EFFECTS OF WINTER OVERSEEDING AND THREE-DIMENSIONAL CLIPPING MANAGEMENT ON WARM-SEASON TURFGRASSES

A Thesis

by

CHARLES HENRY FONTANIER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Agronomy

EFFECTS OF WINTER OVERSEEDING AND THREE-DIMENSIONAL CLIPPING MANAGEMENT ON WARM-SEASON TURFGRASSES

A Thesis

by

CHARLES HENRY FONTANIER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Kurt Steinke
Committee Members,	David Chalmers
	Michael Arnold
Head of Department,	David Baltensperger

May 2010

Major Subject: Agronomy

ABSTRACT

Effects of Winter Overseeding and Three-dimensional Clipping Management on Warm-season Turfgrasses. (May 2010)

Charles Henry Fontanier, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Kurt Steinke

Perennial ryegrass (*Lolium perenne* L.) is commonly overseeded into hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy] turfs during autumn in the southern United States. Overseeding can provide a green, actively-growing turf throughout the winter dormancy period. Improved persistence of perennial ryegrass cultivars has increased management inputs during the spring transition period. Lower input turf systems that provide acceptable winter overseeding quality are preferred, and research aimed at evaluating alternative overseeding species are warranted. Grooming reel attachments allowing for three-dimensional clipping management (3DCM) have become increasingly used by turf managers for reducing grain and thatch, but scientific information on best management practices and canopy effects of 3DCM-grooming are lacking. A field study was conducted at the Texas A&M Turfgrass Field Laboratory in College Station, TX (30.6191˚N, 96.3576˚W), to investigate the effects of overseeding using annual (*Lolium multiflorum* Lam.) and perennial ryegrasses on 3DCM-groomed and non-groomed fairway turfs of ‘Tifway’ hybrid bermudagrass, zoysiagrass [*Zoysia matrella* (L.) Merr. ‘Cavalier’], and seashore paspalum (*Paspalum vaginatum* Sw. ‘Sea Isle 1’). The study was arranged as a randomized complete block split-split-plot with three replications. Species whole main plots were split into three grooming intervals, which were further split into four overseeding treatments. Data were collected assessing visual turf quality, visual turf cover, leaf area index, clipping yield, shoot density, and biomass partitioning.

Results indicate annual ryegrass alone and an annual/perennial ryegrass overseeding mix provided acceptable turf quality, but did not improve turf recovery over perennial ryegrass alone in ‘Tifway’ or ‘Sea Isle 1’ turfs. In ‘Cavalier’ turfs, summer quality was affected by overseeding treatment as follows: control > annual > annual/perennial > perennial. The overseeding tolerance of the warm-season turfgrasses was as follows: ‘Sea Isle 1’ > ‘Tifway’ > ‘Cavalier’. Differences in canopy architecture of warm-season turfgrasses were related to the overseeding tolerance of each species and used to explain plant competition during the spring transition period. Grooming by 3DCM improved late-season turf quality and reduced scalping in ‘Tifway’. Overseeding establishment and canopy architecture were not affected by 3DCM.

DEDICATION

To dad: your work ethic and selfless attitude are worthy of aspiration

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Steinke, and my committee members, Dr. Chalmers and Dr. Arnold, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the Soil and Crop Sciences faculty and staff, especially Mr. Jim Thomas and Dr. Richard White, for making my time at Texas A&M University a great experience. I also want to extend my gratitude to industry partners such as Luber Bros. and Barenbrug for providing equipment and materials for my work.

Finally, thanks to my mother and father for their encouragement and to my wife for her patience and love.

NOMENCLATURE

0x	Not groomed
1x	Groomed by 3DCM Once Weekly
3DCM	Three-dimensional Clipping Management
3x	Groomed by 3DCM Three Times Weekly
LAFR	Leaf Area Frequency Ratio
LAI	Leaf Area Index
LFR	Leaf Frequency Ratio
LMR	Leaf Mass Ratio
LSD	Fisher’s Least Significant Difference
NOS	Not Overseeded
NS	Not Significantly ($p \leq 0.05$) affected by factor
OS	Overseeding
OS-004	Overseeding - 0 parts ‘Panterra’ annual ryegrass, 0 parts ‘Peak’ perennial ryegrass, 4 parts ‘Premier II’ perennial ryegrass
OS-211	Overseeding - 2 parts ‘Panterra’ annual ryegrass, 1 part ‘Peak’ perennial ryegrass, 1 part ‘Premier II’ perennial ryegrass
OS-400	Overseeding - 4 parts ‘Panterra’ annual ryegrass, 0 parts ‘Peak’ perennial ryegrass, 0 parts ‘Premier II’ perennial ryegrass
OSMIX	Overseeding Treatment
SLM	Specific Leaf Mass

TABLE OF CONTENTS

Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE Page

TABLE Page

CHAPTER I

INTRODUCTION: LITERATURE REVIEW

SOUTHERN WINTER OVERSEEDING SYTEMS

Warm-season turfgrasses undergo dormancy (Appendix A) during the cooler temperatures of winter. Overseeding (Appendix A) a warm-season turf with a cool-season turfgrass species is a common autumn practice in the southern United States (Shoulders et al., 1984). Overseeding provides a green, uniform playing surface throughout the winter. The actively growing cool-season grass protects the dormant turf from traffic stress (Palmertree, 1975; Mazur, 1988) and reduces weed pressure (Horgan and Yelverton, 2001). The process of preparing the turf for successful overseeding germination and eventual spring transition (Appendix A) back into warm-season turf can be difficult (Horgan and Yelverton, 2001; Green et al., 2004; Richardson, 2004).

This thesis follows the style of Agronomy Journal.

The Ideal Southern Winter Overseeding System

Depending on management and environmental conditions, most overseeding species germinate within a week after seeding. After germination, a polystand (Appendix A) of cool-season and warm-season turfgrasses exists. The initial overseeded plants extend vertically above the canopy and begin photosynthesizing. At this stage, the plants are vulnerable to traffic, dull mowers, heat and drought stress, and disease (Duble, 1996). Initial overseeding populations are largely single-tillered during the first two months after overseeding date (Kopec et al., 2001). Competition from the new seedlings may weaken the warm-season turf as it approaches dormancy (Hawes, 1982). If establishment of the overseeding is successful, a uniform cool-season turf should dominate the plant community while the warm-season turf enters dormancy. During the winter and early spring, the overseeding out-competes the permanent turf for light, nutrients, and water (Griffin, 1971), while the warm-season turf is either dormant or quiescent. During extreme low temperatures, cool-season turfgrass growth may slow but the color remains green throughout the winter (Beard, 1973). The overseeded cool-season plants tiller when climatic and spatial conditions are favorable (Mazur and Rice, 1999). Dense plant populations arising from high seeding rates may have fewer multi-tillered plants, while lower seeding rates may lead to fewer plants with large tiller to crown ratios (Kopec, et al. 2001). Overseeding species shoot and root growth peak during the moderate temperatures of spring (Beard, 1973). Also during spring the warm-season turf emerges from dormancy, and a polystand of warm- and cool-season turfgrasses reappears. As temperatures continue to climb, the cool-season grass may decline in activity due to increased photorespiration and competition from the permanent turf (Beard, 1973). Ultimately, the turf can return to a warm-season turfgrass monostand by early summer with minimal bare or off-color turf present at any point during the transition.

Warm-Season Turfgrass Winter Dormancy

The autumn in the Southern U.S. is an ideal time for warm-season turfgrasses to store carbohydrates. Moderate temperatures and abundant light in autumn promote the production of sugars under reduced shoot growth resulting in surplus carbohydrates available for storage (Beard, 1973; Dunn and Nelson; 1974, Duble, 1996). Rogers et al. (1977) found zoysiagrasses (*Zoysia* spp.) maintained higher photosynthetic rates under cold temperatures when compared to bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy]. The carbohydrates stored during the autumn are used by the plant to survive winter dormancy and green-up quickly in the spring (Beard, 1973; Dunn et al., 1980; Krans et al., 1992; Horgan and Yelverton, 2001). As soil temperatures decline, warm-season turfgrasses undergo winter discoloration and dormancy (White and Schmidt, 1990). While dormant, plant respiration continues at reduced rates while photosynthesis and growth stop. Lack of chlorophyll causes the plants to become brown or straw-like in color. In the northern limits of adaptation, warm-season turfgrasses become completely dormant and off-color. During the dormancy period, turfgrasses are vulnerable to winter desiccation, low temperature kill, diseases, traffic injury, and weed invasion. The sometimes mild winters of the southern and western U.S. can cause turfgrass canopies to become semi-dormant and maintain some chlorophyll. Even in this semi-dormant state, color and quality loss is substantial (Beard, 1973).

Studies indicate that prolonged dormancy can increase the chance of winter kill in bermudagrass (Chalmers and Schmidt, 1979). Zoysiagrasses have shown greater cold tolerance than bermudagrass (Rogers et al., 1977), while seashore paspalum (*Paspalum vaginatum* Sw.) has less cold tolerance than bermudagrass (Ibitayo et al., 1981). As soil temperatures surpass 10 to 15 degrees C in spring, new shoot formation begins for most warm-season turfgrasses. Shoot regrowth is initiated from meristematic regions on the rhizomes, stolons, and crowns of plants. Turfgrasses with good photosynthetic potential and large carbohydrate reserves tend to initiate shoots most rapidly due to the consumption of stored carboydrates (Beard, 1973) and resulting spring dieback of roots (Duble, 1996). Late-season freezes can slow warm-season recovery (Duble, 1996). Studies have shown that cold-warm-cold cycles did not directly increase dormant bermudagrass winter kill (Chalmers and Schmidt, 1979) but can reduce carbohydrate stores to the point of tiller death (Duble, 1996).

Turfgrass Species of the Southern Winter Overseeding System

Warm-season Permanent Turfs

The three major warm-season turfgrasses for southern golf fairways are bermudagrass, fine-textured zoysiagrass [*Zoysia matrella* (L.) Merr.], and seashore paspalum. All three turfgrasses spread by rhizomes and stolons and tolerate mowing heights below 19 mm. Bermudagrass is the most commonly used turfgrass for fairways and athletics fields in the southern U.S. (Duble, 1996). Origin, distribution, growth characteristics, adaptations, and uses of *Cynodon* spp. are described by Duble (1996). Zoysiagrass (fine-textured) and seashore paspalum have been planted with increasing frequency in niche zones for golf fairways and tees. Zoysiagrass (fine-textured) is noted for its excellent shade and cold tolerance among warm-season turfgrasses. Widespread use is limited by slow establishment rates which increase up-front costs. For a more detailed description of *Zoysia* spp. see Duble (1996). Seashore paspalum has become popular along the gulf coast regions where saline environments and irrigation sources limit bermudagrass success. With water quality becoming an increasingly important issue nationwide, seashore paspalum use is expected to become more prevalent. Origins, growth habit, and uses are described by Duncan and Carrow (2000). Both seashore paspalum and zoysiagrasses are considered lower input turfgrasses which require less cultivation and fertilizer to maintain healthy turf than bermudagrasses.

The majority of prior research investigating winter overseeding discusses perennial ryegrass (*Lolium perenne* L.) seeded into bermudagrass (Horgan and Yelverton, 2001). Bermudagrasses are receptive to winter overseeding; but during cool, wet springs careful management is necessary to prevent delayed post-dormancy transition into summer. Few works exist discussing winter overseeding programs on seashore paspalum or zoysiagrass. Duncan and Carrow (2000) recommend vertical mowing (Appendix A) seashore paspalum turf prior to overseeding, but suggest most cool-season turfgrasses can be overseeded successfully. Seashore paspalum overseeded with various cool-season turfgrasses performed similarly to bermudagrass in Italy, but increased summer persistence of overseeding species was observed in seashore paspalum plots (Volterrani et al., 2001). Overseeding trials in the southwestern U.S. found ‘Sea Isle 2000’ seashore paspalum putting greens tolerated overseeding and transitioned well (Kopec et al. 2004).

Razmjoo et al. (1995) found *Zoysia matrella* could be successfully overseeded but recovered slowly during the growing season. Both Zhang et al. (2008) and Gibeault et al. (1997) found that *L. perenne* provided a good winter cover but persisted into summer and reduced quality on *Zoysia japonica* Steud. athletics fields in Guangzhou, China, and southern California respectively.

Overseeding Species

Several turfgrass species have been used effectively for overseeding warm-season turf including creeping bentgrass (*Agrostis stolonifera* L.), rough bluegrass (*Poa trivialis* L.), fine fescues (*Festuca* spp.), annual ryegrass (*Lolium multiflorum* Lam.), and perennial ryegrass. Desirable overseeding species traits include fast and predictable germination rates, quick establishment into a quality turf, and moderate spring persistence (Shoulders et al. 1984). *Poa trivialis* and *A. stolonifera* are most often associated with overseeding closely mowed putting greens due to their leaf texture, growth habit, and small seeds (Turgeon, 2008). Neither species has gained acceptance for use in fairway overseeding applications (Richardson, 2004). The fescues can provide adequate winter turf quality but are slow to establish in autumn (Watschke and Schmidt, 1992). *Lolium multiflorum* was the first species to be frequently used for overseeding due to rapid germination and establishment rates (Richardson, 2004). *Lolium multiflorum* can provide a dense, uniform winter playing surface, and is characterized as having a coarse texture, light green color, and poor heat tolerance (Beard, 1973). Today, *L. multiflorum* is rarely used for overseeding fairways or athletics fields due to its excessive growth rates, lighter green color and coarser leaf texture, and poor spring persistence (Richardson, 2004). The most commonly used species for overseeding fairways and athletics fields is *L. perenne* (Richardson, 2004), which has a medium texture, dark green color, and good heat and drought tolerance. *Lolium perenne* has a history of superior turf quality and longer spring persistence as compared to *L.*

multiflorum (Beard, 1973). Increased usage of *L. perenne* for permanent turf stands has led to breeding efforts focused on increasing heat, drought, and wear tolerance. As a result, many new *L. perenne* cultivars persist longer into summer to the detriment of the warm-season turf (Richardson, 2004). Increased summer competition from overseeding is frequently associated with poor spring transitions back into warm-season turf.

To combat poor spring transitions resulting from the new, hardier *L. perenne* cultivars, turfgrass breeders and researchers have developed several new or improved species adapted to the southern winter overseeding system. The main emphasis of these breeding efforts has been to develop an alternative overseeding species which has similar turf quality to perennial ryegrass, but maintain a moderate level of persistence. Among the most common alternative overseeding species are intermediate ryegrasses, tetraploid perennial ryegrasses, fine fescues, and improved annual ryegrasses.

The intermediate ryegrasses (*Lolium perenne* L. X *L. multiflorum* Lam.*)* are hybrids between annual and perennial ryegrasses. Due to the ease with which *Lolium* sp. hybridize to create fully fertile germoplasm (Brilman, 2001), intermediate ryegrasses were some of the earliest alternative overseeding species accepted by industry (Schmitz, 1999). Research has illustrated the intermediate ryegrasses improved spring transitions with limited turf quality loss (Richardson, 2004). Although early generations of the hybrid ryegrasses maintained dark green color and fine leaf texture, each new generation increasingly resembled annual ryegrasses. Breeders responded by re-crossing the hybrids with perennial ryegrass in order to stabilize the desired turf traits (Schmitz, 1999).

Colchicine-induced tetraploid perennial ryegrasses have been developed for forage use with limited application to turf systems. The tetraploid ryegrasses have twice the chromosomes as typical diploid perennial ryegrass and a more robust growth habit for improved forage quality (Richardson et al., 2007). Recently, breeders have selected for turf-type characteristics among the tetraploids. Research by Richardson et al. (2007) suggests tetraploid perennial ryegrasses overseeded into bermudagrass fairways provide similar turf quality as *P. trivialis*, intermediate ryegrass, and fine fescue with better transition quality than intermediate ryegrasses or *P. trivialis*.

Fine fescues have been used most commonly in mixes for overseeding putting greens. The fine leaf fescues provide a quality winter turf and moderate spring persistence, but may be slower to establish than the ryegrasses. Richardson et al. (2007) concluded that meadow fescue (*Festuca pratensis* Huds.) was a viable overseeding option and provided improved transitions over *P. trivialis*, intermediate ryegrass, and perennial ryegrass.

Although *L. multiflorum* has been used less frequently, seed companies continue to develop improved cultivars. Several cultivars have become available which have more desirable turf characteristics than the original annual ryegrasses. ‘Panterra’ is an example of an improved turf-type annual ryegrass with improved turf color and a more prostrate growth habit for reduced mowing (Barenbrug USA, 2008). Few refereed data exist which discuss the improved annual ryegrasses. Nelson et al. (2005) discussed overseeding trials of ‘Panterra’ and ‘Axcella’ annual ryegrass in comparison to perennial ryegrasses. They found that turf-type annual ryegrasses provided acceptable winter turf quality and began transitioning in late Apr. in Overton, TX, but perennial ryegrasses had greater turf quality and color. Volteranni et al. (2004) found European annual ryegrass cultivars could be used for acceptable and economical winter turf stands in Italy.

The improved spring transition-friendly turfgrasses have been applied alone or in mixes with conventional perennial ryegrasses. Evenly distributed perennial ryegrass plants improve color and texture of the winter turf. Mixing is also thought to create a naturally more gradual spring transition while allowing managers to customize seed ratios depending on climate and use. The varying levels of persistence among species in an overseeding mix could create a multi-waved spring transition. In an annual/perennial ryegrass mix, the less-persistent annual ryegrass will decline in the first wave and leave behind voids or pockets in which warm-season turf can begin to occupy, while the perennial ryegrass continues to contribute to the color and density of the overall turf. Schmidt and Shoulders (1980) found that mixes containing 25% common *L. multiflorum* with 75% ‘Pennfine’ *L. perenne* did not reduce quality when compared to 100% ‘Pennfine’ *L. perenne*. Additional benefits of mixing species might include reduced costs and improved germination rates. However, few refereed data exist which evaluate any of the improved overseeding turfgrasses alone or in mixes with *L. perenne* for southern winter overseeding systems.

Autumn Establishment

A successful autumn transition to a temporary winter turf stand can be hindered by excessive thatch (Schmidt and Shoulder, 1972; Ward et al. 1974; Duble, 1996), actively growing warm-season turf, disease, low overseeding density, and early onset of suboptimal temperatures (Mazur, 1981). In order to combat these problems, regional recommendations have been made for appropriate seedbed preparation, overseeding dates, and seeding rates.

Seedbed Preparation

Overseeding seedbed preparation typically aims to reduce competition from warm-season turf (Ward et al., 1974; Green et al., 2004), increase seed to soil contact, and manage thatch (Schmidt and Shoulders, 1972). Cultivation throughout the summer to reduce thatch has improved overseeding success on bermudagrass putting greens in Virginia (Schmidt and Shoulders, 1972). Core aeration has been recommended for improving overseeding establishment on golf greens and fairways, but should be performed at least one month prior to overseeding to prevent overseeding concentration in coring holes, while light vertical mowing should be performed weekly to biweekly throughout the year on golf putting greens (Hawes, 1982; Beard and Menn, 1988; Duble, 1996). Early methods of seedbed preparation also included vertical mowing or scalping (Appendix A) just prior to overseeding (Watschke and Schmidt, 1992). Scalping may be accomplished using a vertical mower, a flail mower, or lowering the height of cut (Engelke, 2006). The less dense turf canopy formed by scalping allows seed to better reach the soil for a more uniform winter overseeded turf stand (Gill et al., 1967; Griffin, 1971; Beard, 1973; Shoulders et al., 1984). Studies have found that warm-season turf spring quality and density decrease with increasing severity of vertical mowing before overseeding on bermudagrass putting greens (Johnson, 1986). Other studies found autumn verticutting did not affect spring green-up (Appendix A) of bermudagrass home lawns or putting greens, but few data exist concerning the effects of autumn treatments on fairway turf spring green-up or warm-season species other than bermudagrass (Gill et al., 1967; Green et al., 2004).

The removal of substantial green tissue in autumn may limit the production of carbohydrates needed to regrow shoots after dormancy (Beard, 1973). During a severe scalping incident, turf root growth and carbohydrate production are halted due to the removal of photosynthetically active tissue (Beard, 1973). Insufficient carbohydrate storage can lead to turfgrass winter kill (Knoop, 1987; Horgan and Yelverton, 2001) and delayed post dormancy regrowth. Under these conditions, rapid removal of overseeding in the spring may be necessary to mitigate warm-season turfgrass density loss. The majority of overseeding applications must be made without stoppage of golf play. As a result modern practices usually involve limited disruption of the turf immediately prior to seeding. Rather, care is taken to move the seed into the canopy via irrigation or drag mats (Duble, 1996; Turgeon, 2008).

Seeding Date

Selecting the appropriate seeding date is often difficult due to climatic variations from one year to the other. The goal of proper date selection is to provide an environment which limits warm-season turf competition, reduces the potential for diseases such as *Pythium* damping off and *Rhizoctonia* brown patch (*Rhizoctonia solani* Kuhn), and allows a reasonable amount of time for establishment before the onset of growth-limiting cold temperatures. Duble (1996) recommends overseeding two to three weeks before the first killing frost or when soil temperatures at the four inch depth are 72 degrees F. Turgeon (2008) recommended overseeding twenty to thirty days before the first killing frost or when ambient midday temperatures reach the 70 to 75 degrees F.

Seeding Rate

Overseeding rates are dependent on seed size, desired plant density, mowing height, and plant growth habit. Due to high seedling mortality, overseeding rates are typically much greater than permanent turf establishment rates. Low seeding rates can result in low density, coarse-textured stands, while high seeding rates may result in overcrowded populations and increased disease incidence (Beard, 1973; Watschke and Schmidt, 1992). Brede and Duich (1982) found increased leaf angles and reduced leaf area per tiller, leaf width, and sheath width with increasing seeding rates of Kentucky bluegrass. Common recommendations for overseeding fairways and athletics fields range from 300 to 1200 kg ha^{-1} (Duble, 1996). Within the recommended range, at least two theories exist on specific overseeding rates. Early studies indicated a relatively high seeding rate was most desirable because of more dense populations of single-tillered plants (Duble, 1978). These immature plants had less heat tolerance and died more quickly in the spring allowing for a better transition to warm-season turf (Ward et al., 1974). More recent studies suggest lower seeding rates provide a more ideal spring transition (Mazur and Rice, 1999; Kopec et al., 2001). Mazur and Rice (1999) found that high seeding rates resulted in faster turf cover, greater ryegrass density, reduced leaf widths, and fewer tillers per plant as suggested by earlier studies, but spring transition was slowed despite the immature status of the overseeding. Kopec et al. (2001) found that the immature plants of higher seeding rates have less heat tolerance than the multi-tillered plants in lower seeding rates, but this did not relate to faster reduction of ryegrass populations in spring. Apparently, the more heat tolerant perennial ryegrass varieties used today can persist even in a less mature state if warm-season turfgrass activity is limited. The less dense populations associated with lower seeding rates allow for a faster green-up of warm-season turf and a smoother spring transition. Perhaps, spring transition and ryegrass decline are related more to warm-season turf activity than solely climatic conditions or overseeding plant maturity.

Spring Transition

Competition for light and nutrients occurs in the spring when ryegrass growth and root activity peaks (Duble, 1996). Even in mild climates there is an innate fragility to the spring transition period.

Ideally, the cool-season turf loses vigor and density as the warm-season turf becomes visually evident in the stand with minimal dormant turf or density loss at any point (Green et al., 2004). Bingham et al. (1969) found that a slow, gradual transition was best for continuous golf play, while others insist that overseeding should be removed completely and rapidly in order to eliminate ryegrass competition (Bruneau et al., 2004; Yelverton, 2005). Extended transition periods reduce available time for bermudagrass growth free of competition from ryegrass. Over time, the cycle of extended transition/shortened growing season can lead to substantial quality decline for the warm-season turfgrass (Horgan and Yelverton, 2001; Yelverton, 2005). Forcing early spring shoot regrowth is vital to mitigating winter kill and sparse turf attributed to extended dormancy of warm-season turfgrasses (Chalmers and Schmidt, 1979). However, shade and competition for nutrients are thought to interfere with warm-season turf green-up (Horgan and Yelverton, 2001; Yelverton, 2005). In particular, competition for light may be of most importance; bermudagrasses have been described as having very poor shade tolerance (Beard 1973). Overseeded bermudagrass and seashore paspalum lawns have displayed symptoms of shade stress such as elongated internodes and leaves (Volteranni et al., 2001). Overseeding species may affect the timing and severity of shade applied to the warm-season turfgrass. A fast growing, coarse textured overseeding species such as *L. multiflorum* (Beard, 1973) could be most detrimental to the warm-season turf in the early part of spring green-up due to the greater incidence of shade produced by taller plants (Cattani and Nowak, 2001). Due to longer persistence, perennial ryegrass may have a greater cumulative effect on light competition.

Climate is a dominant factor in speed and quality of spring transition. A hot, dry spring could lead to rapid thinning of the overseeding before adequate recovery of the warm-season turf occurs (Kopec et al., 2001; Mazur, 1988). Conversely a cool, wet spring may allow *L. perenne* to persist until early summer and prevent the warm-season turf from fully recovering from dormancy before stressful summer conditions (Kopec et al., 2001). During such prolonged transitions, the formation of a non-uniform polystand can reduce turf quality. Differences in plant textures, color, growth rate, and growth habits can create an unattractive mottled appearance (Horgan and Yelverton, 2001). In cooler climates such as the transition zone of the U.S., extended dormancy periods or extreme temperatures can lead to winter kill of the warm-season turf and impact spring transition (Hawes, 1982). The shortened summer growing season may also reduce warm-season turf quality in future years (Kopec et al., 2001).

