

## Literature Review

### Introduction

Although limited to warmer climatic regions, bermudagrass (*Cynodon* [L.] Pers.) probably possesses the best overall turf characteristics for fairway use and culture, including excellent wear, heat, and drought tolerance plus a rapid recuperative rate (Beard, 1982). Bermudagrass use in the transition zone between temperate and subtropical climates is accomplished with improved varieties (e.g., 'Midiron' and 'Vamont') with low-temperature hardiness. Bermudagrass, a warm-season grass, tolerates the hot, humid transition zone summers better than cool-season grasses despite entering a dormancy period with the onset of cooler temperatures at the first killing frost. Shorter growing seasons and longer winter dormancy periods typically characterize transition zone climates. Long winter dormancy conditions often result in losing dormant canopy integrity and structure in trafficked areas. This appears to be more of a problem on the coarser-type, cold tolerant bermudagrasses used in the cooler regions. As a result, golf clientele often prefer winter-overseeded bermudagrass due to enhanced winter quality and aesthetics. Beard (1973) defined winter overseeding as a practice where one or more cool-season species are seeded into stands of warm-season species in the fall to provide a green turf during the winter period when the warm-season species are normally brown and dormant. However, spring and summer persistence of overseeded grasses can delay bermudagrass regrowth.

## **Warm-Season Turfgrasses**

A warm-season turfgrass is defined in Turgeon (1996) as a species adapted to favorable growth during warm portions (26.7° to 35.0° C) of the growing season; includes species of the eragrostoid and panicoid subfamilies. Beard (1973) reported warm-season turfgrasses are widely distributed throughout the warm humid, warm subhumid, and warm semiarid climates and were utilized to varying degrees in the transitional zones. The *Cynodon* species, a member of the eragrostoid subfamily, has its origins centered around the Indian Ocean ranging from Eastern Africa to the East Indies (Beard, 1973). In eragrostoid grasses, carbon fixation, in photosynthesis, occurs principally through the C<sub>4</sub> pathway (Turgeon, 1996).

## **Bermudagrass (*Cynodon* sp.)**

Bermudagrass (*C. dactylon* [L.] Pers.) has its center of origin in East Africa (Beard, 1973). Juska and Hanson (1964) reported bermudagrass is found in over one hundred countries throughout the tropical and subtropical areas of the world. The genus *Cynodon* comprises nine species with *C. dactylon* being the most widespread. The distribution of bermudagrass in the United States extends from New Jersey to Maryland, southward to Florida, and westward to Kansas and Texas. Its distribution extends further westward into New Mexico, Arizona, and the major valleys of California with the availability of irrigation. The widespread distribution of *C. dactylon* can be explained by the fact it is a tetraploid with broad genetic diversity (Duble, 1996). Common bermudagrass (*C. dactylon*) and African bermudagrass (*C. transvaalensis* Burt-Davy), a diploid species, are the parents of many finer textured hybrid bermudagrass cultivars in

use today (Turgeon, 1996). The improved turf-type bermudagrasses form a very vigorous, aggressive turf of high shoot density. Leaf width ranges from the medium texture of common bermudagrass to the very fine texture of African bermudagrass (Beard, 1973). Lateral growth of bermudagrass is accomplished by both stolons and rhizomes (Turgeon, 1996).

Burton, DeVane, and Carter (1954) reported bermudagrass to be a long-lived perennial with excellent heat and drought hardiness but poor low temperature tolerance. Bermudagrass is best adapted to moderately well-drained, fertile soils of relatively fine texture but tolerates a wide range of soil types. Ideal bermudagrass growth usually occurs under extended periods of high temperatures, mild winters, and moderate to high rainfall (Duble, 1996). Bermudagrass growth on fine textured soils is usually better than coarse textured soils due to the higher fertility level and soil moisture retention associated with the fine textured soils (Beard, 1973). Bermudagrass tolerates a wide soil pH range of 5.5 to 7.5 (Beard, 1973) but performs best between pH 6.5 and 8.0 (Duble, 1996).

Bermudagrass requires a medium to high intensity of culture and its prostrate growth habit makes it very tolerable of close mowing (Beard, 1973). According to Duble (1996), bermudagrass mowing requirements are dependent upon variety, use, and level of maintenance. Beard (1973) reported mowing bermudagrass frequently maintains good quality and avoids scalping. Typical mowing heights for bermudagrass turf are 1.3 to 2.6 cm; with some dwarf varieties able to tolerate mowing at 0.6 cm (Duble, 1996). The nitrogen fertility requirement according to Pritchett and Horn (1962) is 39.1 to 87.9 kg ha<sup>-1</sup> per growing month. The lowest rate of nitrogen that can be applied and still maintain

acceptable bermudagrass turf for golf fairways is about  $24.4 \text{ kg ha}^{-1}$  per month (Duble, 1996).

With the onset of cool fall temperatures, bermudagrass discolors and remains in a state of dormancy throughout the winter (Beard, 1973). Just prior to dormancy, soluble sugars are converted to starch granules and stored in the stolons, roots, and rhizomes of bermudagrass for the oncoming winter months (Duble, 1996). This reserve of carbohydrates is utilized during spring regrowth. Bermudagrass discoloration usually occurs at the end of the growing season, when average temperatures drop below  $10^{\circ}\text{C}$ . The leaves and stems of bermudagrass remain dormant until average daily temperatures rise above  $10^{\circ}\text{C}$  for several days (Duble, 1996). Pigment loss in the stems and leaves results in a light tan to whitish-tan appearance (Beard, 1973). Discoloration of dormant bermudagrass can be masked, by overseeding the dormant turf with cool-season turfgrasses. This provides a green turf of acceptable playing quality throughout the winter dormancy period.

