made available to public

§ Colonial bentgrass cultivar

Table 2. Cultivars of creeping bentgrass differ in their coverage, establishment rate and stolon and internode length. Improved cultivars of creeping bentgrass are different compared with Penncross.

	30 DAP coverage	**105 DAP coverage**	**Establishment rate†**	**45 DAP mean stolon length‡**	**120 DAP mean internode length§**
Significance¶	**	**	*	**	**
	Mean				
	cm^2		log$_e$(coverage) d^{-1}	cm	
Penncross#	380	8420	0.0425	35.4	3.45
Improved cultivars††	315	6725	0.0399	32.7	2.98
Significance‡‡	**	*	*	NS	**

†Establishment rate was calculated by modeling data to the equation [$\log_e$ (coverage) = (R x DAP) + I], where R is the rate of increase, DAP is days after plugging, and I was equal to the natural logarithm of 93.5 cm^2, which was the starting coverage of all plots.

‡ Mean of 32 stolons (four samples plot^{-1} with four replications over two growing seasons).

§ Mean of 24 internodes (three samples plot^{-1} with four replications over two growing seasons). Internodes were measured 120 DAP by using a dial caliper.

¶ F-test to determine differences among all cultivars of creeping bentgrass. NS, *,**Nonsignificant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Comprised of two cultivars of Penncross.

†† Comprised of 23 cultivars of creeping bentgrass (Table 1).

‡‡ F-test to determine differences between ‘Penncross’ and improved cultivars of creeping bentgrass. NS, *,**Nonsignificant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 3. Creeping bentgrass coverage, establishment rate, mean stolon length and internode length by cultivar. Numbers represent the mean of eight measurements recorded over 2009 and 2010.

Cultivar	**30 DAP† coverage‡**	**105 DAP coverage**	**Establishment rate§**	**45 DAP mean stolon length¶**	**120 DAP mean internode length#**
	cm^2	cm^2	$\log_e$(coverage) d^{-1}	cm	cm
Penncross	391	8973	0.0434	38.1	3.57
Imperial	376	8340	0.0430	35.1	3.05
Crenshaw	344	8754	0.0428	35.8	3.53
SR 1150	337	8477	0.0425	33.3	3.16
Penn G-6	360	9237	0.0425	36.4	3.10
Putter	354	8018	0.0422	36.8	3.02
Penncross	368	7867	0.0416	33.3	3.33
Kingpin	343	6791	0.0408	33.4	3.01
L-93	297	7394	0.0406	36.1	3.60
Southshore	312	7139	0.0405	34.0	3.29
Tyee	287	7246	0.0405	33.9	3.14
MacKenzie	299	6760	0.0402	32.4	3.05
Century	313	7025	0.0401	32.0	2.94
Pennlinks II	320	6400	0.0400	34.1	2.80
Alpha	304	6618	0.0399	34.6	3.01
Crystal Bluelinks	320	6034	0.0396	29.5	3.03
Penn A-4	294	6169	0.0393	32.6	3.02
007	319	5950	0.0392	31.0	2.69
T-1	286	6030	0.0389	33.1	2.80
Declaration	310	5803	0.0387	31.1	2.77
Memorial	317	5803	0.0385	29.6	2.73
Independence	319	5472	0.0383	29.8	2.72
Alister††	292	5673	0.0382	30.0	2.68
LS-44	282	5265	0.0372	28.6	2.99
Bengal	253	4282	0.0355	28.3	2.46
Mean	320	6861	0.0402	32.9	3.02
$LSD_{0.05}$	64	2693	0.0044	5.3	0.58

†Days after planting.

‡Coverage was determined by using digital image analysis.

§ Establishment rate was calculated by modeling data to the equation [$\log_e$ (coverage) = (R x DAP) + I], where R is the rate of increase, DAP is days after plugging, and I was equal to the natural logarithm of 93.5 cm^2, which was the starting coverage of all plots.

¶Mean of 32 stolons (four samples $plot^{-1}$ with four replications over two growing seasons).

#Mean of 24 internodes (three samples $plot^{-1}$ with four replications over two growing seasons). Internodes were measured 120 DAP by using a dial caliper.

††Colonial bentgrass cultivar

Table 4. Growth analyses mean values for two cultivars of creeping bentgrass with differing establishment rates. Forty-eight plants of each cultivar were grown in a growth chamber with set at 25°C with a 14-h photoperiod and fluorescent light supplying an average of 650 µmol m^{-2} s^{-1} photosynthetically active radiation.

	Growth indices[†]							
Cultivar	**RGR**	**CGR**	**ULR**	**LAR**	**SLA**	**LWR**	**SWR**	**RWR**
	mg g^{-1} d^{-1}	mg d^{-1}	g m^{-2} d^{-1}	——— m^2 g^{-1} ———		——— g g^{-1} ———		
Penncross	123[‡] a[§]	52 a	19.3 a	6.8 a	26.0 a	0.240 a	0.584 a	0.176 a
Bengal	130 a	32 b	19.3 a	7.3 a	29.1 a	0.288 b	0.543 b	0.170 a

†RGR, relative growth rate; CGR, crop growth rate; ULR, unit leaf rate; LAR, leaf area ratio; SLA, specific leaf area; LWR, leaf weight ratio; SWR, stem weight ratio; and RWR, root weight ratio.

‡Mean of 64 values (two experimental replications and four harvests of eight plants $harvest^{-1}$).

§Within column, means followed by the same letter are not significantly different at $\alpha = 0.05$.

VARIATION IN GERMINATION CHARACTERISTICS AND CONVERSION OF ESTABLISHED PUTTING GREENS USING NON-DISRUPTIVE TECHNIQUES

A paper to be submitted to *Crop Science*

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ABSTRACT

Improved cultivars of creeping bentgrass (*Agrostis stolonifera* L.) possess superior agronomic characteristics compared with ‘Penncross’ but an economically viable method of renovating golf courses has been elusive. Our objectives were to determine differences in germination characteristics among fifteen cultivars of creeping bentgrass and evaluate the success of converting existing putting greens by interseeding. A logistic function was used to obtain parameters for mean germination time (MGT) as a measure of germination speed, $T_{10\text{-}90}$ as a measure of germination synchrony, and final germination percentage (FGP) as a measure of germination capability. Interseeding was performed on golf course and research putting greens. Two seeding regimes supplying yearly totals of 220 or 659 kg ha^{-1} ‘Penn A-4’ creeping bentgrass seed along with applications of paclobutrazol and bispyribac-sodium were evaluated. There were differences between Penncross and improved cultivars of

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creeping bentgrass in MGT, $T_{10\text{-}90}$, and FGP. Improved cultivars germinated faster with shorter synchrony and exhibited greater ability to germinate. Initial evaluation of the golf course plots indicated a transient shift to Penn A-4, and greater yearly seed amounts hastened establishment. The presence of Penn A-4 was negligible 12 months after initial seeding (MAIS) regardless of seeding regime or chemical applications. Conversion on the research putting green was more persistent with 67% Penn A-4 present 24 MAIS. The varying success between the two sites may be due to differences in overall quality and maintenance levels. The reduction in turfgrass quality needed to permit interseeding should be compared with the cost of a traditional conversion when deciding on a renovation program.

INTRODUCTION

Creeping bentgrass is a cool-season, perennial grass that forms a dense, uniform surface ideal for the play of golf (Beard, 1973). It is the predominant species grown on golf course putting greens in temperate regions of the United States (Christians, 2007), and its use on fairways is gaining popularity due to its superior growth characteristics and playability (Fry and Butler, 1989; Reicher and Hardebeck, 2002). Since its introduction in 1955, Penncross has set the standard for creeping bentgrass cultivars. However, a number of cultivars are available and recently released cultivars of creeping bentgrass possess more desirable agronomic characteristics compared to Penncross. Recently developed cultivars of creeping bentgrass possess increased disease resistance and are better equipped to tolerate close mowing, high traffic, and high temperature than Penncross (Bonos et al., 2001). The recently developed cultivars also possess higher shoot densities that help impede invasion from annual bluegrass (*Poa annua* L.) (Beard et al. 2001; Croce et al. 1998) which is often a major component of established putting greens.

Traditional conversion of turf swards involving the use of non-selective herbicides or soil fumigants is costly and time consuming. Effective methods for converting established turf swards to recently developed cultivars without significant economic loss have been elusive. Interseeding has been proposed as an alternative conversion method. Interseeding is the practice of sowing seed into an established grass sward. The goal is for the introduced cultivar or species to become the major component of the sward over time (Sweeney and Danneberger, 1998). Conversion of established putting greens by using Penncross as the interseeding species has been researched but results have been modest. Gaussoin and Branham (1989) were able to obtain no more than 8% bentgrass conversion after three years of interseeding with Penncross. The lack of establishment is often credited to the inability of the seedlings to compete with mature plants for soil moisture and nutrients (Kendrick and Danneberger, 2002; Cook and Ratcliff, 1984; Snaydon and Howe, 1986). More recently, significant progress has been made interseeding with improved cultivars of creeping bentgrass. Henry et al. (2005) were able to convert 72% of an annual bluegrass putting green to Penn A-4 and ‘L-93’ creeping bentgrass over a 12 month period.