Spring Cultural Practices

Spring transition practices which promote warm-season turf vigor and diminish competition from the overseeding are desirable. Timing nitrogen applications after weather conditions favor bermudagrass growth can improve warm-season turfgrass recovery (Schmidt and Shoulders, 1972; Duble, 1996), but additional practices are typically required for satisfactory transitions (Yelverton, 2005). Mechanical cultivation practices such as scalping, core aeration, or vertical mowing are often recommended for improving spring transition (Palmertree, 1975) because of the poor recuperative potential of ryegrasses (*Lolium* spp.) compared to warm-season turfgrasses such as bermudagrass (Beard, 1973; Duble, 1996). Some have suggested that verticutting may reduce overseeding density, increase light penetration, and warm the soil (Griffin, 1971; Johnson, 1979) leading to improved competitiveness of the warm-season turfgrass while reducing competition from ryegrass (Duble, 1996). Other studies indicate that most cultivation practices are too aggressive and actually slow warm-season turf green-up (Mazur and Wagner, 1987; Kopec, 2001). Horgan and Yelverton (2001) found that no combination of nitrogen fertilizer, scalping, vertical mowing, or aerification consistently removed perennial ryegrass from bermudagrass maintained as a golf fairway. As mentioned previously, warm-season turfgrasses are vulnerable during the spring green-up period, and aggressive cultivation practices may excessively disrupt the reduced root systems. Cultivation is disruptive, expensive, and time consuming. Spring cultivation of overseeded zoysiagrass and seashore paspalum has not been extensively researched. Aggressive cultivation may be more difficult for slow-growing species like zoysiagrasses (Razmjoo et al., 1995) and less scalp-tolerant species like seashore paspalum (Duncan and Carrow, 2005). Regardless of warm-season species, less disruptive and more sustainable practices would be preferred for overseeding systems.

Chemical applications of transition aid herbicides and plant growth regulators have successfully been used for early removal of overseeding (Johnson, 1976; Mazur, 1988; Yelverton, 2005), and products are labeled specifically for this purpose. However, the prohibitive economic costs and poor public opinions associated with spraying herbicides to large acreages diminish the viability of chemical transition aids as a sustainable practice.

Overseeding Programs by Region

Overseeding systems are affected by region. The U.S. can be divided into three regions of similar overseeding systems: the transition zone, the gulf coast, and the southwest regions.

The transition zone represents the northern limits of warm-season turfgrass use in the U.S. The area is centered on 37˚ N latitude and contains parts of Virginia, North Carolina, Alabama, Georgia, and other states. In the transition zone, winter kill and persistence of overseeding can be serious problems affecting bermudagrass performance (Breuninger and Schmidt, 1981). Seedbed preparation prior to overseeding hybrid bermudagrass athletic fields in the transition zone includes core aeration during the growing season and close mowing and dethatching immediately before overseeding (Bruneau et al., 2004). Scalping turf and vertical mowing immediately prior to overseeding is acceptable, but severe scalping should be avoided (Shoulders et al., 1984). In the spring, active management to remove overseeding and promote early warm-season turf regrowth is essential to maintain bermudagrass health (Bruneau et al., 2004; Chalmers and Schmidt, 1979). However, turf managers often encourage ryegrass persistence in order to create a more gradual transition at the risk of substantial bermudagrass decline (Shoulders et al., 1984.)

The gulf coast region of the U.S. has mild winters resulting in periods of dormancy or semi-dormancy. Spring transition of overseeded golf fairways is less problematic in this region than in the transition zone. In Texas, recommendations for overseeding bermudagrass golf greens and fairways have included season-long thatch management and limited fertilization approaching overseeding date. Most experts recommend overseeding on a relatively undisturbed surface (Beard and Menn, 1988; Duble, 1996). Others have recommended vertical mowing in three directions in preparation for overseeding bermudagrass greens (Ward et al., 1974). As overseeding increases in popularity in the gulf coast region, severe seedbed preparation may become more common resulting in increased spring transition problems.

In the southwestern U.S., up to 85% of golf play at resort and daily fee courses occur during winter and spring months. Overseeding systems are a vital part of the industry, and spring transition is the most severe problem associated with overseeding in this region (Kopec et al., 2001; Green et al., 2004). Severe scalping in order to remove all green tissue is frequently practiced in order to ensure successful overseeding establishment. Seedbed preparation can include induction of dormancy by reducing irrigation, applications of diquat, and severe scalping which results in bare soil (Green et al., 2004). Recommended seeding rates in this region range from 500 to 785 kg ha^{-1}, although much higher rates can be found within the region (Kopec et al., 2001).

PLANT INTERACTIONS AMONG CROWDED POPULATIONS

Competition

A plant growing in a crowded population inescapably competes with other members of the plant community above-ground for light and below-ground for water and nutrients. "A plant community is a stand of vegetation consisting of a collection of plant individuals of one or more species at a certain site. Structure and species composition of a stand result from differences between individuals in resource exploitation and from dependences among individuals (Hirose and Werger, 1995)." The structure of a plant community is defined by two competing occurrences: species exclusion or species coexistence. Grime (1974) developed a triangle of factors for determining plant population diversity. In his model stress, disturbance, and competition determine species diversity in a plant population. Stress includes factors such as climate and edaphic properties. Disturbance relates to outside forces such as mowing that affect the 'natural environment' of a population. "Competition is important in both natural and agricultural plant communities. The botanical composition of any mature stand of vegetation is largely determined by competition (Wilson, 1988)." Stress and disturbance create spatial and temporal niches and allow for species coexistence despite the presence of plant competition (Grime, 1974). Zobel (1992) suggests balanced competition between relatively similar species does not result in competitive exclusion. Disturbances such as mowing reduce competition for light and allow for greater co-existence of species (Zobel, 1992). Passarge et al. (2006) studied competition theories using phytoplankton and found competitive exclusion was most the common result of competition.

Root Competition

Wilson (1988) found that root competition impacted plant populations more than shoot competition within pots of *Festuca ovina* L. under greenhouse conditions. King (1971) found root competition for nutrients was of most importance between perennial ryegrass and fine fescue (*Festuca rubra* S59). Wilson and Newman (1987) found both root and shoot competition occurred between *Deschampia flexuosa* (L.) Trin. and *Festuca ovina* in British grassland systems with roots being of greatest importance and little interaction occurring between root and shoot competition. Walker and King (2009) found root competition severely reduced Kura clover (*Trifolium ambiguum* M. Bieb.) growth when sown into a stand of meadow bromegrass (*Bromus biebersteinii* Roem. & Schult.) under greenhouse conditions.

Although root competition is often the major source of competition in grassland systems, attempts to improve soil water and fertility levels have not reduced competition for those resources. Wilson and Newman (1987) found little evidence to suggest competition for phosphorus was reduced by adding P fertilizer. Haugland and Froud-Williams (1999) also found root competition between perennial ryegrass, *Phleum pretense* L., and *Trifolium pretense* L. was not prevented by addition of water or nitrogen. Newman and Andrews (1973) found roots of winter wheat (*Triticum aestivum*) competed strongly under greenhouse conditions for K but not P and related it to ion mobility. McCown and Williams (1968) found root competition for limited sulfur prevented species exclusion of broad-leaf filaree [*Erodium botrys* (Cav.) Bertol] by soft chess [*Bromus mollis* (L.)] until supplemental sulfur was applied. King (1971) found adding nutrients did not alleviate competition for nutrients, but increased competitive ability of existing grasses.

Newman (1973), in a response to a colleague's hypothesis, stated that root competition can maintain avenues for high species diversity. Newman reasoned that plants can find niches in the soil by rooting in different depths, soil microclimate properties, and soil pore sizes. Wilson (1988) found initial root sizes of competing grasses did not affect root competition. These studies agree with the accepted idea that root competition is size symmetrical, that is root size is proportional to competitive gain. More recent studies on unmanaged fields in Michigan indicate root competition can also be size asymmetrical (defined below) if soils are not adequately homogeneous (Rajaniemi, 2003).

Shoot Competition

In many cases, competition for light has been the primary means of competition in mixed grass stands. Haugland and Froud-Williams (1999) found shoot competition from *Lolium perenne* reduced competing forbs more than did root competition. Zobel (1992) suggests the majority of species exclusion is due to light competition. Typically, the plant able to reach the highest point in the canopy will be the dominant species, although models for long-term competition of annual species found intermediate levels of leaf area and stem allocation were most competitive (Pronk et al., 2007). Aan et al. (2006) found species becoming dominant under high soil resources in Estonian grasslands tended to have low leaf area ratios (leaf area per above-ground biomass) and lower tissue nitrogen concentrations. Newman (1973) used the term ‘snowball effect’ to describe the cumulative effects of above-ground competition as tall plants not only capture greater amount light, but increase shading of subordinate plants over time. Others have used the term asymmetric competition. Zobel (1992) defines asymmetric competition as occurring when “the influence of the stronger species on the weaker one on average exceeds the influence of the weaker species on the stronger…[leading] to decreased species richness, through time, as the most successful species gain a progressively greater share of the available resources.” Weiner (1986) used plant size variability in a population of *Ipomoaea tricolor* Cav. to measure asymmetrical competition. Roots more severely reduced plant sizes, but did not affect size variability. Shoot competition did increase variability, and root plus shoot competition increased variability the most. He concluded that shoot competition was primarily asymmetrical, while root competition was symmetrical. Lamb et al. (2009) found shoot, but not root, competition reduced community diversity of grassland mesocosms in Alberta, Canada. Roots did not affect diversity directly, but did so by affecting shoot competition. The root competition induced reduction in shoot growth (caused by a root-shoot interaction) can lead to species exclusions. This finding was similar to McCown and Williams (1968) in which competition for limiting sulfur prevented species exclusion. Upon addition of sulfur to the soil, the dominant species increased shoot growth resulting in exclusionary shoot competition. Rajaniemi et al. (2003) found similar results involving fertilizer mediated exclusion. Martin and Field (1984) found early stages of competition between white clover (*Trifolium repens* L.) and perennial ryegrasses were primarily affected by roots. Over time shoot competition became more important, and nitrogen fertilizer increased competitive effects by increasing ryegrass shoots. Studies by Aan et al. (2006) found taller plants with small leaf area ratios were the most dominant in highly productive sites. They also suggested competition for light was size symmetric in sites where total LAI was less than 2.5, but size asymmetric when LAI was greater than 2.5. These studies indicate the majority of shoot competition is size asymmetric and can lead to species exclusion.

Above-ground competition can also allow for species co-existence. Anten and Hirose (1999) described the concepts of niche separation and found that leaf allocation decreased with increasing shoot height and light availability in tallgrass meadows. Tall species tended to maximize light capture by creating fewer taller shoots, while short plants did so by creating numerous, shorter plants. Hirose and Werger (1995) studied light capture efficiency in relation to biomass allocation of competing grasses in a wet meadow in The Netherlands. They concluded that biomass allocation to non-lamina tissues can be considered an investment towards capturing greater photon flux densities, and subordinate species compete by using biomass more efficiently to capture light. Grime (1974) described tall, dominant plants as competitors and the shorter plants as stress tolerators. Results from Aan et al. (2006) similarly showed plants can respond to competition by either investing in vertical growth to better receive light or by improving light capturing ability via a greater leaf area ratio. Lepik et al. (2005) found plants can respond to competition in one of two ways: by investing in means to pre-empt resources and dominate other species or have greater shoot plasticity (ability to adjust morphology) and increasing fitness under close populations. Vermeulen et al. (2009) used the terms ‘canopy models’ and ‘resource models’ to describe the two competition strategies. They found that intra-specific light competition allows for some genotypes of *Potentilla reptans* to create enough canopy heterogeneity to allow coexistence of both resource and canopy models. Light competition is also dependent on canopy architecture and initial plant sizes. Yokozawa et al. (1996) found canopy architecture affected the ability of some trees to emerge under established stands while not affecting others. Light capture is not only based on leaf area and height but also leaf arrangement and distribution (Anten and Hirose, 1999).

In addition to morphological factors, physiological differences between plants is often most important in determining competitive advantages (Anten and Hirose, 2003).

Kemp and Williams (1980) studied temporal niche separation of C_3 (*Agropyron smithii* Rydb.) and C_4 [*Boutelaua gracilis* (HBK) Lag.] grasses in the North American short grass prairie. They found seasonal moisture stresses were not as important as seasonal temperature changes in determining niche separation.

Research described here relates to competition among mature plants or between seedlings and mature stands. To my knowledge, there is no information on plant competition between actively growing plants and plants emerging from winter dormancy in a grassland system.

Competition in Turf Stands

Turfgrasses can form fairly stable communities, but typically the composition of a population is in constant change (Beard, 1973). The term succession is used to describe the sequence of plant communities derived from disturbance, stress, or competition (Beard, 1973).

Turfgrass communities differ from the grasslands discussed previously in that species diversity is primarily controlled by disturbance in the form of cultural practices. Seasonal and environmental stresses can affect turfgrass communities as in grasslands, but cultural practices such as mowing, fertilization, and irrigation are the strongest manipulators of community structure. Pure competition among plants within a turf environment has been largely ignored by turfgrass scientists, and most research has focused on turf cultural practices or impact of stress on the cultivated turfs. Certainly the competitive ability of turfgrasses can be manipulated by understanding their specific adaptations to tolerate various mowing heights, fertility levels, cultivation, and utility. Above- and below-ground competition have been shown to affect turfgrass communities mowed at 3.1 cm, and therefore the role of turfgrass intra- and inter-specific competition should not be ignored (Brede and Duich, 1986). Future turfgrass science research should aim to better understand direct plant competition. A complete understanding of fundamental plant interactions may reduce the need for greater inputs (e.g. cultural practices) as a means for maintaining desired turfgrass populations.

Whether competition in a turf community is primarily due to above- or below-ground competition has not been well-documented. In irrigated and fertilized turfs, root competition for limiting nutrients is typically regarded as minor (Yelverton, 2005). Shoot competition for light may be of greater importance. The potential for complex interactions in above-ground tissues as described in range ecology may be more difficult in short-mowed turfs, but studies have found vertical stratification of a canopy can exist in turfs mowed as low as 3 cm (Roxburgh et al., 1993). Beard (1973) lists the following factors which influence the competitive ability of turfgrasses: vertical shoot growth rate, form, leaf area, leaf orientation, growth habit, rooting depth and extension rate, nutrient uptake capability, and crown-internode height. Brede and Duich (1986) found perennial ryegrass had the greatest below-ground competitive ability among Kentucky bluegrass and annual bluegrass. In their study, below-ground competition affected plant interactions even when nutrients were not limiting. Hsiang et al. (1997) found similar results illustrating the excellent competitive ability of perennial ryegrass. According to

Brede (1982), competitive advantages of perennial ryegrass, annual bluegrass, and Kentucky bluegrass are derived from seedling vigor, tillering rate, and consistency of growth under competition, respectively. Brede and Duich (1984) found Kentucky bluegrass shoot density and leaf area index decreased with increasing mowing height, while both attributes increased in perennial ryegrass under the same conditions in newly sown turf mixes. Tiller production rate has been associated with greater competitive advantages (Rhodes, 1968) although consistent growth, as opposed to seasonal fluctuations, proved most successful over time (Brede and Duich, 1986). Creeping-type growth habits have also been thought to promote long-term competitive advantages (Juska et al., 1955).

Winter overseeding systems provide unique examples of plant competition. From a broader ecological view, winter overseeding competition between C_3 and C_4 grasses is largely separated by a temporal niche. During the spring transition, direct competition between plants becomes important to the succession of the stand. As described previously, turfgrass research has focused on disturbances as a means of manipulating spring transition communities and concluded environmental stress is a large predictor of succession. However, few studies have been performed examining direct plant competition within the spring transition period of overseeded turfs.

Allelopathy

Allelopathy is “any direct or indirect harmful effect by one plant on another through the production of chemical compounds that escape into the environment” (Rice, 1984). Rhodes (1968) found *Lolium rigidum* Gaudin inhibited seedling growth of competing plants even after entire stand loss. The study was not specifically examining allelopathy, but the author suggested there may be a residual inhibitory effect not explained by direct competition. Lickfeldt et al. (2001) studied allelopathic effects of cool-season turfgrasses on weed populations. Results showed inhibition of weeds were present in petri dishes but not in an agronomic environment. Naqvi and Muller (1975) found inhibitory plant toxins in above- and below-ground parts of annual ryegrasses. They concluded that inhibitory effects of these toxins on other plants were species-dependent. Toxins reduced germination is some species but only retarded growth in others. Brede (1982) found both negative and beneficial allelopathic consequences on the growth of three cool-season turfgrasses, but effects were dwarfed by interactions between plants for light. Several other turfgrass species have been suspected of allelopathic effects, but conclusive evidence of in-field inhibition is lacking.

THREE-DIMENSIONAL CLIPPING MANAGEMENT

Grooming (Appendix A)

Popular turfgrasses for putting green use such as creeping bentgrass and bermudagrass produce stolons and procumbently oriented growth. These horizontally oriented tissues, sometimes referred to as grain (Appendix A), often escape mowing reels and reduce ball roll uniformity leading to slower putting green speeds (Anonymous, 1986). In order to combat grain, turf managers have used brushes, grass combs, and vertical mowers to promote upright growth. Brushes and grass combs (small rakes) are placed between the front roller and the cutting unit of a reel-type mower and push grainy tissues upright into the cutting unit (Anonymous, 1986; Anonymous, 1988; Kierstead, 2006). Vertical mowers have historically been used for remedial thatch management, but during the early 1980’s light and frequent vertical mowing set to just knick the green surface became a popular tool for reducing grain (Chalmers, 1985). Collectively these practices can be referred to as grooming and are often reserved for putting green canopy management. More recently equipment manufacturers have developed a modern turf groomer which uses small vertical mowing units seated between the front roller and the cutting unit of a reel-type mower. The modern turf groomer is the most aggressive canopy management tool for promoting vertical growth of turf and can be used for three-dimensional clipping management (3DCM) (Kierstead, 2006). The first dimension of 3DCM is the width of the mowing unit; the second dimension is the length of the mowing pass; the third dimension is the vertical removal of excessive turf verdure.

Function of Modern Turf Groomers

Grooming by 3DCM equipment entered the turf industry in the 1980's, and Schaffer (1994) reported that up to 75% of superintendents used groomers as part of their cultural management program. Similar to other grooming methods, 3DCM have been thought to create a vertical turf stand and reduce grain leading to a smoother putting surface, increased putting speeds, and the option of raising mowing heights without sacrificing speed (Schaffer, 1994). The modern turf groomers are also used on taller turfs. In turf maintained at golf fairway heights (10 to 20 mm), 3DCM has been used to reduce stemminess (Appendix A) and grain which occurs when the stem elongates and 'leans' in the direction of the mowing pass (Engelke, 2006). Grain results in reduced playability, increased incidence of scalping, and a higher effective height of cut (Turgeon, 2008). Most reel mowers today come with the option of a 3DCM attachment, but scientific data have been limited to putting green studies. Salaiz et al. (1995) studied the effects of light vertical mowing on 'Penncross' creeping bentgrass putting green speeds and found no difference between treatments. Similar results were found by Dunnivant (2008) on 'Tifeagle' bermudagrass putting greens. Preliminary results on taller mowed turfs suggest that 3DCM three days weekly was too aggressive but hastened spring green-up the following year (Sorochan and McElroy, 2007). Other reports have found limited 3DCM effects on turf quality but showed reduced density resulting in improved overseeding stands (Thoms et al., 2008). Best management practices and empirical data explaining the morphological effects of modern grooming by 3DCM on turfgrasses are still needed.

Groomers v. Vertical Mowers

Vertical mowing (verticutting) and 3DCM are frequently classified as similar cultural management practices. Beyond the use of vertical blades, 3DCM practices differ from vertical mowing. Verticutting uses wide (>3.2 mm) vertical blades spaced 13 to 25 mm apart on a dedicated vertical mower or a triplex vertical mowing reel. Goals of vertical mowing can include canopy thinning, removal of thatch, or soil surface cultivation (Turgeon, 2008). The practice can frequently be destructive to the turf surface. According to Engelke (2006), verticutting is a remedial practice recommended to be used 2-3 times per year in order to remove excess thatch and plant material. Grooming by 3DCM uses finer (< 3.2 mm) vertical blades spaced 6 to 13 mm apart to only penetrate the turf canopy 10% - 30% below the height of cut and remove moderate amounts of verdure per application. Unlike vertical mowers, 3DCM reels are attached to a standard reel-type mower and sit in front of the cutting blade to be used simultaneously while mowing. Grooming by 3DCM can be considered a preventative practice for grain and thatch management (Engelke, 2006). Although traditional vertical mowers can be used for clipping management (termed ‘light vertical mowing’), the need for dedicated equipment and the more disruptive, large blades limit their use as groomers of fine turfs. While grooming has historically been a form of vertical mowing, the advent of dedicated grooming reels has created greater distinction between the two practices.

Mowing

Mowing is a fundamental aspect of turfgrass culture which drastically alters the physiological and developmental growth habits of plants. Lowering the height of cut reduces leaf width, carbohydrate storage, and root growth (Beard, 1973; Shearman, 1989) while increasing shoot density, shoot growth (Beard, 1973; Shearman, 1989; Lush and Rogers, 1992), chlorophyll content, and tissue succulence. Lower mowed turfs usually have shallower root systems (Turgeon, 2008). The result is high quality, uniform turf with poor stress tolerances (Beard, 1973; Shearman, 1989). Lowering mowing heights has been found to reduce leaf angles, create more prostrate growth, and increase tillering in Kentucky bluegrass (*Poa pratensis* L.) (Sheffer et al., 1978). Eggens (1981) also found increased leaf numbers per tiller on Kentucky bluegrass in response to mowing, but annual bluegrass responded with increased tillering. According to Duble (1996), bermudagrasses respond to low, frequent mowing by initiating new shoots and result in a denser turf. Lower mowed turfs frequently require increased management inputs due to increased disease susceptibility, more frequent mowing, and decreased drought and wear tolerances (Beard, 1973). The ability to mow turf at taller heights while maintaining the increased turf quality attributed to lower heights would be desirable.

Undocumented Primary Effects of Three-dimensional Clipping Management

The immediate effect of 3DCM is the removal of verdure and lifting of horizontally-inclined tissues. The vertical blades sever leaves and shoots below the bedknife height of cut. The extra material removed is expected to contribute to greater clipping yield. Reducing excess green tissue is expected to directly increase light and air entering the turf canopy.

Undocumented Secondary Effects of Three-dimensional Clipping Management

Secondary effects can be defined as the response of turfgrass plants or the turf microclimate to repeated 3DCM. An example of secondary effects might be the removal of grain and the formation of a more upright growth habit within the turf over time or the expected reduction in clipping yield from subsequent mowings.

Microclimate Effects

Reduced canopy density is though to result in lower relative humidity within the turf microclimate leading to reduced disease pressure (Beard, 1973). Studies have found that disease incidence increased with increasing canopy density in tall fescue (*Festuca arundinacea* Schreb.) (Giesler et al., 1996). Similarly, limiting excess verdure would be expected to reduce disease incidence in warm-season turfgrasses. Increased solar radiation reaching the soil may promote faster warming of the soil. Increased light has also been positively correlated with weed pressure (Johnson, 1979).

Stratified Height of Cut

Because 3DCM blades cut below the bedknife height of cut, multiple heights of turf exist within the canopy. These stratified heights of cut in a turf canopy might affect overall turfgrass morphology, but research on actual morphological effects of grooming on turfgrass canopy structure is lacking. Bermudagrasses have a large proportion of leaves in the upper canopy (i.e. stemminess) and may benefit from frequent clipping management (Biran, 1981).

Undocumented Tertiary Effects of Three-dimensional Clipping Management

Tertiary effects can be defined as the observable results stemming from secondary 3DCM effects. An example of tertiary effects might be the potential extension of autumn color retention and hastening of post dormancy regrowth in the spring in response to warmer soil temperatures from increased solar radiation (Beard, 1973).

Turf Canopy Structure

An un-proven theory proposes that grooming by 3DCM affects turfgrass morphology by stimulating new growth from the crown similar to the effects of frequent close mowing. The theory advocates long-term 3DCM programs create a more compact, open-canopied turf (Engelke, 2006). Ultimately, 3DCM could lead to improved turf quality under taller heights of cut. All information related to this topic is anecdotal and published research investigating effects of 3DCM on turfgrass morphology is lacking.

Thatch

Thatch is a tightly intermingled layer of living and dead organic matter between the soil line and green tissue (White and Dickens, 1984). Thatch accumulation is an obstacle encountered in most intensively-managed warm-season turfgrasses including bermudagrass, zoysiagrass, and seashore paspalum (Hollingsworth et al., 2005; Soper, 1988; Duncan and Carrow, 2000). Turf managers often view grooming as a preventative method of thatch management. The removal of excess verdure and old stems is thought to promote young shoots and leaves (Engelke, 2006). The juvenile tissues have less sclerified plant material and are more easily-decomposed by soil microbes (Ledeboer and Skogley, 1967). Better gas exchange in the canopy and around the soil may improve microbial decomposition of thatch at the soil surface (Beard, 1973). McCarty et al. (2007) found grooming alone did not reduce thatch accumulation on golf course putting greens. Scientific research discussing effects of 3DCM on thatch accumulation in fairway turfs is lacking.

Scalping

Scalping is a common dilemma involved with mowing warm-season turfgrasses such as bermudagrass (Biran, 1981) and seashore paspalum (Duncan and Carrow, 2005). Scalping is typically the result of excess thatch, grain, or stemminess. Bermudagrass is an aggressive thatch-producer prone to scalping (Duble, 1996) due to a stemmy growth habit (Biran, 1981). Management practices which promote erect growth habits and leafiness should reduce scalping. Vertical mowing and 3DCM have been recommended for reducing grain in turf (Kierstead, 2006). Duncan and Carrow (2005) recommended grooming on seashore paspalum for the reduction of scalping. However, published information does not explain the effects of these management practices from a plant morphology viewpoint.

Overseeding Seedbed Preparation and Cultivation

In southern winter overseeding systems, successful overseeding establishment can be hindered by excessive thatch (Schmidt and Shoulders, 1972; Duble, 1996) and actively growing warm-season turf. Ideally autumn cultural practices should improve the seedbed for the temporary turf stand without being excessively disruptive to the permanent turf stand. Weekly light vertical mowing has been recommended for seedbed preparation of golf putting greens in winter overseeding systems (Beard and Menn, 1988). Monthly vertical mowing has been recommended for taller turfs (Duble, 1996). Similarly, frequent use of grooming by 3DCM throughout the growing season may improve overseeding success (Duble, 1996). Anecdotal information suggests that 3DCM encourages faster germination of the overseeding while maintaining a greater percentage of green tissue after scalping (Engelke, 2006). Grooming by 3DCM is thought to decrease thatch and canopy density thereby improving seed to soil contact. Preliminary data from Thoms et al. (2008) show that grooming improved overseeding establishment. Green et al. (2004) found that autumn verticutting and scalping treatments did not affect spring green-up on Tifgreen putting greens, but little data exist concerning the effects of autumn treatments on fairway turf spring green-up. In areas such as the southwestern U.S. where all green tissue is removed before overseeding, spring transition causes difficulties which may be alleviated with a continuous 3DCM program. Studies investigating the effects of grooming on overseeding establishment and spring transition are necessary.

