

**CREEPING BENTGRASS RESPONSE TO PLANT GROWTH REGULATING
SUBSTANCES AND ANNUAL BLUEGRASS COMPETITION**

by

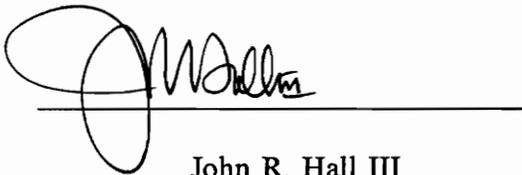
Cale A. Bigelow

Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Crop and Soil Environmental Sciences

APPROVED:



David R. Chalmers (Chairman)



John R. Hall III



R. Jay Stipes

May, 1995

Blacksburg, Virginia

Key words: Turfgrass, Creeping Bentgrass, Plant Growth Regulators

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(ABSTRACT)

Creeping Bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) is the most widely used cool-season turfgrass used for putting greens in North America. Frequently it becomes invaded with a persistent weed, annual bluegrass (*Poa annua* L.). Studies were conducted on a predominately annual bluegrass area managed as a putting green to attempt to quantify the impacts of plant growth regulator, seeding rate, and season on the success of introducing creeping bentgrass. Also, the impact of plant growth regulating substances on creeping bentgrass overall quality and seasonal rootmass production was evaluated. It was observed that creeping bentgrass does not become well established when overseeded into annual bluegrass regardless of plant growth regulator applications or season. Additionally, plant growth regulator application, following seedling emergence reduced creeping bentgrass seedling populations. Competition from established annual bluegrass and close frequent cutting were deemed reasons for lack of creeping bentgrass establishment success. Creeping bentgrass turf was maintained at a high level of quality with plant growth regulating substances. The use of the plant growth regulator trinexapac-ethyl reduced clipping production and was not detrimental to root production. Propiconazole application increased clippings and controlled *Sclerotinia* dollarspot. The application of a proprietary biostimulator material (3D) enhanced creeping bentgrass green color and generally increased rootmass over untreated turf.

Acknowledgments

I would like to express my appreciation to the following people for without their help this work would not have been possible.

I would like to thank David Chalmers for serving as chair of my graduate committee. My deepest, warmest, and most sincere gratitude is expressed. Thank you for serving in so many capacities throughout my college career: teacher, mentor, advisor, and above all a true friend. I owe great debt to you for being a part of my life when the shaping of my personal character was under its greatest influence. I only hope that our friendship can continue across the miles for a long time. Finally thank you for giving me a solid putting stroke for that is the only part of my golf game that will ever likely continue to be good.

I would also like to thank R. Jay Stipes and Jack Hall for serving on my committee and for their encouragement and fatherly advice. Dick Schmidt for his encouragement, advice, support and humor. Dale Wolf and Ted Ellmore for their technical advice and friendship.

The following technicians George Stanger, "Dickie" Sheppard, Charlie McCoy and Phil Keating for their encouragement, friendship, and for helping to keep my plots alive. I also would like to acknowledge Jean Ratliff for teaching me many useful laboratory techniques and always being so pleasant. Oh yeah thanks to W.T. Price for keeping Jones straight and running some PSAs for me.

The very fine ladies of the fourth floor office: Lois, Judy, and Rhonda, for their maternal instincts in helping a young graduate student keep the proper outlook on life as well as individuals.

Graduate students that I would like to acknowledge (in no particular order): Scott McBane (Links thanks you also), Barry Stewart (for refreshing my soils knowledge, and

broadening my view of the world around us), Mike Jones (for being so obnoxious and helping out a couple of times), Sam Doak (for always being so positive), Danny Waddill (for showing me it was possible), Louis "Allen" Linkenhoker, Phil Schroeder, Helena DeMarco, Alfredo Lopez, and Archer Christian, and finally, Jim May for his friendship, encouragement and deep talks about rock and roll.

Student help that I would like to recognize: John Dunker, Tony Hiserman, Michelle Frazier, and Chris Turner.

Faculty members with whom I have been fortunate enough to receive encouragement from, Harlan White, Mark Alley, Ray Reneau, Dave Martens, Ozzie Abaye, Jim McKenna, Greg Evanylo, Eluned Jones and Steve Donohue.

Thanks need to go out to the following soils geeks: Snagle, Pam and Velva for making me laugh. Pam especially for hitting me in the head with the door. I also would like to thank Jody Booze-Daniels for her helpful advice on statistical methods and procedures. I also need to express my extreme appreciation to Bobby Swain and Joyce Smith for their computer support and genuine friendship.

Dr. Rich Hurley and John Patton of Loft's Seed Company for their advice and supplying seed for much of my research. John Parrish of Turf and Garden for supplying seed from Seed Research Corp. Pete Moss of Virginia Turf and Irrigation for the use of a mower to properly maintain my plots.

I would also like to thank Rick Viancour and Greg Otto of the Golden Horseshoe in Williamsburg for letting me probe their greens and showing me their methods of dealing with *Poa annua*.

Lastly and most importantly I need to thank my family and the big guy upstairs who watches over us all. In particular I need to express sincere gratitude to the two most important women in my life. I would like to thank my mother for her constant support and encouragement. Lastly, and probably most importantly I would like to thank my beautiful and loving wife for her support and understanding as well as making sure I understood that the little things really do matter.