A variety of cultural factors designed to grant a competitive advantage to the seedlings is often employed. Varying irrigation (Cattani, 2001; Gaussoin and Branham, 1989) and fertility regimes (Eggens and Wright, 1985), scalping the existing canopy (Kendrick and Danneberger, 2002), and applying plant growth regulators (Gaussoin and Branham, 1989) have all been researched. While some of these cultural practices have shown promise, the major obstacle to their widespread adoption has been the disruptiveness of the practice required to enact a noticeable population shift and the resulting impact on playability. Gap size influences the early success of seedlings (Caruso, 1970). However, significant disruption to the canopy would reduce the uniformity of the playing surface and may not be desirable to golfers. Factors such as germination speed (Smoliak and Johnston, 1975; Milbau et al., 2003) and seed size (Milbau et al., 2003) also influence the success of seed sown into areas with established plants. In addition, seeding at above average rates has been advantageous when trying to establish turf cover when traffic is present (Hoiberg et al., 2009; Minner et al., 2008). Henry et al. (2005) were able to establish > 40% Penn A-4 and L-93 in one season by using an increased seeding rate of 73 kg ha^{-1}. Therefore, while many factors influence the potential success of interseeding, the varied success observed in the literature may partially be attributable to variation in seeding rates and differences in germination characteristics among cultivars of creeping bentgrass.

Research investigating detailed differences in germination characteristics among cultivars of creeping bentgrass is limited. The standard measure of turfgrass seed quality is percentage germination, which is determined by a germination test and reported on the seed label. Standard germination tests evaluate germination at an intermediate first count and again after germination is complete (AOSA, 2007). This is useful as a measure of the final germination percentage (FGP) but does not provide information about the timing of germination. The National Turfgrass Evaluation Program (NTEP) measures seedling vigor by using a one to nine numerical scale (Morris, 2010). These data offer insight into the overall vigor of the seed but provide little information about the differences in speed of germination and uniformity among cultivars. In addition, cultivars evaluated through NTEP comprise a single seed lot. Individual seed lots can vary significantly in their germination characteristics (Ene and Bean, 1975; Naylor and Hutcheson, 1986; Culleton et al., 1991;

Soren and Bibby, 2004). When a single seed lot is used, the germination characteristics of a particular cultivar may be misrepresented, especially if the seed lot is of high or poor quality.

Techniques that fit germination data to curves have proven successful in dipicting detailed measures of germination. The logistic (Schimpf et al., 1977; King and Oliver, 1994) Richards (Berry et al., 1988; Lehle and Putnam, 1982) Weibull (Bahler et al., 1989; Bridges et al., 1989) monomolecular (Bould and Abrol, 1981; Goloff and Bazzaz, 1975) and autocatalytic (Hageseth, 1974; Hageseth and Joyner, 1975) functions have all been used to evaluate germination. An appropriate curve should provide good agreement between actual and predicted values. The germination curves can then be used to derive parameters of germination such as mean germination time (MGT), as a measure of the speed of germination; the time between 10 and 90% germination ($T_{10\text{-}90}$), as a measure of synchrony or germination uniformity; and FGP, as a measure of the viability of the seed.

The objectives of this study were to determine differences in germination characteristics within and among cultivars of creeping bentgrass and to evaluate the ability of a recently developed cultivar of creeping bentgrass to convert an established putting green through interseeding.

MATERIALS AND METHODS

Germination characteristics

Fifteen commercially available cultivars of creeping bentgrass from five different seed companies were used in the study (Table 1). Limited availability of many of the cultivars from multiple years of production resulted in all seed originating from production year 2007. All available seed lots from each manufacturer were obtained and bulk seed lots were cleaned to remove extraneous material before planting. Penncross served as the control and the remaining fourteen cultivars represented improved cultivars of creeping bentgrass.

A sub-sample of 0.25 g of each seed lot was separated into two seed weight fractions using an Iowa air blast seed separator designed by the Iowa State University Seed Testing Laboratory (Aberg et al., 1945). The Iowa air blast seed separator accurately separates a sub-sample into heavy and light seed weight fractions using a vertical stream of air. The heavy seed weight fraction was collected and weighed. This procedure was repeated for all seed lots of each cultivar of creeping bentgrass.

Germination tests were conducted at the Iowa State University Seed Testing Laboratory from February to May 2009. Tests were carried out according to procedures established by the Association of Official Seed Analysts (AOSA, 2007). Four replicates of 100 seeds for each cultivar were placed by hand onto substratum consisting of two layers of blotter paper saturated with a 0.2% solution of KNO_3. Each seed lot represented a replication of each cultivar and therefore these factors were confounded. Cultivars with two seeds lots were planted twice and a fourth replicate was created for cultivars represented by three lots by blending a portion of each lot together so that each cultivar had equal replicates. Blotter papers with seed were set into germination boxes measuring 17- by 28- by 4-cm. Germination boxes were placed into plastic bags and sealed with a twist tie to prevent excess loss of moisture and were subject to a pre-chill period for seven days at 5° C to remove physiological dormancy. After the pre-chill treatment, germination boxes were placed into a single germination chamber (Hoffman Mfg., Albany, OR) maintained at 15/30° C darkness/light for 16/8 h per day (AOSA, 2007). Cool-white fluorescent light provided an average of 550 μmol m^{-2} s^{-1} photosynthetically active radiation and germination boxes were relocated within the chamber daily to account for spatial variability in irradiance.

Germination was recorded twice daily for the first five days and once daily thereafter. Germination was deemed complete when the radical protruded approximately 2 mm from the seed coat. Counts of seed germination were recorded in the same order and at the same time (± 5 min) as the germination boxes were placed into the germination chamber. The experiment was repeated a second time using identical procedures.

Germination data were modeled by using a three parameter logistic function of the form:

$$Y = A/\{1 + B*\exp[-(C*\text{day})]\} \qquad [\ 1\ ]$$

In the equation, Y is the predicted cumulative emergence percentage over time, A is the maximum emergence asymptote, B is the intercept on the Y axis, and C is the germination rate coefficient associated with days. The PROC NLIN procedure of SAS was used to fit germination curves for each seed lot of each cultivar, for a total of 60 germination curves. Estimates from the curve-fitting procedure were used to obtain values for MGT, $T_{10\text{-}90}$, and FGP. Mean germination time in days was calculated from the equation:

$$\text{MGT} = \Sigma f_x\ .\ x/\Sigma f \qquad [\ 2\ ]$$

where f_x = the number of newly germinated seeds on day x and x = the number of days since the beginning of the germination test. Lower MGT values indicate more rapid germination. Time from 10 to 90% germination was calculated as:

$$T_{10\text{-}90} = Y^{1}(0.90) - Y^{1}(0.10) \qquad [\ 3\ ]$$

where Y is the estimated distribution function of the underlying logistic distribution of the germination time. Final germination percentage was calculated as the total number of germinated seeds with normal radicals:

$$\text{FGP} = (\Sigma n/100)*100 \qquad [4]$$

where n is the number of normal seeds that had germinated at each counting. Values for MGT, $T_{10\text{-}90}$, FGP, and seed weight fractions were analyzed using PROC GLM. Means were separated using Fisher's protected least significant difference (LSD) at $\alpha = 0.05$.

Putting green conversion

An interseeding study was conducted on an established practice putting green at Hyperion Field Club in Johnston, IA in 2009 and 2010. Penn A-4 creeping bentgrass was utilized as the interseeding species and all seed originated from the same seed lot. The putting green was a mixed sward of creeping bentgrass and annual bluegrass and had never been seeded with another cultivar of creeping bentgrass. The green had a native soil rootzone with sand topdressing comprising the upper 10 cm of the soil profile with 45 mg kg^{-1} P, 51 mg kg^{-1} K, 3.0% organic matter, and a pH of 7.3. Four replications arranged in a split block experimental design were used to evaluate applications of bispyribac-sodium {sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate}, or paclobutrazol [(+/-)-(R*,R*)-β -[(4-chloro-phenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol] (main plot) or two seeding regimes (subplot within main plot). Whole plots measured 2.4 by 1.4 m and subplots measured 2.4 by 0.8 m. Seeding regimes included seed sown into the canopy twice or nine times for seasonal totals of 220 or 659 kg ha^{-1}. The seeding regime which received two sowings of seed will be referred to as regime one and the seeding regime receiving nine sowings will be referred to as regime two.

The study was initiated each year during the final week of April by using a Maredo (Maredo BV, Leersum, Holland) seeder with vibratory spikes to sow seed across all plots at a rate of 73 kg ha^{-1}. Seeding regime one received a second and final sowing during the last week of July at 146 kg ha^{-1}. Following the initial sowing, seed continued to be sown for regime two at 73 kg ha^{-1} every 14 d, concluding the second week of September. Bispyribac-sodium was applied every 14 d at 140 g ha^{-1} starting the first week of June and concluding the third week of July each year for a total of four applications. A fifth and final application was made 1 October at the same rate. Paclobutrazol was applied every 14 d at 420 g ha^{-1} starting the first week of June and concluding the second week of September each year for a total of eight applications. The above average seeding rates and multiple sowings were utilized in an attempt to partially overcome the attrition experienced by the seedlings and the applications of bispyribac-sodium and paclobutrazol were designed to reduce the overall vigor of the existing turf.

Regular maintenance practices were only slightly altered as the goal was to preserve conditions that would be conducive for the play of golf. A starter fertilizer (12N-28P-10K) was applied at a rate of 49 kg P ha^{-1} following the seeding during the last week of July. Irrigation supplied through hand-watering was conducted during the summer months in order to provide moisture to promote germination. Regular maintenance included daily mowing to a height of 0.3 cm and overhead irrigation applied as necessary. Fertilizer (7N-7P-7K) was applied at a rate of 12.2 kg N ha^{-1} each month of the growing season, and fungicides were applied as needed to control disease.