OBJECTIVES

Therefore the objectives of this study were to evaluate the performance of three mixes of annual and perennial ryegrass on three groomed and non-groomed warm-season turfgrass species and to determine the overseeding tolerance of seashore paspalum and zoysiagrass in comparison to hybrid bermudagrass. The research also quantified effects of three-dimensional clipping management (3DCM) on warm-season turfgrass canopy architecture and investigated 3DCM best management guidelines for turf performance.

CHAPTER II

EFFECTS OF IMPROVED RYEGRASSES ON TURF QUALITY AND SPRING TRANSITION OF SOUTHERN WINTER OVERSEEDING SYSTEMS

In the southern U.S. low winter temperatures can induce dormancy in warm-season turf species. In order to provide an actively-growing playing surface, turf managers often overseed a cool-season turfgrass into the existing permanent turf. Desirable characteristics of cool-season turfgrasses used for overseeding include rapid germination and establishment, the ability to tolerate low winter temperatures, and moderate persistence under warmer temperatures of spring (Schmidt and Shoulders, 1980). Due to rapid germination and establishment rates, annual ryegrass (*Lolium multiflorum* Lam.) was the first species frequently used for overseeding, however excessive growth rates, poor color and texture, and early departure in the spring have reduced the popularity of traditional annual ryegrass cultivars (Richardson, 2004). Perennial ryegrass (*Lolium perenne* L.) has a finer leaf texture, darker green color, and greater spring persistence than annual ryegrass and is the most commonly used species for overseeding golf course fairways and athletics fields (Beard, 1973; Richardson, 2004). Many perennial ryegrass cultivars have excessive spring persistence resulting in poor or unpredictable spring transitions (Appendix A) into warm-season turf (Mazur and Wagner, 1987; Horgan and Yelverton, 2001; Richardson, 2004). Under the ideal spring transition, the cool-season turf loses vigor and density as the warm-season turf increases in density with minimal dormant or sparse turf occurring at any point (Horgan and Yelverton, 2001; Green et al., 2004).

Mechanical cultivation such as vertical mowing (Appendix A), core aeration, and scalping (Appendix A) have been studied for expediting spring transition, but results have been inconsistent and often disruptive to warm-season turfgrass post-dormancy regrowth (Griffin, 1971; Johnson, 1979; Mazur and Wagner, 1987; Horgan and Yelverton, 2001). Chemical applications of transition aid herbicides and plant growth regulators have been successful for removal of overseeding, but prohibitive economic costs and poor public opinions associated with spraying herbicides to large acreages have diminished the viability of chemical transition aids for golf course fairways (Johnson, 1976; Mazur, 1988; Yelverton, 2005). Low input systems are becoming increasingly desirable for winter overseeding.

Turfgrass breeders have introduced new overseeding species aimed at maintaining winter turf quality while limiting overseeding spring persistence. Among the new overseeding species documented in the literature are intermediate ryegrass (*Lolium perenne* L. X *L. multiflorum* Lam.) (Richardson, 2004), tetraploid perennial ryegrass, and meadow fescue (*Festuca pratensis* Huds.) (Richardson et al., 2007). These studies concluded that the new overseeding species improve transition with minimal winter turf quality loss. Improved turf-type annual ryegrasses have finer texture, darker color, and a more prostrate growth habit than previous cultivars of annual ryegrass. Information investigating new annual ryegrass performance for southern winter overseeding systems is needed. Nelson et al. (2005) found that improved turf-type annual ryegrasses provided acceptable winter turf quality and transitioned one month earlier than perennial ryegrasses in common bermudagrass [*Cynodon dactylon* (L.) Pers.] turfs in Overton, TX. Schmidt and Shoulders (1980) found mixes containing 25% common annual ryegrass with 75% ‘Pennfine’ perennial ryegrass did not reduce quality when compared to 100% ‘Pennfine’ perennial ryegrass. However, effects of annual/perennial ryegrass mixes have not been documented using the improved turf-type annual ryegrasses, nor have these annual ryegrasses been studied in zoysiagrass or seashore paspalum. The objective of this study was to evaluate the effects of annual and perennial ryegrass overseeding treatments on winter turf quality and the spring transition of three warm-season turfgrass species.

MATERIALS AND METHODS

A field study was conducted at the Texas A&M Turfgrass Field Laboratory in College Station, TX (30.6191˚N, 96.3576˚W), on three turfgrass species: zoysiagrass [*Zoysia matrella* (L.) Merr. ‘Cavalier’], seashore paspalum (*Paspalum vaginatum* Sw. ‘Sea Isle 1’), and hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy ‘Tifway’]. Plots were sodded Aug. 2006 over a modified rootzone containing a Booneville (fine, smectitic, thermic, chromic, Vertic Albaqualfs) clay amended with coarse sand containing a final particle size distribution of 93.5% sand, 5.1% silt, and 1.4 % clay. The experimental design was a randomized complete block split-split-plot design with three replications. Whole main plots, sub-plots, and sub-sub-plots were randomized at each split of the design. Main species plot sizes were 9.9 m long by 4.0 m wide. Species whole main plots were split by grooming (Appendix A) treatments applied as three-dimensional clipping management (Appendix A) at three frequencies from mid-May through mid-Oct: once per week (1x), three times per week (3x), and not groomed (0x). Grooming reel bench settings were set 40% below the bedknife height of cut using a tee box rated turf groomer (1.3 cm blade spacing). Sub-sub-plots consisted of four overseeding treatments: 100% ‘Panterra’ annual ryegrass (OS-400), 50% ‘Panterra’ annual ryegrass + 25% ‘Peak’ perennial ryegrass + 25% ‘Premier II’ perennial ryegrass (OS-211), 100% ‘Premier II’ perennial ryegrass (OS-004), and an non-overseeded control (NOS). Ryegrass was overseeded in late Oct. 2007 and 2008 using shaker jars at a rate of 976 kg seed ha^{-1}. Overseeding was allowed to naturally transition each spring.

Plots were fertilized at 48 kg N ha^{-1} month^{-1} from May through Aug. using a coarse prilled 21-3-12 water soluble fertilizer (100% ammoniacal N source, Nelson Plant Food Corp., Belleville, TX). Overseeded plots received an additional 48 kg N ha^{-1} every other month from Oct. through Apr. using a greens grade 12-24-8 slow-release fertilizer (50% ammoniacal water soluble N sources, 50% slow release methylene ureas and water insoluble N sources, The Andersons Lawn Fertilizer Division, Inc., Maumee, OH). During ryegrass establishment, plots were irrigated for 10 minutes three times per day for one week amounting to 0.6 cm d^{-1}. From establishment until May the following year, irrigation was aimed at preventing visual ryegrass drought stress. From May until overseeding application, plots were irrigated three times weekly at 2.5 cm per week.

Plots were mowed three days per week with clippings returned using a Jacobsen Greensking 526A (Jacobsen, a Textron Company, Charlotte, NC) walking mower. From Oct. 2007 through May 2008, plots were mowed at 2.5 cm. From May 2008 to Oct. 2008, plots were mowed at 1.9 cm. Minimal grooming treatment effects were seen in 2008, therefore the mowing height was lowered during year two in order to increase stress on the turf and more accurately reflect golf fairway heights. From Oct. 2008 through May 2009, plots were maintained at 1.7 cm. From May 2009 until the end of the study, plots were maintained at 1.3 cm. Mowing direction alternated between north/south and east/west each mowing day. Applications of azoxystrobin (Methyl (E)-2-{2-[6-(2-cyano-phenoxy) pyrimidin-4-yloxy]phenel}-3-methoxyacrylate) were made 21 Mar. 2008 and 23 Oct. 2008 in response to zoysia patch (*Rhizoctonia solani* Kuhn) symptoms. To control fire ants (*Solenopsis invicta* Buren), fipronil (5-amino-1-(2,6-dichloro-4-(trifluoromethyl)phenyl)-4((1,R,S)-(trifluoromethyl)sulfinyl)-1-H-pyrazole-3-carbonitrile) was applied 27 Mar. 2008 and 20 Mar. 2009.

Monthly visual assessments of turf quality were recorded from May through Oct. Ratings were taken immediately after plots were mowed using a scale of 1 to 9 (1 = bare soil or necrotic turf; 2 = very poor density and poor relative color; 3 = poor density and poor relative color; 4 = acceptable density but poor uniformity and poor relative color; 5 = acceptable density but poor uniformity or poor relative color; 6 = acceptable density, uniformity, and relative color; 7 = good density, uniformity, and relative color; 8 = excellent density, uniformity, and relative color; 9 = ideal density, uniformity, and relative color; color was relative to genetic color of species). On overseeded plots, turf quality and % ryegrass coverage (0 to 100%, ±5%) were visually assessed from Nov. through Apr. (Horgan and Yelverton, 2001). Additional visual ratings evaluated incidental scalping severity during summer on a scale of 1 to 6 (1 = 0% brown color, 2 = 5 to 20% brown color, 3 = 25 to 40% brown color, 4 = 45 to 60% brown color, 5 = 65 to 80% brown color, 6 = 85 to 100% brown color).

Leaf area index (LAI), verdure dry mass, and shoot density were measured using a destructive sampling method. One verdure sample from each sub-sub-plot was collected in May, July, and Sept. using a 2.5 cm diameter standard soil probe. Cores were cut at the soil line with scissors, and ryegrass plants were separated and recorded independently from the warm-season turfgrass. Verdure was first separated into green leaves (lamina) and shoots (pseudostems which produced leaf tissue). Shoot density was calculated as shoot number cm^{-2} (Jordan et al., 2003). Leaves were counted and scanned into a flatbed desktop scanner (HP Scanjet G4010, Palo Alto, CA) for digital image analysis (O’Neal et al., 2002). Image analysis software (SigmaScan, Systat Software, Inc., San Jose, CA) was used to calculate total leaf area within the sample. Leaves within the digital images were selected using an “intensity threshold” range of 0 to 196. Total leaf area within the image was calculated using the “measure objects” feature. Leaf area index was calculated as (total green leaf area within the sample)/(sampling area) (Pearce et al. 1965). Lamina and shoots were then placed in separate paper bags to be dried at 60˚ C for 48 hours in a gravity-flow Isotemp Oven (Thermo Fisher Scientific Inc., Waltham, MA). Dry mass of leaves and shoots were measured separately and the masses added to calculate verdure.

Clipping yield was measured monthly from April through Sept. One pass of the previously described walking greens mower was made over the center of each sub-sub-plot representing 2.2 m^2 of turf. Clippings were collected in a standard reel mower basket and put into paper bags for drying at 60˚ C for 48 hours in a gravity-flow Isotemp Oven (Thermo Fisher Scientific Inc., Waltham, MA). Collection occurred on Fridays of a Monday-Wednesday-Friday mowing schedule at the regular mowing height with 1x plots being only mowed during clipping collection, and 3x groomed plots being groomed during clipping collection.

Each parameter was subjected to analysis of variance using a general linear model (SPSS 15.0 for Windows, 2006, SPSS, Inc.). Due to differences in mowing heights, each year was analyzed separately. Individual dates were treated as split plots in time nested within sub-sub-plots resulting in the final model having a split-split-split-plot design. Significant ($p \leq 0.05$) month*treatment, species*treatment, or month*species*treatment interactions were analyzed within month and/or within species. If higher order interactions were not significant ($p \leq 0.05$), means of significant ($p \leq 0.05$) main effects were separated using Fisher’s protected least significant difference (LSD) test. Qualitative data were transformed within years using rank order transformation before being subjected to the above analysis.

RESULTS

Overseeding Establishment and Winter Performance

In the 2007 to 2008 winter, visual ryegrass ground cover demonstrated significant ($p \leq 0.05$) overseeding (OS) treatment main effects (Table 1). Treatment OS-400 had significantly ($p \leq 0.05$) greater coverage than other OS treatments across dates from Nov. 2007 to Feb. 2008 (Table 2). In the 2008 to 2009 winter, visual ryegrass ground cover demonstrated significant ($p \leq 0.05$) date*species and date*OS treatment two-way interactions (Table 1). Further analysis within date showed that OS-400 had greater percent cover than OS-004 on four of seven dates, and OS-211 had greater percent cover than OS-004 on three of seven dates (Table 3). Zoysiagrass had greater ryegrass cover than bermudagrass on one of four dates in 2008 and better cover than seashore paspalum on three of six dates in 2009 (Table 4). A significant ($p \leq 0.05$) species*OS treatment two-way interaction on 18 Dec 2009 showed OS-400 and OS-211 had greater percent cover than OS-004 in seashore paspalum turfs (Table 5).

Table 1. Abbreviated ANOVA table for visual estimates of ryegrass overseeding ground cover and overseeding turf quality. Quality data were analyzed as rank order transformations of original visual ratings. Rank was assigned across all dates within each year.

	---------------Ryegrass Cover---------------				--------Overseeding Quality Rank---------			
Source	df	2007-2008	df	2008-2009	df	2007-2008	df	2008-2009
Rep	2	0.031†	2	0.982	2	0.159	2	0.422
Species	2	0.014	2	0.077	2	0.013	2	0.073
Error (a)	4	0.687	4	0.194	4	0.606	4	0.010
Grooming	2	0.768	2	0.464	2	0.656	2	0.325
Grooming*Species	4	0.330	4	0.773	4	0.554	4	0.415
Error (b)	12	0.720	12	0.011	12	0.198	12	0.065
OSMIX‡	2	0.003	2	0.000	2	0.063	2	0.000
OSMIX*Grooming	4	0.174	4	0.792	4	0.756	4	0.431
OSMIX*Species	4	0.190	4	0.379	4	0.016	4	0.800
OSMIX*Species*Grooming	8	0.473	8	0.955	8	0.760	8	0.257
Error (c)	36	0.270	36	0.205	36	0.012	36	0.000
Date	3	0.000	8	0.000	5	0.000	8	0.000
Date*OSMIX	6	0.254	16	0.000	10	0.000	16	0.000
Date*Grooming	6	0.642	16	0.506	10	0.258	16	0.014
Date*Species	6	0.000	16	0.000	10	0.000	16	0.000
Date*OSMIX*Grooming	12	0.726	32	1.000	20	0.987	32	0.938
Date*Species*OSMIX	12	0.547	32	0.073	20	0.003	32	0.000
Date*Grooming*Species	12	0.155	32	0.910	20	0.092	32	0.138
Date*Species*Grooming*OSMIX	24	0.314	64	1.000	40	0.962	64	0.965
Error (d)	162		432		270		432	

† *p*-value, significant source effect at $p \leq 0.05$.
‡ Overseeding treatment.

Table 2. Main effects of overseeding treatment on visual estimates of ryegrass ground cover on overseeded turfs in winter 2007-2008. Data are across three warm-season turf species, three grooming intervals, and four dates. (n=108).

Treatment	2008
	--%†--
OS-400‡	66.9a§
OS-211¶	65.1b
OS-004#	64.4b
LSD ($p \leq 0.05$)	1.3

† Percent ryegrass coverage measured as a visual rating from 0 to 100%.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
# 100% ‘Premier II’ perennial ryegrass

Table 3. Interaction between overseeding treatment and date on visual estimates of ryegrass ground cover in winter 2008-2009. Data are across three warm-season turf species and three grooming intervals. (n=27).

Treatment	31 Oct	4 Nov	20 Nov	26 Nov	8 Jan	3 Feb	26 Feb
	--%†--						
OS-400‡	27.0a§	75.4a	84.9a	86.5a	93.0a	89.4a	89.8a
OS-211¶	20.9b	73.7a	85.9a	86.7a	93.7a	88.9a	90.4a
OS-004#	0.0c	62.4b	87.6a	84.3b	92.4a	85.0b	91.7a
LSD ($p \leq 0.05$)	6.1	8.7	NS	2.0	NS	2.4	NS

† Percent ryegrass coverage measured as a visual rating from 0 to 100%.
‡ 100% 'Panterra' annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses
 # 100% 'Premier II' perennial ryegrass

Table 4. Interaction between warm-season turf species and date on visual estimates of ryegrass ground cover. Data are across three grooming intervals and three overseeding treatments. (n=27).

	----------------2007 to 2008----------------				----------------------------2008 to 2009------------------------------					
Species	9 Nov	7 Dec	31 Jan	28 Feb	31 Oct	4 Nov	20 Nov	8 Jan	3 Feb	26 Feb
	---%†---									
Zoysiagrass	8.8a‡	62.0a	96.1a	97.3a	11.1a	80.0a	89.4a	95.0a	93.1a	94.4a
Seashore Paspalum	9.9a	63.7a	94.9a	96.8a	18.0a	63.9a	85.4b	92.2a	80.4c	85.7b
Bermudagrass	9.2a	64.4a	86.1b	96.6a	18.9a	67.6a	83.5b	91.9a	89.8b	91.7a
LSD ($p \leq 0.05$)	NS	NS	2.1	NS	NS	NS	2.6	NS	2.4	2.9

† Percent ryegrass coverage measured as a visual rating from 0 to 100%.
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 5. Three-way interaction between date, overseeding treatment, and species on visual estimates of ryegrass coverage on 18 Dec 2008. Data are across three grooming intervals. (n=9).

Treatment	Zoysia	Seashore	Bermuda
	---------------------%†---------------		
OS-400‡	94.4a§	88.3a	88.3a
OS-211¶	95.0a	86.7a	89.4a
OS-004#	95.0a	81.7b	89.4a
LSD ($p \leq 0.05$)	NS	4.1	NS

† Percent ryegrass coverage measured as a visual rating from 0 to 100%.
‡ 100% 'Panterra' annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses
 # 100% 'Premier II' perennial ryegrass

In both years, a significant ($p\leq0.05$) date*species*OS treatment three-way interaction was seen for OS turf quality (Table 1). The interactions were further analyzed within date and species (Tables 6 though 11). In zoysiagrass, OS turf quality was not significantly ($p\leq0.05$) affected by OS treatment on five of six dates in 2008 and seven of nine dates in 2009 (Tables 6 and 9). In seashore paspalum, OS-211 had greater OS turf quality than OS-004 on 28 Feb. and OS-400 on 24 Mar. 2008 (Table 7). The following year in seashore paspalum turfs, OS-211 and OS-004 had greater OS turf quality than OS-400 on both dates in Mar., and OS-004 had the best turf quality among treatments on 20 Apr. 2009 (Table 10). In bermudagrass turfs, OS-004 had greater OS turf quality than OS-400 on all three dates in Mar. and Apr. 2008 and greater OS turf quality than OS-211 on two of three dates in Mar. and Apr. 2008 (Table 8). The following year in bermudagrass turfs, OS-004 had the best OS turf quality among OS treatments on four of nine dates, but the worst OS quality on 26 Feb. 2009 (Table 11).

Table 6. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2007-2008 overseeded zoysiagrass turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	-------------------------2007 to 2008-------------------------					
Treatment	**7 Dec**	**31 Jan**	**28 Feb**	**24 Mar**	**7 Apr**	**14 Apr**
	-----------------------Turf Quality Rank †----------------------					
OS-400‡	102a§	327a	382a	266b	285a	93a
OS-211¶	103a	265a	382a	382a	348a	180a
OS-004#	97a	294a	327a	338ab	348a	195a
LSD ($p \leq 0.05$)	NS	NS	NS	83	NS	NS

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
# 100% ‘Premier II’ perennial ryegrass

Table 7. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2007-2008 overseeded seashore paspalum turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	------------------------------2007 to 2008-----------------------------					
Treatment	**7 Dec**	**31 Jan**	**28 Feb**	**24 Mar**	**7 Apr**	**14 Apr**
	---------------------Turf Quality Rank †------------------------					
OS-400‡	99a§	271a	338a	271b	321a	338a
OS-211¶	88a	186a	294a	365a	348a	321a
OS-004#	121a	263a	212b	331ab	315a	294a
LSD ($p \leq 0.05$)	NS	NS	80	74	NS	NS

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
# 100% ‘Premier II’ perennial ryegrass

Table 8. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2007-2008 overseeded bermudagrass turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	2007 to 2008					
Treatment	**7 Dec**	**31 Jan**	**28 Feb**	**24 Mar**	**7 Apr**	**14 Apr**
	Turf Quality Rank †					
OS-400‡	**89a§**	**159a**	**321a**	**179b**	**131b**	**141b**
OS-211¶	**72a**	**108a**	**321a**	**348a**	**113b**	**164b**
OS-004#	**93a**	**91a**	**294a**	**365a**	**382a**	**294a**
LSD ($p \leq 0.05$)	**NS**	**NS**	**NS**	**56**	**46**	**103**

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
 # 100% ‘Premier II’ perennial ryegrass

Table 9. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2008-2009 overseeded zoysiagrass turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	2008 to 2009								
Treatment	**5 Dec**	**12 Dec**	**18 Dec**	**8 Jan**	**3 Feb**	**26 Feb**	**10 Mar**	**31 Mar**	**20 Apr**
	Turf Quality Rank †								
OS-400‡	**373b§**	**439a**	**486a**	**594a**	**529a**	**429a**	**264a**	**313a**	**347b**
OS-211¶	**505a**	**467a**	**558a**	**630a**	**593a**	**521a**	**333a**	**361a**	**414b**
OS-004#	**486a**	**485a**	**560a**	**612a**	**450a**	**483a**	**164a**	**611a**	**594a**
LSD ($p \leq 0.05$)	**111**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**77**

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
 # 100% ‘Premier II’ perennial ryegrass

Table 10. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2008-2009 overseeded seashore paspalum turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	2008 to 2009								
Treatment	**5 Dec**	**12 Dec**	**18 Dec**	**8 Jan**	**3 Feb**	**26 Feb**	**10 Mar**	**31 Mar**	**20 Apr**
	Turf Quality Rank †								
OS-400‡	328a§	155a	162a	315a	174a	187	193b	396b	448b
OS-211¶	467a	221a	181a	446a	164a	314	294a	558a	504b
OS-004#	305a	73a	144a	401a	80a	328	364a	630a	666a
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	140	94	70

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
 # 100% ‘Premier II’ perennial ryegrass

Table 11. Three-way interaction between date, overseeding treatment, and species on visual overseeding turf quality in 2008-2009 overseeded bermudagrass turfs. Data are presented as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable) across three grooming intervals. Greater rank number indicates superior turf quality. (n=9).

	2008 to 2009								
Treatment	**5 Dec**	**12 Dec**	**18 Dec**	**8 Jan**	**3 Feb**	**26 Feb**	**10 Mar**	**31 Mar**	**20 Apr**
	Turf Quality Rank †								
OS-400‡	191a§	108b	300b	384a	321a	401a	126a	200b	309b
OS-211¶	290a	196b	395ab	480a	388a	459a	136a	232b	339b
OS-004#	352a	303a	490a	545a	264a	226b	76a	471a	484a
LSD ($p \leq 0.05$)	NS	91	125	NS	NS	116	NS	85	99

†Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses
 # 100% ‘Premier II’ perennial ryegrass

Spring Transition

Clipping yields (dry mass) had a significant ($p \leq 0.05$) month*species*OS treatment three-way interaction in 2008 and a significant ($p \leq 0.05$) month*OS treatment two-way interaction in 2009 (Table 12). Data for 2008 were further analyzed within month and species (Table 13). In Apr. 2008, OS-400 and OS-211 treatments resulted in greater clipping yields than OS-004 and NOS treatments within each warm-season turf. In May 2008, OS-211 and OS-004 treatments resulted in greater clipping yields than OS-400 within each warm-season turf and greater than NOS in zoysiagrass and bermudagrass turfs. In May 2009, OS-004 had the greatest clipping yield among OS treatments within seashore paspalum and bermudagrass turfs (Table 14).

Ryegrass contribution to the combined warm-season/cool-season verdure (dry mass) in May was calculated as a percentage and was significantly ($p \leq 0.05$) affected by species but not by OS treatments in 2008 and showed a significant ($p \leq 0.05$) species*grooming interval*OS treatment three-way interaction in 2009 (Table 15). Species main effects in May 2008 showed overseeded zoysiagrass had greater percent ryegrass than overseeded seashore paspalum which had greater percent ryegrass than overseeded bermudagrass (Table 16). In May 2009, examination of the three-way interaction found no consistent explanation for the significant ($p \leq 0.05$) grooming interval influence. Since grooming treatments had not begun for 2009 at the time of data collection, the apparent grooming interval influence was likely due to random error in the spatial hierarchy of the split plot design. Therefore, further analysis proceeded as if only a significant ($p \leq 0.05$) species*OS treatment two-way interaction existed. Data analyzed within OS treatment showed seashore paspalum had the smallest percentage of ryegrass among warm-season turfgrasses within each OS treatment, and zoysiagrass had the greatest percentage of ryegrass within OS-400 and OS-004 treatments but was similar to bermudagrass within OS-211 treatments (Table 17). Percent ryegrass verdure data were then analyzed within species and showed treatment OS-004 had the greatest percentage of ryegrass among OS treatments in zoysiagrass and seashore paspalum turfs but was similar to OS-211 treatments in bermudagrass turfs (Table 18).

Table 12. Abbreviated ANOVA table for clipping yields (dry mass). In 2009, zoysiagrass data were removed from the model due to several missing entries.

	----------Clipping Yield--------			
Source	**df**	**2008**	**df**	**2009**
Rep	**2**	**0.337†**	**2**	**0.065**
Species	**2**	**0.037**	**1**	**0.095**
Error (a)	**4**	**0.005**	**2**	**0.851**
Grooming	**2**	**0.005**	**2**	**0.002**
Grooming*Species	**4**	**0.418**	**2**	**0.270**
Error (b)	**12**	**0.247**	**8**	**0.005**
OSMIX‡	**3**	**0.000**	**3**	**0.013**
OSMIX*Grooming	**6**	**0.856**	**6**	**0.155**
OSMIX*Species	**6**	**0.912**	**3**	**0.177**
OSMIX*Species*Grooming	**12**	**0.489**	**6**	**0.289**
Error (c)	**54**	**0.000**	**36**	**0.864**
Month	**6**	**0.000**	**4**	**0.000**
Month*OSMIX	**18**	**0.000**	**12**	**0.008**
Month*Grooming	**12**	**0.001**	**8**	**0.001**
Month*Species	**12**	**0.000**	**4**	**0.000**
Month*OSMIX*Grooming	**36**	**0.922**	**24**	**0.971**
Month*Species*OSMIX	**36**	**0.020**	**12**	**0.741**
Month*Grooming*Species	**24**	**0.008**	**8**	**0.098**
Month*Species*Grooming*OSMIX	**72**	**0.999**	**24**	**0.970**
Error (d)	**432**		**192**	

† *p*-value, significant source effect at $p \leq 0.05$.
‡ Overseeding treatment.

