Introduction

Fairways constitute the largest portion of playable turfgrass on a golf course, ranging from 30 to 60 acres for an average 18-hole course (Turgeon, 1996). Fairway quality is extremely important from both a functional and an aesthetic standpoint. There are many factors to consider in selecting a proper turf species for fairway use, but ultimately, climatic adaptation becomes the limiting factor. Cool season species such as perennial ryegrass (*Lolium perenne* L.) are adapted to the cooler temperate and subarctic climates, whereas warm season species such as bermudagrass (*Cynodon dactylon* [L.] Pers.) are used primarily in the warmer subtropical and tropical climates. The geographical areas separating the temperate and subtropical climates are commonly referred to as the transition zone. The transition zone presents unique challenges in selecting and managing a turfgrass species that will sustain a long-term, high-quality golf course fairway. Warm season species are prone to winter injury or even death, while cool season species are susceptible to many summer stresses including fungal diseases, high temperatures, and drought.

Literature Review

Turfgrass Adaptation and Use in the Transition Zone

Perennial Ryegrass

Beard (1973) describes perennial ryegrass (*Lolium perenne* L.), a native to the temperate climates of Asia and North Africa, as one of the first cultivated grasses. It prefers cool, moist environments devoid of seasonal temperature extremes (Duble, 1976). It is a cool season, bunch-type grass that may behave as an annual, short-lived perennial, or perennial depending on environmental conditions (Turgeon, 1996). Improved varieties possess greater cold tolerance and wear tolerance, increased heat and drought tolerance, better disease resistance, finer leaf textures, tolerance to closer mowing, and darker green color than common perennial ryegrass (Duble, 1996; Emmons, 1995). These characteristics have made perennial ryegrass an appropriate choice for monostands on golf course fairways in parts of the transition zone. Although these newer varieties are more vigorous, summer stresses usually warrant high levels of maintenance, i.e., fungicide applications and irrigation. Other uses of perennial ryegrass in the transition zone include sports fields, and in mixtures with bluegrass on home lawns (Duble, 1996).

Fine Fescues

Overall, the fescues (*Festuca* L. *sp.*) compose a large genus of over 100 species; however, only six are utilized as turfgrass (Turgeon, 1996). Tall fescue (*F. arundinacea*) and meadow fescue (*F. elatior*) are coarse textured, while the remaining species possess very fine leaf texture and are collectively referred to as fine fescues. Adapted to cool humid regions of the world, fine fescues tolerate shade, drought, low pH, and low fertility (Beard, 1973; Hanson et al., 1969). Variation among fine fescues includes persistence, leaf texture, and growth habit (Beard, 1973). While some fine fescues are best suited as natural low-maintenance grasses, other species are capable of producing excellent quality turfgrass (Ruemmele et al., 1995). Creeping red fescue (*F. rubra* L.ssp. *rubra* and *F. rubra* L. ssp. *trichophylla* Gaud.) is found as two distinct types, a strong creeping type with long thick rhizomes (ssp. *rubra*) and a slender creeping type with short rhizomes (ssp. *trichophylla*). Chewings fescue (*F. rubra* L. ssp. *commutata* Gaud.) is very similar to slender creeping red fescue, but it lacks rhizomes. It is a low-growing, non-creeping bunch type grass that forms a very dense turf and is considered by many to be the most attractive of the fine fescues (Emmons, 1995). Hard fescue (*F. longifolia* Thuill.) and sheep fescue (*F. ovina* L.) are lower maintenance fine fescues often used for soil stabilization or in difficult to mow areas. They possess better drought tolerance and adaptation to poor soils than the other species of fine fescue. Preferred cutting heights range from 3.8 to 7.6 cm, but some species such as chewings fescue tolerate shorter heights (Beard, 1973). Certain varieties of chewings fescue and hard fescue maintained at 3.8 cm in the transitional areas in southern Illinois demonstrated exceptional quality (Diesburg,1993).

Bermudagrass

Bermudagrasses (*Cynodon spp.*) are perhaps the most important and widely adapted warm season grasses in the world. They are thought to have originated in East Africa (Beard, 1973; Emmons, 1995) but are widely distributed throughout tropical and subtropical regions of over 100 countries (Duble, 1996). Throughout the world, bermudagrass is known by many other names including couchgrass, devilgrass, Kweekgrass, gramillia, quickgrass, and wiregrass. As some of these names suggest, bermudagrass is considered a weedy grass in many instances. The genus *Cynodon* comprises nine species, with *C. dactylon* [L.] Pers., (common bermudagrass) being the most widespread. Bermudagrass is a vigorous sod-forming perennial that spreads by stolons and rhizomes, and sometimes seed. It tolerates close mowing, generally between 1.3 and 2.6 cm; however, some dwarf varieties may be mowed at 0.6 centimeters. It is adapted to warm humid and semiarid climates with extended periods of high temperatures, mild winters, and moderate to high rainfall (Duble, 1996).

Winter survival hinders the use of bermudagrass for turf throughout the northern limit of adaptation for warm season turfgrasses (Chalmers and Schmidt, 1979). Bermudagrass enters a winter dormancy period in areas where average daily temperatures are below 10^{O} C. Winter injury on bermudagrass may occur even at normal winter temperatures (2.2 to 7.8 C, daily average) throughout the transition zone

(Bruneau et al., 1993). This injury happens as a direct or indirect result of freezing temperatures, depending on the condition of the plant and associated environmental conditions (Fry, 1990). Indirect injury leads to the death of plant cells, not due to freezing, but rather from desiccation or cellular dehydration. This freeze-induced dehydration is the result of a vapor pressure gradient deficit between the water in plant cells and ice crystals formed outside the cells in plant tissue, usually in the crown region. Water moves from inside the cell toward the ice crystals and cell death occurs when cell water content becomes too low. Direct injury is the result of ice formation in plant cells causing immediate death. This type of injury is usually seen when warm periods in late winter initiate new growth followed by a period of sub-freezing temperatures. Kenna (1989) documented extensive areas of winterkill associated with rapid warm to frigid temperature variance in the transition zone. He concluded that record high temperatures in January followed by record low temperatures in February and fluctuating freezing/thawing cycles in March and April likely led to direct freezing injury of bermudagrass. Davis and Gilbert (1970) demonstrated acclimation of bermudagrass to low temperatures through a hardening process in fall and early winter months, but found decreased hardiness in early spring.

The sensitivity of bermudagrass to freezing temperatures prohibits its use for golf course fairways in the northern United States and often limits its use throughout the transition zone. Research has shown that cold tolerance can be influenced by traffic, shade, plant nutrition, soil moisture, and mowing height (Taliaferro, 1994). Less than ideal growing conditions may predispose bermudagrass to increased winter injury.

Bermudagrass Establishment

Vegetative Methods

Bermudagrass may be established through seed, or most commonly, vegetatively by stolons and/or rhizomes. Most improved bermudagrass varieties are the result of a cross between common bermudagrass (*Cynodon dactylon* L. Pers**.**) and African bermudagrass (*Cynodon transvaalensis* Burtt-Davy). These crosses between different species produce sterile plants known as an interspecific hybrids that must be propagated vegetatively. This procedure was done in early research by Burton (1947) and resulted in Coastal bermuda, an improved forage grass. Burton's work led to the release of the hybrids Tifgreen (328) in 1956 and Tifway (419) in 1960, both of which are standard bermudagrasses used in the southern United States (Foy, 1997). Vegetative establishment is the planting of mature plants and may be done through sprigging, plugging, or sodding. Sprigging consists of planting rhizome or stolon segments, with nodes, and any leaves or roots that may be attached to them. Sprigging is the most practical and most often used method of planting bermudagrass over large acreages such as golf course fairways. Typical establishment rates range from 5 to 25 bushels per acre depending on the intended use and speed of establishment desired (Duble, 1996). Plugging refers to planting small plugs of turf spaced from 15 to 46 centimeters apart, depending on the rate of cover needed. Sodding involves transplanting a mature stand of turf onto a prepared soil site.

Seeded Methods

Until recently, virtually all bermudagrass cultivars used in fine turf situations were single plant, clonally propagated selections (Taliaferro, 1995). Common bermudagrass, also known as ‘Arizona Common’ was the only widely used turf-type bermudagrass variety that could be established from seed (Baltensperger et al., 1993). ‘Arizona Common’ germplasm possesses excellent fertility and seed production potential and has been a worldwide source of bermudagrass seed (Baltensperger et al., 1993). Unfortunately, it lacks the cold tolerance (about -6^{o} C $\pm$ 3^{o}) to survive cold winters in the upper South and transition zone climates (Taliaferro, 1995). The past decade, however, has seen increased efforts toward breeding of improved seeded bermudagrass cultivars (Taliaferro and McMaugh, 1993). Previous research discovered the existence of common bermudagrass germplasm able to breed more winter-hardy seed-propagated cultivars (Ahring et al., 1974; Burton and Hart, 1967; Richardson et al., 1978). Fertility and seed production potential of cold hardy germplasm vary greatly, but typically are substantially lower than that of ‘Arizona Common’ (Taliaferro, 1995). Burton and Hart (1967) were not able to achieve sufficient seed yields to be economically feasible, though others were able to develop clones with larger seed yields (Ahring et al., 1974; Kenna et al., 1983; Richardson et al., 1978). Research in Oklahoma led to the selection of ‘Guymon’, the first cold tolerant seeded cultivar to be released commercially in the United States (Taliaferro et al., 1983). ‘NuMex Sahara’, developed in New Mexico, was selected for high seed production and increased quality over common and ‘Guymon’ (Baltensperger, 1989). Breeding efforts over the last decade have resulted in other improved seed-propagated bermudagrass varieties such as, ‘Primavera’, ‘Sundevil’, ‘Mirage’, and ‘Jackpot’, with others still in experimental stages.

Competition Among Turfgrass Species in a Mixed Sward

The botanical composition of turf species in a mixed sward is largely determined by adaptation to environmental extremes and management. In the transition zone, where neither warm season nor cool season species are well adapted, a combination of warm and cool season turfgrasses may be advantageous (Beard, 1973). Turfgrass stands composed of multiple species may be better able to withstand environmental and pest stresses compared to monoclonal communities (Watschke and Schmidt, 1992). DiPaola and Spak (1990) demonstrated that turf quality of a Kentucky bluegrass and bermudagrass mixture was greater than a bermudagrass monostand during the fall, winter, and spring, or a bluegrass monostand during the summer. Research in southern California showed that several cool season grasses can be seeded into common bermudagrass and persist for four years without annual overseeding (Spaulding and Youngner, 1973). Although it has been determined that mixtures of cool and warm season grasses may be advantageous, there exists continual competition among the species for light, moisture, and nutrients. This competition between species, known as interspecific competition, may occur between cool season or warm season mixtures or a combination of both. Most previous research has investigated competitive interactions between mixtures containing cool season turfgrasses. A study by Marriott and Zuazua (1996) compared perennial ryegrass in monoculture (intraspecific competition) with perennial ryegrass polystands consisting of one of two bluegrasses or two fine fescues (interspecific competition). Tiller numbers and clipping dry weights of perennial ryegrass were greater in mixtures with Kentucky bluegrass and sheep fescue than in monoculture suggesting perennial ryegrass is more efficient when grown with other species than by itself. Intraspecific competition tends to be especially keen as all plants share the same niche. Interspecific competition often allows one species to thrive because other species may occupy a slightly different niche. The Marriott and Zuazua (1996) results showed that perennial ryegrass could dominate other species for resources. According to Danneberger (1993) competition between grass species can occur amongst their tillers and/or roots. Generally, grasses with a high tillering capacity have an advantage over those with a lower tillering capacity (Lush, 1988; Grime and Hunt, 1975) and that capacity is subject to change with seasonal variations (Lush 1988). Brede and Duich (1986) studied both aboveground and below ground interactions and found perennial ryegrass to possess a relatively high tillering capacity as well as a very competitive root system, but annual bluegrass and Kentucky bluegrass competed well aboveground. Carrow and Troll (1977) reported that perennial ryegrass competed well in bluegrass sod, but not in bentgrass. Other research with mixtures of various turfgrasses has shown perennial ryegrass to have a competitive advantage over some species of bluegrass and fescue (Snaydon and Howe, 1986; Carrow and Troll, 1974). Research in Canada compared 24 mixtures consisting of several varieties of four cool season grass species (Hsiang et al., 1997). Perennial ryegrass was the most competitive among the four species and increased in relative frequency in nearly all plots in which it was seeded. Similar competitive trends have been shown with other crops as well. Tan and Crabtree (1990) showed that perennial ryegrass sod, as a vineyard floor vegetation, reduced total content of all measured nutrients in grape leaves. Warm season grasses have also been shown to compete for resources. Weller et al. (1985) conducted field experiments over two years and found that bermudagrass inhibited growth of newly planted peach (cv. Norman) trees. Research with bermudagrass and tall fescue mixtures resulted in both decreased tillering, and plant size of all genotypes of tall fescue due to bermudagrass competition (Bouton et al., 1989).