A second interseeding study was conducted concurrently on an annual bluegrass research putting green at the Iowa State University Horticulture Research Station. The sand modified native soil rootzone had 14 mg kg^{-1} P, 22 mg kg^{-1} K, 2.2% organic matter, and a pH of 8.0. Plots were arranged in a randomized completed block design with three replications. Individual plots measured 0.8 by 6.1 m. Mowing was performed three times a week at 0.3 cm and irrigation was applied daily to prevent drought stress. Treatments included seeding regimes providing yearly totals of 0 or 659 kg ha^{-1}. The equipment, seed, and sowing schedule evaluated were the same as previously described.

RAPD Analysis

Cultivars were distinguished from one another by using random amplified polymorphic DNA (RAPD) markers. The subsequent polymerase chain reaction (PCR) is not influenced by environmental conditions and has been proven effective at distinguishing cultivars of various grass species (Caetano-Annolles et al., 1995; Wu and Lin, 1994; Golembiewski, et al., 1997). Prior to initiation of treatments, random samples were collected in order to obtain a genetic identification of the unknown cultivar. Primer 715 (CCACCACCCA) consistently amplified a 680 bp band in the unknown cultivar that was absent in Penn A-4. Two sets each of 48 samples were amplified to determine the band frequency of the 680 bp fragment. The band was present in 88 and 92% of samples screened. While the possibility of false positive identification was present in our study, RAPD analysis provided a more objective measure to distinguish between bentgrass cultivars compared with visual observation.

Plant samples were collected during the fall each year prior to snowfall and during the following spring for evaluation of Penn A-4 populations. A 1.9 cm diameter soil probe was used to collect 16 random samples from each subplot. Plugs were placed in 12.7 cm wide by 11.4 cm deep pots of sand in a greenhouse. Temperature was 18-25° C and natural sunlight was supplemented with high-pressure sodium lamps that provided 200 μmol m^{-2} s^{-1} of photosynthetic active radiation and a photoperiod of 16/8 (day/night). Six individual creeping bentgrass leaves from each plug were identified by using a dissecting microscope. The samples were pooled and submitted to the Iowa State University Office of Biotechnology DNA facility for DNA isolation and subsequent primer screening. Quantification of extracted DNA was made with a GeneQuant pro (Amersham Biosciences, Piscataway, NJ). The 24 μL amplification reaction mixture contained 2.5 μL primer 715, 0.5 μL of 10 m*M* dNTP mix, 2.5 μL of 10 × PCR buffer (200 m*M* Tris-HCl, ph 8.4, 500 m*M* KCl), 0.75 μL of 50m*M* $MgCl_2$, 16.55 μL of distilled, deionized water, 1 unit *Taq* DNA polymerase, and 1 μL of 100 ng DNA template. The reagents were combined, vortexed for 10 seconds and divided into individual aliquots, then placed into 0.5-ml microfuge tubes. One microliter of DNA template was added to each aliquot, and control samples containing all reagents but without DNA template was included to verify that amplification was the result of genomic DNA and not primer artifacts (Williams et al., 1990).

DNA was amplified in a Techne TC-412 Thermal Cycler (Keison Products, Grants Pass, OR) by using the protocol described by Kendrick and Danneberger (2002). A 3-min soak at 94° C to denature the DNA was followed by 40 cycles of 1 min at 94° C, 1 min at 40 C, and 1 min at 72° C followed by a 15 min extension period at 72° C. The PCR products were resolved in gels containing 1.5% (w/v) agarose in Tris-Acetate-EDTA (TAE) buffer and stained with ethidium bromide. Electrophoresis was conducted in a horizontal electrophoresis system (E-C Apparatus, Corp., Milford, MA). Amplification products were detected under ultraviolet light in an Investigator Eclipse Imaging System (Fotodyne Incorp., Harland, WI).

Polymorphic bands were evaluated for the presence or absence of the distinguishing band at 680 bp and converted to percentage Penn A-4 conversion for each plot. Data were analyzed using PROC GLM (SAS Institute, Cary, NC). Means were separated by using Fisher's protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Germination characteristics

There was no interaction between the two experiments ($p = 0.7674$) so data were pooled across experiments. Cultivars of creeping bentgrass differed in germination characteristics, and improved cultivars exhibited different MGT, $T_{10\text{-}90}$, and FGP compared to Penncross (Table 2). Improved cultivars germinated 5% faster (lower MGT) compared with Penncross. MGT values ranged from 3.46 to 4.19 d with a mean of 3.91 d (Table 3). The cultivars 'Pennlinks II' and 'Mackenzie' had the lowest and highest MGT, respectively. Among cultivars, Pennlinks II, Penn A-4, 'Crystal Bluelinks', 'Declaration', 'T-1', 'Independence', 'Penn A-1', and 'Alpha' had significantly lower MGT values compared with Penncross. These cultivars germinated 4 to 15% faster than Penncross. Pennlinks II had an MGT value that was significantly lower compared with all other cultivars and an MGT value 11% less than all improved cultivars.

Improved cultivars of creeping bentgrass germinated with 21% tighter synchrony (lower $T_{10\text{-}90}$) compared with Penncross (Table 2). Values for $T_{10\text{-}90}$ ranged from 1.30 to 2.04 d with a mean of 1.64 d (Table 3). The cultivars T-1 and Penncross had the lowest and highest $T_{10\text{-}90}$, respectively. Among cultivars, Crystal Bluelinks, Declaration, T-1, Independence, Alpha, L-93, and '007' had significantly lower $T_{10\text{-}90}$ values than Penncross. These cultivars germinated with 24 to 36% shorter synchrony than Penncross.

Improved cultivars of creeping bentgrass exhibited 2% greater germination (higher FGP) than Penncross (Table 2). FGP values ranged from 93.5 to 98.4% with a mean of 96.6% (Table 3). The cultivars Declaration and T-1 had the lowest and highest FGP, respectively. Among cultivars, T-1, Penn A-1, L-93, 'Tyee', 007, and Mackenzie had FGP values 2 to 4% greater than Penncross. Regression analysis revealed an inverse relationship between FGP and $T_{10\text{-}90}$ ($r^2 = 0.15$, $p = 0.0022$,) but not between FGP and MGT.

Significant differences were not observed for seed weight between improved cultivars of creeping bentgrass and Penncross (Table 2). Seed weight fractions ranged from 0.07 to 0.16 g with a mean of 0.12 g (Table 3). The cultivars Alpha and T-1 had seed weight 27 to 31% greater than Penncross, and the cultivar 007 had a seed weight fraction 38% less than Penncross. Linear regression analysis revealed an inverse relationship between seed weight and MGT ($r^2 = 0.22$, $p = <0.0001$). However, seed weight did not significantly influence $T_{10\text{-}90}$, or FGP.

Most research involving improved cultivars of creeping bentgrass has focused on vegetative characteristics. In addition to improved morphological characteristics, our results indicate that improved varieties of creeping bentgrass are generally superior to Penncross with respect to their germination characteristics (Table 2). While some of the differences in germination characteristics between cultivars are small, the differences could be greater in field conditions where the seeds would be subjected to multiple environmental stresses. Larsen et al. (2004) found that differences in MGT were more pronounced at 5/15° C than at 15/25° C. We used alternating temperatures of 15/30° C, which is considered a near optimal temperature regime for germination of creeping bentgrass seeds (AOSA, 2007). However, seeds sown in field conditions would likely experience sub or supra-optimal temperatures depending on when seeding occurs. Henry et al. (2005) found that summer seeding dates resulted in greater establishment of Penn A-4 and L-93 into an annual bluegrass putting green, compared to spring and fall plantings. The success of the summer plantings is likely the result of the annual bluegrass being less competitive during the summer months. Brede (1982) demonstrated that the growth of annual bluegrass nearly stops when day lengths approach their maximum. In addition, Beard (1978) reported a substantial drop in the germination of annual bluegrass when soil temperatures exceed 27° C.

Significant cultivar differences in MGT were observed in our study (Table 2). Differences in MGT among cultivars have also been reported for perennial ryegrass (Naylor, 1982), red fescue, and Kentucky bluegrass (Larson and Bibby, 2004). Our findings also revealed an inverse relationship between seed weight and MGT, indicating that cultivars of creeping bentgrass with heavier seeds possess lower MGT values. The cultivar T-1 had the heaviest seed weight and also possessed one of the lowest MGT values, whereas 007 had the lightest seed weight and exhibited one of the highest MGT values. While not a direct test, the trend in our data is consistent with the findings of Larson et al. (2004) who also discovered MGT values decreased with increasing seed weights in red fescue, perennial ryegrass, and Kentucky bluegrass. It is likely that the inverse relationship between seed weight and MGT may be common among grass species. Seed weight or size has also been shown to affect growth and development in the seedling phase of the life cycle and to increase overall competitive ability (Turnbull et al., 1999). In a turf setting, seeds sown on an established putting green would be subject to a myriad of stresses including competition from neighboring plants, mowing, ball marking, and foot and equipment traffic. Using cultivars of creeping bentgrass with larger sized seeds may hasten establishment under these adverse conditions.

An inverse relationship between MGT and FGP has been reported (Larson and Bibby, 2004; Roberts, 1986) although this relationship was not apparent in our experiment (p = 0.4804). In our study, Declaration had the lowest FGP and the fourth lowest MGT value whereas Mackenzie had the third highest FGP and highest MGT value. The cultivar Declaration germinated very fast despite its low FGP, indicating that MGT is partially under genetic control. We did however discover an inverse relationship between $T_{10\text{-}90}$ and FGP (data not shown). The cultivar T-1 had the highest FGP and the lowest $T_{10\text{-}90}$, whereas Penncross had the second lowest FGP and the highest $T_{10\text{-}90}$ (Table 3). Despite being correlated, this trend was not evident for all cultivars of creeping bentgrass used in this study. Declaration had the lowest FGP and one of the lowest $T_{10\text{-}90}$ values. Similarly, Mackenzie had the third highest FGP and one of the highest $T_{10\text{-}90}$ values.