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Literature Review

Introduction

Bentgrasses (*Agrostis* spp.) are the cool-season turfgrass used most commonly on putting greens in the cool and transitional climatic regions and in the cooler portions of the warm climatic region of the United States. Creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) is the most commonly used *Agrostis* species in North America. A primary concern to the quality of a creeping bentgrass putting green is the ingress of annual bluegrass (*Poa annua* L.). Although not originally planted, the less desirable annual bluegrass will likely invade and become a major portion of the putting green if not controlled. Thus, it is sometimes a species that must be considered when developing a cultural maintenance program (Beard, 1982).

Origins and Adaptation

Beard (1973) describes creeping bentgrass as being native to Eurasia and it has been distributed throughout the world for use in close cut, fine textured turfs. When mowed closely, creeping bentgrass forms a fine textured turf with superior shoot density, uniformity and turfgrass quality. It is primarily confined to areas of recreational use. In contrast, annual bluegrass is one of the five most widely distributed plants in the world (Fenner, 1985). It is believed to be a native of Europe and to have originated from a cross between *Poa infirma* H. B. K., an annual species, and *Poa supina* Schrad., a

creeping perennial. It is suggested to be limited to areas of human habitation (Tutin, 1957).

Beard (1970) characterized annual bluegrass as an opportunistic grass which frequently becomes established in turfs that have been weakened by errors in the cultural program, or because of lack of competition from non-aggressive species. Annual bluegrass establishes into closely clipped moderate to high maintenance turfgrass ecosystems. In particular, it will frequently invade golf course tees in bare areas resulting from divoting, and putting greens where disruptions in the turf occur from landing golf balls and spiked shoes (Beard et. al, 1978). It is considered an asset on heavily-trafficked, compacted soils where it is the only grass to persist (Haes, 1956; Gibeault, 1965). However, annual bluegrass is less tolerant of drought and disease stress, than other turf species (Peel 1982). Annual bluegrass turfs withstand close mowing, are dense and regenerate readily from self-sown seeds. Annual bluegrass is capable of forming a dense, uniform quality turf of intermediate texture.

It is a common early invader of newly sown swards, mainly because of the abundance of seed in the soil (Howe & Chancellor, 1983). Annual bluegrass is generally discouraged, its presence disrupts surface uniformity in golf course tees, fairways and putting greens, and is difficult to maintain in the summer (Lush, 1989). It has a slightly upright growth habit and is paler green in color than many of its closely clipped companion species. Irregularities in aesthetics and golf ball roll are characteristics particularly undesirable in putting greens. Perceptions of turf managers to annual bluegrass

are two-sided. Many see it as a noxious weed in cultivated turf, while in certain situations and climates it is a substantial turf component that must be managed for its beneficial characteristics (Beard et al. 1978).

Annual Bluegrass Ecotypes

Two ecotypes of annual bluegrass have been observed. These ecotypes have been classified as an upright growing true annual ecotype (*Poa annua* var. *annua* L.) and a more prostrate perennial ecotype (*Poa annua* var. *reptans*). These different ecotypes have loosely been related to the culture of the plants. Annual ecotypes have most often been observed to persist with low culture (e.g. minimal fertility, little supplemental irrigation). Conversely, under moderate to high culture, some annual bluegrass plants can produce several generations in a single year thus, allowing the turf to appear perennial-like. Annual bluegrass ecotypes have also been observed to develop stolons which produced flowering shoots (Arber, 1934; Sprague & Burton, 1937). The perennial ecotype has been observed under areas receiving supplemental irrigation, close clipping, and moderate to high fertility inputs. The strong diversity of the plant and the uniqueness of management lends itself to ecotypes possessing characteristics desirable for sports turfs. Some researchers suggest, selections could be made for use in breeding programs (Adams & Bryan, 1980). In Britain, Wells (1974) planted annual bluegrass monthly in the field. He reported tiller numbers were greatest in early seeded plants. He also noted the two ecotypes present in the planted seed lot. The annual, exhibited few secondary tillers (50-

175) and a 15 month life span. The perennial, produced many secondary tillers (250-700) and a life span of roughly 19 months. Variability in the annual bluegrass ecotypes often is cited as the contributing factor to the lack of success in some chemical control programs. This is often the case where there is a high variability in ecotype populations. Turgeon (1971) reported reduced control with endothall on an annual and perennial mixed stand of ecotypes in Michigan.

Growth

Vigorous growth is a characteristic of opportunistic plants, which usually possess a rather short life-cycle, low stress tolerance, and a tendency to accumulate litter (Grime & Hunt, 1975). Research has suggested that annual bluegrass fits this description. Annual bluegrass is quite vigorous, especially during establishment (Brede & Duich, 1986). Annual bluegrass has been shown to have the highest relative seedling growth rate when compared to 132 other species (Grime and Hunt, 1975). Brede and Duich (1986) showed that the relative tillering rate of three cool-season grasses was shown to increase with increasing temperature, daylength, and precipitation. Relative to perennial ryegrass (*Lolium perenne* L.) and Kentucky bluegrass (*Poa pratensis* L.), annual bluegrass had the greatest tillering in early autumn. In this study annual bluegrass plants produced a mean of 25 shoots in a 6 week period from a September, 1981 planting date. This rapid shoot growth and tillering rate contributes to its highly competitive nature. Annual bluegrass growth becomes more rapid when the seedling plant develops its third leaf (Juhren, et. al.

1957).