Plant Growth Regulators

There has been interest in altering the growth rate of turfgrasses through chemical applications during the last half century. Reasons to alter growth include reduced mowings, inhibition of inflorescence, enhanced lateral shoot growth, and altering species composition in mixed swards. There is a common misconception among many turfgrass managers that growth regulators only reduce foliar growth. While this is partially correct, growth regulators can also stimulate growth. By definition, a plant growth regulator (PGR) is an organic compound, natural or synthetic, which, when present or applied in small amounts, results in a change in plant growth or development (DiPaola, 1988). The natural compounds are hormones produced by the plant and include auxins, gibberellins, cytokinins, ethylene, and abscisic acid. Synthetic compounds, while not produced naturally, are capable of altering physiological processes affecting growth. According to Danneberger and Street (1990) both natural and synthetic growth substances regulate or influence cell division and differentiation, root and shoot growth, flowering, senescence, and nucleic acid synthesis.

Classification of Plant Growth Regulators

Early work by Kaufmann (1986a) and Watschke (1985) led to the categorization of PGRs into Type I or Type II compounds. Type I growth regulators are primarily foliar absorbed and can inhibit or suppress growth by stopping cell division and differentiation. Type II growth regulators are primarily root absorbed and suppress growth through the interference of gibberellic acid (GA) biosynthesis, thus reducing cell elongation and subsequent plant organ expansion (Kaufmann, 1986b). The development of recent PGRs has required a differentiation among Type II compounds into early GA and late GA inhibitors. Subsequently a new classification has been developed dividing PGRs into Class A, Class B, and Class C substances (Watschke and DiPaola, 1995). Class A PGRs interfere with the production of gibberellins late in their biosynthetic pathway by inhibiting the hydroxylation of GA_{20} to GA_1 which in turn prevents cell elongation. Class B PGRs interfere with the production of gibberellins early in their biosynthetic pathway, at the Ent-kaurene to Ent-kaurenol transformation step in the pathway. Class C PGRs are mitotic inhibitors and include all the compounds known as Type I PGRS.

PGR Effects on Turfgrass and Species Competition

Class A PGRs

Until recently, the use of PGRs on high quality turf has been somewhat limited due to inconsistent performance and unacceptable turfgrass injury (Christians, 1985; Johnson, 1994). The development of a new generation of PGRs that interfere with the biosynthesis of gibberellins has reduced the risk of foliar burn and enhanced the use of PGRs on high quality turfgrasses (Watschke and DiPaola, 1995). Class A PGRs are known as late gibberellin biosynthesis inhibitors, and trinexapac-ethyl (TE) is the only compound registered for use on turfgrass that falls in this category. TE was first synthesized in 1983 and was identified as CGA-163935. TE has been tested on turfgrasses since 1985 and received labeling in 1993 for use on both warm and cool season turfgrasses (Houseworth and DiPaola, 1996). Wiecko (1997) and Johnson (1992a, 1994) were able to suppress growth of 'Tifway' bermudagrass with applications of TE at 0.1 and 0.2 kg ha^{-1} without lowering turf quality. Further research by Johnson (1997) showed that TE, combined with an iron source, improved turfgrass quality of 'Tifway' bermudagrass, but did not affect vegetative growth. Other researchers have shown that TE enhanced turf quality of several cool season sod types and improved traffic tolerance when applied soon after sod establishment (Krick et al., 1995). Stier and Rogers (1995) evaluated *Poa supina* and *Poa pratensis* under reduced light, dome conditions and simulated soccer traffic and found that while turf quality, growth, and shearing strength declined over a three month period, applications of TE enhanced turf color, quality, density, and chlorophyll levels. Research with perennial ryegrass under golf course fairway culture found that TE reduced turfgrass quality during the first three weeks following initial application, but that the turf recovered fully and even exhibited a denser, darker green appearance two months later (Wetzel and Dernoeden, 1994). There is a lot of interest in the potential for using PGRs to manipulate species composition in a mixed sward. Research in Virginia investigated converting a predominately annual bluegrass putting green turf to creeping bentgrass by interseeding in conjunction with PGR treatments (Bigelow, 1995). Results showed that higher seeded rates generally resulted in greater bentgrass tiller populations, but that TE application did not increase creeping bentgrass seedling survival in annual bluegrass turf. Previous work by Roethler and Christians (1994) confirmed that TE applied at recommended rates does not affect germination of creeping bentgrass, Kentucky bluegrass, or perennial ryegrass.

Class B PGRs

Class B PGRs can be used on moderately to intensively managed turf, but a turf bronzing effect often accompanies foliar growth suppression (Watschke and Dipaola, 1995). Flurprimidol and paclobutrazol are Class B PGRs that interfere with the production of gibberellins early in their biosynthetic pathway. Flurprimidol is described as primarily a root-absorbed compound with some foliar absorption (Beard, 1985; Batten, 1983). Paclobutrazol is similar in that it is taken up by plant roots (Watschke et al., 1992) but foliar absorption is almost non-existent (Barrett & Bartuska, 1982).

The presence of seedheads is considered deleterious to turf quality, thus reducing the number of seedheads is one of many reasons to regulate turfgrass growth (Watschke and DiPaola, 1995). Paclobutrazol has been shown to inhibit seedhead formation (Kageyama, 1989) while flurprimidol has shown little efficacy on seedhead inhibition (Freeborg, 1983; McElroy et al., 1983; Symington et al., 1982; Hurto, 1981; and Watschke, 1981).

Flurprimidol has been shown to provide extended foliar suppression on both warm season (Johnson, 1992b, 1990, 1989; Johnson and Carrow, 1993, 1991,1989) and cool season (Dernoeden, 1984, 1982; Welterlan and Nash, 1984; Freeborg, 1983; Watschke, 1981) turfgrasses. Johnson and Carrow (1993, 1991, 1989) attempted to suppress bermudagrass encroachment into creeping bentgrass putting greens with flurprimidol alone and with other growth regulators and herbicides. Results showed that bermudagrass could be suppressed somewhat with sequential applications of flurprimidol, however unacceptable injury to the creeping bentgrass often occurred.

Studies by Watschke and Engel (1994) revealed that applications of flurprimidol or paclobutrazol to a mixed stand of annual bluegrass and creeping bentgrass favored the growth of the bentgrass. Other researchers found that while paclobutrazol favored creeping bentgrass, flurprimidol did not effectively suppress *Poa annua* var. *reptans*, the perennial subspecies of annual bluegrass (Johnson and Murphy, 1996, 1995). The differential growth suppression of a given species affords the opportunity to manipulate plant competition in a mixed sward. While PGRs suppress plant growth to a certain degree, research has indicated the potential for increased density of a treated stand of turfgrass with both paclobutrazol (Brueninger et al., 1983) and flurprimidol (Dernoeden, 1982, 1984; Watschke, 1981). This suggests that increased density could negate the desired effect of reduced competition from PGR application. Schmidt and Henry (1989) found that spring-applied flurprimidol to bermudagrass overseeded with perennial ryegrass actually reduced early postdormancy growth of bermudagrass. Again this suggests that the PGR application may have increased the eventual competitiveness of the perennial ryegrass. Conversion programs involving seeding a desired species into PGR-treated turf has received some recent attention. Bentgrass establishment by seeding in annual bluegrass turf under putting green culture was not enhanced by applications of flurprimidol (Bigelow, 1995). While this may be due to other factors (i.e. close, frequent mowings), herbicidal effects are also a likely cause. Research by Gaussoin and Branham (1987) and Haley and Fermanian (1989) indicate that flurprimidol has preemergence activity on creeping bentgrass.

Class C PGRs

Class C PGRs, also known as Type I growth regulators, are mitotic inhibitors that essentially stop new growth for a defined period and include such compounds as maleic hydrazide (MH), amidochlor, and mefluidide. MH, one of the earliest growth regulators used on turf, was recommended for foliar suppression and seedhead inhibition of cool-season grasses in rough and semi-rough areas (Elkins, 1983). MH is foliarly absorbed and readily transported in the vascular system. It suppresses turf by stopping cell division in the shoots, roots and buds (Danneberger and Street, 1986; Street, 1980) which can lead to excessive thinning and root loss (Freeborg and Daniel, 1981). MH inhibits reproductive tiller development and is an effective seedhead inhibitor (Billot and Hentgen, 1974). It has been observed to cause severe injury and color loss (Foote and Himmelman, 1967; Boeker, 1969; Elkins, 1974; Elkins and Suttner, 1974; Freeborg and Daniel, 1981) and therefore is used most extensively in low maintenance turf areas (Danneberger and Street, 1990).

Amidochlor is a root-absorbed compound that is effective for suppressing vegetative growth and reducing seedhead production in cool-season turfgrasses (Danneberger and Street, 1990). Amidochlor inhibits both cell division and elongation, but is less injurious than MH.

Mefluidide, which is foliarly absorbed, rapidly inhibits cell division and differentiation in meristematic areas (Kaufmann, 1986a). It was first introduced in 1978 as a seedhead and foliar suppressant for use in rough turf areas (Elkins, 1983; Johnston and Faulkner, 1985). Unlike MH, mefluidide exhibits very little translocation within the plant (Field and Whitford, 1982). This supports research showing that mefluidide had little or no suppressive effect on turfgrass roots (Marcum and Jiang, 1997; Nielson and Wakefield, 1975) In fact, mefluidide has actually been shown to increase annual bluegrass (*Poa annua* L.) root elongaton and maximum rooting depth concurrent with seedhead suppression (Cooper et al., 1987). This suggests that mefluidide may increase an annual bluegrass population, rather than restrict it. Gassoin and Branham (1989), working with a fairway turf in Michigan, found that mefluidide in combination with high nitrogen resulted in annual bluegrass populations that were 8% higher than the control or flurprimidol treated plots. Mefluidide has been effective in seedhead suppression on predominately annual bluegrass golf course fairways (Gaussoin and Branham, 1989; Watschke et al., 1992). While activity has been observed on both warm and cool season grass species (Beard, 1985), season-long seedhead suppression is achieved only with cool season grasses (Anonymous, 1983).

Fry and Dernoeden (1986) conducted research using mefluidide and amidochlor to enhance zoysiagrass establishment in mature perennial ryegrass and Kentucky bluegrass. They concluded that the rate of zoysiagrass coverage was increased in perennial ryegrass, but not in Kentucky bluegrass with these compounds. However, both mefluidide and amidochlor caused unacceptable turfgrass injury, which would limit their use in a conversion program on high quality turf.

Disease impacts on Golf Course Fairway Turfgrass

In the transition zone, golf course fairways consisting of cool season turfgrass species are susceptible to a number of diseases. The most commonly used turfgrasses include creeping bentgrass, Kentucky bluegrass, and perennial ryegrass. These species vary somewhat in their susceptibility to certain diseases, but all are susceptible to the major pathogens causing Pythium blight (*Pythium spp*.) and Rhizoctonia blight (*Rhizoctonia solani* Kuhn), diseases that can be very detrimental to cool season turfgrass during the summer. Another disease, gray leaf spot (*Pyricularia grisea* (Cke.) Sacc.), has been especially damaging to perennial ryegrass during certain years (Dernoeden, 1996). Warm-season grasses are seldom affected by disease during most of the year, but in the transition zone, the occurrence of spring dead spot on bermudagrass, along with the potential for winterkill often discourage their use. The use of cool season and warm season mixtures for golf course fairways would seemingly have potential for reducing the negative impacts imparted on either species.