Putting Green Conversion

Analysis of variance revealed a significant year × treatment interaction for the Hyperion study, so data are presented separately by year. Seeding rate had an effect on the percentage of Penn A-4 coverage six months after initial seeding (MAIS) in 2009 (Table 4). Six months after initial seeding, Penn A-4 was identified in 17-20% and 38-41% of the collected samples for the 220 and 659 kg ha^{-1} seeding rate, respectively. The presence of Penn A-4 dropped to 5-7% and 6-11%, at 12 MAIS for the 220 and 659 kg ha^{-1} seeding rates, respectively. Applications of paclobutrazol and bispyribac-sodium did not hasten establishment to Penn A-4 at either sampling date. However, populations of annual bluegrass were reduced 67% in plots receiving bispyribac-sodium (data not shown). Bispyribac-sodium has been shown to offer postemergence control of annual bluegrass in perennial ryegrass and creeping bentgrass (Branham and Calhoun, 2005).

In 2010, seeding rate and product affected the presence of Penn A-4 six months after initial seeding (Table 4). Penn A-4 was identified in 3-9% and 11-23% of the collected samples for the 220 and 659 kg ha^{-1} seeding rate, respectively. The 659 kg ha^{-1} seeding rate resulted in a 50% increase in the presence of Penn A-4. The lack of initial establishment from the 220 kg ha^{-1} seeding rate in 2010 is likely due to excessive rainfall that washed seed from the two Penn A-4 sowings. Additionally, the control and plots receiving paclobutrazol had 56-61% greater Penn A-4 than plots receiving bispyribac-sodium. Air temperatures over 32° C during the time of bispyribac-sodium applications resulted in a considerable loss in turf density and likely had a detrimental effect on Penn A-4 seedlings. Studies have shown that juvenile creeping bentgrass plants are prone to injury from bispyribac-sodium (Sharp and Branham, 2005). Applications of bispyribac-sodium did not provide control of annual bluegrass in 2010 (data not shown). The long term survival of Penn A-4 in 2010 was minimal with populations 12 MAIS ranging from 3 to 8% (Table 4). Furthermore, additional sowings and applications of paclobutrazol and bispyribac-sodium did not improve establishment of Penn A-4. Although additional sowings hastened establishment 6 MAIS in 2009 and 2010, seeding rate was not significant 12 MAIS in either year. The high seeding rates could have slowed the development of creeping bentgrass seedlings, leaving them at a competitive disadvantage as suggested by Rossi and Millet (1996).

The lack of success of seedlings sown into existing turf canopies is often credited to the inability of the seedlings to compete with mature plants for resources. Cattani (2001) found that seedlings demonstrated reduced plant dry weight, tiller number, and tiller weight when subject to competition from mature turf. Seedlings in this study were also subject to additional stresses common on golf course putting greens such as foot and mower traffic, which could further complicate long term survival. Initial establishment of Penn A-4 seedlings emerging within the turfgrass canopy was observed in these studies and has been noted in other research (Henry et al., 2005; Kendrick and Danneberger, 2002). Initial success could be partially explained by the nature of seedling growth. Seedlings first rely on seed reserves until the new plant emerges above the soil surface (Whalley, et al., 1966). Once the seed reserves are exhausted, the new plant is left to compete against established plants for limited resources.

Long term survival of Penn A-4 was more successful on the research putting green. Forty-two percent of samples were identified as Penn A-4 six months after initial seeding (Table 5). Penn A-4 populations were able to persist on the research green with 45% still present 12 MAIS. Sowing into the existing plots continued because of the persistence of Penn A-4. After the addition of another 659 kg ha^{-1} of seed, the number of samples identified as Penn A-4 had increased to 63 and 67%, 18 and 24 MAIS, respectively. This percentage conversion to Penn A-4 is similar to that found by Henry et al. (2005) who achieved 45 and 72% establishment of Penn A-4, 12 and 24 months after seeding, respectively. The presence of Penn A-4 in the non-seeded control plots could be the result of seed migrating into the plot and false positive amplification.

The success of interseeding in the research setting compared with the golf course setting can partially be attributed to differences in conditioning between the two sites. The research green received far less stress from foot and mower traffic compared with the golf course putting green. However, the overall quality and density of the research green would not be acceptable for a putting green surface, especially during the summer months. While these conditions created a favorable environment for interseeding, the conditions would likely not be tolerated by golfers. These results also demonstrate that when conditions permit interseeding, conversion is not instantaneous but occurs over time. Patchiness of bentgrass cultivars with varying morphological characteristics during the conversion process could compromise uniformity and create undesirable putting conditions. Penn A-4 seedlings extending above the canopy also could reduce ball roll uniformity during germination events.

Researchers have hypothesized the limited success experienced in past conversion experiments may partially be due to cultivar selection (Beard et al., 2001; Henry et al, 2005). Our research demonstrates that cultivars of creeping bentgrass possess varying germination characteristics and that recently developed cultivars generally germinate faster and with more synchrony than Penncross. Conversion in our study was transient when conditions of the putting green were preserved to facilitate play despite the selection of a cultivar with high seed vigor. However, conversion to Penn A-4 was more successful and persistent on a research putting green. These results suggest that the level of maintenance and overall quality of the putting surface influence the success of conversion and may explain the varying success of interseeding in the literature. The overall conditioning of the putting surface along with the time required for conversion with interseeding needs to be weighed against the cost of a traditional conversion when deciding on a renovation program.

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LITERATURE CITED

Aberg, E., R.H. Porter, and W.A. Robbins. 1945. Further experiments with the Iowa air blast seed separator for the analysis of small seeded grasses. Iowa Agr. Exp. Stn. Res. Bul. 340:785-803.

Association of Official Seed Analysts. 2007. Rules for testing seed. AOSA Inc., Las Cruces, NM.

Bahler, C., R.R. Hill Jr., and R.A. Byers. 1989. Comparison of logistic and Weibull functions: The effect of temperature on cumulative germination of alfalfa. Crop Sci. 29:142-146.

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J.B. 1978. Annual bluegrass (*Poa annua* L.): Description, adaptation, culture and control. Available at http://archive.lib.msu.edu/DMC/turfgrass/PDF/rr352.pdf (verified 28 Apr. 2010) Michigan State University, Agr. Exp. Stn., East Lansing, MI.

Beard, J.B., P. Croce, M. Mocioni, A. De Luca, and M. Volterrani. 2001. The competitive ability of thirteen *Agrostis stolonifera* cultivars to annual bluegrass. Int. Turfgrass Soc. Res. J. 9:828-831.

Berry, G.J., R.J. Cawood, and R.G. Flood. 1988. Curve fitting of germination data using the Richards function. Plant Cell Environ. 1:183-188.

Bonos, S.A., K.A. Plumley, W.A. Meyer, J.A. Murphy, B.B. Clarke, W.K. Dickson, J.B. Clark, and D.A. Smith. 2001. Performance of bentgrass cultivars and selections in New Jersey turf trials, p. 1-21. In: A.B. Gould (ed). Rutgers turfgrass proceedings. vol. 33. Rutgers Ctr. Turfgrass Sci, New Brunswick, N.J.

Bould, A. and B.K. Abrol. 1981. A model for germination curves. Seed Sci. Technol. 9:601-611.

Branham, B. and R. Calhoun. 2005. Velocity: *Poa annua* control at last? Golf Course Manage. 73:73-77.

Brede, A.D. 1982. Interaction of three turfgrass species. Ph.D. diss. Pennsylvania State Univ, University Park.

Bridges, D.C., H. Wu, P.J.H. Sharpe, and J.M. Chandler. 1989. Modeling distributions of crop and weed seed germination time. Weed Sci. 37:724-729.

Caetano-Anolles, G., L.M. Callahan, P.E. Williams, K.R. Weaver, and P.M. Gresshoff. 1995. DNA amplification fingerprinting analysis of bermudagrass (*Cynodon*): Genetic relationships between species and interspecific crosses. Theor. Appl. Genet. 91:228-235.

Caruso, J.L. 1970. Early seedling survival of *Melilotus* in bluegrass sod. Ecology 51:553-554.

Cattani, D.J. 2001. Effect of turf competition on creeping bentgrass seedling establishment. Int. Turfgrass Soc. Res. J. 9:850-854.

Christians, N.E. 2007. Fundamentals of turfgrass management. 3rd ed. John Wiley & Sons, Hoboken, NJ.

Cook, S.J., and D. Ratcliff. 1984. A study of the effects of root and shoot competition on the growth of green panic (*Panicum maximum* var. *trichoglume*) seedlings in an existing grassland using root exclusion tubes. J. Appl. Ecol. 21:971-982.

Croce, P.M. Mocioni, and J.B. Beard. 1998. *Agrostis* cultivar characterizations for closely mowed putting greens in a Mediterranean climate, p. 668-678. In.: M.R. Farrally and A.J. Cochran (eds.). Science and golf III. Proc. 3rd World Sci. Congr. Golf, St. Andrews, U.K.

Culleton, N., V. McCarthy, and D. McGilloway. 1991. A note on the germinability and early seedling growth of *L. perenne*. Irish J. Agric. Res. 30:159-161

Eggens, J.L., and C.P.M Wright. 1985. Nitrogen effects on monostands and polystands of annual bluegrass and creeping bentgrass. HortScience. 20:109-110.

Ene, B.N., and E.W. Bean. 1975. Variations in seed quality between certified seed lots of perennial ryegrass, and there relationship to nitrogen supply and moisture status during seed development. J. Br. Grassl. Soc. 30:195-199.