Table 13. Three-way interaction between month, species, and overseeding treatment on clipping yield (dry mass) in 2008. Data are across three grooming intervals and represent 48 hr of growth. (n=9).

	Apr 2008			May 2008		
Treatment	**Zoysia**	**Seashore**	**Bermuda**	**Zoysia**	**Seashore**	**Bermuda**
	g m^{-2}					
OS-400†	**8.3a‡**	**10.4a**	**6.9a**	**6.1b**	**16.1b**	**8.2b**
OS-211§	**7.8a**	**8.0b**	**7.3a**	**8.4a**	**24.0a**	**12.9a**
OS-004¶	**2.5b**	**2.0c**	**3.6b**	**8.9a**	**24.7a**	**15.1a**
NOS#	**1.3b**	**1.5c**	**2.5b**	**5.9b**	**26.7a**	**9.0b**
LSD ($p \leq 0.05$)	**1.7**	**1.6**	**1.6**	**2.3**	**5.0**	**3.1**

† 100% ‘Panterra’ annual ryegrass.
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.
¶ 100% ‘Premier II’ perennial ryegrass.
 # Not overseeded.

Table 14. Interaction between month and overseeding treatment on clipping yield (dry mass) of non-groomed turfs in May 2009. Data are across three warm-season turf species and represent 48 hr of growth. (n=9).

Treatment	**May 2009**
	--g m^{-2}--
OS-400†	**20.1b‡**
OS-211§	**20.3b**
OS-004¶	**29.5a**
NOS#	**17.7b**
LSD ($p \leq 0.05$)	**8.3**

† 100% ‘Panterra’ annual ryegrass.
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.
¶ 100% ‘Premier II’ perennial ryegrass.
 # Not overseeded.

Table 15. Abbreviated ANOVA table for May percent ryegrass of the total verdure (% C3 Verdure) and ryegrass leaf area index (C3 LAI).

	-------------% C3 Verdure-------------				-----------------C3 LAI-------------------			
Source	**df**	**May 2008**	**df**	**May 2009**	**df**	**May 2008**	**df**	**May 2009**
Rep	2	0.404†	2	0.389	2	0.291	2	0.246
Species	2	0.003	2	0.007	2	0.062	2	0.051
Error (a)	4	0.079	4	0.065	4	0.285	4	0.062
Grooming	2	0.449	2	0.500	2	0.208	2	0.436
Grooming*Species	4	0.990	4	0.671	4	0.563	4	0.077
Error (b)	12	0.750	12	0.349	12	0.394	12	0.899
OSMIX‡	2	0.104	2	0.000	2	0.000	2	0.000
OSMIX*Grooming	4	0.996	4	0.521	4	0.679	4	0.910
OSMIX*Species	4	0.889	4	0.028	4	0.360	4	0.001
OSMIX*Species*Grooming	8	0.529	8	0.047	8	0.258	8	0.196
Error (c)	36		36		36		36	

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 16. Main effects of species on percent ryegrass of the total verdure in May 2008. Data are across three grooming intervals and three overseeding treatments. (n=27).

Species	**May 2008**
	--%†--
Zoysia	84.8a‡
Seashore	42.8b
Bermuda	34.0c
LSD ($p \leq 0.05$)	8.3

† 100 * ryegrass verdure dry mass divided by total verdure dry mass.

‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 17. Interaction between overseeding treatment and species on percent ryegrass of May total verdure of overseeded turfs in 2009. Data were analyzed within overseeding treatment across three grooming intervals. (n=9).

Species	OS-400†	OS-211‡	OS-004§
	-------------------%¶----------------------		
Zoysia	56.3a#	72.0a	93.9a
Seashore	16.1c	16.6b	31.6c
Bermuda	33.0b	62.3a	58.6b
LSD ($p \leq 0.05$)	15.6	9.8	14.8

† 100% 'Panterra' annual ryegrass.
‡ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.
§ 100% 'Premier II' perennial ryegrass.
¶ 100 * ryegrass verdure dry mass divided by total verdure dry mass.
# Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 18. Interaction between overseeding treatment and species on percent ryegrass of May total verdure of overseeded turfs in 2009. Data were analyzed within species across three grooming intervals. (n=9).

Species	OS-400†	OS-211‡	OS-004§	LSD ($p \leq 0.05$)
	-----------------------------%¶----------------------			
Zoysia	56.3c#	77.7b	93.9a	16.9
Seashore	16.1b	16.6b	31.6a	8.9
Bermuda	33.0b	62.3a	58.6a	20.4

† 100% 'Panterra' annual ryegrass.
‡ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.
§ 100% 'Premier II' perennial ryegrass.
¶ 100 * ryegrass verdure dry mass divided by total verdure dry mass.
# Means followed by the same letter in a given row are not significantly different (LSD 0.05).

Ryegrass LAI (C3 LAI) data showed a significant ($p \leq 0.05$) OS treatment main effect in 2008, but in 2009 exhibited a significant ($p \leq 0.05$) species*OS treatment two-way interaction (Table 15). In 2008, OS-004 resulted in greater C3 LAI than OS-211 which had greater C3 LAI than OS-400 (Table 19). In 2009, data were analyzed within species and showed OS-004 had greater C3 LAI than OS-400 within each species, but OS-211 was not different from OS-400 in seashore paspalum or bermudagrass turfs (Figure 1).

Warm-season turf LAI (C4 LAI) data exhibited ($p \leq 0.05$) month*OS treatment and month*species two-way interactions both years (Table 20). Data were further analyzed within month. In May 2008, each OS treatment resulted in significantly ($p \leq 0.05$) less C4 LAI than NOS treatments, and OS-400 resulted in the least C4 LAI among OS treatments (Table 21). Seashore paspalum had greater C4 LAI than bermudagrass which had greater C4 LAI than zoysiagrass (Table 22). In May 2009, a significant ($p \leq 0.05$) species*OS treatment two-way interaction showed each OS treatment resulted in significantly ($p \leq 0.05$) less C4 LAI than NOS treatments in zoysiagrass and bermudagrass turfs but not in seashore paspalum turfs (Figure 1).

Combined C3 plus C4 LAI (total LAI) showed a significant ($p \leq 0.05$) species*grooming interval*OS treatment three-way interaction in 2008 and a significant ($p \leq 0.05$) main effect due to OS treatment in 2009 (Table 20). Further analysis of the three-way interaction revealed significance in the ANOVA table can be attributed to differences in magnitude which resulted in seashore paspalum – 3x – OS-400 treatments not being significantly ($p \leq 0.05$) different than other species – 3x – OS-400 combinations despite seashore paspalum having greater total LAI under all other treatments. Considering that grooming did not initiate for the given year until after data were collected for total May LAI, the significant ($p \leq 0.05$) interaction is likely due to random error in the spatial hierarchy of the split plot design. Analysis of May 2008 total LAI for non-groomed turfs showed OS-004 had the greatest total LAI, NOS and OS-211 had similar total LAI to each other, and OS-400 had the least total LAI (Table 22). In May 2009, OS treatment affected total LAI in the following order: OS-004 > NOS > OS-211 > OS-400.

Table 19. Main effects of overseeding treatment on spring transitioning ryegrass leaf area index (LAI) in May 2008. Data are across three warm-season turf species and three grooming intervals. (n=27).

Treatment	**May 2008**
	--LAI--
OS-400†	**0.9c‡**
OS-211§	**1.7b**
OS-004¶	**3.1a**
LSD ($p \leq 0.05$)	**0.4**

† 100% ‘Panterra’ annual ryegrass.
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.
¶ 100% ‘Premier II’ perennial ryegrass.

Table 20. Abbreviated ANOVA tables for warm-season turfgrass leaf area index (C4 LAI) and combined warm- and cool-season turfgrass LAI (Combined C3 + C4 LAI) in May.

	-------------C4 LAI------------				Combined May C3 + C4 LAI			
Source	df	2008	df	2009	df	2008	df	2009
Rep	2	0.146 †	2	0.225	2	0.350	2	0.362
Species	2	0.000	2	0.000	2	0.000	2	0.002
Error (a)	4	0.683	4	0.424	4	0.693	4	0.002
Grooming	2	0.976	2	0.931	2	0.258	2	0.162
Grooming*Species	4	0.991	4	0.996	4	0.889	4	0.184
Error (b)	12	0.002	12	0.039	12	0.125	12	0.793
OSMIX‡	3	0.000	3	0.000	3	0.000	3	0.000
OSMIX*Grooming	6	0.155	6	0.995	6	0.156	6	0.062
OSMIX*Species	6	0.001	6	0.005	6	0.143	6	0.118
OSMIX*Species*Grooming	12	0.934	12	0.973	12	0.048	12	0.113
Error (c)	54	0.442	54	0.966	54		54	
Month	2	0.000	2	0.817				
Month*OSMIX	6	0.000	6	0.001				
Month*Grooming	4	0.816	4	0.645				
Month*Species	4	0.000	4	0.000				
Month*OSMIX*Grooming	12	0.463	12	0.175				
Month*Species*OSMIX	12	0.490	12	0.845				
Month*Grooming*Species	8	0.538	8	0.555				
Month*Species*Grooming*OSMIX	24	0.691	24	0.461				
Error (d)	144		144					

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 21. Interaction between overseeding treatment and month on warm-season turf leaf area index (LAI) in May 2008. Data are across three warm-season turf species and three grooming intervals. (n=27).

Treatment	May 2008
	--LAI--
OS-400†	1.5c‡
OS-211§	2.1b
OS-004¶	2.0b
NOS#	4.2a
LSD ($p \leq 0.05$)	0.4

† 100% ‘Panterra’ annual ryegrass.

‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.

¶ 100% ‘Premier II’ perennial ryegrass.

Not overseeded.

Table 22. Interaction between species and month on warm-season turf leaf area index (LAI) in May 2008. Data are across three grooming intervals and four overseeding treatments. (n=36).

Species	May 2008
	--LAI--
Zoysia	0.9c†
Seashore	4.8a
Bermuda	1.6b
LSD ($p \le 0.05$)	0.4

† Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 23. Main effects of overseeding treatment on combined warm- plus cool-season turfgrass leaf area index (LAI) in May 2008 and 2009. Data from 2008 are across three non-groomed warm-season turf species. (n=9). Data from 2009 are across three warm-season turf species and three grooming intervals. (n=27).

Treatment	--2008†--	--2009--
	---------LAI---------	
OS-400‡	2.7c§	2.4d
OS-211¶	3.8b	3.7c
OS-004#	5.6a	5.1a
NOS††	4.3b	4.2b
LSD ($p \le 0.05$)	1.0	0.5

† Non-groomed turfs

‡ 100% 'Panterra' annual ryegrass.

§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

¶ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.

100% 'Premier II' perennial ryegrass.

†† Not overseeded.

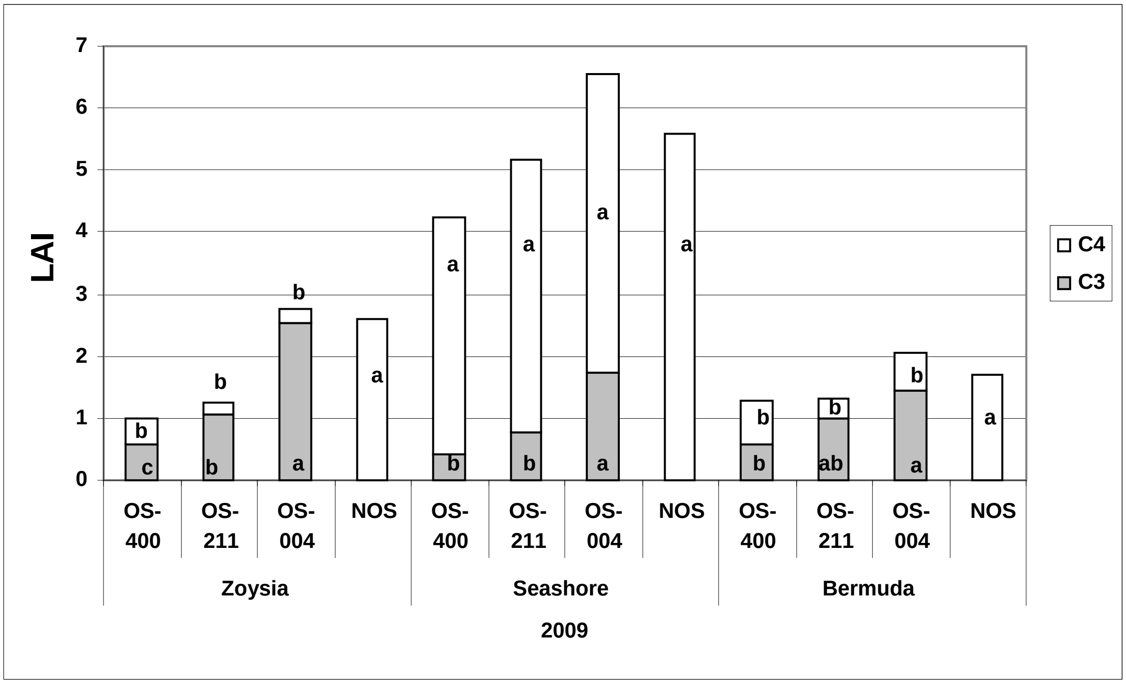

Figure 1. Interactions between overseeding treatment and warm-season turf species on relative contribution of ryegrass (C3) and warm-season turfgrass (C4) to combined leaf area index (LAI) in the spring polystand (Appendix A) in May 2009. Means labeled with the same letter within a given warm-season turf species are not significantly different (LSD 0.05).

Warm-season Turf Recovery

Further analysis of warm-season turf LAI (C4 LAI) revealed a significant ($p \leq 0.05$) species*OS treatment two-way interaction in July 2008 showing each OS treatment had less C4 LAI than NOS treatments in zoysiagrass turfs, but seashore paspalum and bermudagrass C4 LAI were unaffected by OS treatments (Table 24). In July 2009, OS-400 and NOS had greater C4 LAI than other OS treatments (Table 25).

Analysis of warm-season turfgrass shoot density exhibited significant ($p \leq 0.05$) month*species, month*OS treatment, and species*OS treatment two-way interactions in both years (Table 26). Further analysis was performed within month and revealed significant ($p \leq 0.05$) species*OS treatment two-way interactions in July. Analysis within species in July showed in each year OS-211 and OS-004 treatments reduced zoysiagrass shoot density (Table 27). In July of each year, OS treatment did not affect seashore paspalum shoot density. In July 2008, OS-211 and OS-004 reduced bermudagrass shoot density, but in July 2009, OS treatment did not affect bermudagrass shoot density.

Data analysis of clipping yield within species within July 2008 showed each OS treatment reduced clipping yields, and OS-211 and OS-004 reduced yields more than OS-400 (Table 28). In July 2009, analysis within month resulted in a significant ($p \leq 0.05$) species*OS treatment two-way interaction which showed each OS treatment reduced bermudagrass clipping yield, but seashore paspalum clipping yield was not affected by OS treatment.

Table 24. Interaction between overseeding treatment and species on July warm-season turf leaf area index (LAI) in 2008. Data are across three grooming intervals. (n=9).

Species	OS-400†	OS-211‡	OS-004§	NOS¶	LSD ($p\leq0.05$)
	-----------------------------------	----------	--LAI----	----------	------------------------------------
Zoysia	1.4b#	0.9bc	0.5c	2.9a	0.5
Seashore	4.5a	4.9a	4.2a	5.3a	NS
Bermuda	1.7a	1.5a	1.7a	2.1a	NS

† 100% 'Panterra' annual ryegrass.

‡ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.

§ 100% 'Premier II' perennial ryegrass.

¶ Not overseeded.

Means followed by the same letter in a given row are not significantly different (LSD 0.05).

Table 25. Interaction between month and overseeding treatment on warm-season turf leaf area index (LAI) in July 2009. Data are across three warm-season turf species and three grooming intervals. (n=27).

Treatment	July 2009
	--LAI--
OS-400†	10.6a‡
OS-211§	8.7b
OS-004¶	7.7b
NOS#	10.4a
LSD ($p\leq0.05$)	0.7

† 100% 'Panterra' annual ryegrass.

‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

§ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.

¶ 100% 'Premier II' perennial ryegrass.

Not overseeded.

Table 26. Abbreviated ANOVA tables for warm-season turfgrass shoot density.

	---------Shoot Density----------			
Source	**df**	**2008**	**df**	**2009**
Rep	**2**	**0.558†**	**2**	**0.452**
Species	**2**	**0.006**	**2**	**0.017**
Error (a)	**4**	**0.316**	**4**	**0.016**
Grooming	**2**	**0.782**	**2**	**0.700**
Grooming*Species	**4**	**0.473**	**4**	**0.390**
Error (b)	**12**	**0.056**	**12**	**0.268**
OSMIX‡	**3**	**0.000**	**3**	**0.000**
OSMIX*Grooming	**6**	**0.825**	**6**	**0.937**
OSMIX*Species	**6**	**0.000**	**6**	**0.005**
OSMIX*Species*Grooming	**12**	**0.397**	**12**	**0.650**
Error (c)	**54**	**0.505**	**54**	**0.290**
Month	**2**	**0.000**	**2**	**0.000**
Month*OSMIX	**6**	**0.000**	**6**	**0.000**
Month*Grooming	**4**	**0.559**	**4**	**0.397**
Month*Species	**4**	**0.000**	**4**	**0.000**
Month*OSMIX*Grooming	**12**	**0.812**	**12**	**0.916**
Month*Species*OSMIX	**12**	**0.101**	**12**	**0.148**
Month*Grooming*Species	**8**	**0.853**	**8**	**0.108**
Month*Species*Grooming*OSMIX	**24**	**0.890**	**24**	**0.802**
Error (d)	**144**		**144**	

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 27. Interaction between overseeding treatment and species on warm-season turfgrass shoot density in July 2008 and 2009. Data are across three grooming intervals. (n=9).

	-----------------July 2008-------------------			------------------July 2009--------------------		
Species	**Zoysia**	**Seashore**	**Bermuda**	**Zoysia**	**Seashore**	**Bermuda**
Treatment	---No. cm^{-2}--					
OS-400†	**7.1a‡**	**9.7a**	**10.2ab**	**7.3ab**	**12.4a**	**12.0a**
OS-211§	**4.3b**	**12.0a**	**7.5b**	**4.9bc**	**9.4a**	**11.9a**
OS-004¶	**2.0c**	**10.1a**	**8.5b**	**2.8c**	**8.6a**	**11.8a**
NOS#	**7.8a**	**12.0a**	**13.0a**	**10.5a**	**9.0a**	**11.8a**
LSD ($p \leq 0.05$)	**1.9**	**NS**	**3.1**	**3.6**	**NS**	**NS**

† 100% ‘Pant erra’ annual ryegrass.

‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.

¶ 100% ‘Premier II’ perennial ryegrass.

 # Not overseeded.

Table 28. Interaction between overseeding treatment and species on clipping yield (dry mass) in July 2008 and 2009. Data are across three grooming intervals and represent 48 hr of growth. (n=9).

	------------------July 2008--------------------			------------------July 2009--------------------		
Species	**Zoysia**	**Seashore**	**Bermuda†**	**Zoysia**	**Seashore**	**Bermuda**
	--g m^{-2}---					
OS-400‡	**3.3b§**	**7.6b**	**5.1b**	**-**	**76.2a**	**98.5b**
OS-211¶	**2.1c**	**7.2b**	**9.8b**	**-**	**58.7a**	**102.1b**
OS-004#	**1.7c**	**7.3b**	**7.2b**	**-**	**54.9a**	**80.8b**
NOS††	**10.1a**	**10.8a**	**18.6a**	**-**	**65.7a**	**129.5a**
LSD ($p \leq 0.05$)	**1.0**	**1.7**	**6.2**	**-**	**NS**	**22.4**

† Data only include non-groomed plots due to grooming interval interaction.
‡ 100% 'Pant erra' annual ryegrass.
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
¶ 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.
# 100% 'Premier II' perennial ryegrass.
†† Not overseeded.

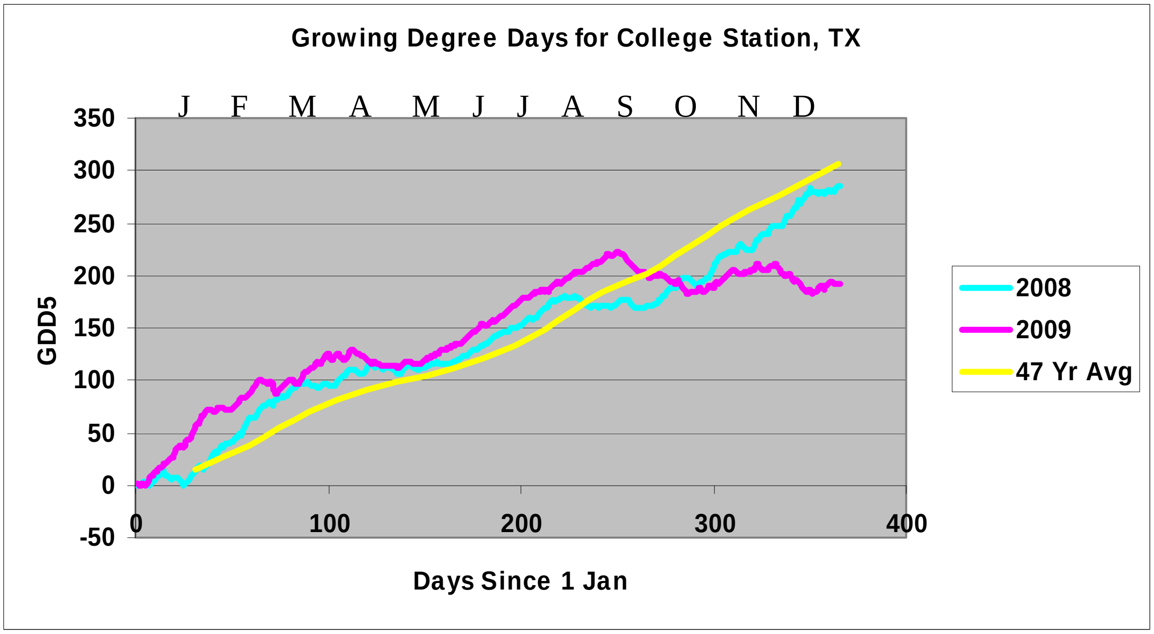

Figure 2. Growing degree days (GDD) for 2008 and 2009 in comparison to 47 year averages in College Station, TX. Data for 2008 and 2009 were collected daily by a weather station at the Turfgrass Field Laboratory. Data for 47 year averages are presented as monthly averages of daily max and min temperatures (Texas ET Network, 2010). [GDD = $(\text{Temperature}_{max}-\text{Temperature}_{min})/2 - 5$] where temperatures are measured in degrees C.

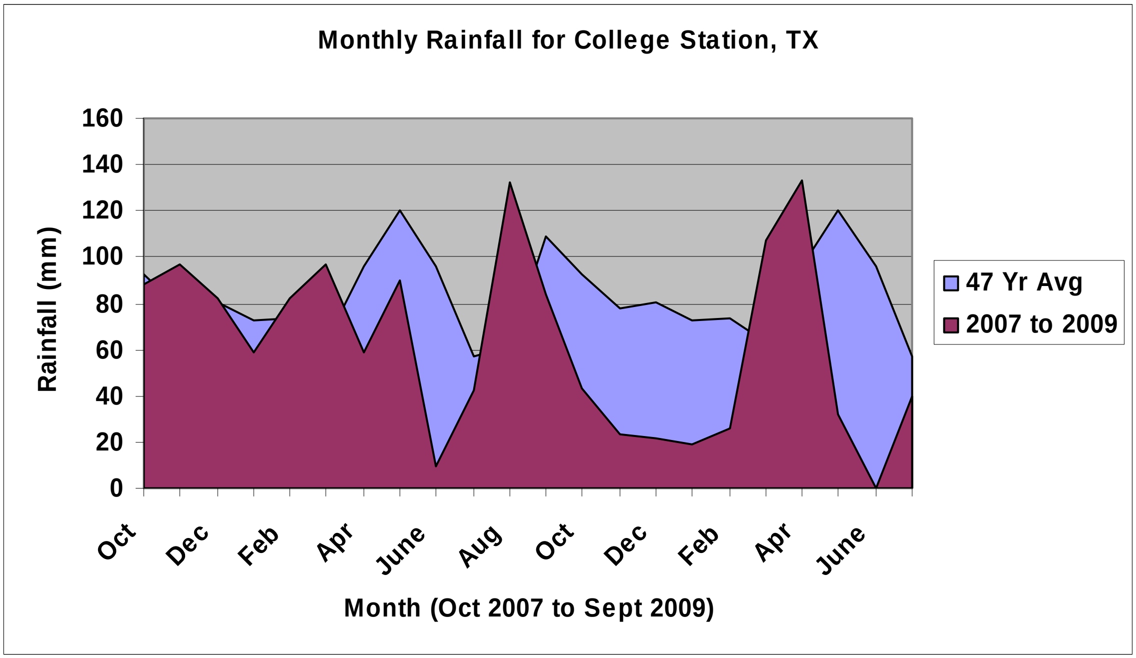

Figure 3. Monthly rainfall from 2007 to 2009 in College Station, TX in comparison to 47 year averages (Texas ET Network, 2010). Data from 2007 to 2009 were collected daily by a weather station at the Turfgrass Field Laboratory.

DISCUSSION

Effects of OS treatment on winter performance, spring transition, and warm-season turf recovery varied with year. Differences in mowing heights, weather patterns, and residual nitrogen levels between years may have influenced the data. A warm and droughty winter necessitated frequent irrigation from 2008-2009 (Figures 2 and 3). The warm conditions and high sodium levels of the irrigation source explains the ryegrass quality loss and percent cover decline in Feb. 2009. An especially hot and dry June 2009 can partly explain why overseeding did not reduce bermudagrass July shoot density or seashore paspalum July clipping yields.