The only environmental limit to more widespread adaptability and use of bermudagrass is temperature, as demonstrated by its dormancy period during the winter months. Duble (1996) reported the northern limits of bermudagrass extend into the transitional zone of the United States, where low temperatures seldom drop below  $-12^{\circ}\text{C}$ . He also reported research has demonstrated bermudagrass will continue to grow with night temperatures as low as  $1.1^{\circ}\text{C}$  if day temperatures are near  $21.1^{\circ}\text{C}$ .

Chalmers and Schmidt (1979) reported the use of bermudagrass for turf throughout the northern limit of adaptation for warm-season turfgrasses to be hindered by winter survival. Winterkill or winter injury are terms commonly used to represent any

injury occurring to a turf during the winter period (Turgeon, 1996). Although winterkill is typically defined as a gradual loss or thinning of bermudagrass turf caused by low temperature injury, Chalmers (1978) reported winter injury includes any number of factors acting alone or in combination to injure dormant bermudagrass turf. These factors include low temperature, length of dormancy, winter moisture availability, cultivar selection, traffic, timing and use of cultural practices, and age of dormant turfgrass. Although bermudagrass is not very cold tolerant, both Turgeon (1996) and Duple (1996) reported interest in bermudagrass near its northern limits has increased due to the development of more cold tolerant turf-type varieties such as 'Midiron' and 'U-3'. 'Midiron' is a cold-hardy bermudagrass typically used in the transition zone.

### **Cool-Season Turfgrasses**

A cool-season turfgrass is defined in Turgeon (1996) as a turfgrass species adapted to favorable growth during cool portions ( $15.6^{\circ}$  to  $23.9^{\circ}$  C) of the growing season; may become dormant or injured during hot weather and includes species of the festucoid subfamily. Cool-season species are widely distributed throughout the cool humid, cool subhumid, and cool semiarid climates and also extend into the transitional zone. Most of the cool-season turfgrasses originated from forest-margin species scattered throughout Eurasia (Beard, 1973). Festucoids are cool-season grasses occurring mostly in temperate and subarctic, and sometimes subtropical climates. They are sometimes referred to as  $C_3$  grasses because carbon fixation, in photosynthesis, occurs principally through the Calvin ( $C_3$ ) cycle (Turgeon, 1996).

### **Ryegrasses (*Lolium* sp.)**

Ryegrasses are distributed within the temperate climatic zone and includes about ten species in the genus *Lolium* (Turgeon, 1996). Not to be confused with cereal rye (*Secale cereale* L.), ryegrass takes its name from a European name (“Rai” grass) and is not related to rye grain (Schroeder and Sprague, 1994). Only three species are utilized to any extent in turfgrass culture; perennial ryegrass (*L. perenne*), annual or Italian ryegrass (*L. multiflorum*), and “intermediate” ryegrass (*L. perenne* x *L. multiflorum*) (Beard, 1973 and Turgeon, 1996). Ryegrasses are known for their rapid germination rate and vigorous seedling growth (Turgeon, 1996). They have a bunch-type growth habit and spread by profuse tillers (Duble, 1996).

### **Perennial Ryegrass (*Lolium perenne*)**

Perennial ryegrass, depending on environmental conditions may behave as an annual, short-lived perennial, or a perennial bunch-type grass (Turgeon, 1996). Beard (1973) reported perennial ryegrass is generally considered to be a short-lived perennial, however it can persist indefinitely if not subjected to extreme high or low temperature stress or drought.

Perennial ryegrass forms a medium textured turf of good shoot density and uniformity (Beard, 1973). Turgeon (1996) reported perennial ryegrass to be adapted to a wide range of soil conditions, with its best growth occurring in neutral, to slightly acidic soils of moderate to high fertility. According to Duble (1996) perennial ryegrass favors moist, well-drained, fertile soils; exhibits good shade tolerance in southern climates; and often survives hot, dry summers of the South in moderately shaded sites.

Perennial ryegrass requires a medium to medium low intensity of culture. The nitrogen fertility requirement ranges from 19.5 to 48.8 kg ha<sup>-1</sup> per growing month or 97.6 to 292.9 kg ha<sup>-1</sup> per year, and higher fertility levels will decrease the tolerance to environmental stress (Beard, 1973; Turgeon, 1996). Perennial ryegrass' tolerance to low mowing heights is evidenced by its use for winter overseeding bermudagrass putting greens.

Perennial ryegrass has several uses due to a broad range of adaptability. One such use listed by both Beard (1973) and Turgeon (1996) is the overseeding of dormant or semi-dormant, warm-season turfs such as bermudagrass for winter quality and color. Beard (1973) stated perennial ryegrass establishes rapidly and provides a uniform green surface for the winter period when seeded at high rates. Duple (1996) suggests the quick establishment from seed makes perennial ryegrass ideal to provide temporary green color during the winter months when bermudagrass is dormant. Also, improved turf-type perennial ryegrasses have greater cold tolerance, wear tolerance, disease resistance, and persistence than the older types. These characteristics have made perennial ryegrasses very popular for overseeding golf courses during winter months (Duple, 1996).