Fry, J.D. and J.D. Butler. 1989. Annual bluegrass and creeping bentgrass evapotranspiration rates. HortScience 24:269-271.

Gaussoin, R.E., and B.E. Branham. 1989. Influence of cultural factors on species dominance in a mixed stand of annual bluegrass/creeping bentgrass. Crop Sci. 29:480-484.

Golembiewski, R.C., T.K. Danneberger, and P.M. Sweeney. 1997. Potential of RAPD markers for use in the identification of creeping bentgrass cultivars. Crop Sci. 37:212-214.

Goloff, A.A., Jr. and F.A. Bazzaz. 1975. A germination model for natural seed populations. J. Theo. Bio. 52:259-283.

Hageseth, G.T. 1974. Effects of noise on the mathematical parameters that describe isothermal seed germination. Plant Physiol. 53:641-643.

Hageseth, G.T. and R.D. Joyner. 1975. Kinetics and thermodynamics of isothermal seed germination. J. Theor. Biol. 53:51-65.

Henry, G.M., S.E. Hart, and J.A. Murphy. 2005. Overseeding bentgrass species into existing stands of annual bluegrass. HortScience. 40:468-470.

Hoiberg, A.H., D.D. Minner, O. Valverde, and F.J. Valverde. 2009. Seeding rates of annual ryegrass that maximize turf cover when sown during traffic. Inter. Turf Soc. Res. J. 11:375-387.

Kendrick, D.J. and T.K. Danneberger. 2002. Lack of competitive success of an intraseeded creeping bentgrass cultivar into an established putting green. Crop Sci. 42:1615-1620.

King, C.A., and L.R. Oliver. 1994. A model for predicting large crabgrass (*Digitaria sanguinalis*) emergence as influenced by temperature and water potential. Weed Sci. 42:561-567.

Larson, S.U. and B.M. Bibby. 2004. Use of germination curves to describe variation in germination characteristics in three turfgrass species. Crop Sci. 44:891-899.

Larson, S.U., C. Andreasen, and P. Kristoffersen. 2004. Differential sowing time of turfgrass species affect the establishment of mixtures. Crop Sci. 44:1315-1322.

Lehle, F.R., and A.R. Putnam. 1982. Quantification of allelopathic potential of sorghum residues by novel indexing of Richards' function fitted to cumulative cress seed germination curves. Plant Physiol. 69:1212-1216.

Milbau, A., I. Nijs, L. Van Peer, D. Reheul, and B.D. Cauwer. 2003. Disentangling invasiveness and invisibility during invasion in synthesized grassland communities. New Phytologist. 159:657-667.

Minner, D.D., and F.J. Valverde, R.M. Pirtle. 2008. Seeding rates that maximize turf cover when sown during traffic. p. 57-62. *In* J.C. Stier et al. (ed.) Proceedings of the Second International Conference on Turfgrass Science and Management for Sports Fields. Proc. 2nd Int. Conf. on Turfgrass, Beijing, China. 24-29 June. 2007.

Morris, K.N. 2010. A guide to NTEP turfgrass ratings. National Turfgrass Evaluation Program. Available at http://www.ntep.org/reports/ratings.htm#seedlvig (verified 28 Apr. 2010). USDA-ARS. Beltsville, MD.

Naylor, R.E.L. 1982. Differences between cultivars of perennial ryegrass in laboratory germination and field emergence. Ann. Appl. Biol. 100(suppl.):106-107.

Naylor, R.E.L., and H.J.A. Hutcheson. 1986. The germination behaviour in soil and compost of different seed lots of perennial ryegrass. Crop Res. 25:123-132.

Reicher, Z.J. and G.A. Hardebeck. 2002. Overseeding strategies for converting golf course fairways to creeping bentgrass. HortScience. 37:508-510.

Roberts, E.H. 1986. Quantifying seed deterioration. p. 101-123. *In* M.B. McDonald, Jr., and C.J. Nelson (ed.) Physiology of seed deterioration. CSSA Spec. Publ. 11. CSSA, Madison, WI.

Rossi, F.S. and S.M. Millett. 1996. Long-term consequences of seeding bentgrasses at high rates. Golf Course Manage. 10:49-52.

Schimpf, D.J., S.D. Flint, and I.G. Palmblad. 1977. Representation of germination curves with the logistic function. Ann. Bot. 41:1357-1360.

Sharp, W., and B.E. Branham. 2005. Effect of velocity on newly seeded creeping bentgrass. 2005 Univ. of Illinois Turf & Nursery Field Day. p. 24-25.

Smoliak, S., and A. Johnston. 1975. Seedling competition of some grasses in mono-and mixed culture under greenhouse conditions. Can. J. Plant Sci. 55:935-940.

Snaydon, R.W., and C.D. Howe. 1986. Root and shoot competition between established ryegrass and invading grass seedlings. J. Appl. Ecol. 23:667-674.

Soren, U.L., and B.M. Bibby. 2004. Use of germination curves to describe variation in germination characteristics in three turfgrass species. Crop Sci. 44:891-899.

Sweeney, P, and K. Danneberger. 1998. Introducing a new creeping bentgrass cultivar through interseeding: Does it work? USGA Green Section Record. 36(5):19-20.

Turnbull, L.A., M. Rees, and M.J. Crawley. 1999. Seed mass and the competition/colonization trade-off: A sowing experiment. J. Ecol. 87:899-912.

Whalley, R.B.D., C.M. McKell, and L.R. Green. 1966. Seedling vigor and the non-photosynthetic stage of seedling growth in grasses. Crop Sci. 6:147-150.

Williams, J.G.K., A R. Kubelik, K.J. Livak, J.A. Rafalski, and S.V. Tingey. 1990. DNA polymorphisms amplified by arbitrary primers are use as genetic markers. Nucleic Acids Res. 18:6531-6535.

Wu, L., and H. Lin. 1994. Identifying buffalograss cultivar breeding lines using random amplified polymorphic DNA (RAPD) markers. J. Am. Soc. Hortic. Sci. 119:126-130.

Table 1. Creeping bentgrass cultivar, number of lots tested, and source of seed material. Standard germination tests were performed according to guidelines established by the Association of Official Seed Analysts (AOSA).

Cultivar	Lots†	Source‡
Pennlinks II§	3	Tee-2-Green
Penn A-4	3	Tee-2-Green
Crystal Bluelinks	2	Tee-2-Green
Declaration	2	Lebanon Seaboard Company
T-1	4	Jacklin Seed Division J.R. Simplot
Independence	2	Lebanon Seaboard Company
Penn A-1	3	Tee-2-Green
Alpha	3	Jacklin Seed Division J.R. Simplot
Memorial	4	The Scotts Company
L-93	3	Jacklin Seed Division J.R. Simplot
Tyee	3	Seed Research of Oregon
Penncross	3	Tee-2-Green
007	3	Seed Research of Oregon
SR1150	3	Seed Research of Oregon
Mackenzie	3	Seed Research of Oregon

†All seeds lots came from production year 2007.

‡Jacklin Seed Division J.R. Simplot, Post Falls, ID; Tee-2-Green, Canby, OR; Seed Research of Oregon, Corvallis, OR; The Scotts Company, Marysville, OH; Lebanon Seaboard Company, Lebanon, PA.

§Sorted according to mean germination time (Table 3).

Table 2. Cultivars of creeping bentgrass differ in their mean germination time (MGT), time from 10 to 90% germination ($T_{10\text{-}90}$), final germination percentage (FGP), and weight. Improved cultivars have different MGT, $T_{10\text{-}90}$, and FGP compared with ‘Penncross’.

	Germination parameters†			
	MGT	$T_{10\text{-}90}$	FGP	Weight‡
Significance§	**	**	**	**
	Mean			
	———————— d ————————		——%——	—— g ——
Penncross	4.09	2.04	94.9	0.11
Improved Cultivars¶	3.90	1.61	96.7	0.12
Significance#	**	**	*	NS

† Germination data were modeled by using Eq [1], $Y = A/\{1 + B*\exp[-(C*\text{day})]\}$. The predicted values were used to obtain values for MGT, $T_{10\text{-}90}$, and FGP.

‡ Seed weight was determined by separating a 0.25 g sample into two seed weight fractions by using an Iowa air blast seed separator designed by the Iowa State University Seed testing Laboratory. The heavy seed weight fraction was collected and weighed.

§ *F*-test to determine differences among all cultivars of creeping bentgrass. NS, *,**- Nonsignificant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

¶ Comprised of 14 cultivars of creeping bentgrass (Table 1). All cultivars of creeping bentgrass were comprised of two to four seed lots from production year 2007.

F-test to determine differences between ‘Penncross’ and improved cultivars of creeping bentgrass. NS, *,**Nonsignificant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 3. Predicted values for mean germination time (MGT), time from 10 to 90% of germination ($T_{10\text{-}90}$), and final germination percentage (FGP) for 15 creeping bentgrass cultivars. Values represent means from eight experimental units.

Cultivar‡	Germination Parameters†			Weight§
	MGT	$T_{10\text{-}90}$	FGP	
	———— d ————	———— d ————	——— % ———	—— g ——
Pennlinks II	3.46	1.79	96.7	0.14
Penn A-4	3.66	1.93	96.9	0.13
Crystal Bluelinks	3.74	1.43	96.3	0.09
Declaration	3.77	1.56	93.5	0.14
T-1	3.82	1.30	98.4	0.16
Independence	3.82	1.46	95.2	0.14
Penn A-1	3.90	1.75	97.2	0.12
Alpha	3.92	1.40	96.8	0.15
Memorial	3.93	1.69	96.3	0.09
L-93	4.03	1.40	97.9	0.12
Tyee	4.08	1.76	97.1	0.11
Penncross	4.09	2.04	94.9	0.11
007	4.11	1.56	97.4	0.07
SR1150	4.14	1.84	97.0	0.13
Mackenzie	4.19	1.72	97.5	0.07
Mean	3.91	1.64	96.6	0.12
LSD¶	0.17	0.39	2.1	0.03

† Germination data were modeled by using Eq [1], $Y = A/\{1 + B{*}\exp[-(C{*}\text{day})]\}$. The predicted values were used to obtain values for MGT, $T_{10\text{-}90}$, and FGP.