The summer of 1995 produced a devastating gray leaf spot epidemic on perennial ryegrass fairways throughout the transition zone (Dernoeden, 1996). Gray leaf spot was first reported to be a serious problem during the early 1970's in ryegrass forages (Trevathan et al., 1994), but later, Landschoot and Hoyland (1992) discovered it on golf course fairways at two golf courses in southeastern Pennsylvania. Gray leaf spot incidence is greatest during periods of high temperature and high humidity and the only effective chemical control is the fungicide chlorothalonil (Couch, 1995).

Fungicide Use

There are many fungicides available with many different modes of action. Contact fungicides are not absorbed by the plant, but are very effective in a preventative control program. Penetrant fungicides are taken up by the plant and may remain localized, be transported acropetally or be transported in both the xylem and phloem (Couch, 1995). This activity within the plant is known as the topical mode of action and differs from the biochemical mode of action. Each fungicide possesses a specific biochemical mode of action that alters the metabolic processes of fungal cells.

Perennial ryegrass golf course fairways in the transition zone are susceptible to a number of diseases throughout the summer period. Preventative fungicide applications are normally required to avoid deteriorating levels of quality or loss of grass. Dernoeden (1991) evaluated the effects of five fungicides on seasonal quality of perennial ryegrass and concluded that all fungicides improved turfgrass quality over nontreated check plots. Most disease control programs schedule rotational use of a number of different fungicides with differing modes of action.

Chlorothalonil and propiconazole are two distinctly different chemicals, that have been effective both alone and together in control of a broad spectrum of disease organisms (Couch, 1995). Chlorothalonil is a contact fungicide effective against many disease pathogens, including *Pyricularia grisea* (Cke.) Sacc, the causal agent of gray leaf spot. Propiconazole is a penetrant-type fungicide that is transported upward within the plant. This systemic activity in the plant offers curative potential if infection of plant tissue has already occurred. Research has shown the use of these two chemicals together is a highly effective disease control strategy. Dernoeden and Davis (1989) and Dernoeden and Fry (1985) demostrated the best control of *Rhizoctonia solani* Kuhn and highest levels of turf quality were achieved with combinations of chlorothalonil and propiconazole.

Growth regulating effects

Some fungicides possess nontarget regulatory activity of plant metabolism. Certain triazole fungicides have been reported to simulate inhibitors of gibberellin biosynthesis in plants (Kane and Smiley, 1983; Sisler et al., 1984; Koller, 1987). However, root and shoot growth responses to the triazole fungicides used were primarily positive. Goatley and Schmidt (1990) demonstrated increased leaf numbers and lateral bud development in Kentucky bluegrass with applications of propiconazole. Research with perennial ryegrass by Lewis et al. (1996) found that propiconazole increased the number of leaves per tiller while reducing the proportion of dead leaves. In addition, the use of fungicides with other plant growth regulators may be advantageous. Findings by Burpee et al. (1996) indicate that pretreatment of turfgrass with the PGR trinexapac-ethyl may enhance the efficacy of both chlorothalonil and propiconazole.

Annual Grass Control

Weed management is an integral part of a turfgrass management program, and especially important in golf course fairways. Typically, preemergence herbicides have been used to control annual grass weeds in turfgrass. Large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and goosegrass (*Eleusine indica* (L.) Gaertn.) are two major weeds targeted in turfgrass weed control programs, with goosegrass being the most difficult to control (Johnson, 1982a). Most herbicides that control goosegrass also control crabgrass, but not all herbicides that control crabgrass will effectively control goosegrass. Therefore, most fairway weed control programs emphasize the control of goosegrass populations.

Selection of a herbicide that will not restrict root growth is vital for newly seeded turf or for recently transplanted sod. Although herbicide use is generally considered beneficial as well as necessary in maintaining high quality turfgrass, studies have indicated reduction in turfgrass quality, and root growth coupled with disease enhancement in some turfgrass species (Bhowmik and Bingham, 1991; Gaskin, 1964; Hummel et al., 1990). The use of preemergence herbicides limits the ability to establish new turfgrass plants from seed; therefore, where areas to be seeded exist, postemergence control of annual grasses may be a more feasible option. However, the use of organic arsenical postemergence herbicides is often accompanied by unacceptable turf injury (Bingham and Shaver, 1981).

Preemergence herbicides

In the transition zone, goosegrass seed begins to germinate in late May or early June (Dernoeden et al., 1984), while crabgrass seed may germinate a few weeks prior to that. Since seeds germinate continuously through the summer, a preemergence herbicide application with a long residual period would seem the most practical means of annual grass control. While there are many herbicides available, there exists varying degrees of efficacy, and many are not effective against goosegrass. Oxadiazon is a preemergence herbicide that has been shown to effectively control both crabgrass and goosegrass. Research has shown that single applications of 3.4 kg ha^{-1} of oxadiazon provides excellent goosegrass control (Johnson, 1982b; Bingham and

Shaver, 1981) and, from an additional study, Dernoeden et al. (1984) concluded that an application of 2.2 kg ha^{-1} could be expected to provide season-long control of goosegrass in the transition zone.

Turfgrass injury may sometimes occur following herbicide applications. Generally, oxadiazon at recommended rates poses no phytotoxicity problems. Dunfield et al. (1987) evaluated the effects of oxadiazon on four bermudagrass cultivars and found even high rates (9 kg a.i. ha^{-1}) to be safe. However, Brede et al. (1987) noted discoloration of perennial ryegrass when the wettable powder formulation of oxadiazon was applied at 3.4 kg a.i. ha^{-1}, although the turf recovered completely within two weeks.

Choi and Johnson (1995) evaluated the effects of sixteen herbicides including oxadiazon on zoysiagrass seedlings in the 2-3 leaf or 4-5 leaf stage. They discovered that treating with oxadiazon was less phytotoxic than most other herbicides while providing good weed control, and resulted in the best establishment. The nature of preemergence herbicides normally prevent their use immediately prior to seeding a desired turfgrass. Siduron is an effective preemergence herbicide that can be applied prior to seeding certain cool season grasses, but it is highly injurious to bermudagrass seedlings. Fermanian et al. (1980) studied the effects of preemergence herbicides on bermudagrass seed germination, and concluded that both siduron and oxadiazon were highly phytotoxic. In the same study, metribuzin was safe for bermudagrass seed establishment; however, it is labeled only for use on established bermudagrass.

Herbicide deactivation with activated charcoal

Herbicide residues in soil often cause turfgrass seedings to fail. Jagschitz (1974) investigated the use of activated charcoal to adsorb chemicals and nullify the harmful effects to allow seed establishment of various cool season turfgrasses. Results showed that activated charcoal improved stands in seedbeds containing many herbicides including oxadiazon. Samples and Brede (1986a) were able to establish 'Plains' bluestem (*Bothriochloa ischaemum* var. *ischaemum* (**L.**) Keng.) from seed following application of eight selected preemergence herbicides using activated carbon at 2013 or 4026 kg ha^{-1} applied to the soil surface. A similar study examined germination of bermudagrass 'Guymon' seeds following five preemergence herbicide applications and subsequent activated charcoal applications (Samples and Brede, 1986b). Activated charcoal applied at 560 and 1120 kg ha^{-1} inactivated the herbicides and permitted bermudagrass establishment.

Postemergence herbicides

Traditionally, postemergence grass weed control has been through single and repeat applications of the organic arsenicals (e.g. MSMA, monosodium methanearsonate and DSMA, disodium methanearsonate). Two to four applications spaced 7 to 10 days apart generally are required to achieve desired control (McCarty, 1993). The rate and number of applications are directly related to the maturity level of the target weed. While warm season grasses are relatively tolerant of these herbicides, organic arsenicals can be very phytotoxic to cool season turfgrasses, especially during periods of high heat. Multiple applications are often necessary to control annual grass weeds and to reduce turfgrass phytotoxicity (Engel and Ilnicki, 1969; Miller and King, 1982). When injury is expected, research has shown that foliar-applied iron enhances bermudagrass tolerance to herbicides (Johnson et al., 1990.)

Weed control is important during turfgrass establishment. Weed seeds often germinate during the optimal times to establish turfgrass and annual grass weeds tend to be very competitive against new turfgrass plants. Carrol et al. (1996) demonstrated enhanced cover from zoysiagrass sprigs with both pre- and postemergence herbicides. When turfgrass seeding is necessary, postemergence weed control is normally practiced. New turfgrass seedlings are somewhat susceptible however to injury from postemergence herbicides. Fenoxaprop-ethyl (0.2 kg ha^{-1}) caused severe injury to seedlings of buffalograss (Buchloe dactyloides (Nutt.) Engelm.) whereas MSMA (2.2 kg ha^{-1}) did not cause any injury (Fry and Upham, 1994). Powell (1981) indicated that MSMA at 4.5 kg a.i. ha^{-1} did not injure perennial ryegrass seedlings.

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Chapter 1

Bermudagrass Seed Establishment into Perennial Ryegrass Under Golf Course Fairway Culture in the Transition Zone as Influenced by Plant Growth Regulator, Herbicide, and Fungicide Application

INTRODUCTION

Turfgrass species used for golf course fairways vary across the United States and may include creeping bentgrass (*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.) fine fescues (*Festuca* sp. L.) in cool climates or bermudagrass (*Cynodon dactylon* [L.] Pers.) and zoysiagrass (*Zoysia japonica* Steud.) in warm climates (Beard, 1982). There are many factors to consider in selecting a proper turf species for fairway use, but ultimately, climatic adaptation becomes the limiting factor. The geographical area separating the temperate and subtropical climates is commonly referred to as the transition zone, and includes much of Virginia and Maryland. The transition zone presents unique challenges in selecting and managing a turfgrass species to sustain a perennial, high-quality golf course fairway. Warm season species such as bermudagrass are prone to winter injury or winter kill, while cool season species such as perennial ryegrass are susceptible to many summer stresses including diseases and drought. Turfgrass stands composed of multiple species may be better able to withstand environmental and pest stresses compared to monoclonal communities (Watschke and Schmidt, 1992).

Bermudagrass is a vigorous, sod-forming perennial adapted to warm humid and semiarid climates with extended periods of high temperatures, mild winters, and moderate to high rainfall (Duble, 1996). Winter survival hinders the use and persistence of bermudagrass for turf throughout the northernmost limits of warm climates (Chalmers and Schmidt, 1979). Bermudagrass enters a winter dormancy in areas where average daily temperatures are below 10^{o} C, and winter injury may occur even at normal winter temperatures (2.2 to 7.8 C, daily average) throughout the transition zone (Bruneau et al., 1993). Less than ideal growing conditions may predispose bermudagrass to increased winter injury. Research has shown that cold tolerance can be influenced by traffic, shade, plant nutrition, soil moisture, and mowing height (Taliaferro, 1994).

Perennial ryegrass is a cool season, bunch-type grass that may behave as an annual, short-lived perennial, or perennial depending on environmental conditions (Turgeon, 1996). Improved varieties possess greater cold and wear tolerance, increased heat and drought tolerance, better disease resistance, finer leaf textures, tolerance to closer mowing, and darker green color than common perennial ryegrass (Duble, 1996; Emmons, 1995). These characteristics have made perennial ryegrass an appropriate choice for monostands in golf course fairway in parts of the transition zone. Although these newer varieties are more vigorous, they are still susceptible to disease outbreaks during periods of high stress in the summer. Environmental conditions during the summer of 1995 led to outbreaks of gray leaf spot (*Pyricularia grisea* (Cke.) Sacc.) that damaged perennial ryegrass fairways throughout the transition zone (Dernoeden, 1996).