### **Annual Ryegrass (*Lolium multiflorum*)**

Annual ryegrass is a cool-season annual or short-lived perennial, bunch-type grass (Turgeon, 1996). Beard (1973) reported the plant adaptations, uses, and cultural requirements of annual ryegrass are quite similar to those for perennial ryegrass. The leaves of annual ryegrass were reported by Mitchell (1954) to be lighter green and coarser in texture than perennial ryegrass. Turgeon (1996) stated annual ryegrass forms a

fine- to coarse-textured turf, depending on seedling rate and density. The shoot density, uniformity, and overall turfgrass quality of an annual ryegrass turf was reported not to be as good as a perennial ryegrass turf (Beard, 1973). Annual ryegrass is best adapted to fertile, wet soils having a pH of 6.0 to 7.0. The mowing quality of annual ryegrass is similar to perennial ryegrass and the nitrogen fertility requirement also ranges from 19.5 to 48.8 kg ha<sup>-1</sup> per growing month (Beard, 1973).

Turgeon (1996) stated annual ryegrass may be used for winter overseeding of dormant or semi-dormant, warm-season turfs in subtropical climates. However, Schmidt and Blaser (1961) reported the early spring death of annual ryegrass results in poor transition to the warm-season turfgrasses. Turgeon (1996) reported annual ryegrass has been partially replaced by improved, turf-type perennial ryegrasses or mixtures of several cool-season species for the overseeding of dormant warm-season turfs. There are no improved cultivars of annual ryegrass for turfgrass use (Turgeon, 1996).

### **Winter Overseeding**

Winter overseeding is the practice of seeding cool-season turfgrasses into warm-season turfgrasses late in their growing season prior to the onset of winter dormancy. It is practiced in sub-tropical climates to provide green, growing turf during the winter period when the warm-season species are brown and dormant (Turgeon, 1996). To achieve effective winter overseeding, the cool-season turfgrass species selected should provide a minimum fall transition period from a green, warm-season turf to a green, actively growing cool-season turf. It also should provide for a minimal transition period back to the green, warm-season turf in the spring (Beard, 1973). Landry (1993) stated

not only will overseeding improve aesthetics with the year round color, the cool-season grasses provide a smoother, more cushioned playing surface that protects the dormant bermudagrass from traffic injury. Beard (1982) stated overseeding bermudagrass fairways was practiced to a limited extent in the southern portion of the warm climatic region. This statement is no longer true. Tremendous increase in overseeding was reported by Hawes (1997). The increased practice of overseeding has included putting greens, tees, fairways, and even roughs are now being overseeded on golf courses in the South. Also, regions where overseeding was generally not a common practice in the past, like the transition zone, now annually overseed (Hawes, 1997).

Despite the benefits of winter overseeding and its increased practice, winter overseeding can have negative impacts. Foy (1998) stated winter overseeding could be thought of as trying to grow two plants with different management requirements in the same place. When management practices are geared to favor the overseeded species, bermudagrass vigor and quality can be compromised. Significant competition from overseeded species can adversely affect fairway quality during spring and early summer transition back to bermudagrass.

### **Complexities of Winter Overseeding**

Overseeding bermudagrass with cool-season turfgrass involves a number of factors: turfgrass selection, seed bed preparation methods, choosing the best seeding date, seeding rate and planting methods, deciding on annual bluegrass (*Poa annua*) control, and care and maintenance of the overseeded stand (Wildmon, 1993). Turf color, texture,

wear and heat tolerance, mowing height, establishment rate, spring transition, and seed quality are factors that can also impact the process.

### **Turfgrass Selection**

Much of the previous overseeding research has focused on cool-season species selection for bermudagrass putting greens or on bermudagrass turf maintained under putting green type conditions. Little research has been reported on bermudagrass fairways or bermudagrass turf maintained under fairway type conditions. Species best adapted for overseeding are those that provide good density and color during the cold winter months, tolerate heavy traffic, and provide a gradual fading out with the onset of warmer temperatures which enhances the transition to bermudagrass (Watschke and Schmidt, 1992).

For many years prior to the 1960's, most overseeding was done using annual ryegrass (Beard, 1973; Turgeon, 1996). Annual ryegrass was a popular choice due to its rapid establishment in the fall and relatively low seed cost. However, its use for winter turf became limited due to low-temperature intolerance, coarse texture, disease susceptibility, and lack of persistence during post dormancy regrowth and transition back to bermudagrass in the spring (Watschke and Schmidt, 1992). During the 1960's, research attempted to identify the best species for winter overseeding. Perennial ryegrass; creeping bentgrass (*Agrostis palustris* Huds *A. stolonifera* L.); colonial bentgrass (*A. capillaris*); Kentucky bluegrass (*Poa pratensis* L.); roughstalk bluegrass (*P. trivialis*); and fine-leaf fescues, creeping red fescue (*Festuca rubra* L. ssp. *rubra*) and chewings fescue (*F. rubra* L. ssp. *commutata* Gaud.) were evaluated individually or in

mixtures of two or more species for overseeding (Beard, 1973; Ward, McWhirter, and Thompson, 1974). According to Schmidt and Shoulders (1964), bulbous bluegrass (*P. bulboea*) and redtop (*Phleum* L.) were tried but found to be inferior for winter overseeding.