‡ Cultivars are sorted according to the MGT column. All cultivars of creeping bentgrass were comprised of two to four seed lots from production year 2007.

§ Seed weight was determined by separating a 0.25 g sample into two seed weight fractions by using an Iowa air blast seed separator designed by the Iowa State University Seed testing Laboratory. The heavy seed weight fraction was collected and weighed.

¶ Means were separated by using Fisher's protected least significant difference at $\alpha = 0.05$

Table 4. Effect of seed rate, paclobutrazol and bispyribac-sodium on the percentage conversion of an established putting green to Penn A-4 creeping bentgrass at Hyperion Field Club in Johnston, Iowa.

	2009				2010			
	Seeding rate (kg ha^{-1})				Seeding rate (kg ha^{-1})			
	220	659	220	659	220	659	220	659
Treatment	6 MAIS[†]		12 MAIS		6 MAIS		12 MAIS	
	%							
Control	20[‡]	41	7	11	9	23	5	8
Paclobutrazol[§]	17	38	5	9	16	19	6	5
Bispyribac-sodium[¶]	19	39	6	6	3	11	5	3
Analysis of variance								
Source of variation								
Seed rate (R)	**[#]		NS		*		NS	
Product (P)	NS		NS		*		NS	
R x P	NS		NS		NS		NS	

† Months after initial seeding. Initial seeding occurred the last week of April.

‡ Means of four replications.

§ Paclobutrazol was applied every 14 d at 420 g ha^{-1} starting the first week of June and concluding the second week of September each year for a total of eight applications.

¶ Bispyribac-sodium was applied every 14 d at 140 g ha^{-1} starting the first week of June and concluding the third week of July each year for a total of four applications. A fifth and final application was made 1 October at the same rate.

NS, *,**Nonsignificant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 5. Effect of seed rate on the percentage conversion of an established putting green to Penn A-4 creeping bentgrass at the Iowa State University Horticulture Research Station near Gilbert, Iowa.

	2009		2010	
Seeding rate (kg ha^{-1})	6 MAIS†	12 MAIS	18 MAIS	24 MAIS
	%			
0	4a‡	2a	8a	13a
659	42b	45b	63b	67b

† Months after initial seeding. Initial seeding occurred the last week of April 2009.

‡ Within columns, means followed by the same letter are not significantly different at $\alpha = 0.05$.

USING BLOGS TO DISSEMINATE INFORMTION IN THE TURFGRASS INDUSTRY

A paper accepted by *The Journal of Extension*

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Abstract

The ability to provide regional information to turfgrass professionals in a timely format can help them avoid potential problems. While traditional, hard-copy based Extension materials can provide a wealth of information, the ability to communicate brief, yet current updates can be invaluable. Two web-based blogs were developed to provide information to turfgrass managers on a local (iaTURF) and international level (Turf Diseases). Data indicated that the blogs reached an average of 34.9 to 148.4 people per day. The use of blogs is an effective means to deliver timely information to a geographically diverse and large number of turfgrass managers.

Introduction

Disseminating information is a key component of Extension. Turfgrass Extension programs

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have traditionally disseminated information through site visits, newsletters, extension bulletins, meetings, seminars, and field days. In addition, Extension offices located in each county or region provide a local presence and emphasize direct contact, networking, and interaction with the people seeking information. However, shifting organizational structure within Extension along with the abundance of information available on the internet is changing the way information is disseminated as well as the way people seek information.

Many Extension programs are using Internet sites and computer-based technologies to disseminate information (Mayfield, Wingenbach & Chamlers, 2006; High & Jacobson, 2005; Rost & VanDerZanden, 2002; Harrison, Kanade & Toney, 2004; LaBorde, 2003; Kraft, 2004). The hope in using these technologies is to extend Extension programs to new audiences who tend to glean much of their information from online sources. Meanwhile, the people seeking information still value conversation, networking and interaction. This human element of getting to know the person behind the information is often critical in determining where people seek information (Coates, 2002). Weblogs, more commonly referred to as blogs, have the potential to effectively disseminate information to large audiences while still providing many of the traditional benefits of personalized Extension contacts.

Advantages of Using Blogs

A blog is a type of website which displays regular updates or commentary listed in chronological order. A host of sites offer free hosting services such as Blogger, WordPress, and others. Content is mainly textual but images and video are often incorporated along with additional interactive features such as chat, polls, and links to other websites and blogs.

Blogs have the potential to change the way Extension agents communicate and offer many advantages as a vehicle for information dissemination.

- **Blogs provide timely, relevant information.** The information required by professionals in the turfgrass industry changes frequently. Because blogs are easily updated, they can be used to filter information to match what is relevant at the time. After all, information is only useful if people can find what they need when they need it.

- **Blogs promote conversation.** Blogs offer the capability to leave comments. Readers can respond with questions, additional information, and offer feedback on a particular topic.

- **The impact of the content can be tracked.** Tracking impact is vital to assessing the effectiveness of disseminated information. The impact of information delivered via blogs can be tracked with web analytics programs which record numerous metrics (Patton and Kaminski, 2010).

- **Blogs create relationships.** Most blogs allow the reader the opportunity to learn about the people contributing content and provide information not only about what a person knows, but what they value.

- **Blogs are easily integrated with other technologies.** Blogs support images, movies, and presentations and can be paired with popular social networking media such as Facebook™, Twitter™, Feedburner, RSS (really simple syndication), and others. This integration allows the individual reader to obtain the information in a format that is best suited for them.

Challenges of Using Blogs

While blogs offer many advantages, there are obstacles that must be addressed.

- **Frequent updates require dedication.** Blogs are often perceived as fluid and constantly changing. This attribute is beneficial to the reader but can be a challenge to the people contributing information especially given the seasonal nature of the turfgrass industry in some parts of the country. How frequently the information is updated depends on many factors but the content will need to stay current in order to keep readers interested and coming back.

- **Availability and speed of Internet access.** Blogs are hosted on the Internet and require access to the Internet to view the information. In addition, blogs may be cumbersome to navigate depending on the Internet connection speed and the amount of pictures, videos, and presentations incorporated on the blog.

- **Preference for traditional methods.** Despite the popularity of new technology there will always be a segment that prefers traditional methods of information dissemination. This market, however, continues to decrease with new technology and within younger generations.

Examples of Blogs for the Turfgrass Industry

Two turfgrass blogs were created in 2009 in order to disseminate information to the turfgrass industry. Below are a brief description and the intended scope of each blog.

iaTURF: A Glimpse of All Things Green (www.iaTURF.blogspot.com). This blog is managed by individuals from Iowa State University. The goal of iaTURF is to provide turfgrass professionals in Iowa and the Midwest with a convenient way to communicate and collaborate with peers, industry professionals, and educators. The blog has multiple contributors including university professors, industry representatives and vendors, golf course superintendents, and students. The iaTURF blog posts topics on a wide range of subjects related to managing turfgrass and other industry related issues. Content is posted as information becomes available and in order to keep turfgrass managers informed on current topics. The length of each post is governed keeping with the idea that obtaining information from the iaTURF blog is quick and convenient.

Turf Diseases: Golf Course Disease Updates by University Professors (www.turfdiseases.blogspot.com). The Turf Diseases blog was established to provide golf course superintendents in the United States (U.S.) timely updates about current problems within five geographic regions. Weekly updates are provided by one of five turfgrass pathologists representing the following regions of the U.S.: Northeast, Southeast, Midwest, West, and South Central. While each region is assigned an update on a specific day of the week, weekend posts were initiated in 2010 to provide updates for a growing international audience. Updates include short snippets of information about current disease problems, control recommendations, weather trends and similar relevant information for professional turfgrass managers. Information is presented in an easy to read and simplified format that includes images, videos, and limited text to make the experience enjoyable, but informational for the reader.

Impact and Findings

Each blog utilizes Google™ Analytics in order to track various metrics (Table 1). During the periods tracked for each blog, the average time spent on iaTURF and Turf Diseases was 68 and 133 seconds, respectively. In addition, a total of 17,903 visits were recorded for iaTURF and 38,878 visits were recorded for Turf Diseases. Although not reported in the metrics, a greater portion of visits occurs between the spring and fall months when turfgrass management is at its peak. Typical of what is expected for an online community, only 1.7 to 2.9% of the visitors utilized dial-up Internet connections to visit the site. Surprisingly, a similar number of people accessed iaTURF (2.4%) and Turf Diseases (5.5%) via mobile devices compared with dial-up Internet connections.

The ability to extend content to new users in an effort to reach a larger audience can be a challenging task for a newly developed blog. In the case of iaTURF and Turf Diseases, 46.1

and 27.1% of the users visited the website as direct traffic, respectively. The remainder of the visitors to each blog was directed by their referring sites (31.2 to 35.4%), via search engines such as Google and Bing (18.5 to 27.3%), or by other unknown methods (0.02 to 14.4%).

Visitors to the Turf Diseases blog represented 49 of 50 states within the U.S. as well as the District of Columbia. States with the largest number of visitors included Pennsylvania (3731), New York (2352), North Carolina (2352), and California (1997). It is likely that the promotion of the site by individual blog authors and/or at regional state meetings influenced the traffic from individual states. While a majority of visitors to the Turf Diseases blog were from the U.S. (33,039), nearly 6,000 visitors were from 117 other countries or territories (Figure 1).