This research focuses on enhancing summer quality of a perennial ryegrass monostand on a golf course fairway in the transition zone through late-spring establishment of bermudagrass from seed. The successful establishment of bermudagrass in this manner has the potential to offset declining quality of perennial ryegrass during periods of disease stress, while possibly reducing fungicide applications.

OBJECTIVES

The objectives of this study were to evaluate the contribution from late-spring seeded bermudagrass to perennial ryegrass fairway quality using:

A) A plant growth regulator to reduce perennial ryegrass competition

B) A post-emergence herbicide prior to bermudagrass seeding to attempt to control crabgrass and/or goosegrass.

C) Summer fungicide applications to prevent disease incidence

MATERIALS AND METHODS

Field studies were conducted at two sites, one being a perennial ryegrass fairway in Centreville, Virginia, and the other an area of perennial ryegrass simulated as a fairway in Blacksburg, Virginia. The perennial ryegrass varieties were unknown at both sites. Centreville, located in northern Virginia, is considered to possess a transition zone climate. The Centreville site was a Penn silt loam, located on the 16th fairway at Chantilly National Golf and Country Club in, while the Blacksburg site was a mature stand of perennial ryegrass on a Frederick silt loam at the Virginia Tech Turfgrass Research Center. Treatments at both sites were identical with only the dates of initial treatments and schedule of subsequent treatments varying. The experiment included 36 treatments comprised of four variables and replicated four times (Table 1.1). These variables included: bermudagrass 'Mirage' seed, (seeded or not seeded); plant growth regulator (PGR) trinexapac-ethyl, (none or full rate); post-emergence herbicide monosodium methanarsenate (MSMA), (none, 7d intervals at half rate, or 14d intervals at full rate); and fungicides chlorothalonil and propiconazole (none, half rate, or full rate). Plot size was 1.8 x 1.8 meters and there were a total of 144 plots at each location arranged in a split-block randomized design. Plots at both locations were mowed three times a week at a 1.6 centimeter cutting height, and irrigation was provided as needed to prevent moisture stress.

CENTREVILLE STUDY

The Centreville study was begun on 10 May, 1996 with applications of MSMA at 1.12 and 2.24 kg a.i. ha^{-1}. The 1.12 kg rate is considered a half rate and was applied on a weekly basis, (5 May, 17 May, 24 May) while the full rate of 2.24 lb was applied a at two week interval (5 May, 24 May) until two weeks prior to seeding date for

Table 1.1 Treatments for 1996 Centreville and Blacksburg field studies.

Trt #	**Seed** †	**PGR** ‡	**Fungicide** §	**Herbicide** ¶
1	Seed	TE	None	None
2	Seed	TE	None	MSMA 7 days
3	Seed	TE	None	MSMA 14 days
4	Seed	TE	Half rate	None
5	Seed	TE	Half rate	MSMA 7 days
6	Seed	TE	Half rate	MSMA 14 days
7	Seed	TE	Full rate	None
8	Seed	TE	Full rate	MSMA 7 days
9	Seed	TE	Full rate	MSMA 14 days
10	Seed	None	None	None
11	Seed	None	None	MSMA 7 days
12	Seed	None	None	MSMA 14 days
13	Seed	None	Half rate	None
14	Seed	None	Half rate	MSMA 7 days
15	Seed	None	Half rate	MSMA 14 days
16	Seed	None	Full rate	None
17	Seed	None	Full rate	MSMA 7 days
18	Seed	None	Full rate	MSMA 14 days
19	None	TE	None	None
20	None	TE	None	MSMA 7 days
21	None	TE	None	MSMA 14 days
22	None	TE	Half rate	None
23	None	TE	Half rate	MSMA 7 days
24	None	TE	Half rate	MSMA 14 days
25	None	TE	Full rate	None
26	None	TE	Full rate	MSMA 7 days
27	None	TE	Full rate	MSMA 14 days
28	None	None	None	None
29	None	None	None	MSMA 7 days
30	None	None	None	MSMA 14 days
31	None	None	Half rate	None
32	None	None	Half rate	MSMA 7 days
33	None	None	Half rate	MSMA 14 days
34	None	None	Full rate	None
35	None	None	Full rate	MSMA 7 days
36	None	None	Full rate	MSMA 14 days

† 'Mirage' bermudagrass seeded at 98 kg ha^{-1}
‡ Trinexapac-ethyl at 0.25 kg ha^{-1}
§ Propiconazole + chlorothalonil at half (0.5 kg +1.5 kg ha^{-1}) and full (1 kg + 3 kg ha^{-1}) rates
¶ MSMA (monosodium salt of methylarsonic acid) at 7 (1.12 kg a.i. ha^{-1}) or 14 days (2.24 kg a.i. ha^{-1})

bermudagrass. On 7 June, plots to receive bermudagrass seed were vertically mowed and seeded at 98 kg ha^{-1} using a 0.9 meter drop-type spreader. Fungicide and PGR treatments were also intiated 7 June, with propiconazole and chlorothalonil applied at half (0.5 kg +1.5 kg ha^{-1}) and full rates (1 kg + 3 kg ha^{-1}) and trinexapac-ethyl applied at 0.25 kg ha^{-1}. Trinexapac-ethyl was only applied 7 June, while fungicide treatments followed a two-week preventative schedule through the end of August.

BLACKSBURG STUDY

The Blacksburg study was initiated on 21 May, 1996 with applications of MSMA at 1.12 and 2.24 kg a.i. ha^{-1}. The 1.12 lb rate is considered a half rate and was applied on a weekly basis, (21 May, 28 May, 4 June) while the full rate of 2.24 lb was applied at two week intervals (21 May, 4 June) until two weeks prior to seeding date for bermudagrass. On 18 June, plots to receive bermudagrass seed were vertically mowed and seeded at 98 kg ha^{-1} using a 0.9 meter drop-type spreader. Fungicide and PGR treatments were also initiated at this time, with propiconazole and chlorothalonil applied at half (0.5 kg +1.5 kg ha^{-1}) and full rates (1 kg + 3 kg ha^{-1}) and trinexapac-ethyl applied at 0.25 kg ha^{-1}. Trinexapac-ethyl was only applied 18 June, while fungicide treatments followed a two-week preventative schedule through the end of August.

Treatment Evaluation

Observations during this study consisted of visual ratings of quality, disease, crabgrass (*Digitaria sp*.) infestations, and bermudagrass establishment. Quality data was recorded on a scale of 1 to 9, (1 = brown or dead turfgrass, 9 = very dense, uniform turf) where 5 would be indicative of an acceptable level of quality for a fairway turf. Disease data was also on a 1 to 9 scale, where 1= severely diseased or damaged turf, and 9 = no disease present. Crabgrass infestation and bermudagrass establishment was estimated as a percentage of area of the total plot, from 0 to 100 percent. The crabgrass data relied on natural infestations since crabgrass was not overseeded. Quality data was recorded from June through September while disease data was only recorded from June through August, during periods of disease pressure. Crabgrass emergence was first noted in early July, and was monitored into August. Bermudagrass seedling establishment was very slow; therefore, percent bermudagrass was not measured until early September in Centreville. All data was subjected to analysis of variance (ANOVA) procedures using the SAS (SAS, 1985) system. Treatment means were compared using Fishers least significant difference (LSD) test, which performs pairwise t-tests.

Results

At both locations, perennial ryegrass quality ratings generally remained above acceptable levels throughout the summer, although there was a gradual decline in quality from July through August for all treatment variables. It should be noted that the climatic conditions of the summer included subnormal temperatures and higher than average rainfall (Appendix 1), both of which favor the persistence of a cool season turfgrass. Furthermore, Blacksburg, Virginia, at an elevation of greater than 600 meters, has a climate more conducive to growth and persistence of perennial ryegrass.

CENTREVILLE STUDY

Treatment evaluation

The establishment of bermudagrass was minimal for most treatments ranging from 2 to 20 percent (Table 1.2). Fungicide ($P<.01$) and PGR ($P<.05$) treatments were significant for bermudagrass establishment, while herbicide treatments were not. There were no significant interactions among factors in bermudagrass establishment. Final quality ranged from poor (< 5) in non-fungicide treated turf to excellent (5 to 7) in fungicide treated turf (Table 1.3). There were no significant interactions that influenced turf quality.

Bermudagrass seeding effects

Bermudagrass seeding slightly improved summer quality over non-seeded plots during August and September, but was significant only on 16 August (Table 1.4). Bermudagrass seeding did not influence disease incidence during any observations over the summer. Plots were seeded on 7 June 1996, and while bermudagrass

Table 1.2 Visual estimates on 9 September, 1996 of percent bermudagrass in perennial ryegrass fairway plots seeded with 'Mirage' bermudagrass at 98 kg ha^{-1} on 7 June, 1996 in Centreville, Virginia.

Trt #	PGR ‡	Fungicide §	Herbicide¶	Bermudagrass -- % --
1	TE	None	None	20.0 a *****
2	TE	None	MSMA 7 days	20.0 a
3	TE	None	MSMA 14 days	17.5 ab
4	TE	Half rate	None	4.5 c
5	TE	Half rate	MSMA 7 days	4.0 c
6	TE	Half rate	MSMA 14 days	4.5 c
7	TE	Full rate	None	5.3 c
8	TE	Full rate	MSMA 7 days	4.8 c
9	TE	Full rate	MSMA 14 days	2.3 c
10	None	None	None	15.0 ab
11	None	None	MSMA 7 days	13.8 ab
12	None	None	MSMA 14 days	12.5 b
13	None	Half rate	None	4.0 c
14	None	Half rate	MSMA 7 days	3.5 c
15	None	Half rate	MSMA 14 days	3.5 c
16	None	Full rate	None	2.0 c
17	None	Full rate	MSMA 7 days	2.0 c
18	None	Full rate	MSMA 14 days	2.5 c

Interactions:

PGR * Fung.	NS **
PGR * Herb.	NS
Fung * Herb.	NS

‡ Trinexapac-ethyl at 0.25 kg ha^{-1}

§ Propiconazole + chlorothalonil at half (0.5 kg +1.5 kg ha^{-1}) and full (1 kg + 3 kg ha^{-1}) rates

¶ MSMA (monosodium salt of methylarsonic acid) at 7 days (1.12 kg a.i. ha^{-1}) or 14 days (2.24 kg a.i. ha^{-1})

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

****** Interactions are not significant (NS) when P>.05

Table 1.3 Visual estimates on 9 September, 1996 of final quality in perennial ryegrass fairway plots in Centreville, Virginia.

Trt. †	**PGR** ‡	**Fungicide** §	**Herbicide**¶	**Quality (9 Sept)**
1	TE	None	None	4.3
2	TE	None	MSMA 7 days	4.8
3	TE	None	MSMA 14 days	3.5
4	TE	Half rate	None	6.0
5	TE	Half rate	MSMA 7 days	6.0
6	TE	Half rate	MSMA 14 days	6.3
7	TE	Full rate	None	5.0
8	TE	Full rate	MSMA 7 days	5.8
9	TE	Full rate	MSMA 14 days	7.0
10	None	None	None	4.3
11	None	None	MSMA 7 days	4.8
12	None	None	MSMA 14 days	4.0
13	None	Half rate	None	6.0
14	None	Half rate	MSMA 7 days	5.5
15	None	Half rate	MSMA 14 days	5.3
16	None	Full rate	None	5.5
17	None	Full rate	MSMA 7 days	6.0
18	None	Full rate	MSMA 14 days	6.8
19	TE	None	None	3.8
20	TE	None	MSMA 7 days	4.3
21	TE	None	MSMA 14 days	3.8
22	TE	Half rate	None	6.3
23	TE	Half rate	MSMA 7 days	5.5
24	TE	Half rate	MSMA 14 days	5.3
25	TE	Full rate	None	6.3
26	TE	Full rate	MSMA 7 days	6.0
27	TE	Full rate	MSMA 14 days	6.3
28	None	None	None	4.0
29	None	None	MSMA 7 days	4.3
30	None	None	MSMA 14 days	4.0
31	None	Half rate	None	4.8
32	None	Half rate	MSMA 7 days	5.3
33	None	Half rate	MSMA 14 days	5.0
34	None	Full rate	None	6.0
35	None	Full rate	MSMA 7 days	6.5
36	None	Full rate	MSMA 14 days	6.0
LSD (0.05)				1.3
Interactions:	PGR * Fung., PGR * Herb., Fung. * Herb.			NS

† Treatments 1-18 were seeded with bermudagrass (98 kg ha^{-1}), treatments 19-36 were not seeded.
‡ Trinexapac-ethyl at 0.25 kg ha^{-1}
§ Propiconazole + chlorothalonil at half (0.5 kg +1.5 kg ha^{-1}) and full (1 kg + 3 kg ha^{-1}) rates
¶ MSMA (monosodium salt of methylarsonic acid) at 7 (1.12 kg a.i. ha^{-1}) or 14 days (2.24 kg a.i. ha^{-1})

Table 1.4 Bermudagrass seeding effects on 1996 perennial ryegrass summer quality in Centreville, Virginia.