Growth differences have also been associated with photoperiod (Eggens, 1979). Shoot growth is more responsive to long day lengths than root growth. This causes a decline in the root-shoot ratio under long day lengths (Lovvorn, 1945; Peterson & Loomis, 1949). In comparison, stolon growth of creeping bentgrass is enhanced by day lengths in excess of 13 h (Allard & Evans, 1941). Brede (1982) reported a four fold increase in annual bluegrass shoot production compared to Kentucky bluegrass when daylight was increased. Tillering rates of Kentucky bluegrass and annual bluegrass did not differ at 10 h of daylength. However, at 15 h of daylight, annual bluegrass tillered more quickly, than Kentucky bluegrass.

Competitive dominance of one grass species over another is often a result of interaction of plant parts above ground (e.g. leaves, stolons, tillers, shoots), below ground (e.g. rhizomes, roots), or both. Bogart and Beard (1973) suggested intense tillering as the reason for annual bluegrass dominance in established golf course fairways, maintained under moderate to high levels of culture, which were initially planted to creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.).

Optimum Temperatures for Growth

Annual bluegrass is a cool-season grass species and Beard (1968) defined the optimum conditions for annual bluegrass growth to be between 16 and 21 C for shoot growth and 13 to 18 C for root growth. Hawes (1965) compared annual bluegrass and

'Penncross' creeping bentgrass growth rates at temperatures ranging from 7 C up to 35 C. He found that the optimum temperature for annual bluegrass growth to be between 13 and 18 C. This is roughly 6 C less than the optimum soil temperature for 'Penncross' creeping bentgrass. Annual bluegrass produced more shoot and root growth at 24 C and 18 C than creeping bentgrass. Earlier, Beard (1959) had reported higher numbers of bentgrass roots at 16 C although the growth rate did not vary appreciably at 16 C, 21 C, or 27 C. Additionally, Hawes (1965) showed that annual bluegrass plants did not mature as rapidly at 7 and 13 C and annual bluegrass plants grown at 29 and 35 C quickly matured and died.

Annual bluegrass density will decline and eventually the plant will die as temperatures are increased or decreased from the optimum. It is quite prone to injury or complete kill from heat or cold stress that, in comparison, are not particularly damaging to creeping bentgrass or Kentucky bluegrass (Beard, et. al, 1978). Lethal heat stress occurs at temperatures near 40 C (Fischer, 1967). The tolerance of annual bluegrass to ice damage is poor in comparison to creeping bentgrass (Beard, 1964).

Seed Production

Most cool-season grasses will not produce seed under low clipping heights. Annual bluegrass has been observed to produce seed at clipping heights less than 6 mm. Annual bluegrass inflorescence development is most rapid at 27 C and is substantially reduced at lower temperatures (Bogart, 1972). Since annual bluegrass is likely to be severely

injured by summer stresses or low temperatures annual seed production and germination allows it to persist, at least seasonally. In contrast, most other cool-season grasses are better able to tolerate unfavorable environmental conditions. One example of this is drought induced dormancy of Kentucky bluegrass. Annual bluegrass has no such dormancy mechanism, therefore once permanently wilted, it dies (Watschke and Schmidt, 1992). The ability of it to recover and be a dominant species is dependent upon its ability to seed prolifically. The population continues to exist as a turf sward through perpetuation of seedlings originating from an expansive soil seed bank. This seed bank varies depending upon the ecotype.

Seed of both ecotypes has been observed to germinate during most of the year (Wells, 1974). Generally, in the transition zone of the United States and further North, the major pulse of flowering occurs in the late winter to early spring period. Estimates indicate annual seed production rates of up to 650,000 seeds m^{-2} (Lush 1988a). Annual bluegrass has been reported to produce four times as many seedheads at pH 6.5 than 4.5 on a loamy sand soil (Juska & Hanson 1969).

Gibeault (1974) characterized the perennial ecotype as producing seeds later in the season than the annual ecotype. Lush (1989) reported that seeds collected from putting green populations tend to be smaller than seeds collected from roughs or fairways. The progeny from the putting green seed bank tend to be smaller and flower later, than seed collected from other locations. Wu et. al, (1987) reported that annual bluegrass populations collected from a Southern California golf course, fairway and rough were

similar to each other but differed from that of the putting green populations in growth habit, dry mass production, flowering, seed size, and germination. Seeds from each population establish best in the type of turf and cultural system, from which they originated (Lush, 1989).

Lush (1988b) observed a golf course putting green in Southern Australia. She observed that annual bluegrass tillers flowered in the spring and then died, but the populations were perpetuated by the germination of seedlings from a large soil seed bank (170, 000 seeds m^{-2}). Annually, seed in the seed bank swelled to as many as 210, 000 seeds m^{-2} . After a pulse of germination, seed numbers in the soil often declined to a base of 30, 000 seeds m^{-2} in the fall and winter. Another researcher, Renny (1964), observed a single annual bluegrass plant growing in British Columbia. This plant produced 360 seeds in a single growing season. From this he estimated that where annual bluegrass grows the soil may contain as many as 7415 seeds m^{-2} .

For most grasses, a dense turf canopy will allow little weed invasion. This is particularly true for weeds first introduced as seeds, since many weed species germination is often inhibited by shading (Silverton, 1980). Lush (1988a) notes that the existing vegetation of a golf putting green is not enough to suppress annual bluegrass germination. The environmental conditions prevailing in greens (e.g. sufficient water and nutrients) may favor seeds that germinate soon after they are shed (Lush, 1989). The perpetual seedbank enables annual bluegrass to colonize any open areas created by surface disruption (Lush, 1988b).