The vast majority of visitors to the iaTURF blog originated from Iowa and the Upper Midwest Region of the U.S. (Figure 2). The state of Iowa and its six neighboring states comprised 52.2 and 23.9% of the visits, respectively. The remainder of the U.S. accounted for 23.9% of the traffic to the iaTURF site. The desire of the authors to manage the content of the iaTURF site to a Midwest audience is reflected by the concentration of traffic in that region.

Discussion and Conclusion

Traditional hard-copy based Extension updates have been the standard for delivering relevant information to the end user; however, the use of web-based media continues to increase. While the development of new Extension materials can be a difficult task, the use of blogs to provide brief, but timely information can make it easier for both the author and the reader. A benefit of this format is the ability to deliver quick, relevant information to end users in a variety of formats. Blogs do present challenges including the cyclical nature of visits by season and the preference by some for traditional Extension based methods.

Analytics from two blogs designed for the turfgrass industry indicate that between 34.9 and 148.4 people visited the sites per day. The continual source of visits may reflect the timely, fluid nature of the content. This is in contrast with traditional Extension based materials which tend to be more static. While on the site, readers spent an average of 1 to 2 minutes reading content. The time readers spend on each site may partially be due to the authors intentionally limiting the amount of content to cater to turfgrass professionals busy schedules. These results indicate a need to continue to provide brief, but relevant information in a timely manner.

Another benefit of developing blog content is the potential to reach a larger number of individuals. For instance, the introduction of international updates to the Turf Diseases site was initiated in response to traffic from countries other than the United States. Blog developers must also pay attention to the factors driving traffic to their respective sites. While many visitors to the iaTURF and Turf Diseases blogs reached the sites directly, 53.9 and 62.9% of the visitors found the blogs by some other means. Both iaTURF and Turf Diseases utilize Facebook as a vehicle to reach additional readers. Since pairing the blogs, Facebook has accounted for 15.6 and 9.4% of the referrals for iaTURF and Turf Diseases, respectively. This data indicates the power of integrating these blogs with social media sites as well as the importance of gaining referrals from other subject-related websites. The ability to integrate blog content with other social media outlets gives the end user the ability to select which format or delivery method best suits their social media use habits. The use of blogs makes it easier to share relevant content in a timely fashion and increases the ability of Extension to reach a larger audience. While the development of a blog can be an effective resource, the dissemination of the blog content to a variety of social media sites will be an important consideration to increase awareness and deliver content in a format appropriate for a wide range of end users.

References

Coates, D. (2002). Blogs as trusted sources and knowledge filters. Retrieved February 24, 2010, from http://www.extension.iastate.edu/mt/dcoates/extras/blogs2002_part_one.html

Harrison, J. D., Kanade, S.S., & Toney, A. H. (2004). Agricultural environmental management information system: An online decision support tool. *Journal of Extension* [On-line], 42(1). Article 1TOT4. Available at: http://www.joe.org/joe/2004february/tt4.php

High, J. & Jacobson, M. (2005). Internet-based natural resource Extension. *Journal of Extension* [On-line], 43(3). Article 3RIB9. Available at: http://www.joe.org/joe/2005june/rb9.php

Kraft, C. (2004). Pond management: An evaluation of Web-based information delivery. *Journal of Extension* [On-line], 42(1) Article 1FEA3. Available at: http://www.joe.org/joe/2004february/a3.php

LaBorde, L. (2003). Impact of the Penn State food safety Web site as a food safety information resource for Extension professionals. *Journal of Extension* [On-line], 41(2). Article 2RIB5. Available at: http://www.joe.org/joe/2003april/rb5.php

Mayfield, C. A., Wingenback, G. J., & Chalmers, D. R. (2006). Using CD-based materials to teach turfgrass management. *Journal of Extension* [On-line], 44(2). Article 2FEA5. Available at: http://www.joe.org/joe/2006april/a5.php

Patton, A.J., & Kaminski, J.E. (2010). Tracking the impact of your web-based content. Journal of Extension [On-line], 48(4) Article 4TOT1. Available at: http://www.joe.org/joe/2010august/tt1.php

Rost, B., & VanDerZanden, A. M. (2002). A case study of online learners participating in the Oregon State University Extension Service Master Gardener training program. *Journal of Applied Communications*, 86(2), 7-16.

Figure 1. Geographic Distribution of Visitors to the Turf Disease Updates Blog Between 1 January and 19 September 2010. A Total of 38,878 Visits from 118 Countries/Territories Were Recorded During this Period.

Figure 2. Geographic Distribution of Visitors to the iaTURF Blog Between 24 June 2009 and 19 Sept 2010. A Total of 16,695 Visits from 50 States and the District of Columbia Were Recorded During this Period.

Table 1. Impact of Two Blogs as Measured by Google™ Analytics.

	iaTURF[1]	Turf Disease Updates[2]
Site Usage		
Average time on site (in seconds)	68	133
Visits	17,903	38,878
Page views	26,929	76,951
Visitor Information		
New visitors	38.1%	41.9%
Returning visitors	61.9%	58.1%
Average pages per visit	1.5	1.98
Internet Connection Speed		
High speed	74.6%	79.1%
Dial-up	2.9%	1.7%
Other/unknown	22.5%	19.2%
Mobile[3]	2.4%	5.5%
Traffic Sources		
Direct traffic	46.1%	27.1%
Referring sites	35.4%	31.2%
Search engines	18.5%	27.3%
Other	0.02%	14.4%

[1] Data was obtained between 24 June 2009 and 19 Sept 2010.

[2] Data was obtained between 1 Jan and 19 Sept 2010.

[3] Visits to each blog via mobile devices are included within “Other/Unknown” internet connect speed data.

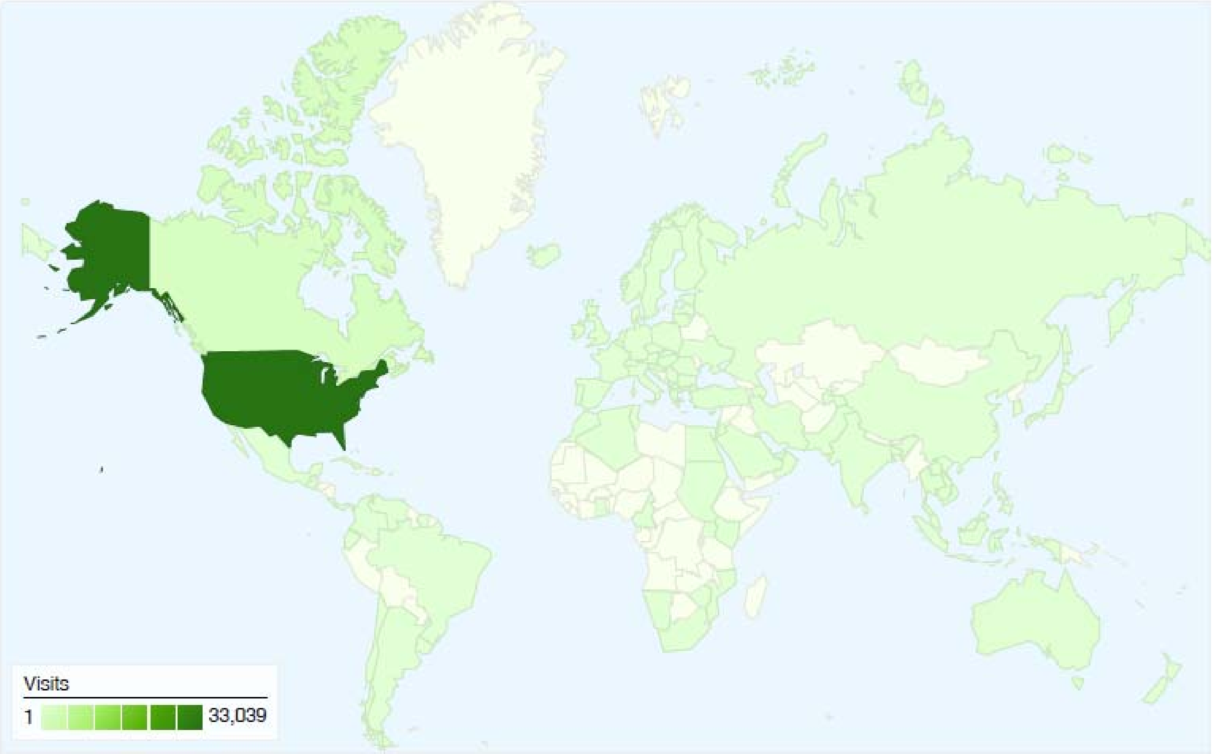

Fig. 1.