Results of this study demonstrated annual ryegrass and annual/perennial ryegrass mixes are viable options for quality overseeded winter turfs in the southern U.S. Annual ryegrass promoted faster establishment and greater masking of dormant turf. In OS-211 treatments, annual ryegrass dominated the stand and improved visual cover, but adequate perennial ryegrass was present to improve spring persistence. Treatments OS-400 and OS-211 maintained the most consistent winter cover during stressful conditions. Seashore paspalum and zoysiagrass canopies blended well with ryegrasses in autumn and spring polystands (Appendix A) regardless of OS treatment. Due to seashore paspalum's poor winter color, quality loss associated with the appearance of dormant turf was more noticeable than in other turfs. Bermudagrass autumn and spring polystands had worse quality than other cool-season/warm-season polystands, but OS-004 polystands had better quality than OS-400 or OS-211 polystands in bermudagrass turfs.

Similar to Nelson et al. (2005), the turf-type annual ryegrass began to decline in quality and cover earlier in spring than perennial ryegrass. Spring growth of annual ryegrass was rapid, stemmy, and fibrous. White shoot tips resulted from mowing stress of shredding the stemmier growth habit of annual ryegrass in spring in OS-400 and OS-211 treatments. Mowing stress was most prevalent in zoysiagrass and bermudagrass polystands due to greater visual ryegrass cover. In seashore paspalum turfs, OS-211 persisted similarly to OS-400, but in bermudagrass turfs, OS-211 persisted more similarly to OS-004 treatments. Measurements in this study did not differentiate between individual annual and perennial ryegrass plants, but the differences in spring persistence of OS-211 as affected by warm-season species may indicate that ryegrass species dominance within an OS treatment may be related to the permanent warm-season turfgrass species.

Treatments OS-400 and OS-211 hastened spring transition and improved zoysiagrass summer recovery, but none of the OS treatments provided acceptable zoysiagrass recovery. Treatment OS-004 resulted in severe turf failure and bare soil remaining present into Aug. on some plots. Without additional transition aid inputs, winter overseeding using annual or perennial ryegrass is not recommended on zoysiagrass turfs. Despite differences in persistence among OS treatments, seashore paspalum summer recovery was affected similarly by each OS treatment. Incidental scalping was observed in seashore paspalum turfs in June 2009 and was most prevalent under OS-004 treatments. These results are not understood but may be related to greater available nitrogen from winter fertilizer applications. As a result of the scalping, several measurables appeared to show a reduction in seashore paspalum recovery due to OS-004 treatments. These data should not be confused with results seen in other species that were associated with ryegrass competition.

Annual ryegrass alone or in a perennial ryegrass mix promoted faster OS transitions, but did not consistently improve warm-season turf recovery. Previous work has shown that annual ryegrass can be allelopathic towards other plants meaning chemicals released by annual ryegrass inhibit growth of neighboring plants (Naqvi and Muller 1975). The presence of inhibitory chemicals from annual ryegrass could explain the lack of improvement in seashore paspalum and bermudagrass recovery despite earlier removal of OS competition. Without further study, the role of allelopathy in spring transition cannot be determined. In addition to allelopathy, OS species size and growth cycle may affect warm-season turf recovery. Annual ryegrass is a more robust plant than perennial ryegrass and imparts larger voids upon its demise. These larger voids equate to a greater total area for an individual warm-season plant or stolon to recover. Reduced warm-season turf density in early summer may be the result of greater separation of warm-season turfgrass shoots by annual ryegrass plants. Optimal growth of annual ryegrass was observed to be earlier in the spring than for perennial ryegrasses and may occur during a more vulnerable period for warm-season turfgrasses. Initial delays in warm-season turfgrass recovery after annual ryegrass overseeding could be explained by the greater competition during initial post-dormancy regrowth.

CONCLUSION

Perennial ryegrass should remain the preferred overseeding species for the majority of southern golf course fairways where spring transition is not an annual management problem. Annual/perennial ryegrass mixes can be used to reduce costs of 100% perennial ryegrass blends with minimal quality loss. Benefits of using a mix also include improved initial establishment and a more consistent masking of dormant turf during periods of stress. Optimal overseeding performance might be desired at different times of the year for different turf managers depending on their respective events calendars. Annual ryegrass and annual/perennial ryegrass mixes performed better than perennial ryegrasses alone in Dec. through early Feb. Perennial ryegrasses performed best from late Mar. to late May. Annual ryegrasses had noticeably faster growth rates than perennial ryegrasses throughout the winter and spring. Increased maintenance involved in mowing a faster growing turf may also be worth consideration to turf managers. During this study, plots were exposed to generous nitrogen fertility, sodium-containing irrigation water, occasional drought, lack of disruptive seedbed preparation, and unusually warm winter temperatures. These conditions are ideal for a successful spring transition. Further research is needed testing annual/perennial ryegrass overseeding under less ideal conditions such as those found in the U.S. transition zone. Future research should examine the species community structure of a mixed overseeding stand under varying seeding ratios, nitrogen levels, and climates.

CHAPTER III

AN ECOLOGICAL PERSPECTIVE ON THE SPRING TRANSITION OF SOUTHERN WINTER OVERSEEDING SYSTEMS

Winter overseeding systems are standard industry practice for many golf courses and athletic fields that receive significant use during winter months in the southern U.S. The most common southern winter overseeding system involves perennial ryegrass (*Lolium perenne* L.) being sown into hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy]. Zoysiagrass [*Zoysia matrella* (L.) Merr.] and seashore paspalum (*Paspalum vaginatum* Sw.) have been used with increasing frequency as lower input and niche-type turfgrasses for golf course fairways, but data on their potential to be overseeded using annual (*L. multiflorum* Lam.) and perennial ryegrasses are lacking. Razmjoo et al. (1995) found *Z. matrella* could be successfully overseeded using various cool-season turfgrasses but recovered slowly during the growing season. Both Zhang et al. (2008) and Gibeault et al. (1997) found that perennial ryegrass provided a good winter cover but persisted into summer and reduced quality on *Z. japonica* Steud. athletic fields in Guangzhou, China, and southern California respectively. Duncan and Carrow (2000) suggest the majority of cool-season turfgrasses can be overseeded into seashore paspalum. In Italy, Volterrani et al. (2001) found cool-season turfgrasses persisted longer in seashore paspalum than bermudagrass. The literature has focused on overseeding research that tests various cultural practices, seeding rates, and overseeding species. Few studies have directly compared overseeding treatments on varying permanent warm-season turf species.

The interspecific competition between warm-season turfgrasses and ryegrasses during the spring transition (Appendix A) of overseeded turfs has not been described from a focused ecological perspective. Industry and scientific consensus suggest that spring transition management should be aimed at shifting the equilibrium of the spring polystand (Appendix A) to favor the competitiveness of bermudagrass, but the majority of previous overseeding research has made assumptions about the primary means of competition between turf species. Whether competition is primarily derived from root systems taking up nutrients and water or above ground shoot competition for light is not fully understood. Snaydon and Howe (1986) found that competition between perennial ryegrass and grassy weed seedlings was primarily due to below-ground competition for nitrogen. Berendse (1979) described grassland models in which plant species can co-exist under root competition if they have different rooting depths and the shallower-rooted species dominates the upper profile. In theory, the deeper-rooted species has a larger pool from which to draw nutrients and water (this is assuming a homogenous soil). In a turf system, nitrogen and water are typically less limiting than in natural systems. Assuming appropriate irrigation and fertility management, it is doubtful below-ground competition for limiting resources is a primary factor in overseeding spring transitions (Yelverton, 2005). However, several studies have found that the addition of a limiting nutrient or water did not abate competition for that resource (Wilson and Newman, 1987; Haugland and Fraud-Williams, 1999). Rather, studies often show application of a limiting nutrient increases the effects of competition by favoring the more dominant plant in the polystand (McCown and Williams, 1968; King, 1971; Martin and Field, 1984; Rajaniemi et al., 2003).

Above-ground competition for light is often considered more important than below-ground competition in overseeded turf systems (Yelverton, 2005). Few studies relate plant morphology to competitive ability in a turf polystand. Beard (1973) lists several characteristics which may affect competitiveness, but research in an overseeding system is lacking. Numerous plant interaction studies have been performed in rangeland systems. One useful theory used to explain aboveground competition among plants describes two models for competition: ‘resource models’ and ‘canopy models’ (Vermeulen et al., 2009). Resource models compete by producing positive net carbon gain under the lower light levels of dense populations. Resource models can successfully occupy the lower parts of the vertical canopy and allocate more resources towards light harvesting components than support structures. Plants which follow the canopy model compete by overtopping other plants to capture light at the highest point in the canopy. Canopy models would most likely have a higher maximum photosynthetic rate, but may also partition larger amounts of energy towards stem tissue in order to reach taller heights. The light gradient created by plant canopies can create opportunities for both models to co-exist even within the same species (Vermeulen et al., 2009). Other studies on grassland ecology have developed similar theories (Grime, 1974; Hirose and Werger, 1995; Lepik et al., 2005; Aan et al., 2006). Others have found that vertical strata exist even within short communities such as mowed turfs; therefore the ecological principles used in the grassland sciences may explain plant community interactions in a turf environment (Roxburgh et al., 1993).

The objectives of this study were to evaluate the overseeding tolerance of three warm-season turfgrasses and quantify long-term effects of competition from overseeding on warm-season turf species.

MATERIALS AND METHODS

A field study was conducted at the Texas A&M Turfgrass Field Laboratory in College Station, TX (30.6191˚N, 96.3576˚W), on three turfgrass species: ‘Cavalier’ zoysiagrass, ‘Sea Isle 1’ seashore paspalum, and ‘Tifway’ hybrid bermudagrass. Plots were sodded Aug. 2006 over a modified root zone containing a Booneville (fine, smectitic, thermic, chromic, Vertic Albaqualfs) clay amended with coarse sand having a final particle size distribution of 93.5% sand, 5.1% silt, and 1.4 % clay. The experimental design was a randomized complete block split-split-plot design with three replications. Whole main plots, sub-plots, and sub-sub-plots were randomized at each split of the design. Main species plot sizes were 9.9 m long by 4.0 m wide. Species whole main plots were split by grooming (Appendix A) treatments applied as three-dimensional clipping management (Appendix A) at three frequencies from mid-May through mid-Oct: once per week (1x), three times per week (3x), and not groomed (0x). Grooming reel bench settings were set 40% below the bedknife height of cut using a tee box rated turf groomer (1.3 cm blade spacing). Sub-sub-plots consisted of four overseeding treatments: 100% ‘Panterra’ annual ryegrass (OS-400), 50% ‘Panterra’ annual ryegrass + 25% ‘Peak’ perennial ryegrass + 25% ‘Premier II’ perennial ryegrass (OS-211), 100% ‘Premier II’ perennial ryegrass (OS-004), and an non-overseeded control (NOS). Ryegrass was overseeded in late Oct. 2007 and 2008 using shaker jars at a rate of 976 kg seed ha^{-1}. Overseeding was allowed to naturally transition in the spring.

Plots were fertilized at 48 kg N ha^{-1} month^{-1} from May through Aug. using a coarse prilled 21-3-12 water soluble fertilizer (100% ammoniacal N source, Nelson Plant Food Corp., Belleville, TX). Overseeded plots received an additional 48 kg N ha^{-1} every other month from Oct. through Apr. using a greens grade 12-24-8 slow-release fertilizer (50% ammoniacal water soluble N sources, 50% slow release methylene ureas and water insoluble N sources, The Andersons Lawn Fertilizer Division, Inc., Maumee, OH). From May through Oct., plots were irrigated three times weekly at 2.5 cm per week. During overseeding establishment, plots were irrigated three times daily for one week at 0.6 cm d^{-1}. During the winter months, irrigation was applied to prevent visual ryegrass drought stress. Plots were mowed three days per week with clippings returned using a Jacobsen Greensking 526A (Jacobsen, a Textron Company, Charlotte, NC) walking mower. From Oct. 2007 through May 2008, plots were mowed at 2.5 cm. From May 2008 to Oct. 2008, plots were mowed at 1.9 cm. Minimal grooming treatment effects were seen in 2008, therefore the mowing height was lowered during year two in order to increase stress on the turf and more accurately reflect golf fairway heights. From Oct. 2008 through May 2009, plots were maintained at 1.7 cm. From May 2009 until the end of the study, plots were maintained at 1.3 cm. Mowing direction alternated between north/south and east/west each mowing day. Applications of azoxystrobin (Methyl (E)-2-{2-[6-(2-cyano-phenoxy) pyrimidin-4-yloxy]phenel}-3-methoxyacrylate) were made 21 Mar. 2008 and 23 Oct. 2008 in response to zoysia patch (*Rhizoctonia solani* Kuhn) symptoms. To control fire ants (*Solenopsis invicta* Buren), fipronil (5-amino-1-(2,6-dichloro-4-(trifluoromethyl)phenyl)-4((1,R,S)-(trifluoromethyl)sulfinyl)-1-H-pyrazole-3-carbonitrile) was applied 27 Mar. 2008 and 20 Mar. 2009.

Monthly visual assessments of turf quality were made from May through Oct. Ratings were taken immediately after plots were mowed using a scale of 1 to 9 (1 = bare soil or necrotic turf; 2 = very poor density and poor relative color; 3 = poor density and poor relative color; 4 = acceptable density but poor uniformity and poor relative color; 5 = acceptable density but poor uniformity or poor relative color; 6 = acceptable density, uniformity, and relative color; 7 = good density, uniformity, and relative color; 8 = excellent density, uniformity, and relative color; 9 = ideal density, uniformity, and relative color; color was relative to genetic color of species). On overseeded plots, quality and % ryegrass coverage (0 to 100%, ±5%) were visually assessed from Nov. through Apr. (Horgan and Yelverton, 2001). Additional visual ratings evaluated incidental scalping severity during summer on a scale of 1 to 6 (1 = 0% brown color, 2 = 5 to 20% brown color, 3 = 25 to 40% brown color, 4 = 45 to 60% brown color, 5 = 65 to 80% brown color, 6 = 85 to 100% brown color).

Canopy attributes, shoot density, and verdure dry mass allocation were measured using a destructive sampling method. One core from each sub-sub-plot was collected in May, July, and Sept. using a 2.5 cm diameter standard soil probe. Cores were cut at the soil line with scissors, and ryegrass plants were separated and recorded independently from the warm-season turfgrass. Verdure was separated into green leaves (lamina) and shoots (pseudostems which produced a fully expanded leaf). Shoot density was calculated as shoot number cm^{-2} (Jordan et al., 2003). Leaves were counted and scanned into a flatbed desktop scanner (HP Scanjet G4010, Palo Alto, CA) for digital image analysis (O'Neal et al., 2002). Image analysis software (SigmaScan, Systat Software, Inc., San Jose, CA) was used to calculate total leaf area within the sample. Leaves within the digital images were selected using an "intensity threshold" range of 0 to 196. Total leaf area within the image was calculated using the "measure objects" feature. Leaf area index was calculated as (total green leaf area within the sample)/(sampling area) (Pearce et al. 1965). Lamina and shoots were then placed in separate paper bags to be dried at 60˚ C for 48 hours in a gravity-flow Isotemp Oven (Thermo Fisher Scientific Inc., Waltham, MA). Dry mass of leaves and shoots were measured separately and the masses added to calculate verdure. Relationships between leaf area, dry mass, and leaf and shoot number were compared among warm-season turfgrass species. Calculated relationships included leaf frequency ratio (leaf number/shoot number), leaf mass ratio (g leaf dry mass/ g shoot dry mass), leaf mass (mg leaf dry mass/ leaf number), specific leaf mass (mg leaf dry mass/ cm^2 leaf area), leaf size (mm^2 leaf area/ leaf number), and leaf area frequency ratio (mm^2 leaf area/ shoot number).

Each parameter was subjected to analysis of variance using a general linear model (SPSS 15.0 for Windows, 2006, SPSS, Inc.). Due to differences in mowing heights, each year was analyzed separately. Individual dates were treated as split plots in time nested within sub-sub-plots resulting in the final model having a split-split-split-plot design. Significant ($p \leq 0.05$) month*treatment, species*treatment, or month*species*treatment interactions were analyzed within month and/or within species. If higher order interactions were not significant ($p \leq 0.05$), means of significant ($p \leq 0.05$) main effects were separated using Fisher's protected least significant difference (LSD) test. Qualitative data were transformed within years using rank order transformation before being subjected to the above analysis.

RESULTS

Overseeding Tolerance of Warm-season Turfgrasses

Warm-season turf quality was significantly ($p \leq 0.05$) affected in both years by a month*species*OS treatment three-way interaction (Table 29). In 2008, data analysis within month and species demonstrated each OS treatment reduced zoysiagrass June and July turf quality, but seashore paspalum and bermudagrass June and July turf quality were not affected by OS treatments (Table 30). In June and July 2009, OS reduced zoysiagrass quality, and OS-400 had better quality than OS-004 on 27 July 2009 (Table 31). Each OS treatment reduced seashore paspalum quality on 17 June 2009, but only OS-004 reduced quality on 27 June 2009. Bermudagrass quality was not affected by OS treatment on 17 June or 22 July 2009. A grooming interval*OS treatment two-way interaction was significant ($p \leq 0.05$) in bermudagrass on 27 June 2009 and in seashore paspalum on 22 July 2009 (Table 32). In 27 June 2009 bermudagrass turfs, NOS resulted in the best quality, but closer analysis of the grooming interval*OS treatment interaction showed OS treatment was only significant ($p \leq 0.05$) in 1x grooming treatments. On 22 July 2009 in seashore paspalum turfs, OS-400 resulted in the best quality, but closer analysis of the grooming interval*OS treatment interaction showed those differences only occurred within 3x grooming intervals.

Table 29. Abbreviated ANOVA tables for turf quality visual ratings and verdure (dry mass). Quality data were analyzed as rank order transformations of original visual ratings. Rank was assigned across all dates within each year.

	---------Turf Quality Rank-----------				--------------Verdure--------------			
Source	**df**	**2008**	**df**	**2009**	**df**	**2008**	**df**	**2009**
Rep	**2**	**0.999†**	**2**	**0.232**	**2**	**0.165**	**2**	**0.296**
Species	**2**	**0.003**	**2**	**0.014**	**2**	**0.005**	**2**	**0.001**
Error (a)	**4**	**0.052**	**4**	**0.078**	**4**	**0.251**	**4**	**0.325**
Grooming	**2**	**0.490**	**2**	**0.620**	**2**	**0.941**	**2**	**0.929**
Grooming*Species	**4**	**0.035**	**4**	**0.521**	**4**	**0.833**	**4**	**0.955**
Error (b)	**12**	**0.023**	**12**	**0.105**	**12**	**0.009**	**12**	**0.076**
OSMIX‡	**3**	**0.000**	**3**	**0.000**	**3**	**0.000**	**3**	**0.000**
OSMIX*Grooming	**6**	**0.446**	**6**	**0.470**	**6**	**0.373**	**6**	**1.000**
OSMIX*Species	**6**	**0.000**	**6**	**0.000**	**6**	**0.001**	**6**	**0.001**
OSMIX*Species*Grooming	**12**	**0.088**	**12**	**0.708**	**12**	**0.689**	**12**	**0.931**
Error (c)	**54**	**0.004**	**54**	**0.012**	**54**	**0.837**	**54**	**0.794**
Month	**9**	**0.000**	**6**	**0.000**	**2**	**0.000**	**2**	**0.000**
Month*OSMIX	**27**	**0.000**	**18**	**0.000**	**6**	**0.000**	**6**	**0.000**
Month*Grooming	**18**	**0.000**	**12**	**0.003**	**4**	**0.147**	**4**	**0.778**
Month*Species	**18**	**0.000**	**12**	**0.000**	**4**	**0.004**	**4**	**0.000**
Month*OSMIX*Grooming	**54**	**0.993**	**36**	**0.828**	**12**	**0.434**	**12**	**0.097**
Month*Species*OSMIX	**54**	**0.000**	**36**	**0.022**	**12**	**0.788**	**12**	**0.735**
Month*Grooming*Species	**36**	**0.000**	**24**	**0.227**	**8**	**0.685**	**8**	**0.306**
Month*Species*Grooming*OSMIX	**108**	**0.977**	**72**	**1.000**	**24**	**0.995**	**24**	**0.492**
Error (d)	**648**		**432**		**144**		**144**	

† *p*-value, significant source effect at $p \leq 0.05$.
‡ Overseeding treatment.

Table 30. Three-way interactions between month, species and overseeding treatment on turf quality in 2008. Data were analyzed as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable). Larger rank number indicates superior quality. (n=9).

Species	Treatment	Apr	May	June	July
		-----------------Turf Quality Rank†------------------			
Zoysia	OS-400‡	485b§	51c	82b	396b
	OS-211¶	781a	191c	147b	257c
	OS-004#	854a	690a	217b	91d
	NOS††	50c	450b	710a	910a
	LSD ($p \leq 0.05$)	140	155	196	134
Seashore	OS-400	854a	563c	611a	909a
	OS-211	854a	771b	503a	910a
	OS-004	910a	909a	549a	909a
	NOS	55b	909a	731a	910a
	LSD ($p \leq 0.05$)	67	114	NS	NS
Bermuda	OS-400	590b	63a	215a	464a
	OS-211	517b	110a	181a	481a
	OS-004	910a	220a	158a	496a
	NOS	63b	286a	188a	581a
	LSD ($p \leq 0.05$)	97	NS	NS	NS

† Rank was assigned across all dates within each year.

‡ 100% ‘Panterra’ annual ryegrass.

§ Means followed by the same letter in a given column within species are not significantly different (LSD 0.05).

¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.

 # 100% ‘Premier II’ perennial ryegrass.

†† Not overseeded.

Table 31. Three-way interactions between month, species and overseeding treatment on turf quality in 2009. Data were analyzed as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable). Larger rank number indicates superior quality. (n=9).

Species	Treatment	5 May	17 June	27 June	22 July
		----------------Turf Quality Rank†------------------			
Zoysia	OS-400‡	362b§	232b	281b	281b
	OS-211¶	467ab	198b	172bc	172b
	OS-004#	581a	227b	108c	108b
	NOS††	490ab	609a	609a	609a
LSD ($p \leq 0.05$)		149	106	170	203
Seashore	OS-400	504b	536ab	361a	*
	OS-211	578ab	432bc	300ab	*
	OS-004	694a	376c	177b	*
	NOS	627ab	599a	371a	*
LSD ($p \leq 0.05$)		105	118	125	*
Bermuda	OS-400	352b	421b	*	524a
	OS-211	412ab	363bc	*	574a
	OS-004	536a	296c	*	419a
	NOS	296b	619a	*	454a
LSD ($p \leq 0.05$)		129	100	*	NS

† Rank was assigned across all dates within each year.
‡ 100% ‘Panterra’ annual ryegrass.
§ Means followed by the same letter in a given column within species are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.
 # 100% ‘Premier II’ perennial ryegrass.
†† Not overseeded.
*** Significant ($p \leq 0.05$) interaction between overseeding treatment and grooming interval.**

Table 32. Interaction between grooming interval and overseeding treatment on turf quality of 27 June bermudagrass and 22 July seashore paspalum turfs in 2009. Data were analyzed as rank order transformations of original ratings (1=worst, 9=best, 6=acceptable). Larger rank number indicates superior quality. (n=3).

	Bermudagrass (27 June 2009)			Seashore Paspalum (22 July 2009)		
Treatment	0x†	1x	3x	0x	1x	3x
	------------------------------Turf Quality Rank‡----------------------------					
OS-400§	349a¶	282b	350a	433a	493a	564a
OS-211#	389a	223b	245a	356a	493a	269b
OS-004††	312a	144b	178a	365a	524a	281b
NOS‡‡	245a	525a	353a	193a	524a	317b
LSD ($p \leq 0.05$)	NS	234	NS	NS	NS	205

† 0x = non-groomed, mowed at 13 mm; 1x = groomed once weekly at 40% below mowing height; 3x = groomed three times weekly at 40% below mowing height.
‡ Rank was assigned across all dates within each year.
§ 100% 'Panterra' annual ryegrass.
¶ Means followed by the same letter in a given column are not significantly different (LSD 0.05).
 # 50% 'Panterra' annual ryegrass, 25% 'Peak' and 25% 'Premier II' perennial ryegrasses.
†† 100% 'Premier II' perennial ryegrass.
‡‡ Not overseeded.

Warm-season turf verdure (dry mass) demonstrated significant ($p \leq 0.05$) month*species, month*OS treatment, and species*OS treatment two-way interactions in both years (Table 30). Data analysis within month demonstrated significant ($p \leq 0.05$) species*OS treatment interactions in May and July of both years (Table 33). In May of both years, OS treatments reduced warm-season turf verdure within each species. In July 2008, OS-211 and OS-004 reduced zoysiagrass verdure, OS-400 and OS-004 reduced seashore paspalum verdure, and each OS treatment reduced bermudagrass verdure. In July 2009, each OS treatment reduced zoysiagrass verdure, OS did not affect seashore paspalum verdure, and OS-211 and OS-004 reduced bermudagrass verdure. Treatment OS-400 resulted in greater July zoysiagrass verdure than OS-004 each year, but OS-211 was not significantly ($p \leq 0.05$) different from OS-400 or OS-004.

Scalping severity was visually assessed in June 2009 in response to incidental scalping across seashore paspalum and bermudagrass turfs. Data analysis showed a significant ($p \leq 0.05$) species*OS treatment two-way interaction (Table 34). In seashore paspalum turfs, OS-004 had the greatest scalping severity, while in bermudagrass turfs, NOS had the greatest scalping severity (Table 35).

Table 33. Interactions between warm-season turf species and overseeding treatment on verdure (dry mass) within May, July, and Sept. Data are across three grooming intervals. (n=9).