Beard (1973) stated research in the 1960's, performed mostly on bermudagrass putting greens throughout the southern United States, showed overseeding mixtures containing two to four species; such as bentgrass, red fescue, ryegrass, rough bluegrass, or Kentucky bluegrass, were more desirable in terms of overall performance and turfgrass quality during the winter dormancy period and led to a minimum transition period. Ward et al. (1974) reported on a series of extensive overseeding trials throughout the South on golf courses and at land grant universities, by Wilson and Latham, resulted in a mixture containing three cool-season species being recommended for overseeding bermudagrass greens. This mixture was most commonly: fifteen percent bentgrass, twenty-five percent rough bluegrass, and sixty percent red fescue. Annual ryegrass was often added to this mixture to increase wear tolerance (Ward et al., 1974). Beard (1973) reported a mixture was preferable for winter overseeding since no one species is available that possesses all the desirable characteristics in an overseeded turf. Mixtures provide a broader genetic base against loss of stand due to disease or severe cold weather, and give a more gradual transition in the spring (Ward et al., 1974). Under adverse environments in Texas, polystands consistently provided better overseeded turf than monostands and the highest putting green quality in winter was achieved with a mixture of eighty percent perennial ryegrass and twenty percent rough bluegrass in two out of three years (Batten et al., 1981).

McWhirter and Ward (1970) stated improved cultivars of perennial ryegrass have quick germination and establishment, are fine textured, very frost tolerant, and fade out more gradually than annual ryegrass, rough bluegrass, or the red fescues. These desirable features led to perennial ryegrass monostands replacing mixtures for overseeding bermudagrass greens. Hurley (1990) singled out turf-type perennial ryegrasses as the most popular choice for winter overseeding of dormant bermudagrass turf. Perennial ryegrass earned its popularity by having the ability to germinate and establish quickly and produce an attractive turf that withstands traffic.

### **Seeding Rate and Establishment**

Successful establishment of overseeded turf is greatly dependent upon seedbed preparation. Of all operations performed before the date of overseeding, the establishment quality of the overseeded turf is directly related to seedbed preparation procedures. Seedbed preparation is equally important for establishment of an overseeded turf as it is for establishment of a new, “permanent” turf. One of the greatest causes of a poor stand of overseeded grasses is poor seedbed preparation. Thatch, compacted soils, and weeds in the seedbed can result in thin stands and seedling diseases during the early stages of overseeding (Duble, 1996). According to Turgeon (1996), a thatch layer can adversely affect the growth and survival of overseeded grasses since seedlings that develop in the thatch layer are more prone to injury from cold temperatures, traffic, and other stresses than if they developed in the soil. Ward et al. (1974) reported the development of overseeded grasses for winter turf are seriously impeded by thatch build-up on vigorously growing bermudagrass.

The removal of thatch by frequent summer cultivation was shown by Schmidt and Shoulders (1972) to subsequently improve the winter turf quality of overseeded bermudagrass putting greens in Virginia. Cultivation methods to reduce or eliminate thatch should be performed throughout the growing season of the warm-season turfgrass. Duple (1996) stated light vertical mowing during late summer and fall helps to reduce thatch in bermudagrass turf. Coring or core aeration is another cultural procedure that will reduce thatch. According to Duple (1996), early spring, late spring, and late summer are ideal times to aerify bermudagrass in order to alleviate compaction, reduce thatch, and develop a seedbed. Warm-season turfs (putting greens, tees, or fairways) to be overseeded should be core aerated three to four weeks prior to overseeding (Beard, 1973; DiPaola and Gilbert, 1982). The aeration will open the warm-season turf to help ensure seed-soil contact, which is essential for seed germination. Watschke and Schmidt (1992) stated aeration performed too close to the time of overseeding permitted seeds to accumulate in the holes created by the tines thus resulting in poor germination patterns. It is important for holes created by aerification tines heal over prior to overseeding, otherwise the germination and growth of the overseeded turf will not be uniform (DiPaola and Gilbert, 1982). Duple (1996) stated warm-season turfs should not be aerated after the first of September because it promotes annual bluegrass germination.

Topdressing after overseeding was found to be essential for proper seed-soil contact to occur when overseeding putting greens (DiPaola and Gilbert, 1982). However, it should be emphasized that topdressing is typically only performed when overseeding putting greens. Topdressing in conjunction with overseeding has been reported to be too

time-consuming and expensive to be conducted on areas such as golf course fairways (DiPaola and Gilbert, 1982).

Beard (1973) stated seeding rates used for winter overseeding are much higher than rates used for the establishment of permanent cool-season turfs. The higher seeding rates are a result of high seedling mortality caused by the effects of traffic. Duple (1996) suggests that low seeding rates result in thin stands of winter grasses and high populations of annual bluegrass. Through the years recommendations as to optimum seeding rates for overseeding cool-season turfgrasses have fluctuated. Ward et al. (1974) reported overseeding experiments were conducted during the 1960's and early 1970's in Mississippi to determine the optimum seeding rates for both monostands and mixtures of cool-season turfgrasses on putting greens. The data obtained from this research led to a seeding rate recommendation of 1700 kg ha<sup>-1</sup> for perennial ryegrass overseeded onto putting greens. Research in southeastern Virginia reported by Schmidt and Shoulders (1980) concluded seeding rates from 250 to 490 kg ha<sup>-1</sup> is adequate for overseeding fairways and similar turf areas. Duple (1996) stated golf course fairways are typically overseeded at a rate equivalent to twenty-five percent of the rate overseeded on golf putting greens and recommended a rate of 1708.8 kg ha<sup>-1</sup> when overseeding perennial ryegrass on putting greens. Therefore, a seeding rate of 427.2 kg ha<sup>-1</sup> would meet this twenty-five percent requirement. These seeding rates are still employed by today's professional turfgrass managers along with higher rates (Chalmers, 1997).