Temperature influence on seed germination

Seedling survival and seedling vigor depends upon the speed of germination and rate of seedling growth (Wright et. al, 1978). Blaser et. al. (1956a, b) observed that seeding date can markedly affect the establishment rate of different species, since seed germination and establishment rates are dictated by soil temperatures. Establishment rates vary primarily as a response to temperature and its effect on germination time as well as initial seedling growth rate. The cardinal temperatures; a minimum, optimum, and maximum, for germination vary considerably from one species to another. Annual bluegrass and Kentucky bluegrass have an intermediate tolerance to low temperature germination. Creeping bentgrass has extremely slow low-temperature germination (Beard, 1980).

The recommended temperatures for optimum annual bluegrass germination are between 20-30 C (Beard, 1980; Anonymous, 1981). Cokerham and Whitworth (1967) concluded that 16 C was the optimum temperature for annual bluegrass seed germination. Alternate low (10 C) and high (21 C) temperatures have been shown to promote germination of unripe annual bluegrass seeds (Hovin, 1957). Wu et. al, (1987) found that high temperature (25 C) germination was different among golf course populations of annual bluegrass. Seeds collected from a golf course putting green have an increased high temperature viability in relation to seed collected from a golf course rough populations.

Germination studies conducted by Eggens and Ormond (1982) reported that

'Penncross' creeping bentgrass seed is generally insensitive to elevated temperature regimes. Creeping bentgrass seeds continued to germinate even at temperatures not favorable for annual bluegrass germination. Of the turfgrass species they tested annual bluegrass was the most sensitive to elevated temperatures. Annual bluegrass seed germination was significantly less at alternating day/night temperatures of 34/28 C (54 %) than at 25/18 (92 %), and was prevented at 40/30 C. Annual bluegrass did not germinate at 40/30 C regardless of pretreatment at 25 C for up to 24 hours. In contrast, 'Penncross' creeping bentgrass seed germinated well (74 %) at 40/30 C (day/night) temperatures or when moved from 40/30 to 25/18 to 40/30 (95 %).

Normally at heights of cut greater than 1.25 cm, a dense stand of turf will shade the soil surface and is capable of preventing annual bluegrass seed germination and subsequent invasion. However, openings in the turf will result in rapid germination of the existing annual bluegrass seeds (Beard et. al, 1978).

Light although not always necessary for annual bluegrass seed germination has been observed to enhance germination (Hovin, 1957; Renney, 1964). Researchers have reported that annual bluegrass has a strong light requirement for seed germination compared to Kentucky bluegrass and creeping bentgrass (Engel, 1969; Neidlinger, 1965). In contrast creeping bentgrass and Kentucky bluegrass also need light for maximum germination. Covering Kentucky bluegrass and creeping bentgrass seeds 1.3 cm deep reduced establishment of Kentucky bluegrass slightly, and 'Seaside' creeping bentgrass up to 60%. 'Penncross' creeping bentgrass was reduced 75 %. Covering the seeds with 0.32

cm or less resulted in the densest stands of 'Penncross' creeping bentgrass (Madison, 1966). Toole and Koch (1977) showed that 'Penncross' and 'Seaside' creeping bentgrass require red light during part of temperature cycles for germination. They determined that the germination of bentgrasses is under phytochrome control. Therefore, in situations where bentgrasses are overseeded adequate light must be available for maximum germination.

Annual bluegrass, germinates and grows aggressively during the cooler portions of the year. It tends to dominate a sward at low temperatures during spring seedings of cool-season grasses (Laude, 1957). Chilling treatments of seed collected from the golf course roughs, fairways and putting greens indicate that dormancy also plays a role in the establishment of annual bluegrass. In populations collected from golf course roughs, dormancy enhanced establishment by delaying seedling emergence until the growing season began (Lush, 1988a). The seed of the ecotype collected from areas not supplemented with irrigation often exhibits a post harvest dormancy (Gibeault, 1974, Lush, 1989).

Root Development

Annual bluegrass will produce roots at depths comparable to Kentucky bluegrass and the bentgrasses. This is contrary to what has been published in the popular literature where it is considered to be inherently shallow rooted. These references are primarily drawn from observations of annual bluegrass growing in compacted soils where little

vegetation persists.

Research comparing creeping bentgrass, Kentucky bluegrass and annual bluegrass under similar mowing, fertilization, and soil conditions reveals the capability of annual bluegrass to produce rooting depths similar to the other tested species (Sprague & Burton, 1937; Bogart, 1972; Wilkinson & Duff, 1972). Root growth of creeping bentgrass and annual bluegrass was the same at any given depth, when grown under the same soil bulk density. This demonstrates that annual bluegrass is not inherently shallow rooted. During the study a bulk density of 1.4 was not sufficient to impede root growth of either grass. Annual bluegrass success cannot be explained by rooting ability, but likely is a result of its continuous seed production and renewal of growth during cool seasons (Wilkinson & Duff, 1972).

Root mass is influenced by soil type and soil reaction. Juska and Hanson (1969) found that annual bluegrass rootmass increased significantly with pH in loamy sand soil, but in a silt loam soil there was no significant difference between pH 4.5 and 6.5. Mean yields of annual bluegrass crowns and clippings were much greater on a silt loam than a loamy sand soil. Annual bluegrass has been observed to grow superior to Kentucky bluegrass at a lower pH on a silt loam. This was explained by the soil being more prone to compaction and an increased base exchange capacity (Juska & Hanson 1969).