		-------------2008------------			-------------2009------------		
Species	**Treatment**	**May**	**July**	**Sept**	**May**	**July**	**Sept**
		-------------------------------g cm^{-2}------------------------------					
Zoysia	**OS-400‡**	**4.2b‡**	**41.5ab**	**31.9a**	**6.3b**	**26.3b**	**19.9a**
	OS-211¶	**5.7b**	**23.1bc**	**32.3a**	**6.9b**	**14.1bc**	**18.1a**
	OS-004#	**4.7b**	**11.3c**	**33.4a**	**1.9b**	**7.1c**	**17.4a**
	NOS††	**42.2a**	**47.6a**	**38.8a**	**31.1a**	**40.0a**	**19.4a**
	LSD ($p \leq 0.05$)	**6.9**	**22.0**	**NS**	**8.3**	**12.3**	**NS**
Seashore	**OS-400**	**28.4b**	**52.8bc**	**47.8a**	**29.8b**	**39.2a**	**40.1a**
	OS-211	**35.9b**	**63.8ab**	**49.8a**	**30.5b**	**34.4a**	**38.9a**
	OS-004	**35.7b**	**50.6c**	**55.3a**	**33.5b**	**28.3a**	**37.8a**
	NOS	**58.5a**	**73.1a**	**47.5a**	**48.2a**	**38.2a**	**36.3a**
	LSD ($p \leq 0.05$)	**11.1**	**13.2**	**NS**	**9.3**	**NS**	**NS**
Bermuda	**OS-400**	**17.2c**	**36.2b**	**29.1a**	**12.8b**	**26.8ab**	**19.1a**
	OS-211	**22.6bc**	**26.8c**	**22.1a**	**6.6c**	**25.7b**	**18.4a**
	OS-004	**26.0b**	**31.0bc**	**37.2a**	**10.5bc**	**22.9b**	**17.1a**
	NOS	**37.7a**	**45.5a**	**26.4a**	**23.3a**	**33.1a**	**19.4a**
	LSD ($p \leq 0.05$)	**8.6**	**8.9**	**NS**	**5.1**	**13.1**	**NS**

† 100% ‘Panterra’ annual ryegrass.

‡ Means followed by the same letter in a given column within species are not significantly different (LSD 0.05).

§ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.

¶ 100% ‘Premier II’ perennial ryegrass.

 # Not overseeded.

Table 34. Abbreviated ANOVA table for rank order of scalping severity in June 2009. Severity data were analyzed as rank order transformations of original visual ratings. Ranks were assigned across bermudagrass and seashore pasplum.

Source	df	Scalping Severity Rank
Rep	2	0.380†
Species	1	0.369
Error (a)	2	0.203
Grooming	2	0.362
Grooming*Species	2	0.271
Error (b)	8	0.001
OSMIX‡	3	0.050
OSMIX*Grooming	6	0.435
OSMIX*Species	3	0.003
OSMIX*Species*Grooming	6	0.138
Error (c)	36	

† *p*-value, significant source effect at $p \leq 0.05$.
‡ Overseeding treatment.

Table 35. Interaction between overseeding treatment and species on visual assessments of scalping severity on seashore paspalum and bermudagrass turfs in June 2009. Data were analyzed as rank order transformations of original ratings (1=least, 6=most) and are across three grooming intervals. Larger rank numbers indicate greater severity of scalping.

Treatment	Seashore	Bermuda
	--Severity Rank†--	
OS-400‡	34b§	28b
OS-211¶	40b	27b
OS-004#	55a	29b
NOS††	36b	43a
LSD ($p \leq 0.05$)	13	12

† Rank was assigned across both species within year.
‡ 100% ‘Panterra’ annual ryegrass.
§ Means followed by the same letter are not significantly different (LSD 0.05).
¶ 50% ‘Panterra’ annual ryegrass, 25% ‘Peak’ and 25% ‘Premier II’ perennial ryegrasses.
 # 100% ‘Premier II’ perennial ryegrass.
†† Not overseeded.

Warm-season Turf Canopy Attributes

Data related to warm-season turf canopy architecture were analyzed within non-overseeded turfs in order to eliminate the possible influence of competition from ryegrass. In 2008, significant ($p \leq 0.05$) species main effects were seen in specific leaf mass (SLM) and leaf mass; and significant ($p \leq 0.05$) month*species two-way interactions were seen in LAI, leaf frequency ratio (LFR), leaf mass ratio (LMR), leaf size, and leaf area frequency ratio (LAFR) (Table 36). In 2009, significant ($p \leq 0.05$) species main effects were seen in LAI, LMR, leaf size, SLM, leaf mass, and LAFR; and significant ($p \leq 0.05$) month*species interactions were seen in LFR (Table 37). In 2008, zoysiagrass had the greatest SLM and leaf mass (Table 38). In 2009, zoysiagrass had the greatest leaf mass but had a SLM similar to that of bermudagrass. In May and July 2008, bermudagrass had a greater LFR than zoysiagrass, but species were not significantly ($p \leq 0.05$) different in 2009 (Table 39). In May 2008, each turfgrass had a similar LMR, but within July and Sept. 2008 and across all 2009 dates zoysiagrass had the largest LMR (Tables 38 and 39). In 2008, seashore paspalum had larger leaves (area basis) than zoysiagrass on two of three dates, and seashore paspalum and zoysiagrass had larger leaves than bermudagrass on each date in 2008 (Table 39). In 2009, significant ($p \leq 0.05$) main effects demonstrated seashore paspalum had larger leaves than zoysiagrass which had larger leaves than bermudagrass (Table 38). In 2008, seashore paspalum had a greater LAFR than bermudagrass on each date and a greater LAFR than zoysiagrass in May and Sept. (Table 39). Species main effects in 2009 demonstrated seashore paspalum had a greater LAFR than zoysiagrass which had a greater LAFR than bermudagrass (Table 39). Seashore paspalum had the greatest LAI within each date in 2008 and across all dates in 2009 (Tables 38 and 39).

Table 36. Abbreviated ANOVA tables for various canopy attributes of non-overseeded turfs in 2008. [LAI=leaf area index, LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

Source	df	LAI	LFR	LMR	Leaf Size	SLM	Leaf Wt.	LAFR
Rep	2	0.573†	0.837	0.853	0.571	0.897	0.478	0.743
Species	2	0.001	0.011	0.012	0.003	0.001	0.005	0.010
Error (a)	4	0.363	0.260	0.377	0.006	0.588	0.023	0.014
Grooming	2	0.730	0.804	0.393	0.216	0.981	0.135	0.667
Grooming*Species	4	0.818	0.216	0.892	0.268	0.974	0.295	0.314
Error (b)	12	0.101	0.107	0.284	0.979	0.493	0.969	0.679
Month	2	0.002	0.741	0.613	0.002	0.000	0.022	0.027
Month*Grooming	4	0.456	0.252	0.582	0.864	0.530	0.693	0.505
Month*Species	4	0.001	0.000	0.000	0.001	0.226	0.075	0.000
Month*Species*Grooming	8	0.943	0.787	0.457	0.901	0.414	0.818	0.965
Error (c)	36							

† *p*-value, significant source effect at $p \leq 0.05$.

Table 37. Abbreviated ANOVA tables for various canopy attributes of non-overseeded turfs in 2009. [LAI=leaf area index, LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

Source	df	LAI	LFR	LMR	Leaf Size	SLM	Leaf Wt.	LAFR
Rep	2	0.390†	0.870	0.550	0.648	0.364	0.434	0.440
Species	2	0.003	0.026	0.007	0.000	0.013	0.007	0.000
Error (a)	4	0.432	0.213	0.314	0.302	0.396	0.052	0.849
Grooming	2	0.960	0.224	0.107	0.888	0.388	0.388	0.567
Grooming*Species	4	0.946	0.149	0.139	0.855	0.703	0.504	0.570
Error (b)	12	0.423	0.740	0.849	0.954	0.444	0.881	0.784
Month	2	0.023	0.002	0.001	0.001	0.562	0.006	0.001
Month*Grooming	4	0.218	0.679	0.976	0.661	0.365	0.354	0.475
Month*Species	4	0.115	0.019	0.889	0.537	0.448	0.667	0.691
Month*Species*Grooming	8	0.142	0.797	0.914	0.791	0.896	0.664	0.578
Error (c)	36							

† *p*-value, significant source effect at $p \leq 0.05$.

Table 38. Main effects of species on various canopy attributes of non-overseeded turfs. Data are across three grooming intervals and three months. Turfs were mowed at 19 mm in 2008 and 13 mm in 2009. (n=27) [LAI=leaf area index, LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

Species	-----------2008---------		--2009--					
	SLM	Leaf Wt	Leaf Size	SLM	LMR	Leaf Wt	LAFR	LAI
	mg cm^{-2}	mg leaf^{-1}	mm^2 leaf^{-1}	mg cm^{-2}		mg leaf^{-1}	mm^2 shoot^{-1}	
Zoysia	7.6a†	0.89a	7.8b	8.2a	1.4a	0.61a	23.8b	2.2b
Seashore	4.3c	0.60b	10.2a	4.6b	1.0b	0.46b	38.2a	4.4a
Bermuda	6.8b	0.36c	3.7c	7.2a	0.8b	0.26c	14.3c	1.5c
LSD ($p \leq 0.05$)	0.7	0.12	1.3	1.3	0.2	0.08	5.5	0.7

† Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 39. Interactions between species and month on various canopy attributes of non-overseeded turfs. Turfs were mowed at 19 mm in 2008 and 13 mm in 2009. (n=9).

Canopy Attribute	Year	Date	Zoysia	Seashore	Bermuda	LSD ($p \leq 0.05$)
Leaf area index (LAI)	2008	May	2.7b†	6.9a	3.0b	0.9
		July	2.9b	5.3a	2.1b	1.1
		Sep	3.5b	5.2a	1.0c	1.0
Leaf frequency ratio	2008	May	2.6c	3.3b	4.8a	0.4
		July	2.9b	4.1a	3.7a	0.7
		Sep	3.0b	4.3a	3.2b	0.5
	2009	May	3.1a	3.8a	4.3a	NS
		July	3.2a	3.5a	4.0a	NS
		Sep	2.6a	3.7a	3.0a	NS
Leaf mass ratio	2008	May	0.92a	0.75a	0.96a	NS
		July	1.27a	0.75b	0.58b	0.3
		Sep	1.24a	0.78b	0.39c	0.2
Leaf area frequency ratio, mm^2 no.$^{-1}$	2008	May	28.4b	61.5a	34.4b	7.8
		July	37.7a	44.8a	17.3b	13.0
		Sep	35.7b	60.0a	14.0c	10.1
Leaf size, mm^2 leaf^{-1}	2008	May	11.1b	18.7a	7.1c	2.5
		July	12.7a	11.1a	4.6b	2.5
		Sep	11.8b	14.2a	4.5c	2.3

† Means followed by the same letter in a given row are not significantly different (LSD 0.05).

Perennial Ryegrass Canopy Attributes

Canopy attributes of overseeded perennial ryegrass in OS-004 treatments were compared to the corresponding non-overseeded warm-season turf attributes in May of each year. Perennial ryegrasses were still visually un-stressed and vigorously growing at the time of sampling. ‘Panterra’ annual ryegrass attributes are not discussed due to substantial decline in plant health at the time of sampling. Data showed significant ($p \leq 0.05$) differences between zoysiagrass and perennial ryegrass in LFR, leaf size, SLM, and LAFR in 2008, but no differences in 2009 (Table 40). Significant ($p \leq 0.05$) differences between seashore paspalum and perennial ryegrass were seen in LMR, leaf size, SLM, and LAFR in 2008, and in LFR and LAFR in 2009 (Table 41). Significant ($p \leq 0.05$) differences between bermudagrass and perennial ryegrass were seen in LFR, leaf size, and SLM in both years (Table 42). Zoysiagrass had smaller leaves than perennial ryegrass in 2008 but similar leaves to perennial ryegrass in 2009 (Tables 43 and 44). Seashore paspalum had larger leaves than perennial ryegrass in 2008 and a greater LAFR both years. Bermudagrass had a greater LFR and a smaller leaf size than perennial ryegrass both years. Zoysiagrass had a larger SLM than perennial ryegrass in 2008 but a similar SLM to perennial ryegrass in 2009; bermudagrass had a larger SLM than perennial ryegrass both years; and seashore paspalum had a smaller SLM than perennial ryegrass in 2008 but a similar SLM to perennial ryegrass in 2009.

Table 40. Abbreviated ANOVA tables for various May canopy attributes of zoysiagrass versus perennial ryegrass overseeded into zoysiagrass. [LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

		2008					2009				
Source	**df**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**
Rep	**2**	**0.652†**	**0.425**	**0.621**	**0.710**	**0.899**	**0.298**	**0.542**	**0769**	**0.384**	**0.786**
Groom	**2**	**0.284**	**0.410**	**0.027**	**0.705**	**0.196**	**0.620**	**0.867**	**0.826**	**0.671**	**0.565**
Error (a)	**4**	**0.174**	**0.618**	**0.714**	**0.345**	**0.725**	**0.534**	**0.253**	**0.397**	**0.532**	**0.807**
OSMIX‡	**1**	**0.003**	**0.101**	**0.047**	**0.009**	**0.001**	**0.956**	**0.191**	**0.122**	**0.066**	**0.175**
Groom*OSMIX	**2**	**0.268**	**0.566**	**0.676**	**0.517**	**0.139**	**0.603**	**0.372**	**0.264**	**0.738**	**0.398**
Error (b)	**6**										

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 41. Abbreviated ANOVA tables for various May canopy attributes of seashore paspalum versus perennial ryegrass overseeded into seashore paspalum. [LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

		2008					2009				
Source	**df**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**
Rep	**2**	**0.204†**	**0.376**	**0.117**	**0.345**	**0.277**	**0.109**	**0.381**	**0.221**	**0.166**	**0.645**
Groom	**2**	**0.243**	**0.875**	**0.460**	**0.841**	**0.330**	**0.188**	**0.097**	**0.386**	**0.477**	**0.598**
Error (a)	**4**	**0.806**	**0.392**	**0.329**	**0.318**	**0.387**	**0.724**	**0.716**	**0.926**	**0.700**	**0.604**
OSMIX‡	**1**	**0.133**	**0.003**	**0.016**	**0.047**	**0.013**	**0.004**	**0.302**	**0.076**	**0.172**	**0.004**
Groom*OSMIX	**2**	**0.505**	**0.190**	**0.944**	**0.436**	**0.750**	**0.546**	**0.119**	**0.746**	**0.934**	**0.900**
Error (b)	**6**										

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 42. Abbreviated ANOVA tables for various May canopy attributes of bermudagrass versus perennial ryegrass overseeded into bermudagrass. [LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio].

		2008					2009				
Source	**df**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**	**LFR**	**LMR**	**Leaf Size**	**SLM**	**LAFR**
Rep	**2**	**0.768†**	**0.459**	**0.262**	**0.788**	**0.189**	**0.621**	**0.789**	**0.148**	**0.213**	**0.222**
Groom	**2**	**0.954**	**0.174**	**0.175**	**0.759**	**0.160**	**0.814**	**0.816**	**0.933**	**0.590**	**0.933**
Error (a)	**4**	**0.647**	**0.590**	**0.666**	**0.310**	**0.835**	**0.337**	**0.441**	**0.750**	**0.411**	**0.820**
OSMIX‡	**1**	**0.000**	**0.083**	**0.002**	**0.029**	**0.300**	**0.000**	**0.171**	**0.012**	**0.015**	**0.873**
Groom*OSMIX	**2**	**0.178**	**0.274**	**0.195**	**0.290**	**0.111**	**0.403**	**0.892**	**0.975**	**0.900**	**0.758**
Error (b)	**6**										

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 43. Comparison of various canopy attributes between perennial ryegrass and warm-season turfgrasses in May 2008. Data are across three grooming intervals and represent turfs mowed at 19 mm. Perennial ryegrass data were collected from transitioning overseeded turfs and compared to the corresponding non-overseeded warm-season turf attributes. [LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio]. (n=9).

Species	LFR	LMR	SLM	Leaf Size	LAFR
			mg cm^{-2}	mm^2 leaf^{-1}	mm^2 shoot^{-1}
Perennial ryegrass†	**3.5**	**1.35**	**5.5**	**13.9**	**46.8**
Zoysia‡	**2.6**	**0.92**	**7.6**	**11.1**	**28.4**
***p*-value§**	***0.003***	***0.101***	***0.009***	***0.047***	***0.001***
Perennial ryegrass	**3.0**	**1.35**	**4.7**	**13.7**	**41.5**
Seashore	**3.3**	**0.75**	**3.6**	**18.7**	**61.5**
***p*-value**	***0.133***	***0.003***	***0.047***	***0.016***	***0.013***
Perennial ryegrass	**3.2**	**1.34**	**5.1**	**11.9**	**39.2**
Bermuda	**4.8**	**0.96**	**6.0**	**7.1**	**34.4**
***p*-value**	***0.000***	***0.083***	***0.029***	***0.002***	***0.300***

† 100% 'Premier II' perennial ryegrass overseeded into the corresponding warm-season turf species at 976 kg ha^{-1}.

‡ Not overseeded.

§ Significant difference between each mean is indicated by $p \leq 0.05$.

Table 44. Comparison of various canopy attributes between perennial ryegrass and warm-season turfgrasses in May 2009. Data are across three grooming intervals and represent turfs mowed at 13 mm. Perennial ryegrass data were collected from transitioning overseeded turfs and compared to the corresponding non-overseeded warm-season turf attributes. [LFR=leaf frequency ratio, LMR=leaf mass ratio, SLM=specific leaf mass, LAFR=leaf area frequency ratio]. (n=9).

Attribute	LFR	LMR	SLM	Leaf Size	LAFR
			mg cm^{-2}	mm^2 leaf^{-1}	mm^2 shoot^{-1}
Perennial ryegrass†	**3.1**	**1.28**	**5.1**	**8.2**	**25.3**
Zoysia‡	**3.1**	**1.52**	**7.7**	**9.8**	**30.6**
***p*-value§**	***0.956***	***0.191***	***0.066***	***0.122***	***0.175***
Perennial ryegrass	**2.5**	**1.37**	**4.1**	**8.0**	**20.2**
Seashore	**3.8**	**1.11**	**4.8**	**11.7**	**43.8**
***p*-value**	***0.004***	***0.302***	***0.172***	***0.076***	***0.004***
Perennial ryegrass	**2.9**	**1.28**	**5.0**	**6.8**	**19.5**
Bermuda	**4.3**	**0.96**	**6.4**	**4.7**	**19.9**
***p*-value**	***0.000***	***0.171***	***0.015***	***0.012***	***0.873***

† 100% 'Premier II' perennial ryegrass overseeded into the corresponding warm-season turf species at 976 kg ha^{-1}.

‡ Not overseeded.

§ Significant difference between each mean is indicated by $p \leq 0.05$.

DISCUSSION

For the purpose of discussion, overseeding tolerance can be defined as an interpretation of empirical data including quality of the overseeding polystand and rate of permanent turf stand recovery. The overseeding tolerance of warm-season turfgrasses in this study should be ranked as follows: ‘Sea Isle 1’ > ‘Tifway’ > ‘Cavalier’.

Warm-season turfgrasses used in this study had different above-ground canopy architectures. ‘Cavalier’ zoysiagrass may be described as having long and slender leaves emerging from shortened stem tissues. ‘Sea Isle 1’ seashore paspalum turfgrasses produced wide leaves that emerged from medium-tall stems with an even distribution of leaves throughout the canopy. ‘Tifway’ hybrid bermudagrass was observed as having long, woody stems with the majority of leaf tissue in the upper portion of the canopy. Perennial ryegrass was observed as having long and slender leaves emerging from shortened stem tissues. Upright, slender, leafy canopies emerge from decumbent stems and can be quantified as those with a high LMR, a low LFR, and a high LAFR. Branching, stemmy (Appendix A) canopies emerge from ascending stems and could be quantified as those having a small LMR, a high LFR, and a small LAFR. In this study, warm-season turfgrass canopies can be ranked from most upright, slender, leafy to most branched and stemmy as follows: ‘Cavalier’ > ‘Sea Isle 1’ > ‘Tifway’. Data show that perennial ryegrass had a high LMR and moderate to low LFR suggesting an upright, slender, leafy canopy structure similar to ‘Cavalier’ zoysiagrass.

The differences found in above-ground morphology can be related to the overseeding tolerance of each warm-season turfgrass. Strategies for above-ground competition in grassland canopies have been described by Vermeulen et al. (2009) as falling into two categories: canopy models and resource models. Upright, slender, leafy turfgrasses can be compared to resource models, while branching, stemmy turfgrasses could be compared to canopy models. According to the theory, two plants can co-exist in spatial niches created by differing above-ground strategies. However, if two plants are competing in similar above-ground environments, the dominant species can exclude the subordinate species from the stand.

Prior research has found that zoysiagrass does not tolerate overseeding well (Razmjoo et al., 1995; Gibeault et al., 1997; Zhang et al., 2008). However, no studies have adequately explained the mechanisms for overseeded zoysiagrass failure. In this study, both seashore paspalum and bermudagrass but not zoysiagrass became prominent components of the visual turf canopy during early spring transition while ryegrass was still actively growing (personal observation). The slower growth rates usually attributed to zoysiagrasses most likely affected their competitiveness and ability to recover but do not explain why in a mowed turf zoysiagrass rarely became visually evident before substantial ryegrass decline. ‘Cavalier’ zoysiagrass had the most similar canopy structure to perennial ryegrass, and thus used a similar strategy for above-ground competition: the resource model. In early spring, ryegrass was the dominant plant species due to favorable environmental conditions for growth and was able to exclude zoysiagrass from the visual canopy until substantial overseeding had departed. Lack of an overtopping mechanism, as seen in the ascending stems of canopy models, prevented ‘Cavalier’ zoysiagrass from contributing to the visual canopy or effectively competing for light in the dense overseeding stand.

‘Sea Isle 1’ seashore paspalum utilized an intermediate canopy architecture and competed effectively both high and low in the canopy. The intermediate strategy allowed seashore paspalum to overtop the ryegrass forming a visually evident polystand, but greater leaf area and uniform leaf distribution permitted seashore paspalum to crowd out ryegrass lower in the canopy as well. An attribute contributing towards seashore paspalum’s overseeding tolerance may have been the small SLM. Previous work has shown positive correlation between specific leaf area (SLM^{-1}) and leaf elongation rates (Arredondo and Schnyder, 2003).

Several trends emerged which demonstrated ‘Tifway’ bermudagrass to be most similar to the canopy model described by Vermeulen et al. (2009). The majority of ‘Tifway’ leaf tissue is in the upper portion of the canopy which provides an opportunity to intercept light at the highest point. As a result, bermudagrass was able to overtop the overseeding species, while spatial niches lower in the canopy strata allow for co-existence of perennial ryegrass. Manipulating the equilibrium of the bermudagrass/perennial ryegrass polystand has been the major emphasis of previous winter overseeding research. However until dramatic environmental changes occur, the two species tolerate each other’s presence potentially leading to an unpredictable spring transition.

CONCLUSION

A successful spring transition of overseeded southern turfs is dependent on many factors including weather, cultural practices, edaphic properties, and overseeding species. This study showed warm-season turfgrass canopy architecture also impacts overseeding success. Results showed turfgasses with stemmier growth habits (e.g. ‘Tifway’ bermudagrass) were able to overtop overseeded ryegrasses during spring competition for light. More upright, slender, leafy-canopied turfgrasses (e.g. ‘Cavalier’ zoysiagrass) were unable to overtop ryegrass resulting in poor overseeding tolerance. Similar differences in above-ground morphology may be expected among differing genotypes within a species and aid in determining the competitiveness of turfgrasses during the spring transition period. It is important to recognize that root morphology, root growth cycles, and total rooting were not examined in this study. The effects of below-ground competition should not be excluded as a possible influence in the overseeding tolerance of warm-seaon turfgrasses.

CHAPTER IV

EFFECTS OF THREE-DIMENSIONAL CLIPPING MANAGEMENT ON WARM-SEASON TURFGRASS CANOPIES AND TURF QUALITY

Three-dimensional clipping management (3DCM) is synonymous with the modern concept of grooming. The first dimension of 3DCM is the width of the mowing unit; the second dimension is the length of the mowing pass; the third dimension is the vertical removal of excessive turf verdure. Grooming (Appendix A) by 3DCM can be more specifically defined as the use of narrow (< 3.2 mm wide) vertical blades spaced 6 to 13 mm apart to penetrate the turf canopy 10% - 30% below the bedknife height of cut (Engelke, 2006). Grooming reels are attached to a standard reel-type mower and are seated in front of the cutting blade to be used simultaneously while mowing. In turf maintained at fairway heights, 3DCM is thought to promote upright growth and reduce grain (Appendix A) and thatch accumulation, while others suggest 3DCM also mitigates scalping (Appendix A) incidence (Duncan and Carrow, 2005). The turf industry accepts that 3DCM results in a more vertically-oriented turf, but science-based best management practices have not been established. Recent studies on ‘Tifeagle’ bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy ‘Tifeagle’] and creeping bentgrass (*Agrostis palustris* Huds. ‘Penncross’) golf putting greens concluded grooming did not affect putting green speeds, carbohydrate content, rooting depth, or thatch accumulation (Salaiz et al., 1995; Dunnivant, 2008).

Mowing is a fundamental aspect of turfgrass culture that drastically alters the physiological and morphological growth habits of plants. Lowering turf mowing heights is known to reduce leaf width, carbohydrate storage, and root growth (Beard 1973, Shearman, 1989) while increasing shoot density and shoot growth (Beard 1973, Shearman, 1989; Lush and Rogers, 1992). One study found reduced mowing heights led to reduced leaf angles, a more prostrate growth, and increased tillering in Kentucky bluegrass (*Poa pratensis* L.) (Sheffer et al., 1978). According to Duble (1996), bermudagrasses [*Cynodon dactylon* (L.) Pers.] respond to low, frequent mowing by initiating new shoots to form a more dense turf. Grooming by 3DCM may affect turf communities similarly to mowing as both are forms of defoliation. Anecdotal information suggests that 3DCM promotes greater lamina tissue distribution throughout the turf canopy (Engelke, 2006). Most reel mowers today come with the option of a 3DCM reel, but empirical data quantifying the canopy effects of 3DCM on turfgrasses are lacking.

In southern winter overseeding systems, successful overseeding (Appendix A) establishment can be hindered by excessive thatch and an actively growing warm-season turf (Schmidt and Shoulders, 1972; Duble, 1996). Ideally autumn cultural practices should improve the seedbed for the temporary turf stand without being excessively disruptive to the permanent turf stand. Weekly light vertical mowing (Appendix A) of golf putting greens and monthly vertical mowing of taller turfs have been recommended for seedbed preparation in winter overseeding systems (Beard and Menn, 1988; Duble, 1996). Dunnivant (2008) found grooming did not improve overseeding [*Poa trivialis*

(L.), 8.4 kg ha^{-1}] density on bermudagrass putting greens. The effects of year-long 3DCM programs have not been studied in fairway turfs. Further studies investigating the effects of 3DCM on overseeding establishment are warranted. The objectives of this study were to observe effects of 3DCM on turf quality and overseeding establishment, evaluate 3DCM best management practices on fairway height turf, and quantify turf canopy effects of 3DCM programs.