Gadd (1990) reported that trends toward lighter seeding rates is based on the theory that fewer plants made for an easier transition as compared to a higher number of plants, and thus the increased competition from higher seeding rates. Using 490 kg ha<sup>-1</sup>

or greater seeding rates is attributed to an alternate hypothesis that higher seeding rates better facilitates transition back to bermudagrass the following spring than lower seeding rates. The theory suggests higher seeding rates increase competition between overseeded plants and encourage the plants to remain in a juvenile state, which would then facilitate spring transition. Landry (1993) stated the increased competition caused by the greater density of cool-season grasses, when overseeded at higher rates, tends to delay transition to bermudagrass. Recommended rates for overseeding bermudagrass fairways commonly range from 244.1 to 488.2 kg ha<sup>-1</sup> with higher rates (896.7 to 1120.8 kg ha<sup>-1</sup>) used in some situations (DiPaola and Gilbert, 1982; Landry, 1993; and Duble, 1996).

### **Overseeding Date**

Danneberger (1993) reported overseeding establishment could be influenced by plant competition. If cool-season species are overseeded too early, while the bermudagrass is still actively growing, the bermudagrass will outcompete the new cool-season seedlings (Beard, 1973; Ward et al., 1974). Planting too early also may lead to seedling disease problems (Duble, 1996). If the cool-season species are overseeded too late, the onset of cooler temperatures will also hinder cool-season seedling establishment (Beard, 1973). Duble (1996) stated the ideal time to overseed bermudagrass is after bermudagrass has nearly ceased growing but before freezing temperatures are expected. Overseeding should take place a minimum of fifteen to thirty days before the first expected frost (Ward et al., 1974; DiPaola and Gilbert, 1982; and Duble, 1996). Wildmon (1993), Landry (1993), and Duble (1996) reported a more specific method of timing for overseeding to be when the soil temperature at the 10.2 cm depth reaches the

22.2<sup>o</sup> to 25.6<sup>o</sup> C range. Landry (1993) suggests timing winter overseeding when nighttime air temperatures are consistently in the 10<sup>o</sup> C range and midday air temperatures are averaging just below 21.1<sup>o</sup> C.

### **Interspecies Competition**

Danneberger (1993) defines interspecific competition as the battle between individuals of different species for limited resources. He also stated overseeding is a unique example of interspecific competition. Beard (1973) reported neither warm-season nor cool-season grasses are well adapted in the transition zone and a mixture of warm and cool-season grasses may be advantageous in that region. Previous research has suggested mixtures of different species may be better able to withstand both environmental stresses and pests than monostands (Watschke and Schmidt, 1992).

The uniqueness of interspecific competition alluded to by Danneberger, is the cool-season species is seeded into an already existing stand of warm-season grasses. Most previous research and examinations of interspecific competition has investigated competitive interactions between mixtures of cool-season turfgrasses. The problems encountered in overseeded bermudagrass are during cool-season seedling establishment and during transition back to bermudagrass the following growing season; often referred to as spring transition.

A major problem may be encountered during post dormancy transition to bermudagrass. Cool, wet spring temperatures can prolong dormancy in addition to increasing competition from the overseeded cool-season species. Both factors can retard bermudagrass growth. If environmental conditions following this scenario lead to a

quick decline of the overseeded cool-season grass, a weak and thin bermudagrass turf is the result (Foy, 1998).

### **Annual Bluegrass Control**

It was previously mentioned Duble (1996) reported aerification prior to overseeding should not be performed after September 1, to avoid promoting annual bluegrass germination. Menn and Beard (1987) stated annual bluegrass was the number one cool-season, grassy weed problem on winter overseeded bermudagrass. Danneberger (1993) reported weed control, primarily annual bluegrass, is important to successful overseeding.

Although annual bluegrass can be controlled with preemergent herbicides (Bingham et al., 1969), research has shown most overseeded species compete well with annual bluegrass (Menn and Beard, 1987; Watschke and Schmidt, 1992). Schmidt and Shoulders (1980) reported perennial ryegrass was quick to establish and competitive to annual bluegrass on overseeded putting greens in southeastern Virginia. Duble (1996) stated perennial ryegrass should be the dominant grass planted when overseeding in conjunction with the use of pre-plant preemergent herbicides for annual bluegrass control. Other cool-season species such as rough bluegrass, fescues, and bentgrasses are more sensitive to preemergent herbicides than perennial ryegrass.

Research reported by Menn and Beard, in the mid-1980's from College Station, Texas showed higher overseeding rates of perennial ryegrass often reduced annual bluegrass invasion on bermudagrass putting greens. The study concluded overseeding rates of perennial ryegrass of 1708.8 to 1953.0 kg ha<sup>-1</sup> have a marked effect on reducing

annual bluegrass populations, and overseeding rates of 976.5 kg ha<sup>-1</sup> and less form a more open turf canopy that is more conducive to annual bluegrass invasion at putting green canopy heights (Menn and Beard, 1987).

### **Post-Overseeding Practices**

Wildmon (1993) stated follow-up care is the most critical aspect of any overseeding program, regardless of the amount of preparation. Mistakes or poor judgment in the areas of mowing, watering, fertilization, and pest management can lead to poor stands of overseeded turfgrasses (Duble, 1996). Watschke and Schmidt (1992) cited damping-off diseases, caused by *Pythium*, *Rhizoctonia*, and *Fusarium* sp., can reduce the density of newly overseeded turf. Extremely high seeding rates (2,120 to 4,240 kg ha<sup>-1</sup>) have resulted in creating a more favorable environment for disease (Ward et al., 1974). The use of fungicide-treated seed could be used for overseeding and would reduce the likelihood of disease incidence (Wildmon, 1993; and Turgeon, 1996). Preventative fungicide programs can also greatly reduce seedling diseases in the overseeding. However, fungicide applications to golf course fairways are more costly compared to putting greens due to the amount of area overseeded.