Advances in video technology have enabled video recording methods for root observation. In Michigan, Murphy et al. (1994) studied seasonal root growth in creeping bentgrass / annual bluegrass polystands. They compared both grasses under two

management systems, a golf putting green and a golf course fairway. The fairway situation consisted of clipping two to three times a week at 1.3 cm. The putting green was mowed five times per week at 6 mm. Findings concluded that root numbers for both grasses followed a seasonal pattern. The seasonal pattern in rooting was as follows: roots were greatest early in the growing season followed by a decline in July, with a small resumption of growth in the fall months. Creeping bentgrass had a seasonal root growth pattern that included a period of greatest root activity in the months of March through June, with a second but smaller period of activity occurring in October. Annual bluegrass root measurements (i.e. counts, weights and root density) were less than creeping bentgrass under both management situations. The root system of the creeping bentgrass recovered during late summer, whereas the annual bluegrass turf showed little recovery from summer root decline.

Cutting Height

Bogart and Beard (1973) suggest 2.54 cm as the optimum cutting height for annual bluegrass. Since the 2.54 cm turf had significantly increased the shoot density over higher (3.75, 5.08, and 6.25 cm) and a lower (1.25 cm) height of cut. Annual bluegrass is capable of being seasonally, competitive under very short heights of cut (< 6 mm) as indicated by its prolific production of seed and the plants ability to reproduce vegetatively on golf-greens (Cline et al., 1993). Leaf density increases and leaf blades become more narrow as the clipping height is reduced (Piper & Oakley, 1927; Beard, 1973). Once the

planted species becomes stressed below the optimum clipping height, annual bluegrass is able to regenerate from an existing soil seed bank.

FERTILIZER INFLUENCE

Soil Reaction

Annual bluegrass prefers mildly acid soil (Sprague & Burton, 1937). The ideal pH for growth of annual bluegrass was defined as 6.1 although adequate growth was reported at pH 4.2 and 5.0 (Sprague & Evaul, 1930). Carrow (1972) observed that annual bluegrass grew better at a pH of 6.5 than at 5.0 or 5.5, on four mineral soils ranging in texture from a loamy sand to a silty clay loam, as well as on a peat soil. The improved growth of annual bluegrass at pH 6.5 is primarily attributed to better nutrient availability, particularly phosphorus (Juska & Hanson, 1969). Annual bluegrass stands can also be reduced by acidifying the zone of seed germination using sulfur or sulfur containing fertilizers (Varco & Sartain, 1986).

In contrast, Beard (1973) states that creeping bentgrass tolerates a wide range of soil types but is best adapted to fertile, fine textured soils of moderate acidity and good water holding capacity. A pH of 5.5 to 6.5 is preferred. This pH results in the best utilization of provided nutrients.

Nitrogen

Generally, it is stated in the popular literature that annual bluegrass plant numbers increase with increasing nitrogen (N) fertility levels. However, annual bluegrass is able to persist under both low and high levels of fertility (Kerr, 1968).

Beard (1970) characterized annual bluegrass as needing a high level of nitrogen fertility. He suggested that the level of fertility be 9.8 to 48.8 kg N per ha⁻¹ per month. Adams (1980), observed that the percent annual bluegrass in a polystand with perennial ryegrass increased with N levels at three mowing heights. Eggens and Wright (1985) reported that the competitiveness of annual bluegrass was decreased as the amount NH₄ in a nutrient solution increased.

Data of other researchers does not support the conclusion that high N levels increase annual bluegrass populations. N fertility significantly affected annual bluegrass populations in only 1 of 3 years in a mixed stand of creeping bentgrass and annual bluegrass. In that year plots receiving 98 kg N ha⁻¹ yr⁻¹ had significantly less annual bluegrass than those receiving 293 kg N ha⁻¹ yr⁻¹ (Gaussoin & Branham, 1989).

Phosphorus

A unique situation arises with annual bluegrass and phosphorus (P) applications. In most situations, annual bluegrass is considered a weedy grass and its control and diminishment is desirable. Therefore, P nutrition should be monitored carefully in situations where annual bluegrass is managed as a weedy species. In some situations,

however, annual bluegrass is the predominant species and is managed for maximum survival. In either case P nutrition can play a major role.

The optimum tissue P for annual bluegrass was determined to be 0.52 dry ashed grams P kg⁻¹ indicating a high requirement for phosphorus (Varco & Sartain, 1986). Waddington et al. (1978) reported an increase in annual bluegrass as soil P increased from 27 to 210 kg ha⁻¹. Goss et al. (1975) found that P applications increased annual bluegrass encroachment into creeping bentgrass at all levels of N with greatest infestation occurring at moderate N.

Some encroachment of annual bluegrass may be explained by an improved drought tolerance resulting from fertilizer applications (Escritt & Legg, 1970; Turner & Hummel, 1992). Dest and Allison (1981) studied P and N applications on a 95% annual bluegrass putting green that was managed for maximum annual bluegrass survival. P applications as compared to no P increased both density and survival of annual bluegrass. They reported that P application should be adjusted upwards along with N to maximize annual bluegrass survival. P application, particularly in fall months where the major pulse of annual bluegrass seeds germinate, is correlated with P and increased annual bluegrass populations.

In relation to annual bluegrass control, calcium arsenate herbicides were once prescribed as an effective control measure. Carrow and Rieke (1972) stated that high P may reduce the effectiveness of arsenates on annual bluegrass. Thus, decreasing the control achieved by this chemical.