MATERIALS AND METHODS

A field study was conducted at the Texas A&M Turfgrass Field Laboratory in College Station, TX (30.6191˚N, 96.3576˚W), on three turfgrass species: zoysiagrass [*Zoysia matrella* (L.) Merr. 'Cavalier'], seashore paspalum (*Paspalum vaginatum* Sw. 'Sea Isle 1'), and 'Tifway' hybrid bermudagrass. Plots were sodded Aug. 2006 over a modified root zone containing a Booneville (fine, smectitic, thermic, chromic, Vertic Albaqualfs) clay amended with coarse sand having a final particle size distribution of 93.5% sand, 5.1% silt, and 1.4 % clay. The experimental design was a randomized complete block split-split-plot design with three replications. Whole main plots, sub-plots, and sub-sub-plots were randomized at each split of the design. Main species plot sizes were 9.9 m long by 4.0 m wide. Species whole main plots were split by grooming treatments applied as 3DCM at three frequencies from mid-May through mid-Oct: once per week (1x), three times per week (3x), and not groomed (0x). Grooming reel bench settings were set 40% below the bedknife height of cut using a tee box rated turf groomer (1.3 cm blade spacing). Sub-sub-plots consisted of four overseeding treatments: 100% ‘Panterra’ annual ryegrass (OS-400), 50% ‘Panterra’ annual ryegrass + 25% ‘Peak’ perennial ryegrass + 25% ‘Premier II’ perennial ryegrass (OS-211), 100% ‘Premier II’ perennial ryegrass (OS-004), and an non-overseeded control (NOS). Ryegrass was overseeded in late Oct. 2007 and 2008 using shaker jars at a rate of 976 kg seed ha^{-1}. Overseeding was allowed to naturally transition each spring.

Plots were fertilized at 48 kg N ha^{-1} month^{-1} from May through Aug. using a coarse prilled 21-3-12 water soluble fertilizer (100% ammoniacal N source, Nelson Plant Food Corp., Belleville, TX). Overseeded plots received an additional 48 kg N ha^{-1} every other month from Oct. through Apr. using a greens grade 12-24-8 slow-release fertilizer (50% ammoniacal water soluble N sources, 50% slow release methylene ureas and water insoluble N sources, The Andersons Lawn Fertilizer Division, Inc., Maumee, OH). From May through Oct., plots were irrigated three times weekly at 2.5 cm per week. During overseeding establishment, plots were irrigated three times daily for one week at 0.6 cm d^{-1}. During the winter months, irrigation was applied to prevent visual ryegrass drought stress. Plots were mowed three days per week with clippings returned using a Jacobsen Greensking 526A (Jacobsen, a Textron Company, Charlotte, NC) walking mower. From Oct. 2007 through May 2008, plots were mowed at 2.5 cm. From May 2008 to Oct. 2008, plots were mowed at 1.9 cm. Minimal grooming treatment effects were seen in 2008, therefore the mowing height was lowered during year two in order to increase stress on the turf and more accurately reflect golf fairway heights. From Oct. 2008 through May 2009, plots were maintained at 1.7 cm. From May 2009 until the end of the study, plots were maintained at 1.3 cm. Mowing direction alternated between north/south and east/west each mowing day. Applications of azoxystrobin (Methyl (E)-2-{2-[6-(2-cyano-phenoxy) pyrimidin-4-yloxy]phenel}-3-methoxyacrylate) were made 21 Mar. 2008 and 23 Oct. 2008 in response to zoysia patch (*Rhizoctonia solani* Kuhn) symptoms. To control fire ants (*Solenopsis invicta* Buren), fipronil (5-amino-1-(2,6-dichloro-4-(trifluoromethyl)phenyl)-4((1,R,S)-(trifluoromethyl)sulfinyl)-1-H-pyrazole-3-carbonitrile) was applied 27 Mar. 2008 and 20 Mar. 2009.

Monthly visual assessments of turf quality were made from May through Oct. Ratings were taken immediately after plots were mowed using a scale of 1 to 9 (1 = bare soil or necrotic turf; 2 = very poor density and poor relative color; 3 = poor density and poor relative color; 4 = acceptable density but poor uniformity and poor relative color; 5 = acceptable density but poor uniformity or poor relative color; 6 = acceptable density, uniformity, and relative color; 7 = good density, uniformity, and relative color; 8 = excellent density, uniformity, and relative color; 9 = ideal density, uniformity, and relative color; color was relative to genetic color of species). On overseeded plots, quality and % ryegrass coverage (0 to 100%, ±5%) were visually assessed from Nov. through Apr. (Horgan and Yelverton, 2001). Additional visual ratings evaluated incidental scalping severity during summer on a scale of 1 to 6 (1 = 0% brown color, 2 = 5 to 20% brown color, 3 = 25 to 40% brown color, 4 = 45 to 60% brown color, 5 = 65 to 80% brown color, 6 = 85 to 100% brown color).

Canopy attributes, shoot density, and verdure dry mass allocation were measured using a destructive sampling method. One core from each sub-sub-plot was collected in

May, July, and Sept. using a 2.5 cm diameter standard soil probe. Cores were cut at the soil line with scissors, and ryegrass plants were separated and recorded independently from the warm-season turfgrass. Verdure was separated into green leaves (lamina) and shoots (pseudostems which produced a fully expanded leaf). Shoot density was calculated as shoot number cm^{-2} (Jordan et al., 2003). Leaves were counted and scanned into a flatbed desktop scanner (HP Scanjet G4010, Palo Alto, CA) for digital image analysis (O'Neal et al., 2002). Image analysis software (SigmaScan, Systat Software, Inc., San Jose, CA) was used to calculate total leaf area within the sample. Leaves within the digital images were selected using an "intensity threshold" range of 0 to 196. Total leaf area within the image was calculated using the "measure objects" feature. Leaf area index was calculated as (total green leaf area within the sample)/(sampling area) (Pearce et al. 1965). Lamina and shoots were then placed in separate paper bags to be dried at 60˚ C for 48 hours in a gravity-flow Isotemp Oven (Thermo Fisher Scientific Inc., Waltham, MA). Dry mass of leaves and shoots were measured separately and the masses added to calculate verdure. Relationships between leaf area, dry mass, and leaf and shoot number were compared among warm-season turfgrass species. Calculated relationships included leaf frequency ratio (leaf number/shoot number), leaf mass ratio (g leaf dry mass/ g shoot dry mass), leaf mass (mg leaf dry mass/ leaf number), specific leaf mass (mg leaf dry mass/ cm^2 leaf area), leaf size (mm^2 leaf area/ leaf number), and leaf area frequency ratio (mm^2 leaf area/ shoot number).

Thatch depth was measured using a compressed soil plug test. Each sub-sub-plot was randomly sampled using a 2.5- cm soil probe during spring and late autumn. A 150 g mass was placed on each plug to reproduce the natural thatch compression occurring under a turf. The compressed plugs were measured with a ruler (White and Dickens, 1984) at 120° intervals around the circumference of each core and the average recorded (Stier and Hollman, 2003). Clipping yield was measured monthly from April through Sept. One pass of a walking greens mower was made over the center of each sub-sub-plot representing 2.2 m^2 of turf. Clippings were collected in a standard reel mower basket and put into paper bags for drying at 60° C for 48 hours in a gravity-flow Isotemp Oven (Thermo Fisher Scientific Inc., Waltham, MA). Collection occurred on Fridays of a Monday-Wednesday-Friday mowing schedule at the regular mowing height with 1x plots being only mowed during clipping collection, and 3x groomed plots being groomed during clipping collection.

Each parameter was subjected to analysis of variance using a general linear model (SPSS 15.0 for Windows, 2006, SPSS, Inc.). Due to differences in mowing heights, each year was analyzed separately. Individual dates were treated as split plots in time nested within sub-sub-plots resulting in the final model having a split-split-split-plot design. Significant ($p \leq 0.05$) month*treatment, species*treatment, or month*species*treatment interactions were analyzed within month and/or within species. If higher order interactions were not significant ($p \leq 0.05$), means of significant ($p \leq 0.05$) main effects were separated using Fisher’s protected least significant difference (LSD) test. Qualitative data were transformed within years using rank order transformation before being subjected to the above analysis.

RESULTS

Turf Quality

Zoysiagrass turf quality ratings were dramatically affected by OS treatments in previously described analyses. For this chapter, zoysiagrass was removed from the model in order to better understand the effects of grooming interval on seashore paspalum and bermudagrass. In 2008, data analysis showed a significant ($p \leq 0.05$) month*species*grooming interval three-way interaction (Table 45). Further analysis of the interaction within month and species demonstrated no significant ($p \leq 0.05$) grooming interval effects on bermudagrass turfs, but 1x and 3x grooming intervals reduced seashore paspalum turf quality on three dates in Oct. (Table 46). Analysis of 2009 data revealed several significant ($p \leq 0.05$) two-way interactions with month (Table 45). Further analysis within month demonstrated nearly significant ($p \leq 0.05$) grooming interval effects in Aug., Sept., and Oct. 2009 suggesting a seasonal trend. Data were separated into early 2009 (May, June, July) and late 2009 (Aug., Sept., Oct.) in order to better describe this trend. In early 2009, significant ($p \leq 0.05$) month*species, month*grooming interval, and grooming interval*OS treatment two-way interactions were seen, but data analysis of late 2009 turf quality revealed significant ($p \leq 0.05$)

Table 45. Abbreviated ANOVA tables for turf quality of bermudagrass and seashore paspalum turfs. Quality data were analyzed as rank order transformations of original visual ratings. Rank was assigned across all dates within each year.

	---Turf Quality Rank---------------------------------------							
Source	**df**	**Whole Year 2008**	**df**	**Whole Year 2009**	**df**	**Early 2009†**	**df**	**Late 2009**
Rep	**2**	**0.053‡**	**2**	**0.261**	**2**	**0.176**	**2**	**0.480**
Species	**1**	**0.001**	**1**	**0.027**	**1**	**0.290**	**1**	**0.041**
Error (a)	**2**	**0.787**	**2**	**0.520**	**2**	**0.529**	**2**	**0.007**
Groom	**2**	**0.011**	**2**	**0.629**	**2**	**0.606**	**2**	**0.014**
Groom * Species	**2**	**0.076**	**2**	**0.832**	**2**	**0.705**	**2**	**0.186**
Error (b)	**8**	**0.035**	**8**	**0.000**	**8**	**0.000**	**8**	**0.140**
OSMIX§	**3**	**0.000**	**3**	**0.501**	**3**	**0.003**	**3**	**0.013**
OSMIX * Groom	**6**	**0.284**	**6**	**0.031**	**6**	**0.005**	**6**	**0.662**
OSMIX * Species	**3**	**0.002**	**3**	**0.540**	**3**	**0.558**	**3**	**0.709**
OSMIX * Groom * Species	**6**	**0.312**	**6**	**0.127**	**6**	**0.173**	**6**	**0.511**
Error (c)	**36**	**0.747**	**36**	**0.970**	**36**	**0.918**	**36**	**0.991**
Month	**9**	**0.000**	**6**	**0.000**	**3**	**0.000**	**2**	**0.006**
Month * OSMIX	**27**	**0.000**	**18**	**0.000**	**9**	**0.000**	**6**	**0.911**
Month * Groom	**18**	**0.000**	**12**	**0.003**	**6**	**0.013**	**4**	**0.458**
Month * Species	**9**	**0.000**	**6**	**0.000**	**3**	**0.000**	**2**	**0.049**
Month * OSMIX * Groom	**54**	**1.000**	**36**	**0.872**	**18**	**0.600**	**12**	**0.962**
Month * Groom * Species	**18**	**0.000**	**18**	**0.802**	**9**	**0.258**	**6**	**0.973**
Month * OSMIX * Species	**27**	**0.000**	**12**	**0.108**	**6**	**0.055**	**4**	**0.779**
Month * Species * Groom * OSMIX	**54**	**0.999**	**36**	**0.989**	**18**	**0.727**	**12**	**0.980**
Error (d)	**432**		**288**		**144**		**96**	

†Early 2009 = May, June, or July; late 2009 = Aug, Sep, and Oct.
‡ *p*-value, significant source effect at $p \leq 0.05$.
§ Overseeding treatment.

Table 46. Three-way interaction between grooming interval, species, and month on seashore paspalum turf quality in 2008. Data were analyzed as rank transformations of original visual ratings (1=worst, 9=best, 6=acceptable). A larger rank number indicates superior quality. (n=12).

Grooming Interval	**28 May**	**18 June**	**23 July**	**20 Aug**	**24 Sep**	**8 Oct**	**15 Oct**	**22 Oct**
No. week^{-1}†	--Turf Quality Rank ‡--							
0x	**517a§**	**327a**	**606a**	**606a**	**578a**	**559a**	**480a**	**475a**
1x	**545a**	**443a**	**606a**	**606a**	**536a**	**393b**	**260b**	**293b**
3x	**508a**	**412a**	**606a**	**606a**	**545a**	**336b**	**174b**	**203b**
LSD ($p \leq 0.05$)	**NS**	**NS**	**NS**	**NS**	**NS**	**75**	**74**	**76**

† Mowing height = 19 mm. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).
‡ Rank was assigned across all dates within each year.
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

grooming interval main effects (Table 45). Further analysis of early 2009 data within OS treatment revealed significant ($p \leq 0.05$) month*grooming interval two-way interactions only in non-overseeded turfs. Treatments OS-400, OS-211, and OS-004 were not significantly ($p \leq 0.05$) affected by grooming interval (data not shown). Analysis of non-overseeded turfs in early 2009 within each date demonstrated significant ($p \leq 0.05$) grooming interval effects on 27 June and 22 July. On 27 June 2009, 0x grooming intervals had the best turf quality, but on 22 July 2009, 1x had the best turf quality (Table 47). In late 2009, 3x grooming intervals had the greatest turf quality (Table 48).

Table 47. Interaction between grooming interval and month on early season quality of non-overseeded turfs in 2009. Data were analyzed as rank order transformations of original visual ratings (1=worst, 9=best, 6=acceptable). A larger rank number indicates superior quality. (n=9).

Grooming Interval	17 June	27 June	22 July
No. week^{-1}†	------Turf Quality Rank ‡------		
0x	362a§	868a	192b
1x	415a	323b	333a
3x	418a	241b	190b
LSD ($p \leq 0.05$)	NS	169	123

† Mowing height = 13 mm. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).
‡ Rank was assigned across all dates within each year.
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 48. Main effects of grooming interval on bermudagrass and seashore paspalum late season quality in 2009. Data were analyzed as rank order transformations of original visual ratings (1=worst, 9=best, 6=acceptable). A larger rank number indicates superior quality. Data are across three months, two warm-season turf species, and four overseeding treatments. (n=72).

Grooming Interval	Aug. – Oct. 2009
No. week^{-1}†	--Turf Quality Rank ‡--
0x	225b§
1x	232b
3x	278a
LSD ($p \leq 0.05$)	32.7

† Mowing height = 13 mm. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).
‡ Rank was assigned across all dates within each year.
§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Incidental scalping was visually assessed for severity on bermudagrass turfs in Aug. 2008 and on bermudagrass and seashore paspalum turfs in June 2009. These data showed significant ($p \leq 0.05$) grooming interval main effects in 2008 (Table 49). In 2009, grooming main effects and species*grooming interval two-way interactions were not significant ($p \leq 0.05$), but the grooming interval error term was highly significant ($p \leq 0.05$) suggesting variation across replications (Table 34). Examination of boxplots revealed that variation among replications was isolated within seashore paspalum turfs; therefore further analysis was performed within species in order to better investigate scalping severity on bermudagrass turfs (Figure 4). Analysis of 2009 data within species showed significant ($p \leq 0.05$) grooming interval main effects for bermudagrass turfs (Table 49). Grooming intervals 1x and 3x in 2008 and interval 3x in 2009 reduced scalping severity of bermudagrass turfs (Table 50).

Table 49. Abbreviated ANOVA table for bermudagrass scalping severity in Aug. 2008. Severity data were analyzed as rank order transformations of original visual ratings. Rank was assigned within bermudagrass in 2008 and across bermudagrass and seashore paspalum in 2009.

		----Scalping Severity-----	
Source	**df**	**Aug. 2008**	**June 2009**
Rep	**2**	**0.022†**	**0.007**
Groom	**2**	**0.010**	**0.002**
Error (a)	**4**	**0.772**	**0.950**
OSMIX‡	**3**	**0.000**	**0.042**
Groom * OSMIX	**6**	**0.415**	**0.098**
Error (b)	**18**		

† *p*-value, significant source effect at $p \leq 0.05$.

‡ Overseeding treatment.

Table 50. Main effects of grooming interval (2008) and species by grooming interval interaction (2009) on bermudagrass scalping severity. Data were analyzed as rank order transformations of original visual estimates (1=least severe, 6=most severe). A larger rank number indicates greater severity of scalping. (n=12).

Grooming Interval	**Aug 2008**	**June 2009**
No. week^{-1} †	**- Severity Rank- ‡**	
0x	**23a§**	**38a**
1x	**17b**	**36a**
3x	**15b**	**20b**
LSD ($p \leq 0.05$)	**5**	**11**

† Mowing height = 19 mm in 2008, 13 mm in 2009. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).

‡ Rank was assigned within bermudagrass in 2008 and across seashore paspalum and bermudagrass in 2009.

§ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

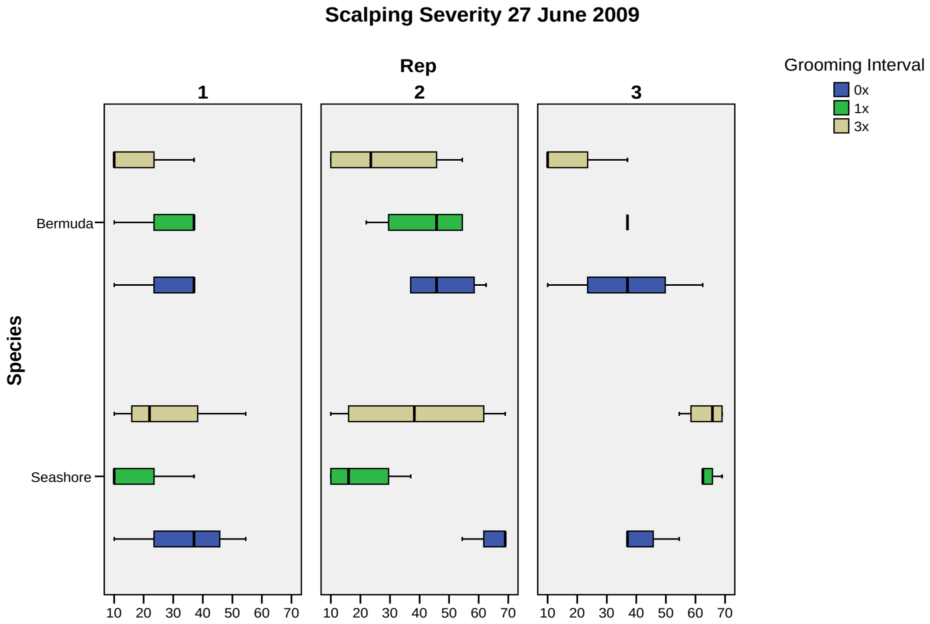

Figure 4. Boxplots of seashore paspalum and bermudagrass June 2009 scalping severity ranks separated by replication. Data are rank order transformations of original visual ratings (1=least severe, 6=most severe). Rank was assigned across bermudagrass and seashore paspalum within 2009. Turfs were mowed at 13 mm, and data are across four overseeding treatments. (0x = non-groomed, 1x = groomed weekly at 40% below mowing height, 3x = groomed three times weekly at 40% below mowing height.)

Clipping Yield

In order to focus on the effects of grooming interval on clipping yield (dry mass), data were analyzed within non-overseeded turfs. Data analysis demonstrated significant ($p \leq 0.05$) grooming interval main effects in both years (Table 51). Means separation demonstrated that 3x grooming intervals had greater clipping yields than 0x and 1x grooming intervals in both years (Table 52). A second analysis was performed on clipping yields as a derived variable summed over the entire year (cumulative clipping yield). These data included all plots in 2008, but due to substantial bermudagrass encroachment, zoysiagrass was removed from the model in 2009. In both years, data showed significant (*p*≤0.05) grooming interval main effects on cumulative clipping yields (Table 51). In 2008, 3x grooming intervals had the largest clipping yield, and 1x clipping intervals had the smallest yields (Table 53). In 2009, 3x grooming had the greatest clipping yields, but 1x grooming was similar to the non-groomed treatment.

Effects of 3DCM on Canopy Architecture and Overseeding

Grooming by 3DCM did not affect turfgrass canopy attributes including verdure dry mass, LAI, leaf mass ratio, leaf frequency ratio, leaf size, or leaf mass (Tables 29, 36, and 37). Grooming did not affect visual assessments of overseeding establishment (Table 1).

Table 51. Abbreviated ANOVA tables for clipping yield (dry mass) of non-overseeded turfs and cumulative clipping yield (dry mass) of seashore paspalum and bermudagrass turfs.

	----------Clipping Yield-----------				-Cumulative Clipping Yield-			
Source	**df**	**2008**	**df**	**2009**	**df**	**2008**	**df**	**2009**
Rep	**2**	**0.294†**	**2**	**0.101**	**2**	**0.337**	**2**	**0.065**
Species	**2**	**0.198**	**2**	**0.126**	**2**	**0.037**	**1**	**0.095**
Error (a)	**4**	**0.012**	**4**	**0.366**	**4**	**0.005**	**2**	**0.851**
Groom	**2**	**0.034**	**2**	**0.000**	**2**	**0.005**	**2**	**0.002**
Species * Groom	**4**	**0.124**	**4**	**0.238**	**4**	**0.418**	**2**	**0.270**
Error (b)	**12**	**0.098**	**12**	**0.777**	**12**	**0.196**	**8**	**0.005**
Month‡	**6**	**0.000**	**4**	**0.000**	**3**	**0.000**	**3**	**0.013**
Month * Groom	**12**	**0.080**	**8**	**0.153**	**6**	**0.716**	**6**	**0.155**
Month * Species	**12**	**0.000**	**8**	**0.000**	**6**	**0.908**	**3**	**0.177**
Month * Groom * Species	**24**	**0.299**	**16**	**0.857**	**12**	**0.428**	**6**	**0.289**
Error (c)	**108**		**71**		**54**		**36**	

† *p*-value, significant source effect at *p*≤0.05.
‡ Overseeding treatment was used as a factor in place of month for cumulative yields.

Table 52. Main effects of grooming interval on clipping yield (dry mass) of non-overseeded turfs. Data are across three warm-season turf species and represent 48 hours of growth. Data are across seven collection dates in 2008 and five collection dates in 2009. [n=63 (2008); n=45 (2009)].

Grooming Interval	2008	2009
No. week^{-1}†	-------g m^{-2}------	
0x	10.6b‡	47.8b
1x	9.2b	46.9b
3x	12.6a	70.8a
LSD ($p \leq 0.05$)	1.8	11.4

† Mowing height = 19 mm in 2008, 13 mm in 2009. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

Table 53. Main effects of grooming interval on cumulative clipping yield (dry mass). Data from 2008 are summed across seven collection dates on zoysiagrass, seashore paspalum, and bermudagrass turfs. Data from 2009 are summed across five collection dates and do not include zoysiagrass turfs. Data for both years are across four overseeding treatments. Individual dates represented 48 hr of growth. [n=36 (2008); n=24 (2009)].

Grooming Interval	2008	2009
No. week^{-1}†	-------g m^{-2}-------	
0x	63.1b‡	221.7b
1x	57.3c	227.0b
3x	73.5a	342.3a
LSD ($p \leq 0.05$)	3.2	26.4

† Mowing height = 19 mm in 2008, 13 mm in 2009. 0x = Not groomed. 1x= Groomed weekly (40% below mowing height). 3x = Groomed three times weekly (40% below mowing height).
‡ Means followed by the same letter in a given column are not significantly different (LSD 0.05).

DISCUSSION

In 2008, turf quality was not affected by 3DCM treatments; therefore the mowing height was lowered for year two in an attempt to increase stress on the turfgrasses. In autumn of 2008, mowing heights were reduced from 1.9 cm to 1.7 cm to accommodate the lower target height for the following year. Lowering the mowing height corresponded with quality loss seen in Oct. 2008 on both 3x and 1x groomed seashore paspalum turfs. These results suggest speculation that turfs under long-term 3DCM can maintain quality under the temporary mowing height reductions common before major golf tournaments is not valid for seashore paspalum turfs. This conclusion is confounded by the continuous application of 3DCM treatments while mowing heights were being reduced. A more focused study would involve a season-long 3DCM program followed by temporary mowing height reductions upon ceasing 3DCM.

In spring 2009, the mowing height was gradually lowered from 1.7 cm to 1.3 cm prior to grooming treatment initiation. Seashore paspalum turfs were ‘puffy’ (Appendix A) and resistant to mowing height reductions. An increasing gap between the effective height of cut (height of turf after mowing) and the mower’s bench setting height of cut (expected mowing height as set on a reel mower) led to widespread scalping events in seashore paspalum plots. In 0x intervals, seashore paspalum turfs maintained good quality but became increasingly puffy until a critical max was reached and scalping occurred. In 3x intervals, grooming by 3DCM promoted rapid corrections in the effective height of cut but caused severe scalping and immediate quality loss. In 1x intervals, grooming by 3DCM immediately reduced quality but gradually reduced verdure while limiting the severity of seashore paspalum scalping events.

Grooming by 3DCM improved bermudagrass turf quality and reduced scalping each year. Grooming in several instances reduced seashore paspalum turf quality although late season 2009 ratings showed long-term effects may be beneficial. Under more appropriate nitrogen levels, grooming may have had a more positive effect on seashore paspalum turf quality.

Clipping yield data can only be compared between the 0x and 1x intervals and 0x and 3x intervals. The comparison of 1x and 3x yields is confounded by the differences in harvest, that is 1x intervals were a two-dimensional harvest and 3x intervals were a three-dimensional harvest. The importance of the 0x versus 3x comparison is that the three-dimensional harvest significantly ($p \leq 0.05$) increases yields over two-dimensional harvests. The importance of the 0x versus 1x comparison is that a three-dimensional clipping two days before a two-dimensional harvest did not reduce clipping yields in both years. High nitrogen levels prompted rapid recovery and widespread scalping which may have reduced the impact of 1x intervals on yield in 2009.