Frequent irrigation is important the first several weeks after overseeding to establish the cool-season species. Wildmon (1993) recommends frequent, light watering the initial days after planting. Late evening watering produces a disease conducive environment and should be avoided (Duble, 1996). DiPaola and Gilbert (1982) stated that newly overseeded putting greens or fairways should initially be irrigated two to three times a day.

Landry (1993) stated it is best to avoid fertilization until after seedling emergence, generally two to three weeks after planting. If fertigation is available, this can be an ideal tool for establishing and maintaining overseeding (Wildmon, 1993). Nitrogen application rates of 24.4 to 48.8 kg ha<sup>-1</sup> per month should be adequate (Landry, 1993).

Post-overseeding mowing uses mowers with sharp blades to achieve a sharp clipping and to avoid pulling up the young seedlings (DiPaola and Gilbert, 1982; Wildmon, 1993; Landry, 1993; Duple, 1996).

### **Post Dormancy Transition**

The overall success of a winter overseeding program is directly related to the success of post dormancy (PD) transition. A gradual decline and loss of the winter overseeded grasses coordinated with the spring green-up and active bermudagrass shoot growth is an ideal transition (Beard, 1982). Horgan and Yelverton (1997a) suggested that a true spring transition has become more difficult to achieve with the development of heat, disease, and drought tolerant perennial ryegrass varieties used for winter overseeding. Post dormancy transition can occur gradually or very abruptly. Hawes (1982) reported three major types of poor PD transitions: (1) death of bermudagrass by winterkill; (2) severe thinning of the bermudagrass by a lengthy and strong competition from the overseeded grasses; and (3) sudden death of the overseeded grasses.

Bermudagrass begins to recover from winter dormancy by producing new shoots from the nodes of previously dormant stolons and rhizomes (Duple, 1996). DiPaola, Beard, and Brausand (1982) suggested early bermudagrass PD green-up is accompanied by a rapid dieback of old roots and production of new roots according to research results

obtained in Texas. This phenomenon of new shoot and root production in conjunction with old root dieback could account for the vulnerability of the bermudagrass to low temperatures and competition from winter grasses during the PD transition period.

There are several different factors affecting the PD transition back to bermudagrass. These factors include environmental influences, bermudagrass health and vigor prior to dormancy, cultural practices, and the influence of any winter overseeding (Duble, 1996; and Green et al., 1998). Bermudagrass health and vigor is the single, most important factor to influence PD transition. Without a strong, healthy bermudagrass turf, a rapid PD transition will not occur. Green et al. (1998) reported healthy rhizomes, roots, and bud tissue associated with the bermudagrass crowns are characteristic of a healthy bermudagrass prior to PD growth. Maintaining a strong, healthy bermudagrass in late summer and fall is the only way to help provide for a strong, healthy bermudagrass the following growing season. Some recommendations for maintaining a strong, healthy bermudagrass in the fall involves good nutrition, proper mowing heights, and overseeding practices with minimal disruption to the bermudagrass turf.

### **Influence of Environmental Factors**

The major environmental factors affecting bermudagrass PD recovery are temperature, shade, moisture, soil conditions, competition, and traffic (Duble, 1996). Overseeded turfs compound the shade effects and compete with bermudagrass during PD regrowth. Duble (1996) reported work at Texas A&M University showed bermudagrass PD regrowth begins when nighttime temperatures remain above 15.6 °C for several days in the spring and soil temperature reaches 17.8 °C at the 10.2 cm depth. Green et al.

(1998) reported research conducted in North Carolina and Texas depicted PD transition occurs naturally when soil and air temperatures are above 26.7<sup>o</sup>C, when perennial ryegrass roots begin to decline.

Duble (1996) reported PD recovery of bermudagrass could be delayed when the bermudagrass is growing on compacted soil. The compacted soil restricts oxygen availability to the roots and can have the same impact on the turf as wet soil conditions. Wet soil conditions can lead to a very inefficient conversion of energy reserves in the plant to soluble sugars. Thus, energy reserves are depleted with little new growth produced to support the bermudagrass plant when exposed to prolonged wet soil conditions (Duble, 1996). Too little soil moisture in late winter and spring can also cause significant losses of lateral buds through desiccation. Thus, bermudagrass PD recovery is delayed until the areas killed by desiccation fill in from stolon and/or rhizome growth (Duble, 1996). The presence of an overseeded cool-season turf shades the bermudagrass canopy of much desired sunlight during the spring which can delay soil warming and PD regrowth (Duble, 1996).

Foy (1998) reported the worst case scenario for PD transition is a cool, wet spring followed by a rapid buildup of high humidity and hot temperatures. The cool, wet spring allows the overseeded, cool-season species to develop a mature character and simultaneously retard the PD growth of the base bermudagrass. The onset of high humidity and high temperatures then leads to a quick decline in the overseeded species exposing a weak, thin bermudagrass turf cover. Another poor scenario for PD transition is when periods of temperatures, favorable for bermudagrass regrowth are interrupted by occasional freezing temperatures. This can kill the new, green bermudagrass leaves, thus

requiring more new leaves to be produced. This delays spring recovery and places a greater demand on the reserve carbohydrates in the bermudagrass stolons and rhizomes (Duble, 1996).

### **Influence of Cultural Effects**

DiPaola and Gilbert (1982) reported PD transition from overseeded turf back to warm-season turf requires as much effort as the process of winter overseeding in the fall. The removal of the overseeded turf must be culturally encouraged in the PD transition period. Cultural practices which will favor bermudagrass growth over cool-season overseeded turf should begin two to three weeks after new bermudagrass growth is first observed. These cultural practices include soil coring (aerification), verticutting (vertical mowing), and lower mowing height.