Overall, annual bluegrass infestations may be reduced by limiting phosphorus applications and maintaining the soil pH near 5.0, but the infested turfgrass must be tolerant of these conditions (Varco & Sartain, 1986).

Potassium

Potassium (K) response has been related to weed encroachment and wear tolerance. Waddington et al. (1978) reported an increase in annual bluegrass encroachment into bentgrass as soil K increased from 52 to 245 kg of K ha⁻¹ due to K fertilization. This is possibly due to an improved heat and drought tolerance. Overall, Beard (1973) states that the heat and drought tolerance of annual bluegrass is poor.

ANNUAL BLUEGRASS / CREEPING BENTGRASS COMMUNITIES

Annual bluegrass is rarely intentionally managed as a monostand for sports turf situations. On golf courses it is commonly managed in accordance with the planted species such as creeping bentgrass or Kentucky bluegrass. A knowledge of the life cycle and species population flux is advantageous to the turfgrass manager.

Researchers have reported seasonal above ground species population fluctuations in temperate zone putting greens (Lush, 1988a; Kearwer et. al, 1989; Cline et al., 1993) The annual bluegrass/creeping bentgrass population fluctuations on golf course putting greens appear to be controlled by the interplay of biological processes (genetics and

physiology) inherent in the species and environmental conditions as modified by cultural practices (Cline et al., 1993). Annual bluegrass controls the population dynamics of annual bluegrass / creeping bentgrass polystands on golf-greens. This is in contrast to the observation that creeping bentgrass is the more aggressive species under fairway conditions in Michigan (Branham, 1986). Under putting green management creeping bentgrass has a limited ability to encroach upon patches of dying annual bluegrass before new seedlings establish (Lush, 1988a). Winter and early spring conditions determine what the initial annual bluegrass population will be like. However, during the course of the growing season the "normal" cycle of annual bluegrass/creeping bentgrass population will likely shift toward creeping bentgrass and return to annual bluegrass (Cline et al., 1993).

In Minnesota, Kearwer et. al, (1989) reported these data showing a sample population fluctuation observed on a creeping bentgrass/annual bluegrass turf maintained under putting green management: early May annual bluegrass (90%), creeping bentgrass (10%); mid-summer annual bluegrass (24%), creeping bentgrass (76%); and late fall annual bluegrass (81%), creeping bentgrass (19%). In a similar situation, Lush (1988a) observed that overall turf density appeared not to be affected by species composition (e.g. creeping bentgrass or annual bluegrass). She reported that the annual bluegrass plants present in summer months are most often observed as single shoots (Lush 1988a).

Cultural Management

The most successful control practice for annual weeds is a competitive, high

density turf, particularly when weed germination is occurring. In Michigan, studies have shown that reducing the annual bluegrass seed bank by collecting clippings can reduce annual bluegrass populations under golf course fairway conditions (Gaussoin & Branham, 1989). Not removing turfgrass clippings containing annual bluegrass seeds is an unintended form of annual bluegrass overseeding. This replenishes the annual bluegrass seed bank.

Additional management practices to minimize annual bluegrass invasion include minimizing surface disturbances. Traffic scars or scars created by divots, will often result in annual bluegrass ingress to the ensuing open areas (Lush, 1988a).

The deliberate creation of a seedbank of the managed species (e.g. creeping bentgrass) to counteract the colonizing ability of annual bluegrass is suggested by some researchers (Lush, 1988b). A large seed bank of the managed species is advocated, so that if disturbances do occur the environmental conditions favorable for germination of annual bluegrass will also be favorable for germination of the managed species (Lush, 1988b). Gaussoin and Branham (1989) reported that overseeding annual bluegrass in the fall with creeping bentgrass increased populations of creeping bentgrass 8% when compared to non-overseeded plots and overseeding was only effective in plots receiving daily irrigation or treated with the plant growth regulator (PGR) flurprimidol. They also reported that the greatest significant decrease in annual bluegrass (28%) occurred in plots where clippings were removed, no PGR was applied and plots are overseeded in the fall (Gaussoin & Branham, 1989).

Allelopathy

Allelopathic compounds can exist in any plant part, but tend to be in highest concentration in leaves and seeds (Rice, 1974). Muller (1959) reported that, even though allelopathic effects may be subtle, their cumulative presence over the long term may be quite significant in the ecology of mixtures.

Brede (1982) reported that Kentucky bluegrass germination was lower in the presence of annual bluegrass seedlings. Extracts from mature annual bluegrass had no effect. In a field study with annual bluegrass, perennial ryegrass, and Kentucky bluegrass, Brede (1982) concluded that allelopathy, which was both beneficial and detrimental, was an important contributing factor in the interaction of these three species. The allelopathic effects began at germination and continued throughout the development of the mature stand. Annual bluegrass has been reported to secrete a water insoluble toxin that may inhibit creeping bentgrass seedlings (Brede & Harris, 1987). However, after two growing seasons in the field under putting green situation Brede (1991) found no consistent effects on turf color, foliar ground cover, shoot density, or disease incidence to indicate an allelopathic effect from annual bluegrass. He concluded that the dominance of annual bluegrass over creeping bentgrass was strictly of a competitive nature.

CHEMICAL CONTROL

Under current management efforts few attempts are made to eliminate all annual bluegrass plants. The goal is best described as the reduction of annual bluegrass to

minimize large scale loss of turf in those periods when this species may fail (Engel & Ilnicki, 1969). Many chemical strategies have been developed for the control of annual bluegrass. These include herbicidal means as well as plant growth regulation.