Grooming did not improve overseeding establishment, but ideal conditions for overseeding success led to excellent ryegrass germination and establishment in all plots. Whether 3DCM would improve overseeding establishment under less ideal conditions is not known; further research investigating grooming under varying traffic, nitrogen, and irrigation regimes may provide different results.

CONCLUSION

Grooming by 3DCM improved late-season bermudagrass quality and reduced scalping severity. Under the untrafficked conditions and high nitrogen levels used in this study, grooming three days per week improved quality most frequently. Under more realistic conditions, grooming once per week may have been adequate, but further study is required.

Grooming by 3DCM improved seashore paspalum quality in late 2009 but reduced turf quality in several other instances. Further research is needed for seashore paspalum 3DCM best management practices.

Grooming by 3DCM did not affect turfgrass canopy architecture or overseeding establishment.

Further research is needed to better understand best management practices and the effects of grooming on turfgrass canopies. Future studies should examine grooming under a range of fertility levels and various abiotic stresses.

CHAPTER V

CONCLUSION

Results from two years of field data indicate an improved annual ryegrass (*Lolium multiflorum* Lam.) has excellent potential for use as quality temporary winter turfs in southern climates. Overseeding mixes of annual and perennial ryegrass (*L. perenne* L.) can improve turf color, leaf texture, and spring persistence in comparison to annual ryegrasses alone. Data did not show consistent improvements in bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt Davy ‘Tifway’] or seashore paspalum (*Paspalum vaginatum* Sw. ‘Sea Isle 1’) turf density, quality, or growth due to using annual ryegrass alone or mixes with perennial ryegrasses in comparison to perennial ryegrass alone. For the typical College Station climate, perennial ryegrasses would be expected to provide the best winter turf quality without substantial transition problems during early summer on turf mowed from 1.3 to 1.9 cm.

Zoysiagrass [*Zoysia matrella* (L.) Merr. ‘Cavalier’] did not tolerate overseeding under any of the applied treatments. ‘Tifway’ bermudagrass transitioned more slowly than ‘Sea Isle 1’ seashore paspalum, but both turfgrasses tolerated each overseeding treatment.

Differences in canopy architecture were found among warm-season turfgrasses. ‘Cavalier’ zoysiagrass had the most leafy, upright, slender canopy emerging from a decumbent shoot base, while ‘Tifway’ bermudagrass produced small leaves emerging from branched, ascending stems. ‘Sea Isle 1’ seashore paspalum had an intermediate growth habit producing a leafy canopy emerging from branched, ascending stems. These differences in morphology can be related to each species' overseeding tolerance. Perennial ryegrasses tended to be leafy and decumbent and visually had similar canopy architecture as 'Cavalier' zoysiagrass. Due to similar means of above ground growth, 'Cavalier' and ryegrasses competed in similar niches within the spring polystand (Appendix A). During the spring, environmental conditions and high nitrogen rates favored ryegrasses which were able to exclude zoysiagrass from the visual turf canopy. 'Tifway' used an ascending stem architecture to overtop the canopy and grow in areas of reduced competition. Seashore paspalum was capable of competing both within and above the canopy.

Grooming by 3DCM during the summer did not affect warm-season turfgrass canopy architecture or consistently reduce subsequent clipping yields. Grooming by 3DCM improved turf quality of 'Tifway' bermudagrass due to reduced scalping severity, but did not consistently improve 'Sea Isle 1' turf quality.

REFERENCES

Aan, A., L. Hallik, O. Kull. 2006. Photon flux partitioning among species along a productivity gradient of an herbaceous plant community. J. Ecol. 94: 1143-1155.

Anonymous. 1986. New look at faster greens. SportsTURF. Nov/Dec: 25.

Anonymous. 1988. Enquiries and replies (grass combs – an Ulster Bowling Club). J. of the Sports Turf Res. Institute. R.D.C. Evans (ed.). 64: 188-189.

Anten, N.P.R., T. Hirose. 1999. Interspecific differences in above-ground growth patterns result in spatial and temporal partitioning of light among species in a tall-grass meadow. J. Ecol. 87: 583-597.

Anten, N.P.R., T. Hirose. 2003. Shoot structure, leaf physiology, and daily carbon gain of plant species in a tallgrass meadow. Ecol. 84: 955-968.

Arredondo, J.T., H. Schnyder. 2003. Components of leaf elongation rate and their relationship to specific leaf area in contrasting grasses. New Phytologist. 158: 305-314.

Barenbrug USA. 2008. Scientific bermudagrass winter overseeding solution. Available at http://www.barusa.com/. [verified 25 Aug. 2008]. Barenbrug USA. Tangent, OR.

Beard, J. 1973. Turfgrass: Science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J., W. Menn. 1988. Texas system of winter overseeding I. Grounds Maintenance. 23: 14-16, 83.

Brede, A.D. 1982. Interactions of three turfgrass species. Ph.D. dissertation. The Pennsylvania State University, University Park, PN.

Brede, A.D., J.M. Duich. 1982. Cultivar and seeding rate effects on several physical characteristics of Kentucky bluegrass turf. Agron. J. 74: 865-870.

Brede, A.D., J.M. Duich. 1984. Initial mowing of Kentucky bluegrass-perennial ryegrass seedling turf mixtures. Agron. J. 76: 711-714

Brede, A.D., J.M. Duich. 1986. Plant interaction among *Poa annua*, *Poa pratensis,* and *Lolium perenne* turfgrasses. Agron. J. 78: 179-184.

Berendse, F. 1979. Competition between plant populations with different rooting depths. I. Theoretical considerations. Oecologia. 43: 19-26.

Bingham, S.W., R.E. Schmidt, C.K. Curry. 1969. Annual bluegrass control in overseeded bermudgass putting green turf. Agron. J. 61: 908-911.

Biran, I. 1981. Turfgrass responses to total and partial defoliation. HortScience. 16: 74-76.

Breuninger J.M., R.E. Schmidt. 1981. Post-dormancy growth of bermudagrass as influenced by low temperatures and selected preemergence herbicides. Agron. J. 73: 945-949.

Bruneau, A.H., C.H. Peacock, R.J. Cooper, E.J. Erickson. 2004. *Cynodon* spp. management programs for the upper transition zone in the southeastern United States. Acta Hortic. 661: 551-557.

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

Chalmers, D.R. 1985. Putting green management. Golf Course Manage. May: 50,52.

Chalmers, D.R., R.E. Schmidt. 1979. Bermudagrass survival as affected by deacclimation, low temperatures, and dormancy. Agron. J. 71: 947-949.

Cockerham, S.T. 2008. Culture of natural turf athletic fields. Handbook of Turfgrass Management and Physiology. Pessarakli, M. (ed.) CRC Press, Boca Raton, FL. 151-170.

Duble, R.L. 1978. Overseeding bermudagrass turf. Southern Golf. 9: 20-23.

Duble, R.L.. 1996. Turfgrasses: Their management and use in the southern zone. 2nd ed. Texas A&M University Press, College Station, TX.

Duncan, R.R., Carrow, R.N. 2000. Seashore paspalum: The environmental turfgrass. Chelsea, MI: Ann Arbor Press. xiv, [8], 281 pp.

Duncan, R.R., Carrow, R.N. 2005. Preventing failure of seashore paspalum greens: proper management techniques can prevent problems and failure in paspalum greens. Golf Course Manage. Mar. 73: 99-102.

Dunn, J.H., C.J. Nelson. 1974. Chemical changes occurring in three bermudagrass turf cultivars in relation to cold hardiness. Agron. J. 66: 28-31.

Dunn, J.H., C.J. Nelson, J.L. Sebaugh. 1980. Characterization of thatch, rhizomes, carbohydrates, and spring deadspot in twenty cultivars of bermudagrass. J. Am. Soc. Hortic. Sci. 105: 653-657.

Dunnivant, W.E. 2008. Grooming frequency and spacing effects on a Tifeagle bermudagrass putting green. MS Thesis. Auburn University. Auburn, AL.

Engelke, M.C. 2006. The benefit of turf groomers. Proc. Aust. Turf Conf. Brisbane, Australia. July 17-21.

Eggens, J.L. 1981. Response of *Poa pratensis* L. (Kentucky bluegrass) and *Poa annua* L. (annual bluegrass) to mowing and plant competition. Int. Turfgrass Soc. Res. J. 4: 123-128.

Gibeault, V.A., S.T. Cockerham, R. Autio, S.B. Ries. 1997. The enhancement of zoysia winter colour. Int. Turfgrass Soc. Res. J. 8: 445-453.

Giesler, L.J., G.Y. Yuen, G.L. Horst. 1996. The microclimate in tall fescue turf as affected by canopy density and its influence on brown patch disease. Plant Disease. 80: 389-394.

Gill, W.J., W.R. Thompson, C.Y. Ward. 1967. Species and methods for overseeding bermudagrass greens. The Golf Course Superintendent. Sept./Oct.: 10-17.

Green, R.L., G.J. Klein, F. Merino, V. Gibeault. 2004. Influence of fall-applied treatments on spring transition of an overseeded bermudagrass green. HortScience. 39: 424-428.

Griffin, H.M. 1971. Overseeding, 1971, to transition 1972. USGA Green Section Record. 7: 1-4.

Grime, J.P. 1974. Vegetation classification by reference to strategies. Nature. 250: 26-31.

Haugland, E., R.J. Froud-Williams. 1999. Improving grasslands: The influence of soil moisture and nitrogen fertilization on the establishment of seedlings. J. Appl. Ecol. 36: 263-270.

Hawes, D. 1982. Some ideas for easing the southern transition blues. USGA Green Section Record. Nov./Dec.: 1-3.

Hirose, T., M.J.A. Werger. 1995. Canopy structure and photon flux partitioning among species in a herbaceous plant community. Ecol. 76: 466-474.

Hollingsworth, B.S., E.A. Guertal, R.H. Walker. 2005. Cultural management and nitrogen source effects on ultradwarf bermudagrass cultivars. Crop Sci. 45: 486-493.

Horgan, B., F. Yelverton. 2001. Removal of perennial ryegrass from overseeded bermudagrass using cultural methods. Crop Sci. 41: 118-126.

Hsiang, T., K. Carey, B. He, J.L. Eggens. 1997. Composition of mixtures of four turfgrass species four years after seeding under non-wear conditions. Int. Turfgrass Soc. Res. J. 8: 671-679.

Ibitayo, O.O. 1981. Cold hardiness of bermudagrass and *Paspalum vaginatum* Sw. HortScience. 16: 683-684.

Johnson, B.J. 1976. Transition from overseeded cool-season grass to warm-season grass with pronamide. Weed Sci. 24: 309-311.

Johnson, B.J.. 1979. Vertical mowing and herbicide treatments on thatch in Bermudagrass (Cynodon dactylon) turf. Weed Sci. 27: 14-17.

Johnson, B.J.. 1986. Response to vertical mowing and ethofumesate treatments for annual bluegrass control in bermudagass turf. Agron. J. 78: 495-498.

Jordan, J.E., R.H. White, D.M. Vietor, T.C. Hale, J.C. Thomas, M.C. Engelke. 2003. Effect of irrigation frequency on turf quality, shoot density, and root length density of five bentgrass cultivars. Crop Sci. 43: 282-287.

Juska, F.V., J. Tyson, C.M. Harrison. 1955. The competitive relationship of Merion bluegrass as influenced by various mixtures, cutting heights, and levels of nitrogen. Agron. J. 47: 513-518.

Kemp, P.R., G.J. Williams III. 1980. A physiological basis for niche separation between *Agropyron smithii* (C”3) and *Bouteloua gracilis* (C’4). Ecol. 61: 846-858.

Kierstead, T. 2006. The reel world. Grounds Maintenance. 41(3): 56, 58-59.

King, J. 1971. Competition between established and newly sown grass species. J. Br. Grassld Soc. 26: 221-229.

Knoop, W.E. 1987. Enhancing spring transition. Lawn Servicing. Intertec Publ., Overland Park KS. 4(2): 11.

Kopec, D.M. 2001. Forced transition of Tifway 419 using select cultural management practices. University of Arizona College of Agriculture 2001 Turfgrass and Ornamental Research Report. Available at http://ag.arizona.edu/pubs/crops/az1246/. [verified 3 Dec 2008].

Kopec, D.M., J. Gilbert, K. Marcum, M. Pessarakli, D. Jensen. 2001. Effect of overseeding rate on spring transition. USGA Green Section Record. July/Aug.: 10-12.

Kopec, D., J. Gilbert, M. Pessarakli. 2004. Overseed performance of Sea Isle 2000 seashore paspalum. University of Arizona College of Agriculture 2004 Turfgrass, Landscape and Urban IPM Research Summary. Available at http://cals.arizona.edu/pubs/crops/az1359/. [verified 6 April 2010].

Krans, J.V., H.W. Philley, J.M. Goatley, M. Tomaso-Petterson. 1992. The relationships of rhizome density, sod strength, and spring green-up in bermudagrass. Agron. Abstr. 84: 172.

Lamb, E.G., S.W. Kembel, J.F. Cahil Jr. 2009. Shoot, but not root, competition reduces community diversity in experimental mesocosms. J. Ecol. 97: 155-163.

Landau, S.I. (Ed.) 2003. The new Webster's concise dictionary of the English language. Encyclopedic Edition. Trident Press Int., Naples, FL.

Ledeboer, F.B., C.R. Skogley. 1967. Investigations into the nature of thatch and methods for its decomposition. Agron. J. 39: 320-323.

Lepik, M., J. Liira, K. Zobel. 2005. High shoot plasticity favours plant coexistence in herbaceous vegetation. Oecologia. 145: 465-474.

Lickfeldt, D.W., T.B. Voigt, B.E. Branham, T.W. Fermanian. 2001. Evaluation of allelopathy in cool season turfgrass species. Int. Turfgrass Soc. Res. J. 9: 1013-1018.

Lush, W.M., M.E. Rogers. 1992. Cutting height and the biomass and tiller density of *Lolium perenne* amenity turfs. J. Appl. Ecol. 29: 611-618.

McCown, R.L., W.A. Williams. 1968. Competition for nutrients and light between the annual grassland species *Bromus Mollis* and *Erodium Botrys*. Ecol. 49: 981-990.

Martin, M.P.L.D., R.J. Field. 1984. The nature of competition between perennial ryegrass and white clover. Grass and Forage Sci. 39: 247-253.

Mazur, A.R. 1981. Cool-season/warm-season turfgrass management in the transition zone. USGA Green Section Record. Nov./Dec.: 10-12.

Mazur, A.R. 1988. Influence of plant growth regulators on transition of bermudagrass putting green overseeded with perennial ryegrass. J. of the Am. Soc. for Hortic. Sci. 113: 367-373.

Mazur, A.R., J.S. Rice. 1999. Impact of overseeding bermudagrass with various amounts of perennial ryegrass for winter putting turf. HortScience. 34: 864-866.

Mazur, A.R., D.F. Wagner. 1987. Influence of aeration, topdressing, and vertical mowing on overseeded bermudagrass putting green turf. HortScience. 22: 1276-1278.

McCarty, L.B., M.F. Gregg, J.E. Toler. 2007. Thatch and mat management in an established creeping bentgrass golf green. Agron. J. 99: 1530-1537.

Naqvi, H.H., C.H. Muller. 1975. Biochemical inhibition (allelopathy) exhibited by Italian rye-grass (*Lolium multiflorum* L.). Pak. J. Bot. 7: 139–147.

Nelson, L.R., J. Crowder, H.B. Pemberton. 2005. Performance and transition date of a turf-type annual ryegrass in comparison to perennial ryegrass and fine fescues. Hortechnology. 15: 304-308.

Newman, E.I. 1973. Competition and diversity in herbaceous vegetation. Nature. 244: 310.

Newman, E.I., R.E. Andrews. 1973. Uptake of phosphorus and potassium in relation to root growth and root density. Plant and Soil. 38: 49-69.

O’Neal, M.E., D.A. Landis, R. Isaacs. 2002. An inexpensive, accurate method for measuring leaf area and defoliation through digital image analysis. J. of Economic Entomol. 95: 1190-1194.

Palmertree, H.D. 1975. Management of overseeded greens during spring transition period cool-season grasses protect against cold, allow growth in areas of traffic. Golf Superintendent. Mar.: 27-29.

Passarge, J., S. Hol, M. Escher, J. Huisman. 2006. Competition for nutrients and light: stable coexistence, alternative stable states, or competitive exclusion. Ecological Monogr. 76: 57-72.

Pearce, R.B., R.H. Brown, R.E. Blaser. 1965. Relationship between leaf area index, light interception and net photosynthesis in orchardgrass. Crop Sci. 5: 553-556.

Pronk, T.E., F. Schieving, N.P.R. Anten, M.J.A. Werger. 2007. Plants that differ in height investment can coexist if they are distributing non-uniformly within an area. Ecological Complexity. 4: 182-191.

Rajaniemi, T.K. 2003. Evidence for size asymmetry of belowground competition. Basic and Appl. Ecol. 4: 239-247.

Rajaniemi, T.K., V.J. Allison, D.E. Goldberg. 2003. Root competition can cause a decline in diversity with increased productivity. J. Ecol. 91: 407-416.

Razmjoo, K., T. Imada, and S. Kaneko. 1995. Overseeding manilagrass [*Zoysia matrella* (L.) Merr.] with cool-season turfgrasses. J. of Turfgrass Manage. 1: 43-52.

Rhodes, I. 1968. The growth and development of some grass species under competitive stress. 1. Competition between seedlings, and between seedlings and established plants. J. of the British Grassland Soc. 23: 129-136.

Rice, E.L. 1984. Allelopathy. Academic Press, New York.

Richardson, M.D. 2004. Morphology, turf quality, heat tolerance of intermediate ryegrass. HortScience. 39: 170-173.

Richardson, M.D., K.W. Hignight, R.H. Walker, C.A. Rodgers, D. Rush, J.H. McCalla, D.E. Karcher. 2007. Meadow fescue and tetraploid perennial ryegrass – two new species for overseeding dormant bermudagrass turf. Crop Sci. 47: 83-90.

Rogers, R.A., J.H. Dunn, C.J. Nelson. 1977. Photosynthesis and cold hardening in zoysia and bermudagass. Crop Sci. 17: 732.

Roxburgh, S.H., A.J. Watkins, J.B. Wilson. 1993. Lawns have vertical stratification. J. of Vegetation Sci. 4: 699-704.

Salaiz, T.A., G.L. Horst, R.C. Shearman. 1995. Mowing height and vertical mowing frequency effects on putting green quality. Crop Sci. 35: 1422-1425.

Schaffer, L. 1994. Turf groomers: Conditioning greens with these devices can help achieve smoother more consistent putting surfaces. Golf Course Manage. Apr. 62: 110, 112.

Shearman, R.C. 1989. Physiology of turfgrass mowing: As the intensity of cultural practice input increases, so does the maintenance cost. Golf Course Manage. Feb. 57: p. 23, 26, 28, 30.

Sheffer, K.M., T.L. Watschke, J.M. Duich. 1978. Effect of mowing height on leaf angle, leaf number, and tiller density of 62 Kentucky bluegrasses. Agron. J. 70: 686-689.

Schmidt, R.E., J.F. Shoulders. 1972. Winter turf development on dormant bermudagass as influenced by summer cultivation and winter N fertilization. Agron. J. 64: 435-437.

Schmidt, R.E., J.F. Shoulders. 1980. Seasonal performance of selected temperate turfgrasses overseeded on bermudagrass turf for winter sports. p. 75-86. *In* J.B. Beard (ed.) Proc. 3rd Int. Turf. Res. Conf., Munich, Germany. 11-13 July 1977. Int. Turfgrass Soc., and ASA, CSSA, and SSSA, Madison, WI.

Schmitz, J. 1999. A smooth transition. Golf Course Manage. July. 67: 108, 112, 118, 120, 122.

Shoulders, J.F., H.B. Couch, R.E. Schmidt. 1984. Overseeding for improved winter turf. Golf Course Manage. Sept.: 50-54.

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

Soper, D.Z. 1988. Effects of clipping disposal, nitrogen, and growth retardants on thatch and tiller density in zoysiagrass. Crop Sci. 28: 325-328.

Sorochan, J., J. S. McElroy. 2007. Frequent grooming effects on surface quality of bermudagrass and zoysiagrass fairway turf with and without trinexapac-ethyl. 2007 USGA Turfgrass and Environmental Research Summary. p. 62.

Stier, J., A. Hollman. 2003. Cultivation and topdressing requirements for thatch management in A and G bentgrass and creeping bluegrass. HortScience 38: 1227-1231.

Texas ET Network. 2010. ET and weather data. Available at http://texaset.tamu.edu/etinfo.php. [verified 22 Mar. 2010].

Thoms, A., J. Sorochan, T. Samples, J.S. McElroy, D. Kopsell. 2008. Wear tolerance of bermudagrass varieties with mowing events and overseeding for athletic fields in the transition zone. 2008 ASA-CSSA-SSSA Joint Ann. Meet.: [Abstracts]. Houston, TX. p. 45489.

Turgeon, A.J. 2008. Turfgrass management, 8th edition. Pearson Prentice Hall, Upper Saddle River, New Jersey.

Vermeulen, P.J., J.F. Stuefer, N.P.R. Anten, H.J. During. 2009. Carbon gain in the competition for light between genotypes of the clonal herb *Potentilla reptans*. J. Ecol. 97: 508-517.

Volteranni, M., M. Gaetani, S. Magni, S. Miele. 2004. Bermudagrass autumn overseeding with annual ryegrass. Acta Hortic. 661: 353-356.

Volteranni, M., S. Miele, S. Magni, M. Gaetani, G. Pardini. 2001. Bermudagrass and seashore paspalum winter overseeded with seven cool-season turfgrasses. Int. Turgrass Soc. Res. J. 9: 957-961.

Walker, J.A., J.R. King. 2009. Above- and below-ground competition between Kura clover (*Trifolium ambiguum*) and meadow bromegrass (*Bromus biebersteinii*): a greenhouse study. Can. J. Plant Sci. 89: 21-27.

Ward, C.Y., E.L. Mcwhirter, W.R. Thompson, Jr. 1974. Evaluation of cool-season turf species and planting techniques for overseeding bermudagrass golf greens. p. 480-495. *In* E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf., Blacksburg, VA. 19-21 June 1973. ASA – CSSA. Madison, WI.

Watschke, T.L., R.E. Schmidt. 1992. Ecological aspects of turf communities. *Turfgrass*. D.V. Waddinton, R.N. Carrow, R.C. Shearman (ed.) Agron. Monogr. 32. ASA, Madison, WI. 129-174.

Weiner, J. 1986. How competition for light and nutrients affects size variability in Ipomoea Tricolor populations. Ecol. 67: 1425-1427.

White, R.H., R. Dickens. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. Agron. J. 76: 19-22.

White, R.H., R. Schmidt. 1990. Fall performance and post-dormancy growth of 'Midiron' bermudagrass in response to nitrogen, iron, and benzyladenine. J. Am. Soc. Hort. Sci. 115: 57-61.

Wilson, J.B. 1988. Shoot competition and root competition. J. Appl. Ecol. 25: 279-296.

Wilson, J.B., E.I. Newman. 1987. Competition between upland grasses: Root and shoot competition between *Deschampsia flexuosa* and *Festuca ovina*. Acta Oecologia/Oecologia Generalis. 8: 501-509.

Yelverton, F. 2005. Spring transition: Going, going, gone. USGA Green Section Record. Mar./Apr.: 22-23.

Yokozawa, M., Y. Kubota, T. Hara. 1996. Crown architecture and species coexistence in plant communities. Ann. of Bot. 78: 427-447.

Zhang, J.M., J. Luo, J. Zhang, S.S. Lin, S.X. Mo, L.J. Lu. 2008. Winter overseeding zoysiagrass sports turf with cool-season turfgrasses in southern China. Acta Hortic. 783: 85-95.

Zobel, M. 1992. Plant species coexistence: The role of historical, evolutionary and ecological factors. Oikos. 65: 314-320.

APPENDIX A

GLOSSARY

Grain: the undesirable, procumbently oriented growth of leaves, shoots, and stolons in turf (Turgeon, 2008).

Groom: to comb or brush; to prepare by training or developing (Landau, 2003). In turf, grooming can take the form of grass combs, brushes, vertical mowers, or modern 3DCM reels. Each technique is thought to train the turf to grow in a more desirable habit for improved quality or playability.

Overseeding: the process of seeding a cool-season turfgrass into an existing warm-season turf in order to provide a green surface during the winter dormancy period (Turgeon, 2008).

Polystand: the presence of two or more actively growing turfgrasses both contributing to a visual turf canopy. In this document, a polystand refers to warm- and cool-season turfgrasses competing in the spring transition period.

Puffy: perceived springy feeling due to fast-growing, stemmy top growth (Cockerham, 2008).

Spring green-up (Post-dormancy regrowth): the initial appearance of green shoots during the spring when favorable growing conditions cause a turf to break winter dormancy (Beard, 1973).

Scalping: the excessive removal of green tissue resulting in a ‘stubbly, brown appearance’ due to exposed crowns and stems (Turgeon, 2008).

Spring transition: the return from a uniform winter overseeded turf cover to a dense, actively growing warm-season permanent turf (Hawes 1982, Kopec et al. 2001). The ideal spring transition is gradual and limits the amount of thin or dormant turf visible (Green et al., 2004).

Stemminess: a great percentage of total leaf area is in the top portion of the canopy while the lower part of the plant is lacking in green leaf tissue. Stemminess is associated with small leaf mass ratios.

Three-dimensional Clipping Management (3DCM): synonymous with the modern concept of turf grooming. The first dimension is the width of the mowing unit; the second dimension is the length of the mowing pass; the third dimension is the vertical removal of excessive turf verdure.

Vertical mowing: the use of vertically rotating blades to sever stolons, to remove thatch, or to improve soil conditions. Vertical mowers are dedicated machines or reels and must be used separately from traditional mowers (Engelke, 2006).

Winter Dormancy (Dormancy): is the pause of growth and death of leaf tissue in a turfgrass due to extended low soil temperatures in winter (Beard, 1973).

VITA

Name: Charles Henry Fontanier

Address: 233 Heep Center
2474 TAMU,
College Station, TX 77843

Email Address: cfontanier@ag.tamu.edu

Education: B.S., Agronomy, Horticulture; Texas A&M University (College Station), 2007

M.S., Agronomy; Texas A&M University (College Station), 2010