Seed	Quality Rating †					
--kg ha^{-1}--	21-Jun	4-Jul	19-Jul	2-Aug	16-Aug	9-Sep
98	6.6 a*	6.8 a	6.4 a	6.0 a	5.8 a	5.4 a
0	6.7 a	6.7 a	6.4 a	5.8 a	5.4 b	5.2 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

seedlings were first noticed in middle July, the impact from bermudagrass seeding was not expressed until mid-August.

PGR effects

The seeding establishment of bermudagrass was significantly increased as a result of the 7 June application of trinexapac-ethyl (Table 1.5). PGR-treated plots resulted in a mean percent bermudagrass established of 9.2 percent, while untreated plots had 6.5 percent. Late-spring applied trinexapac-ethyl did not influence turfgrass quality at any time (Table 1.6). Generally, trinexapac-ethyl did not affect disease incidence. The one exception was on 21 June when PGR-treated plots had more disease activity than untreated plots.

Fungicide effects

Plots treated with either half or full rates of propiconazole and chlorothalonil had significantly higher levels of quality than untreated plots from July through September, but the rate of fungicide did not influence quality until September (Table 1.7).
By August 16, non-fungicide treated plots had declined to below acceptable quality levels, and declined even further by September. Quality levels were normally directly associated with disease levels at that time. Disease incidence in perennial ryegrass was significantly greater in untreated plots than in plots treated with half or full rates of propiconazole and chlorothalonil during all observations (Table 1.8). The presence or abscence of fungicide applications did influence the establishment

Table 1.5 Visual estimates on 9 September, 1996 of percent bermudagrass in perennial ryegrass fairway plots seeded with ‘Mirage’ bermudagrass at 98 kg ha^{-1} on 7 June, 1996 in Centreville, Virginia as influenced by plant growth regulator, fungicide, and herbicide application.

Treatment Variable	Rate (kg ha^{-1})	% Bermudagrass
Trinexapac-ethyl	0.25	9.2 a †
Trinexapac-ethyl	0	6.5 b
Propiconazole + Chlorothalonil	1 + 3	3.1 b
Propiconazole + Chlorothalonil	0.5 + 1.5	4.0 b
Propiconazole + Chlorothalonil	0	16.5 a
MSMA	2.24 (a.i.)	7.1 a
MSMA	1.12 (a.i.)	8.0 a
MSMA	0	8.5 a

† Means in the same treatment variable followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probability level.

Table 1.6 Trinexapac-ethyl (TE) effects on 1996 perennial ryegrass quality in Centreville, Virginia.

TE	Quality Rating †						
kg ha^{-1}	7-Jun	21-Jun	4-Jul	19-Jul	2-Aug	16-Aug	9-Sept
0.25	6.6 a*	6.6 a	6.7 a	6.4 a	5.8 a	5.4 a	5.3 a
0	6.6 a	6.7 a	6.7 a	6.5 a	5.9 a	5.7 a	5.2 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 1.7 Propiconazole (PPC) and chlorothalonil (C) effects on 1996 perennial ryegrass quality in Centreville, Virginia.

Fungicide	Quality Rating †						
---kg ha^{-1}---	7-Jun	21-Jun	4-Jul	19-Jul	2-Aug	16-Aug	9-Sep
0	6.8 a*	6.5 a	6.6 a	6.1 b	5.4 b	4.5 b	4.1 c
0.5 (PPC) + 1.5 (C)	6.4 b	6.7 a	6.8 a	6.7 a	6.2 a	6.0 a	5.6 b
1.0 (PPC) + 3.0 (C)	6.6 ab	6.7 a	6.8 a	6.6 a	6.1 a	6.3 a	6.1 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 1.8 Propiconazole (PPC) and chlorothalonil (C) effects on 1996 disease incidence in perennial ryegrass in Centreville, Virginia.

Fungicide	Disease Rating †			
---kg ha^{-1}---	21-Jun	4-Jul	19-Jul	2-Aug
0	8.1 b*	8.5 b	7.4 b	7.9 c
0.5 (PPC) + 1.5 (C)	8.7 a	8.8 a	8.3 a	8.8 a
1.0 (PPC) + 3.0 (C)	8.8 a	8.6 ab	8.4 a	8.3 b

† Disease ratings were recorded on a 1 to 9 scale, where 1 = severely diseased or dead turf, 9 = no disease present.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

success of seeded bermudagrass (Table 1.5). Fungicide application at half and full rates led to mean bermudagrass establishment of only 4.0 percent and 3.1 percent respectively. Conversely, those plots not treated with fungicides resulted in mean bermudagrass establishment of 16.5 percent, a highly significant increase.

Herbicide effects

Generally, late spring applications of MSMA did not influence plot quality (Table 1.9). Plots treated with 2.24 kg a.i. ha^{-1}on 14d intervals had higher quality ratings throughout the summer, but the differences were small and only significant during observations in June and July. MSMA applications were not significant for weed control at the Centreville location due to lack of a significant crabgrass population. Mean crabgrass infestations did not exceed 1 percent for any treatment variable. Disease incidence was generally unaffected by MSMA applications, except on 21 June, where untreated plots had slightly higher levels of disease. MSMA did not affect the establishment of bermudagrass at any time duing the experiment (Table 1.5).

Table 1.9 MSMA effects on 1996 perennial ryegrass quality in Centreville, Virginia.

MSMA	Quality Rating †						
---kg ha^{-1}---	7-Jun	21-Jun	4-Jul	19-Jul	2-Aug	16-Aug	9-Sep
0	6.6 a*	6.5 b	6.7 a	6.4 ab	5.9 a	5.8 a	5.17a
1.12	6.5 a	6.7 ab	6.6 a	6.4 b	5.8 a	5.5 a	5.38a
2.24	6.6 a	6.8 a	6.8 a	6.6 a	6.0 a	5.5 a	5.25a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

*Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

BLACKSBURG STUDY

Bermudagrass seeding effects

Bermudagrass seeding on 18 June, 1996 in Blacksburg was unsuccessful. Establishment varied from no bermudagrass to traces (< 1%) of bermudagrass. Therefore, this data is not reported for the Blacksburg site. Bermudagrass seeding did not influence summer quality of the perennial ryegrass plots, disease incidence, or crabgrass infestations at any time during the rating period (Table 1.10).

PGR effects

Trinexapac-ethyl applied prior to bermudagrass seeding did not enhance seed establishment as it did in Centreville. Quality ratings of perennial ryegrass were generally slightly higher on plots treated with trinexapac-ethyl, and were significantly higher during two recording dates (Table 1.11), although differences were small. Disease incidence and crabgrass infestations were not affected by trinexapac-ethyl (Table 1.11).

Fungicide effects

Plots treated with either half or full rates of propiconazole and chlorothalonil had significantly higher levels of quality than untreated plots in August and September, and the full rate resulted in significantly higher quality than the half rate in September only (Table 1.12). Disease ratings taken on 29 July indicated a highly significant increase in disease incidence on untreated plots, while plots treated with half and full rates were both virtually disease free (Table 1.12).

Table 1.10 Bermudagrass seeding effects on 1996 summer quality, disease incidence, and percent crabgrass on perennial ryegrass in Blacksburg, Virginia.

Seed	Quality Rating †				Disease Rating ‡	% Crabgrass
---kg ha^{-1}---	19-Jun	3-Jul	14-Aug	14-Sep	29-Jul	14-Aug
98	4.9 a*	5.1 a	5.2 a	5.7 a	8.2 a	6.7 a
0	4.9 a	5.1 a	5.2 a	5.7 a	8.1 a	6.3 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

‡ Disease ratings were recorded on a 1 to 9 scale, where 1 = severely diseased or dead turf, 9 = no disease present.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 1.11 Trinexapac-ethyl (TE) effects on 1996 summer quality, disease incidence, and percent crabgrass on perennial ryegrass in Blacksburg, Virginia.

TE	Quality Rating †				Disease Rating ‡	% Crabgrass
--kg ha^{-1}--	19-Jun	3-Jul	14-Aug	14-Sep	29-Jul	14-Aug
0.25	5.0 a*	5.1 a	5.3 a	5.8 a	8.2 a	6.3 a
0	4.8 b	5.1 a	5.2 a	5.6 b	8.2 a	6.7 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

‡ Disease ratings were recorded on a 1 to 9 scale, where 1 = severely diseased or dead turf, 9 = no disease present.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 1.12 Propiconazole (PPC) and chlorothalonil (C) effects on 1996 summer quality, disease incidence, and percent crabgrass on perennial ryegrass in Blacksburg, Virginia.

Fungicide	Quality Rating †				Disease Rating ‡	% Crabgrass
---(kg ha^{-1})---	19-Jun	3-Jul	14-Aug	14-Sep	29-Jul	14-Aug
0	4.9 a*	5.3 a	4.2 b	4.5 c	6.7 b	7.1 a
0.5 (PPC) + 1.5 (C)	4.9 a	5.0 a	5.6 a	6.2 b	8.9 a	6.9 a
1.0 (PPC) + 3.0 (C)	4.9 a	5.1 a	5.9 a	6.4 a	8.9 a	5.5 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

‡ Disease ratings were recorded on a 1 to 9 scale, where 1 = severely diseased or dead turf, 9 = no disease present.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Herbicide effects

Turf quality was generally unaffected by late spring applications of MSMA (Table 1.13). Plots treated with 1.12 kg a.i. ha^{-1}on 7d intervals tended to have slightly higher quality ratings, but the difference was significant compared to untreated plots only during an observation in August, and there was no significant difference when compared to plots treated with 2.24 kg a.i. ha^{-1}on 14d intervals. Disease incidence was unaffected by herbicide treatments (Table 1.13). Percent crabgrass data recorded on 14 August indicated an increase in crabgrass in nontreated plots (7.9%) compared to plots treated with 1 lb ai/a on 7d intervals (5.0%) (Table 1.13).

Table 1.13 MSMA effects on 1996 summer quality, disease incidence, and percent crabgrass on perennial ryegrass in Blacksburg, Virginia.

MSMA		Quality Rating †			Disease Rating ‡	% Crabgrass
--kg ha^{-1}--	19-Jun	3-Jul	14-Aug	14-Sep	29-Jul	14-Aug
0	4.9 a*	5.2 a	5.1 b	5.6 a	8.0 a	7.9 a
1.12	4.9 a	5.1 a	5.4 a	5.8 a	8.3 a	5.0 b
2.24	4.9 a	5.2 a	5.2 ab	5.7 a	8.2 a	6.5 ab

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

‡ Disease ratings were recorded on a 1 to 9 scale, where 1 = severely diseased or dead turf, 9 = no disease present.

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference (LSD) at 0.05 probability level.