Hawes (1982) reported aerification helps get bermudagrass shoots up through the overseeded turf, but the purpose of aerification is to get warm air into the soil. However, Landry (1993) stated attempting to force soil temperature increases by aeration can lead to early spring growth and premature reduction of the overseeded turf, when cool spring temperatures follow. Another method to enhance soil warming and enhance bermudagrass PD recovery is from lower mowing heights. A gradual lowering of mowing height further speeds soil warming while increasing the stress on the cool-season, overseeded turf. Landry (1993) stated a mowing height, which prevents overseeded grasses from shading out the bermudagrass is critical to a smooth PD transition. However this may be more difficult to obtain on golf course fairways or with

coarse types of bermudagrass intolerant of mowing heights typical for bermudagrass cultivars used on putting greens.

The best tool a turfgrass manager has to manage PD transition on overseeded bermudagrass putting greens is light, frequent verticutting (Hawes, 1982). Verticutting reduces overseeded turf density allowing additional light to penetrate through the canopy to the bermudagrass, while also creating openings through which the bermudagrass can grow. Beard (1982) stated verticuttings are best timed prior to initiation of PD bermudagrass green-up so as not to aggravate problems with bermudagrass spring root decline. However, the effects of verticutting to thin the new perennial ryegrasses used for overseeding are different from the results of verticutting annual ryegrass on overseeded bermudagrass putting greens (Ledeboer, 1973). Ledeboer (1973) also reported new perennial ryegrasses have the ability to regenerate new tillers quickly and will respond to verticutting with tiller growth, if temperatures are not too hot. Therefore, verticutting to thin out newer perennial ryegrass varieties should not be done as long as temperatures favor perennial ryegrass growth. More severe verticutting to reduce thatch on bermudagrass putting greens and fairways should be done before bermudagrass greens-up in the spring, but only after the danger of a prolonged period of cold temperatures has past (Duble, 1996). Otherwise, verticutting should be delayed until bermudagrass has completely recovered.

More recent research suggests verticutting does not affect PD transition of overseeded bermudagrass. Horgan and Yelverton (1997b) examined the effects of verticutting, scalping, aerification, verticutting + scalping, and ammonium nitrate applied to moist cool-season foliage on overseeded bermudagrass in Raleigh, North Carolina

maintained under golf course fairway conditions. With the exception of ammonium nitrate treatment, all cultural treatments were applied every two weeks. The findings over a two-year period concluded that perennial ryegrass transitioned out for all cultural treatments at the same time as the nontreated control. The determining factors in removing the overseeded perennial ryegrass were presumed to be more related to environmental conditions (high air temperatures and high relative humidity).

### **Influence of Chemical Effects**

With cultural treatments to enhance PD transition performing inconsistently and the strong influence environmental factors have on PD transition, research has been conducted to examine the effects of chemical herbicides and plant growth regulators on PD transition. Johnson (1976) studied the effects of pronamide [3,5-dichloro-N-(1,1-dimethyl-2-propynyl)benzamide] on PD transition of 'Game' and 'Manhattan' perennial ryegrass overseeded 'Tifdwarf' bermudagrass in the Piedmont region of Georgia. The bermudagrass was maintained at 2.5 cm and pronamide was applied at 0.8, 1.7, and 3.4 kg ha<sup>-1</sup> in late February, late March, and early and late April. Johnson (1976) found pronamide gradually reduced the growth of perennial ryegrass and permitted the initiation of PD bermudagrass growth with little competition. However, it was discovered plots treated with pronamide received lower total turfgrass cover and turf quality ratings than untreated plots during the transition period. However, the reduction in turf stand and quality was minimal when pronamide was applied March 10 at 0.8 kg ha<sup>-1</sup>. Johnson concluded from this research an optimum date of pronamide application

for the Piedmont region of Georgia to be March 20. Therefore, it can be concluded that pronamide's success in PD transition depends on rates and application timing.

Johnson (1994) also studied the effects of two herbicides on PD transition of a perennial ryegrass overseeded bermudagrass putting green in Georgia. Diclofop, (+/-)-2[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid and dithiopyr, S,S-dimethyl-2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbothioate were tested at 0.6, 0.8, 1.1 kg ha<sup>-1</sup> and 0.6, 1.1 kg ha<sup>-1</sup> respectively. In this study, Johnson included pronamide as a chemical check. He concluded dithiopyr had no effect on PD perennial ryegrass transition back to bermudagrass while diclofop hastened the transition. The transition of perennial ryegrass back to bermudagrass with diclofop was effective with all rates of application throughout late spring until mid-July and the transition obtained from diclofop treatments was equal to the transition obtained with pronamide applied at 0.6 kg ha<sup>-1</sup> in a single application.

More recent research on herbicides' influence of PD transition was performed by Horgan and Yelverton (1997a). The effects of several herbicides applied separately to overseeded perennial ryegrass in an attempt to enhance PD transition to bermudagrass were examined at two locations in North Carolina. Glyphosate, N-(phosphonomethyl) glycine; atrazine, 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine; imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid; pronamide, and diclofop were evaluated. Glyphosate provided the best removal of perennial ryegrass when applied to dormant bermudagrass. Atrazine yielded rapid removal of perennial ryegrass but caused two weeks of unacceptable turfgrass quality when applied late May to June whereas pronamide resulted in a good PD

transition while maintaining acceptable turfgrass quality (Horgan and Yelverton, 1997a). They also reported single and multiple applications of diclofop and pronamide were the most consistent in providing an acceptable PD transition at both test locations. Also, multiple diclofop applications yielded a better transition than a single application when cooler temperatures persist.