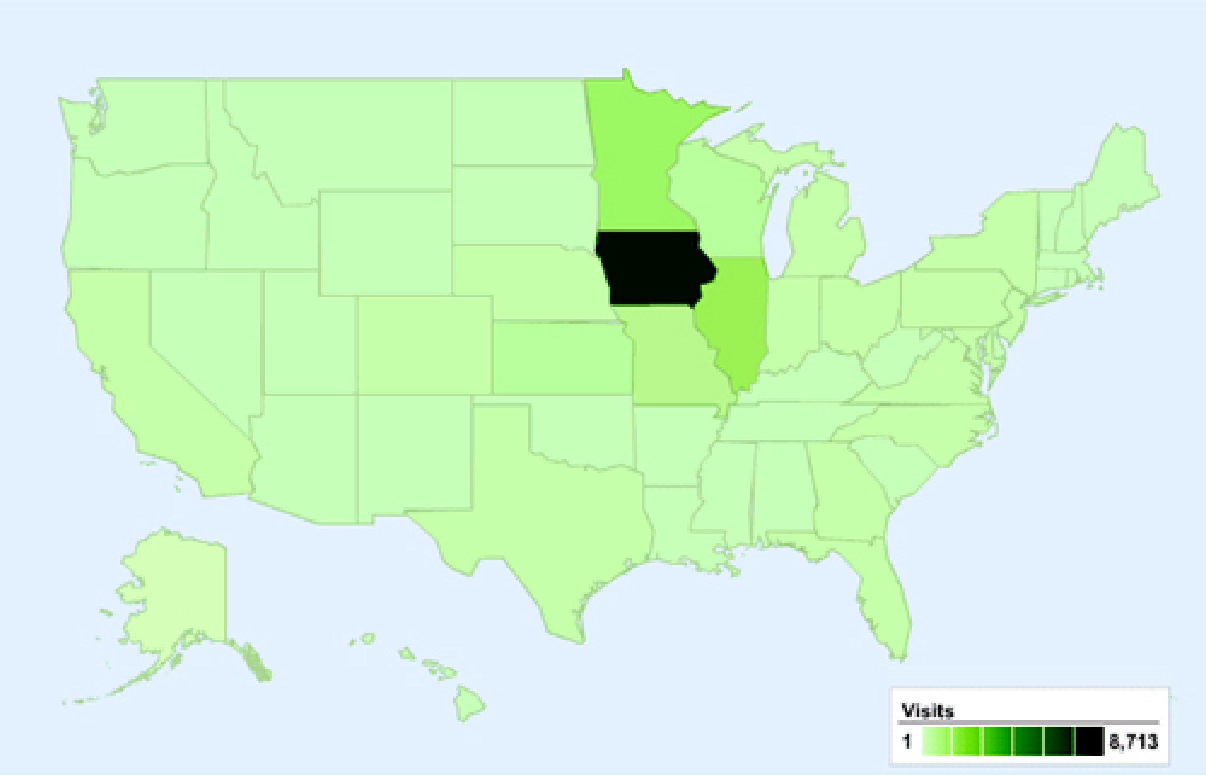

Fig.2.

GENERAL CONCLUSIONS

The objectives of this research were to 1) identify cultivars of creeping bentgrass that possess superior recuperative potential, 2) examine differences in establishment rates among cultivars and determine the factors associated with differential growth rates, 3) identify cultivars that possess superior germination characteristics, and 4) evaluate the effectiveness of renovating an existing creeping bentgrass putting green via interseeding.

Recuperative potential studies

The recuperative potential of bentgrass cultivars was influenced by variation in environmental conditions from 2009 to 2010. In 2009, all cultivars had divot recovery rates similar with Penncross although improved cultivars did exhibit greater shoot densities. In 2010, the cultivars SR 1150, T-1, and Kingpin had divot recovery rates significantly slower compared with Penncross. Shoot density was inversely proportional to divot recovery rate. Stability analysis indicated that the cultivars Alpha, Crenshaw, LS-44, Penn A-4, Penncross, Pennlinks II, Putter and Southshore exhibited consistent, above average lateral spread across the two years in this study.

Creeping bentgrass is commonly used on golf course putting greens, tees, and fairways (Christians, 2007). Large voids, or divots are often troublesome in creeping bentgrass and recuperative potential from surrounding stolons is a desirable trait. Our data indicates that the increased shoot densities of recently developed cultivars of creeping bentgrass may hinder their recuperative potential compared with lower shoot density cultivars. However, cultivars of creeping bentgrass with increased shoot densities have been shown to better resist invasion from annual bluegrass (Croce et al., 1998). This trade-off between recuperative potential and shoot density needs to be considered when selecting cultivars for specific use areas. Higher shoot density cultivars may be better suited for areas where lower populations of annual bluegrass are desired. Alternately, lower shoot density cultivars may be better suited for areas where damage from divoting is severe and recovery is important.

Establishment rate studies

Cultivars of creeping bentgrass displayed varying lateral spread, and stolon and internode lengths. Penncross exhibited greater lateral spread and longer internodes compared with improved cultivars. Bengal had the slowest lateral spread and the shortest mean stolon and internode length. Internode and stolon length were positively correlated as well as internode length and establishment rate indicating that cultivars with long internodes also possess fast establishment rates and longer stolons. Growth analysis indicated that Penncross and Bengal produce similar amounts of dry matter but Penncross allocates more dry matter into stolons than leaves. Variation in dry matter partitioning could partially explain differences in lateral spread among cultivars of creeping bentgrass.

Our results indicate that cultivars of creeping bentgrass possess varying establishment rates and that Penncross had a greater capability for lateral spread compared with recently developed cultivars. Positive relationships were found between internode and stolon length and between internode length and lateral spread. These findings indicate that internode length is an important morphological characteristic influencing the lateral spread of creeping bentgrass cultivars. Furthermore, the observed variation in lateral spread could result from differences in dry matter partitioning among cultivars.

Because creeping bentgrass is often used in areas subject to heavy traffic and wear, differences in lateral spread would be of great interest to turfgrass practitioners who are trying to maximize turfgrass cover. While our data indicate that Penncross is superior to recently developed cultivars with respect to lateral spread, its main disadvantage is its potential for invasion by annual bluegrass, an inevitable inhabitant of intensely managed turf (Christians, 2007). Tiller density is also an important shoot morphological characteristic in creeping bentgrass that plays an important role in traffic tolerance and turf recovery (Hawes, and Decker, 1977; Lush, 1990). Research has shown that tiller density also affects the competitive ability of creeping bentgrass to annual bluegrass (Beard et al., 2001) but tiller density is inversely related to internode length (Cattani, 1999). The vegetative characteristics should be matched with desired site usage requirements for optimum performance when selecting cultivars of creeping bentgrass.

Germination Studies

There were differences between Penncross and improved cultivars of creeping bentgrass in MGT, $T_{10\text{-}90}$, and FGP. Improved cultivars germinated 5% faster with 21% shorter synchrony and exhibited a 2% greater ability to germinate. Seed weight was negatively correlated with MGT indicating that cultivars of creeping bentgrass with heavier seeds possess lower MGT values. Final germination percentage was inversely correlated with $T_{10\text{-}90}$.

In addition to improved morphological characteristics, our results indicate that improved cultivars of creeping bentgrass are generally superior to Penncross with respect to their germination characteristics. Germination characteristics partially dictate the establishment and species composition of turf swards. Henry et al. (2005) demonstrated that recently developed cultivars of creeping bentgrass were better suited for interseeding compared with Penncross. Therefore, the varied success of interseeding may be attributable to differences in germination characteristics among cultivars of creeping bentgrass such as MGT, $T_{10\text{-}90}$, FPG, and weight.

Interseeding Studies

A transient shift to Penn A-4 occurred on the golf course putting green but was not able to persist. The lack of establishment is likely due to competition from the surrounding turf and mechanical and environmental stresses (Cook and Ratcliff, 1984; Snaydon and Howe, 1986). Increased yearly seed amounts along with applications of paclobutrazol and bispyribac-sodium did not improve establishment of Penn A-4 compared to untreated plots. During the first year of the study, the percentage of annual bluegrass was reduced in plots treated with bispyribac-sodium. However, significant loss of density occurred during the second year of the study from bispyribac-sodium applications. Conversion on the research putting green was more persistent with 67% Penn A-4 present two years after initial seedings. The varying success between the two sites may be due to differences in overall quality and maintenance levels.

Converting an established putting green to a new cultivar of creeping bentgrass was affected by the overall condition of the existing turf sward. The reduction in turfgrass quality necessary in order to permit interseeding should be compared with the cost of a tradition conversion when deciding on a renovation program. Additionally, bispyribac-sodium appears to have the capability to remove annual bluegrass from established turf areas but needs to be used with caution to avoid a loss in turf density.

Literature Cited

Beard, J.B., P. Croce, M. Mocioni, A. De Luca, and M. Volterrani. 2001. The comparative competitive ability of thirteen *Agrostis stolonifera* cultivars to *Poa annua*. Int. Turfgrass Soc. Res. J. 9:828-831.

Cattani, D.J. 1999. Early plant development in ‘Emerald’ and ‘UM67-10’ creeping bentgrass. Crop Sci. 39:754-762.

Christians, N.E. 2007. Fundamentals of turfgrass management. 3rd ed. John Wiley & Sons, Hoboken, NJ.

Cook, S.J., and D. Ratcliff. 1984. A study of the effects of root and shoot competition on the growth of green panic (*Panicum maximum* var. *trichoglume*) seedlings in an existing grassland using root exclusion tubes. J. Appl. Ecol. 21:971-982.

Croce, P., M. Mocioni, and J.B. Beard. 1998. *Agrostis* cultivar characterization for closely mowed putting greens in a Mediterranean climate. p. 668-678. *In* M.R. Farrally and A.J. Cochran (ed.) Science and golf III. Proc. 3rd World Sci. Congr. Golf, St. Andrews, U.K.

Hawes, D.T. and Decker, A.M. 1977. Healing potential of creeping bentgrass as affected by nitrogen and soil temperature. Agron. J. 69:212-214.

Henry, G.M., S.E. Hart, and J.A. Murphy. 2005. Overseeding bentgrass species into existing stands of annual bluegrass. HortScience. 40:468-470.

Lush, W.M. 1990. Turf growth and performance evaluation based on turf biomass and tiller density. Agron. J. 82:505-511.

Snaydon, R.W., and C.D. Howe. 1986. Root and shoot competition between established ryegrass and invading grass seedlings. J. Appl. Ecol. 23:667-674.