Discussion and Conclusions

Overall plot quality was not significantly improved in either location at any time from bermudagrass seeding, although mean quality levels were slightly higher from August through September for seeded plots in Centreville. Results from these studies indicate that it is difficult to establish bermudagrass seed into fairway stands of perennial ryegrass, especially those treated with preventative fungicide applications that maintained excellent density. The competitive nature of perennial ryegrass has been well documented by researchers (Hsiang et al., 1997; Marriott and Zuazua, 1996; Brede and Duich, 1986; Snaydon and Howe, 1986; Carrow and Troll, 1974, 1977). The high density and overall vigor of the perennial ryegrass compete with bermudagrass seedlings for light, moisture, and nutrients. Plots in Centreville developed small (3.1%) to moderate (16.5%) amounts of bermudagrass, while in Blacksburg, not more than a trace (< 1%) of bermudagrass developed under any treatment. This is most likely due to climatic differences in Blacksburg, which has lower temperatures and less disease pressure than does Centreville.

Trinexapac-ethyl applications did not influence overall turfgrass quality to any significant degree in Centreville; however in Blacksburg, plots treated with trinexapac-ethyl had significantly higher quality levels three months following application. Previous research with perennial ryegrass under golf course fairway culture found reduced turfgrass quality during the first three weeks following initial trinexapac-ethyl application, but turf recovered fully and even exhibited a denser, darker green appearance than untreated turf after two months (Wetzel and Dernoeden ,1994).

Bermudagrass establishment was significantly enhanced in Centreville with trinexapac-ethyl applied prior to seeding. This suggests that the competitive ability of perennial ryegrass was somewhat suppressed allowing increased seedling development. Fry and Dernoeden (1986) were able to achieve increased zoysiagrass establishment in PGR-treated perennial ryegrass than in non-treated controls, but not without some turf injury.

In Centreville, bermudagrass did not establish well in plots treated with preventative fungicide applications ($\leq$ 4%) compared to plots receiving no fungicides (16.5%). This may be attributed to reduced competition from untreated perennial ryegrass, which would allow for greater seedling development. Late-summer perennial ryegrass disease incidence, as indicated in Table 1.8, was significantly higher in untreated plots, and is directly related to unacceptable levels of turfgrass quality in August and September (Table 1.7). Bermudagrass establishment was greatly enhanced in these plots due to decreased competition in diseased perennial ryegrass. Although significant amounts of bermudagrass established in these plots, the transition from all perennial ryegrass to increasing amounts of bermudagrass did not occur without periods of unacceptable turf quality.

Late-spring applications of MSMA had no effect on turfgrass quality or disease incidence at either location. Crabgrass populations were insignificantly small in Centreville, while in Blacksburg, pre-plant applications of 1.12 kg a.i. ha^{-1} MSMA on 7d intervals resulted in lower amounts of crabgrass than in untreated plots. The herbicide

MSMA did not influence bermudagrass establishment in Centreville, and was not considered to be a deterrent to bermudagrass seed establishment.

The degree of difficulty in establishing bermudagrass seed into perennial ryegrass turf was correlated with the health of the ryegrass. The high density, vigor, and overall competitiveness of the fungicide treated perennial ryegrass greatly inhibited bermudagrass seed establishment.

These results indicate the use of trinexapac-ethyl offers potential for increased establishment success. Additionally, other methods of reducing perennial ryegrass competition need to be investigated, as well as factors that may influence seeding success (preplant cultivation, i.e., aerification, vertical mowing and closer mowing). Future research should address these factors and explore the competitive effects of existing turf species on bermudagrass seed establishment.

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Chapter 2

Competitive Effects of Perennial Ryegrass and Chewings Fescue on Bermudagrass Seed Establishment as Influenced by Glyphosate, Cultivation, and Herbicide Treatments

INTRODUCTION

All plants within a turfgrass community affect and are affected by neighboring plants within that community (Beard, 1973). Plants are continually competing for light, water, nutrients and essential gases, all of which are necessary to survive. The competitive ability of each turfgrass species is influenced by seasonal growth patterns, as well as growth habit and rate, and tolerance to stress (Watschke and Schmidt, 1992). According to Danneberger (1993) competition between grass species can occur in their tillers and/or roots. Generally, a grass with a high tillering capacity has an advantage over those with a lower tillering capacity (Lush, 1988; Grime and Hunt, 1975) and that capacity is subject to change with seasonal variations (Lush, 1988).

Previous research has done much to recognize the competitive abilities of perennial ryegrass. Brede and Duich (1986) studied both above ground and below ground interactions and found perennial ryegrass to possess a relatively high tillering capacity as well as a very competitive root system. Research with mixtures of various turfgrasses has shown perennial ryegrass to have a competitive advantage over other species (Snaydon and Howe, 1986; Carrow and Troll, 1974). Research in Canada compared 24 mixtures comprised of varieties of perennial ryegrass, fine fescue, Kentucky bluegrass, and tall fescue (Hsiang et al., 1997). Perennial ryegrass was the most competitive among the four species and increased in relative population percentage in nearly all plots in which it was seeded.

In the transition zone, where neither warm season nor cool season grasses are well adapted, a combination of warm and cool season turfgrasses may be advantageous (Beard, 1973). Dipaola and Spak (1990) demonstrated that turf quality of a Kentucky bluegrass and bermudagrass mixture was greatly improved over a bermudagrass monostand during the fall, winter, and spring, and over bluegrass monostands during the summer. However, due to competition, difficulty often arises in establishing a companion species in an existing mature turfgrass.

Traditionally, cool season and warm season mixtures consist of a cool-season species, such as perennial ryegrass, being seeded into an existing warm season turf prior to winter dormancy of the warm season species. Establishment is usually successful due to lower growth rates of warm season grasses associated with decreasing temperatures as well as the high vigor of ryegrass seedlings. Seeding a warm season grass, such as bermudagrass, into mature cool season turfgrasses has received limited attention since until recently, ‘Arizona Common’, a non-hardy variety, was the only seeded bermudagrass available. The advent of improved, cold hardy seeded bermudagrass cultivars may offer the opportunity to introduce a warm season grass into existing cool season swards, and potentially improve summer quality during stressful periods in the transition zone. When turfgrasses are seeded in the spring, postemergence weed control is normally practiced unless preemergence herbicides are deactivated with activated charcoal prior to seeding. However, new seedlings are somewhat susceptible to injury from application of some postemergence herbicides. Fenoxaprop-ethyl (0.2 kg ha^{-1}) caused severe injury to seedlings of buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) whereas MSMA (2.2 kg ha^{-1}) did not cause any injury (Fry and Upham, 1994).

Snaydon and Howe (1986) demonstrated the resistance of mature perennial ryegrass to invading grass seedlings, and concluded that ryegrass plants competed with seedlings mainly below-ground. Powell (1983) reported increased establishment of seeded zoysiagrass in glyphosate-treated Kentucky bluegrass than in untreated turfgrass. Unfortunately, the use of a non-selective herbicide during warm season seeding establishment into a high quality, cool season turfgrass such as a golf course fairway may not be feasible. Glyphosate applied in narrow strips across a existing stand may offer a means of establishing bermudagrass seed, while not severely lowering quality standards

Bermudagrass seeding into a less competitive turf such as fine fescue may increase establishment success while reducing or eliminating competition from existing stands of perennial ryegrass would certainly enhance bermudagrass seeding establishment.

OBJECTIVES

The objectives of this study were to determine how bermudagrass seed establishment into existing stands of perennial ryegrass and chewings fescue is influenced by:

A) Preplant cultivation

B) Fungicide applications

C) Glyphosate

D) Activated charcoal to deactivate preemergence herbicide applications

MATERIALS AND METHODS

Perennial ryegrass ‘Palmer II’ and Chewings fine fescue ‘Shadow’ were seeded separately on 24 September, 1996 at the Virginia Tech Turfgrass Research Center, in Blacksburg, Virginia. The existing soil was a Frederick silt loam (clayey, mixed, mesic, Typic Paleudult), located on a south-facing gentle slope (~ 2%) that previously contained mixed grasses and weeds. Two appications of glyphosate were made in late summer, and existing vegetation was tilled several times and smoothed to create a seedbed. The site received 98 kg ha^{-1} of nitrogen through the fall, followed by an additional 73 kg ha^{-1} in the spring, and irrigation was supplemented as needed during seedling establishment. The turf was mowed at 5 centimeters height with a rotary type mower through the fall period, and gradually reduced to 1.75 centimeters with a reeltype mower the following spring. Plots (1.8 x 1.8 meter) were imposed in early May on the perennial ryegrass and chewings fescue turf. Each species was treated as a separate experiment with treatments arranged in a complete randomized block experimental design, replicated four times. Sixteen treatments comprised: (1) preplant cultivation (aerification + vertical mowing); (2) preemergence herbicide (oxadiazon) with activated charcoal application; (3) non-selective herbicide application (glyphosate) with activated charcoal (five 2.5 cm strips, three 7.6 cm strips); and fungicides (propiconazole + chlorothalonil) (Table 2.1). Data was subjected to statistical analysis on the SAS (SAS, 1985) system using least square means, which accounts for unbalanced treatment combinations, and Fishers least significant means (LSD) test.

Table 2.1 Treatments for 1997 perennial ryegrass and fine fescue field studies in Blacksburg, Virginia.

Trt #	Ground Prep.	Herbicide †	Glyphosate ‡	Fungicide §
1	aerify + vert.mow	none	none	preventative
2	aerify + vert.mow	oxadiazon	none	preventative
3	aerify + vert.mow	oxadiazon	2.5 cm strips	preventative
4	aerify + vert.mow	oxadiazon	7.6 cm strips	preventative
5	aerify + vert.mow	none	none	none
6	aerify + vert.mow	oxadiazon	none	none
7	aerify + vert.mow	oxadiazon	2.5 cm strips	none
8	aerify + vert.mow	oxadiazon	7.6 cm strips	none
9	none	none	none	preventative
10	none	oxadiazon	none	preventative
11	none	oxadiazon	2.5 cm strips	preventative
12	none	oxadiazon	7.6 cm strips	preventative
13	none	none	none	none
14	none	oxadiazon	none	none
15	none	oxadiazon	2.5 cm strips	none
16	none	oxadiazon	7.6 cm strips	none

† Oxadiazon at 2.24 kg a.i. ha^{-1} includes activated charcoal application prior to seeding
‡ Glyphosate applied in five 2.5 cmstrips or three 7.6 cm strips over 1.8 m x 1.8 m plot
§ Preventative fungicide applications of propiconazole + chlorothalonil (1 kg + 3 kg ha^{-1})

Schedule of Treatments

All treatments were done concurrently on both the perennial ryegrass and Chewings fescue studies. On 6 May, 1997, oxadiazon (Ronstar 2G) was applied at 2.24 kg a.i. ha^{-1} to selected plots. On 18 June, activated charcoal was applied at 336 kg ha^{-1} to all plots that received oxadiazon, with certain plots receiving charcoal over the whole plot, while other plots received charcoal along with glyphosate applied in 2.5 cm or 7.6 cm strips across the plot. This application was performed using a template cut from large sheets of plywood, where one template had five 2.5 cm x 1.8 m strips and the other template had three 7.6 cm x 1.8 m strips cut out. The template was placed over the plot, and the application was made by spraying over the top using a backpack sprayer. Selected plots were aerified and vertical mowed. Seeding followed on 20 June. Whole plots were seeded at 98 kg ha^{-1} using a 0.9 meter drop-type spreader. Fungicide treatments began on 2 July and consisted of propiconazole and chlorothalonil at 1 kg + 3 kg ha^{-1}respectively. Fungicide applications were initiated at the onset of moderate disease pressure, and continued through late August on a two-week preventative schedule. Plots were mowed 3-4 times a week at 0.75 centimeters and irrigation was applied as needed during seedling development.