PLANT GROWTH REGULATORS (PGRs)

Growth and PGRs

In an organism growth is defined as an irreversible increase in size, and it is accomplished by a combination of cell division and cell enlargement (Steeves & Sussex, 1989). Turfgrass growth can at times (e.g. spring) be unwieldy when trying to maintain an aesthetically pleasing, uniform and natural looking surface. Kaufmann (1986a) stated that cool-season grasses produce up to one-half their total annual foliar growth during a 6 wk period in the spring. Hence, the appeal of plant growth regulators (PGRs) to decrease the number of necessary mowings has been realized. In addition, particularly in golf situations, PGRs have become a tool in the continual struggle for annual bluegrass management.

Growth regulators have been used on Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Shreb.), and several other grasses since 1952 (Elkins, 1983). The term 'growth regulator' implies to most turf managers a synthetic chemical that will cause reduction of foliar growth. Although partially correct, this term is too restrictive in the sense that certain growth regulators can also stimulate growth. A plant growth regulator (PGR) is an organic compound that when applied in low concentration can

affect the physiological processes and growth and development in the plant (Danneberger and Street, 1990). Growth regulating compounds can be divided into natural and synthetic products. Natural compounds are hormones produced by the plant. These include abscisic acid, gibberellic acid, ethylene, auxin, cytokinins and others. Synthetic substances are not developed endogenously, but when applied exogenously they induce endogenous processes. Both natural and synthetic growth substances regulate or influence cell division and differentiation, root and shoot growth, germination, flowering, photosynthesis, and sterol synthesis (Danneberger and Street, 1990). The ideal PGR would retard vertical leaf growth but permit active growth of roots, rhizomes, tillers, and horizontal leaf growth. This would permit continued new growth, including new leaves that are essential to maintain a uniformly green, dense turf resistant to wear, disease, and insect damage, and able to overcome environmental stress injury (Elkins, 1983).

Many turfgrass managers have considered PGRs to be the panacea to mowing, however problems have been reported. Some of the problems associated with PGRs include possible phytotoxicity and discoloration, potential to thin or lower density, and potential to cause damage in periods of inhibited growth from environmental stress (i.e. disease or temperature stress).

The most serious concern in using PGRs is the possible effect on turfgrass roots and rooting. Stunted roots resulting from PGR use would be deleterious to the ability of the sward to maintain itself, especially during heat and drought stress (Shearing & Batch, 1982). Research concerning the relationship of PGR's and their effects on rooting is

inconsistent, even when identical experiments were performed two consecutive years (Freeborg & Daniel, 1981). Results of studies involving various turfgrass species have shown the following: roots were not affected but resumed growth before the foliage (Wakefield & Fales, 1977); the duration of root suppression mirrored that of the foliage (Wakefield & Dore, 1974); or prolonged root suppression may (Schmidt & Bingham, 1977) or may not (Dernoeden, 1984) be detectable the following year. Generally researchers have found that PGR's cause root renewal interference (Schmidt & Bingham, 1977) even if it is temporary (McCarty et al., 1985; Wakefield & Fales, 1977; Wakefield & Dore, 1974; Fales et al., 1976).

Classification of PGRs

Kaufmann (1986a) and Watschke (1985) categorized growth suppressing compounds as Type I and Type II. Type I compounds (e.g. Mefluidide (Embark)) can inhibit or suppress the growth and development of susceptible grass species. These growth inhibiting compounds are absorbed by the foliage and can rapidly stop cell division and differentiation in meristematic areas. Type II growth-suppressing compounds are crown and root absorbed to allow for some initial growth.

Type II growth (e.g. Flurprimidol (Cutless), Paclobutrazol (Scott's TGR)) regulators suppress grass growth through the interference of gibberellic acid (GA) biosynthesis, reducing cell elongation and subsequent plant organ expansion (Kaufmann, 1986b). Recently classifications for plant growth regulators have been under reevaluation.

Industry representatives have advocated an additional delineation be added. Type II PGRs should be subdivided into early GA, and late GA inhibitors. Early GA biosynthesis inhibitors are classified as stopping GA biosynthesis at the ent-kaurene to ent-kaurenol transformation step in the pathway. Flurprimidol and Paclobutrazol would fall into this classification. Late GA biosynthesis inhibitors stop the pathway at the production of GA₁ which prevents cell elongation. Newer PGRs such as Trinexapac-ethyl (Primo) fall under this classification (DiPaola, 1994).

Type I (Mefluidide)

Mefluidide was commercially introduced in 1978 as a seedhead and foliar suppressant for use in rough turf areas (Elkins, 1983; Johnston & Faulkner, 1985). It is active on both warm and cool-season species (Beard, 1985), but season long seedhead control is achieved with applications to cool-season grasses only (Anonymous, 1983).

Kaufman (1980) once stated that of all the growth regulating materials that have been on the market, mefluidide undoubtedly was the most effective one in reducing growth. Mefluidide has been used successfully for seedhead suppression on golf course fairways that are predominantly annual bluegrass (Gaussoin & Branham, 1989; Watschke et al., 1992). Seedhead suppression results in improved playing conditions and aesthetic quality and has been observed to improve summer stress tolerance. Cooper et al. (1987) concluded that mefluidide applications which provided good seedhead suppression, also prevented root decline in annual bluegrass. Mefluidide has not been labeled by the

manufacturer at full rates for creeping bentgrass putting greens. Gaussoin and Branham (1989) working with a fairway turf in Michigan, applied mefluidide in combination with high N fertility which resulted in annual bluegrass populations that were 8% higher than control or flurprimidol treated plots. In the same study, mefluidide also increased populations of annual bluegrass relative to the control or flurprimidol treated turf when clippings were removed.