### **Plant Growth Regulators**

Turgeon (1996) reported plant growth regulators (PGR's) were introduced over forty years ago to reduce mowing requirements by inhibiting turfgrass shoot growth when applied to utility turfs. According to Watschke, Prinster, and Breuninger (1992), the removal of unneeded foliar growth results in substantial maintenance expense primarily in the form of labor, equipment, and fuel. Therefore, if a mowing "pattern" is not a requirement for the aesthetic acceptability of a turf, growth suppression by chemical means is acceptable. According to Danneberger and Street (1990), a PGR is an organic compound, when applied in a low concentration, can affect the physiological processes and growth and development in the plant. Plant growth regulators may be natural or synthetic. Natural PGR's are produced by the plant and are hormones. They include abscissic acid, auxins, cytokinins, ethylene, gibberellins, and others. It is important to note the definition of PGR only mentions the word "affect" without specifying how a PGR may affect the growth and development of a plant. Many turfgrass managers incorrectly imply PGR's only reduce foliar growth, when in fact PGR's may also stimulate plant growth.

## **Classification of PGR's**

Plant growth regulators were originally categorized as Type I or Type II compounds from early work performed by Kaufmann and Watschke (Watschke et al., 1992). A Type I PGR can inhibit or suppress the growth and development of susceptible grass species. These growth inhibiting compounds are absorbed foliarly and can rapidly stop cell division and differentiation in meristematic areas; whereas, growth-suppressing compounds are crown and root absorbed and allow for some initial growth. Type II PGR's suppress grass growth through the interference of gibberellin biosynthesis, thus reducing cell elongation and subsequent plant organ expansion (Watschke et al., 1992).

However, the development of more PGR's has required a differentiation among the Type II compounds into either early or late gibberellic acid (GA) inhibitors. This led to a new classification system being developed dividing PGR's into Class A, Class B, and Class C substances (Watschke and DiPaola, 1995). Class A PGR's interfere with the production of GA late in the biosynthetic pathway inhibiting the hydroxylation of GA<sub>20</sub> to GA<sub>1</sub> which in turn prevents cell elongation. Class B PGR's interfere with the production of GA early in the biosynthetic pathway, at the Ent-kaurene to Ent-kaurenol transformation step in the pathway. Class C PGR's are mitotic inhibitors and include all the compounds formerly known as Type I PGR's (Watschke and DiPaola, 1995).

## **Trinexapac-ethyl (TE)**

Trinexapac-ethyl [4-(cyclopropyl-alpha-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethyl ester] is a foliar absorbed cyclohexanedione turfgrass growth regulator that can inhibit shoot growth in numerous turfgrass species (Fagerness and

Penner, 1998b). Trinexapac-ethyl is a Class A PGR and is the only compound registered for use on turfgrass in this category. Originally identified as CGA-163935 (Abbot et al., 1991) TE was first synthesized in 1983, has been tested on turfgrasses since 1985, and received labeling in 1993 for use on both cool and warm-season turfgrasses.

Trinexapac-ethyl has been found to effectively suppress vegetative growth of ‘Tifway’ bermudagrass (Wiecko, 1997 and Johnson, 1997). When TE was applied at 0.2 kg ha<sup>-1</sup> followed by 0.1 kg ha<sup>-1</sup> three weeks after the initial application, TE provided consistent suppression for four weeks of both ‘Tifway’ and common bermudagrasses (Johnson, 1994). Johnson (1997) also found that when TE was combined with an iron source, it significantly improved turfgrass quality of ‘Tifway’ bermudagrass without affecting vegetative growth. Trinexapac-ethyl is labeled for applications to warm-season grasses prior to overseeding to aid in the establishment of overseeded cool-season turf and its product label claims TE applications on bermudagrass prior to overseeding have no adverse effects on PD transition.

Wetzel and Dernoeden (1994) reported TE’s influence on turfgrass quality when applied to perennial ryegrass at 0.29 kg ha<sup>-1</sup>. Turfgrass quality was reduced by TE during the first three weeks following initial applications, but not thereafter. It was reported the turf exhibited leaf tip yellowing one week after treatment, however most TE-treated plots exhibited a darker green color and more dense turf when compared to untreated plots approximately seven weeks after treatment. Despite the more dense and darker green appearance of TE-treated turf, overall turfgrass quality was not significantly improved.

## **PGR Effects on Post Dormancy Transition**

Previous research to examine the potential influences of PGR's on PD transition from overseeded species back to warm-season species has been conducted. Mazur (1988) examined the influences of four PGR's on the PD transition from overseeded 'Yorktown II' perennial ryegrass back to 'Tifgreen' bermudagrass from 1982 to 1985 on a 'Tifgreen' bermudagrass putting green in South Carolina. Pronamide; ethephon, 2-chloroethylphosphonic acid; mefluidide, *N*-(2,4-dimethyl-5-[[trifluoromethyl]-sulfonyl]amino]phenyl)acetamide; and maleic hydrazide, 1,2-dihydro-3,6-pyridazinedione, were examined separately at various application rates. This research concluded all four PGR's were effective in increasing bermudagrass coverage (enhancing PD transition) when compared to untreated areas; however, all PGR's except ethephon reduced turfgrass quality when compared to untreated areas. Typically, the higher rates of PGR application exhibited lower turfgrass quality than lower PGR application rates (Mazur, 1988).

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