Results, Perennial Ryegrass Study

Generally, quality ratings remained above acceptable levels for golf course fairways throughout the summer. Typical summer stresses such as disease, high temperatures, or drought were atypical, and subsequently influenced the overall results. Disease was never severe enough to collect disease data, and fungicide treatments did not affect quality or bermudagrass establishment. The health and vigor of the perennial ryegrass provided an environment to enhance the competitive nature of perennial ryegrass on bermudagrass establishment from overseeding. Generally, quality levels remained high when ignoring glyphosate scars and were unaffected by treatment combinations (Table 2.2). Final ratings from 13 October summarized by treatment number indicate high levels of bermudagrass in cultivated plots as well as plots treated with strips of glyphosate (Table 2.2). There were not however, any significant interactions among factors within each treatment.

Cultivation Effects

Bermudagrass seeding was done on 20 June, and germination was evident by 30 June. Cultivation treatments of aerification and vertical mowing associated with seeding, were disruptive to the existing turf. All plots aerified and vertical mowed had significantly lower quality levels following cultivation than uncultivated plots into October (Table 2.3). However, ground preparation was highly significant ($P<.01$) in the successful establishment of bermudagrass (Table 2.4). Plots aerified and vertical mowed had significantly higher percentages of bermudagrass than those not cultivated during all three ratings from August to October.

Preemergence Herbicide/Activated Charcoal Effects

Crabgrass infestations in plot areas were too low to ascertain any effect from a late-spring application of oxadiazon. Oxadiazon, along with activated charcoal, applied prior to bermudagrass seeding, did not affect quality of perennial ryegrass at any time (Table 2.5) nor did it significantly influence bermudagrass establishment (Table 2.6).

Table 2.2 Visual estimates recorded on 13 October of percent bermudagrass and final quality in perennial ryegrass plots seeded with 'Mirage' bermudagrass at 98 kg ha $^{-1}$ on 20 June, 1997 in Blacksburg, Virginia.

Trt#	Ground Prep.	Herbicide †	Glyphosate ‡	Fungicide §	% Bermudagrass	Quality (ignoring scars)
1	aerify + vert.mow	none	none	preventative	10.8	6.5
2	aerify + vert.mow	oxadiazon	none	preventative	2.3	5.8
3	aerify + vert.mow	oxadiazon	2.5 cm strips	preventative	17.5	5.8
4	aerify + vert.mow	oxadiazon	7.6 cm strips	preventative	26.3	6.8
5	aerify + vert.mow	none	none	none	16.5	6.3
6	aerify + vert.mow	oxadiazon	none	none	4.5	6.3
7	aerify + vert.mow	oxadiazon	2.5 cm strips	none	23.8	5.8
8	aerify + vert.mow	oxadiazon	7.6 cm strips	none	26.3	6.8
9	none	none	none	preventative	1.3	6.8
10	none	oxadiazon	none	preventative	1.0	6.8
11	none	oxadiazon	2.5 cm strips	preventative	9.3	6.5
12	none	oxadiazon	7.6 cm strips	preventative	16.3	7.0
13	none	none	none	none	2.3	6.5
14	none	oxadiazon	none	none	2.3	6.3
15	none	oxadiazon	2.5 cm strips	none	13.5	6.5
16	none	oxadiazon	7.6 cm strips	none	13.8	6.0
LSD (0.05)					15.6	1.2

Interactions:				
	Ground Prep * Herbicide	NS ¶	Herbicide * Glyphosate	NS
	Ground Prep * Glyphosate	NS	Herbicide * Fungicide	NS
	Ground Prep * Fungicide	NS	Glyphosate * Fungicide	NS

† Oxadiazon at 2.24 kg a.i. ha $^{-1}$ includes activated charcoal application prior to seeding
‡ Glyphosate applied in five 2.5 cmstrips or three 7.6 cm strips over 1.8 m x 1.8 m plot
§ Preventative fungicide applications of propiconazole + chlorothalonil (1 kg + 3 kg ha $^{-1}$)
¶ Interactions are not significant (NS) when P>.05

Table 2.3 Preplant cultivation (aerification + vertical mowing) effects on 1997 quality of perennial ryegrass in Blacksburg, Virginia.

Cultivation	Mean Quality Rating †			
	11-Jun	31-Jul	14-Aug	13-Oct
With Ground Prep.	6.4	5.7 b	6.0 b	6.2 b
Without Ground Prep.	6.3	6.4 a	6.4 a	6.6 a
LSD (0.05)	NS*	0.3	0.3	0.3

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.4 Preplant cultivation (aerification + vertical mowing) effects on 1997 whole plot percent bermudagrass in perennial ryegrass in Blacksburg, Virginia.

Cultivation	Percent Bermudagrass		
	13-Aug	15-Sep	13-Oct
With Ground Prep.	12.0 a*	14.8 a	15.7 a
Without Ground Prep.	5.4 b	7.2 b	7.1 b
LSD (0.05)	4.9	5.5	5.6

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.5 Influence of oxadiazon followed by activated charcoal prior to seeding on 1997 quality of perennial ryegrass in Blacksburg, Virginia.

		Mean Quality Rating †			
Oxadiazon	A.Charcoal	11-Jun	31-Jul	14-Aug	13-Oct
---kg ha^{-1}---					
2.24	450	6.3	6.1	6.2	6.3
0	0	6.4	5.9	6.2	6.5
LSD (0.05)		NS*	NS	NS	NS

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.6 Influence of oxadiazon followed by activated charcoal prior to seeding on 1997 whole plot percent bermudagrass in perennial ryegrass in Blacksburg, Virginia.

		Percent Bermudagrass		
Oxadiazon	A.Charcoal	13-Aug	15-Sep	13-Oct
---kg ha^{-1}---				
2.24	450	8.6	12.0	12.8
0	0	8.3	7.9	7.1
LSD (0.05)		NS*	NS	NS

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Glyphosate Effects

As expected, glyphosate treatments were highly significant ($P<.01$) to bermudagrass establishment. Plots treated with strips of glyphosate had significantly higher percentages of bermudagrass establishment than nontreated plots (Table 2.7). Plots treated with 7.6 cm strips had slightly higher amounts of bermudagrass than in plots treated with 2.5 cm strips throughout the summer. Quality ratings were recorded with no penalty for scars left from glyphosate strips, and perennial ryegrass quality generally remained high (Table 2.8). While quality levels of plots treated with 7.6 centimeter strips of glyphosate were slighly higher than plots treated with 2.5 cm strips as well as untreated plots, there is no apparent explanation or justification for this occurrence.

Scar healing

The 2.5 cm and 7.6 cm strips of glyphosate imposed significant scars to heal. Visual estimates were recorded of healing or coverage due to bermudagrass as well as tillering of perennial ryegrass. Bermudagrass coverage was higher in 7.6 cm strips (44%) than 2.5 cm strips (23%) (Table 2.9). Scar healage by perennial ryegrass tillering was minimal (<17%).

Final Quality Data

On 13 October, final quality ratings were taken by normal criteria of ignoring scars and rating living turfgrass as well as overall quality, which did count unhealed scars against plot quality. When scars were not considered, perennial ryegrass quality

Table 2.7 Glyphosate effects on 1997 whole plot percent bermudagrass in perennial ryegrass in Blacksburg, Virginia.

	Percent Bermudagrass		
Glyphosate	13-Aug	15-Sep	13-Oct
None	4.7 b*	4.5 b	4.5 b
2.5 cm strips	11.3 a	15.6 a	16.0 a
7.6 cm strips	14.1 a	19.4 a	20.6 a

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Table 2.8 Glyphosate effects on 1997 quality (ignoring scars) of perennial ryegrass in Blacksburg, Virginia.

	Mean Quality Rating †			
Glyphosate	11-Jun	31-Jul	14-Aug	13-Oct
None	6.3 a*	5.9 b	6.1 b	6.4 ab
2.5 cm strips	6.5 a	6.1 ab	6.1 b	6.1 b
7.6 cm strips	6.3 a	6.5 a	6.6 a	6.6 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Table 2.9 Percent healing in 2.5 and 7.5 cm glyphosate-treated strips on 10 October, 1997 by bermudagrass and tillering of perennial ryegrass.

Glyphosate	---------% Scar Healed by---------	
	Bermudagrass	P. Rye tillering
2.5 cm strips	22.7 b*	16.9 a
7.6 cm strips	43.8 a	11.6 a

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

was well above acceptable (Table 2.2). However, when scars were considered, turfgrass quality was unacceptable where 2.5 or 7.6 cm strips of glyphosate were applied (Table2.10).

Results, Chewings Fescue Study

Generally, quality ratings remained above acceptable levels for golf course fairways throughout the summer. Typical summer stresses such as disease, high temperatures, or drought were atypical, and subsequently influenced the overall results. Disease was never severe enough to collect disease data. Fungicide treatments did not affect quality or bermudagrass establishment. Chewings fescue offered a means of comparison with perennial ryegrass to study the competitive nature of both grasses on bermudagrass seed establishment. Generally, quality levels remained high and were unaffected by treatment combinations. Final ratings from 13 October summarized by treatment number indicate high levels of bermudagrass in cultivated plots as well as plots treated with strips of glyphosate (Table 2.11). There were not however, any significant interactions among factors within each treatment.

Cultivation and Seeding Effects

Bermudagrass seeding was done on 20 June, and germination was evident by 30 June. Cultivation treatments associated with seeding, aerification and vertical mowing, were disruptive to the existing turf. Because of this disruption, all plots aerified and vertical mowed had significantly lower quality levels than uncultivated plots (Table 2.12). Ground preparation was however, highly significant ($P<.01$) in the establishment success of bermudagrass (Table 2.13). Plots that were aerified and

Table 2.10 Final quality (13 October, 1997) comparisons of perennial ryegrass by both ignoring and accounting for glyphosate scars in assessing turfgrass quality.

Glyphosate	Quality † (ignoring scars)	Quality (counting scars)
2.5 cm strips	6.1 b	3.9 b
7.6 cm strips	6.6 a	3.4 b

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Table 2.11 Visual estimates recorded on 13 October of percent bermudagrass and final quality in Chewings fescue plots seeded with 'Mirage' bermudagrass at 98 kg ha $^{-1}$ on 20 June, 1997 in Blacksburg, Virginia.

Trt#	Ground Prep.	Herbicide †	Glyphosate ‡	Fungicide §	% Bermudagrass	Final Quality (ignoring scars)
1	aerify + vert.mow	none	none	preventative	22.5	5.3
2	aerify + vert.mow	oxadiazon	none	preventative	28.8	6.0
3	aerify + vert.mow	oxadiazon	2.5 cm strips	preventative	27.5	5.8
4	aerify + vert.mow	oxadiazon	7.6 cm strips	preventative	38.8	5.5
5	aerify + vert.mow	none	none	none	22.5	6.0
6	aerify + vert.mow	oxadiazon	none	none	13.8	5.8
7	aerify + vert.mow	oxadiazon	2.5 cm strips	none	35.0	5.3
8	aerify + vert.mow	oxadiazon	7.6 cm strips	none	33.8	5.5
9	none	none	none	preventative	3.3	7.0
10	none	oxadiazon	none	preventative	9.5	7.0
11	none	oxadiazon	2.5 cm strips	preventative	8.8	5.5
12	none	oxadiazon	7.6 cm strips	preventative	22.5	6.5
13	none	none	none	none	3.3	6.0
14	none	oxadiazon	none	none	6.8	5.8
15	none	oxadiazon	2.5 cm strips	none	13.8	5.5
16	none	oxadiazon	7.6 cm strips	none	23.8	6.5
LSD (0.05)					14.0	1.5

Interactions:	Ground Prep * Herbicide	NS ¶	Herbicide * Glyphosate	NS
	Ground Prep * Glyphosate	NS	Herbicide * Fungicide	NS
	Ground Prep * Fungicide	NS	Glyphosate * Fungicide	NS

† Oxadiazon at 2.24 kg a.i. ha $^{-1}$ includes activated charcoal application prior to seeding
‡ Glyphosate applied in five 2.5 cmstrips or three 7.6 cm strips over 1.8 m x 1.8 m plot
§ Preventative fungicide applications of propiconazole + chlorothalonil (1 kg + 3 kg ha $^{-1}$)
¶ Interactions are not significant (NS) when P>.05

Table 2.12 Preplant cultivation (aerification + vertical mowing) effects on 1997 quality of chewings fescue in Blacksburg, Virginia.

Cultivation	Mean Quality Rating †			
	11-Jun	31-Jul	14-Aug	13-Oct
With Ground Prep.	5.7	4.6 b	4.5 b	5.6 b
Without Ground Prep.	6.1	5.7 a	5.6 a	6.2 a
LSD (0.05)	NS*	0.4	0.5	0.5

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.13 Preplant cultivation (aerification + vertical mowing) effects on 1997 whole plot percent bermudagrass in chewings fescue in Blacksburg, Virginia.

Cultivation	Percent Bermudagrass		
	13-Aug	15-Sep	13-Oct
With Ground Prep.	13.2 a	22.6 a	27.8 a
Without Ground Prep.	4.2 b	9.2 b	11.3 b
LSD (0.05)	3.4	4.7	5.0

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

vertical mowed had significantly higher percentages of bermudagrass during all three ratings from August to October. The surface disruption from preplant cultivation that lowered quality levels seemingly decreased competition from the existing turf and enhanced germination and establishment of bermudagrass seed.

Preemergence Herbicide/Activated Charcoal Effects

Crabgrass infestations in plot areas were too low to ascertain any effect from a late-spring application of oxadiazon. Oxadiazon, along with activated charcoal, applied prior to bermudagrass seeding resulted in greater bermudagrass establishment (Table 2.14), but it did lower the quality of chewings fescue plots in July and August (Table 2.15).

Glyphosate Effects

As expected, glyphosate treatments were highly significant ($P<.01$) to bermudagrass establishment. Plots treated with 2.5 cm or 7.6 cm strips of glyphosate had significantly higher percentages of bermudagrass establishment than untreated plots (Table 2.16).

Table 2.14 Influence of oxadiazon followed by activated charcoal prior to seeding on 1997 whole plot percent bermudagrass in chewings fescue in Blacksburg, Virginia.

		Percent Bermudagrass		
Oxadiazon	A.Charcoal	13-Aug	15-Sep	13-Oct
---kg ha^{-1}---				
2.24	450	9.9 a	17.8 a	21.9 a
0	0	5.1 b	10.1 b	12.8 b
LSD (0.05)		3.9	5.4	5.7

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.15 Influence of oxadiazon, followed by activated charcoal prior to bermudagrass seeding, on 1997 quality of chewings fescue in Blacksburg, Virginia.

		Mean Quality Rating †			
Oxadiazon	A.Charcoal	11-Jun	31-Jul	14-Aug	13-Oct
---kg ha^{-1}---					
2.24	450	5.9	4.9	4.8	5.9
0	0	6.0	5.8	5.8	6.1
LSD (0.05)		NS*	0.5	0.7	NS

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

* Means in the same column not followed by a letter are not significantly (NS) different under Fishers least significant difference (LSD) at 0.05 probability level.

Table 2.16 Glyphosate effects on 1997 whole plot percent bermudagrass in chewings fescue in Blacksburg, Virginia.

	Percent Bermudagrass		
Glyphosate	13-Aug	15-Sep	13-Oct
None	5.6 b	10.7 c	13.7 c
2.5 cm strips	11.3 a	17.2 b	21.3 b
7.6 cm strips	12.5 a	25.0 a	29.7 a

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Plots treated with 7.6 cm strips had slightly higher amounts of bermudagrass than in plots treated with 2.5 cm strips throughout the summer. Quality ratings were recorded with no penalty for scars left from glyphosate strips; however, following glyphosate application, chewings fescue quality fell below acceptable levels in the summer, but recovered by fall (Table 2.17).

Scar healing

The 2.5 cm and 7.6 cm strips of glyphosate imposed significant scars to heal. Visual estimates were recorded of healing or coverage due to bermudagrass as well as tillering of chewings fescue. Bermudagrass coverage was higher in 7.6 cm strips (44%) than 2.5 cm strips (23%) (Table 2.18). Chewings fescue tillering contributed well to scar healing (18-35%).

Final Quality Data

On 13 October, final quality ratings were taken by normal criteria of ignoring scars and rating living turfgrass as well as overall quality, which did take into account unhealed scars. When scars were not considered, chewings fescue quality was above acceptable (Table 2.11). However, when scars were accounted for, turfgrass quality was unacceptable where 2.5 cm or 7.6 cm strips of glyphosate had been applied (Table 2.19).

Table 2.17 Glyphosate effects on 1997 quality (ignoring scars) of chewings fescue in Blacksburg, Virginia.

	Mean Quality Rating †			
Glyphosate	11-Jun	31-Jul	14-Aug	13-Oct
None	6.0 a	5.6 a	5.6 a	6.1 a
2.5 cm strips	5.7 a	4.7 b	4.3 b	5.5 a
7.6 cm strips	6.0 a	4.8 b	4.8 b	6.0 a

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Table 2.18 Percent healing in 2.5 and 7.5 cm glyphosate-treated strips on 10 October, 1997 by bermudagrass and tillering of Chewings fescue.

	---------% Scar Healed by---------	
Glyphosate	Bermudagrass	Chewings fescue tillering
2.5 cm strips	32.6 b*	35.3 a
7.6 cm strips	60.9 a	18.1 b

***Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Table 2.19 Final quality (13 October, 1997) comparisons of chewings fescue by both ignoring and accounting for glyphosate scars in assessing turfgrass quality.

Glyphosate	Quality † (ignoring scars)	Quality (counting scars)
2.5 cm strips	5.5 a	4.3 b
7.6 cm strips	6.0 a	3.9 b

† Quality ratings were recorded on a 1 to 9 scale, where 1 = dead turf, and 9 = maximum turf quality.

*****Means followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probablility level.

Discussion and Conclusions

The competitive qualities of perennial ryegrass have been well documented in research (Hsiang et al., 1997; Brede and Duich, 1986; Snaydon and Howe, 1986; Carrow and Troll, 1974). Interseeding establishment using non-selective herbicides such as glyphosate to eliminate perennial ryegrass competition should greatly improve the introduction of bermudagrass into an existing turf. Results from this study show significantly higher percentages of bermudagrass established in plots when the existing turf was removed in 2.5 cm or 7.6 cm strips using glyphosate. The 2.5 cm strip treatment was comprised of five 2.5 cm strips across a 1.8 x 1.8 meter plot (7% of total area) while the 7.6 cm strip treatment was comprised of three 7.6 cm strips across the plot (12.5% of total area). Comparisons of treatments indicate the increased surface area in 7.6 cm treatments resulted in consistently higher percentages of bermudagrass than in 2.5 cm treatments. This is seemingly a direct result of the reduced competition by elimination of more of the existing cool season turfgrass.

There appears to be differences in the competitive abilities of perennial ryegrass and chewings fescue. The most accurate measure or means of comparison between these two species in the two separate studies lies in bermudagrass establishment in plots that did not receive any glyphosate. On 13 August, bermudagrass population in perennial ryegrass (4.7%) and chewings fescue (5.6%) plots was low for both species. However, over the subsequent two months, bermudagrass in chewings fescue increased to 13.7% while it remained unchanged in perennial ryegrass. Although in separate studies, this suggests the competitive ability of perennial ryegrass was much greater than chewings fescue in restricting bermudagrass establishment as well as lateral movement from glyphosate-treated strips. On 13 October, chewings fescue had 10% more bermudagrass in plots with 7.6 cm strips and 5% more bermudagrass in plots with 2.5 cm strips than perennial ryegrass. Perennial ryegrass inhibited bermudagrass stolons from encroaching from the glyphosate-treated strips.

Quality was generally above acceptable levels for perennial ryegrass and chewings fescue throughout the duration of this study. Besides glyphosate, the main deterrent to turfgrass quality was cultivation prior to seeding. The cultivation treatment of aerification and vertical mowing, while proving disruptive to the surface quality of treated plots, did significantly enhance establishment success over broadcasting the seed over the surface. In Kentucky, Powell (1983) observed similar results with seeded zoysiagrass in that establishment by vertical mowing was superior to either slit-seeding or broadcast methods into an existing Kentucky bluegrass turf.

From these studies it can be concluded that seeded bermudagrass can be substantially introduced into a turf through selective glyphosate applications to small percentages of the existing stand. Perennial ryegrass appears more inhibitory to bermudagrass establishment than chewings fescue, especially when no glyphosate is applied. Chewings fescue not only exhibited more lateral tillering than perennial ryegrass, but also demonstrated greater coverage by bermudagrass in the 2.5 cm and 7.6 cm scars imparted by glyphosate. Further research with other chemicals such as growth regulating materials is needed to investigate the competitive effects of perennial ryegrass on bermudagrass seeding establishment into existing turfgrass stands.

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Summary

Chapter 1

Bermudagrass does not become well established when seeded into healthy stands of perennial ryegrass. It was hypothesized that late-spring seeding of bermudagrass would establish in early summer and potentially contribute to improved summer quality of perennial ryegrass during periods of decline due to disease or extreme stress. The use of a plant growth regulator was evaluated for reducing the growth of perennial ryegrass and improving bermudagrass establishment. Results showed that while PGR-treated plots established slightly higher percentages of bermudagrass than non-treated plots, the establishment success was below the desired level. Bermudagrass establishment was only successful in perennial ryegrass that did not receive fungicide applications. Disease incidence during late summer caused thinning of perennial ryegrass and allowed bermudagrass seedlings to develop. Bermudagrass establishment was highly unsuccessful in fungicide-treated perennial ryegrass, which remained healthy and competitive throughout the summer. As such it will be difficult to interseed improved bermudagrass types into well managed, unstressed perennial ryegrass. More effective means of regulating perennial ryegrass competition is needed to be able to introduce bermudagrass into existing stands of perennial ryegrass through interseeding.

Chapter 2

Due to the competitive nature of perennial ryegrass, the use of glyphosate in small strips was evaluated as a means of introducing bermudagrass seed into existing stands. To learn more about competive effects, chewings fescue was included in this study as an alternative cool season turf to evaluate another species for interseeding competition. Results showed that selective removal of existing turf with glyphosate strips was an effective means of increasing effectiveness of bermudagrass seed establishment. Aerification and vertical mowing prior to seeding was significant to establishment success. It was hypothesized that chewings fescue might be less competitive than perennial ryegrass and permit greater establishment of bermudagrass seed. This appeared to be true as chewings fescue plots had consistently higher amounts of bermudagrass than perennial ryegrass plots. Bermudagrass establishment was again highly unsuccessful in perennial ryegrass plots that were not treated with glyphosate strips. These results reaffirm those from 1996 studies in that bermudagrass seeding establishment into healthy stands of perennial ryegrass is difficult. However, bermudagrass establishment into healthy chewings fescue not treated with glyphosate was somewhat successful. This suggests that chewings fescue may be less competitive than perennial ryegrass. Successful bermudagrass introduction into perennial ryegrass through interseeding requires a means of reducing or eliminating perennial ryegrass competition.

Appendix 1. 1996 temperature and rainfall data in Centreville, Virginia.

	May	June	July	August
Average High (^oC)	21.3	28.7	27.9	28.3
Average Low (^oC)	9.6	16.6	17.7	17.0
Precipitation (cm)	16.3	9.4	12.2	11.2
Soil Temp. (^oC)	18.3	25.6	26.7	25.0

Vita

Christopher Bryan Gooch was born April 22, 1974 in Chesapeake, Virginia to Robbin Elaine and Edwin Allen Gooch III. He graduated from William Campbell High School in Naruna, Virginia in June, 1990. In the fall of 1990, he enrolled at Liberty University in Lynchburg, Virginia, before transferring to Virginia Polytechnic Institute and State University in the fall of 1991. In May 1995, he graduated from the department of Crop and Soil Environmental Sciences in the turf management option. Graduate school began in the fall of 1995 and continued through 1997. Upon completing the requirements for the Master of Science degree in the department of Crop and Soil Environmental Sciences in 1998, Bryan accepted a position with Bayer Corporation in the Garden and Professional Care segment of the Agriculture division.