Mefluidide at 0.48 kg ha^{-1} caused excellent reduction in growth, and improved the color of the turf (Kavanagh, 1986). Watschke et. al, (1979) found that low frequent rates of Mefluidide provided better seedhead inhibition than single high rates and the effect was longer lasting. Growth regulators used reduced the number of seeds produced by annual bluegrass, which affected the number of seeds that germinated in the soil. However, the sheer number of remaining seeds in the soil were enough to allow annual bluegrass to be self perpetuating. Very low rates (0.07 kg ha^{-1}) can be applied to putting greens contaminated with annual bluegrass and seedhead suppression can be accomplished without significant injury to the bentgrass (Watschke et. al, 1992). Several researchers (Watschke, 1976, 1979, Chappell et al., 1977; Schott et al., 1977) have reported that mefluidide caused unacceptable phytotoxicity on fine-textured species and suggest its use be limited to rough turf areas.

Mode of Action

The mode of action of mefluidide is not completely understood. Wilkenson (1982)

stated that it may act to inhibit gibberellic acid (GA) biosynthesis and cell elongation. Truelove et al. (1977) however concluded that since the growth retarding action of mefluidide could not be reversed with exogenous applications of GA, there was an additional activity on plant growth. The activity of mefluidide is lessened if irrigation or rainfall occurs within 8 hrs of application (DiPaola & Lewis, 1989).

Mefluidide is foliarly absorbed and unlike MH (Maleic hydrazide) exhibits little translocation to other leaf organs, roots, and lateral growth meristems (Field & Whitford, 1982; WSSA, 1983). Penetration of leaf tissue occurs most readily at basal leaf sheaths and leaf axils (WSSA, 1983) and because of limited movement, a uniform spray coverage and distribution is essential (Anonymous, 1983). Uptake is complete within 4 to 6 h after application (Tautvydas, 1983) and by 96 h 90 % of the absorbed material is not yet metabolized (Field & Whitford, 1982). Activity is at the leaf base where cell division and elongation occur causing a reduction in sheath extension and canopy height (Anonymous, 1983). Mefluidide also causes uncontrolled cell division in reproductive apices, this distorts stem extension and impairs seedhead development (Field & Whitford, 1982). Retardation occurs by inhibited cell division and meristematic activity of responsive plant areas that come into contact with this compound (WSSA, 1983). Elkins (1983) emphasized that applications of lower concentrations inhibit cell elongation but will not inhibit cell division.

Type II Early (Flurprimidol, Paclobutrazol)

The plant growth regulators (PGRs) paclobutrazol and flurprimidol have been available for annual bluegrass suppression in bentgrass golf greens. Paclobutrazol and flurprimidol are considered Type II growth regulators since they inhibit gibberellin biosynthesis and suppress internode elongation (Kaufman, 1989). These materials are root absorbed (xylem-mobile) and work by reducing the competitive ability of the annual bluegrass for 3 to 8 wk after application. Paclobutrazol is xylem mobile only and requires root uptake to reach the basal growing points of the grass plants (Lever et. al, 1982; Sugavanam, 1984).

Paclobutrazol and flurprimidol have been reported to differentially suppress the competitive ability of certain species. For example, application of either paclobutrazol or flurprimidol to a mixed stand of annual bluegrass and creeping bentgrass favors the growth of the bentgrass due to its unaffected stolon development compared to the annual bluegrass (Watschke and Engel, 1994). The effectiveness of paclobutrazol on annual bluegrass is attributed to the greater uptake by a shallower rooted annual bluegrass plant (Kageyama, 1989). This differential concentration in root uptake allows the established creeping bentgrass to outcompete annual bluegrass. Paclobutrazol and flurprimidol have been used successfully on golf course fairways to reduce annual bluegrass and increase cover of more desirable species, particularly creeping bentgrass (Shoop et al., 1986). Creeping bentgrass vertical shoot elongation development is retarded, while stolon growth continues after treatment. Conversely, growth of annual bluegrass is severely suppressed.

This differential growth suppression of species in a mixed stand provides the turfgrass manager a tool with which to manipulate plant competition. Flurprimidol has also been shown to have some preemergence activity on both annual bluegrass and creeping bentgrass (Gaussoin & Branham, 1987), thus potentially limiting bentgrass overseeding at or near treatment time when rates of 0.56 kg ha⁻¹ or greater are used.

Results of Type II PGR applications have been inconsistent. Two consecutive years of paclobutrazol at 1.68 kg ha⁻¹ reduced annual bluegrass 28% four months after the final treatment. Flurprimidol had little or no activity on *Poa annua* var. *reptans* regardless of rate and frequency of application. Paclobutrazol and flurprimidol applications applied in the fall caused moderate injury to creeping bentgrass, but the turf recovered in four to six weeks (Johnson & Murphy, 1994).

Annual Bluegrass Inflorescence Suppression

Research has shown that paclobutrazol at 0.56 kg ha⁻¹ significantly enhanced the conversion to bentgrass as well as reduced the visibility of annual bluegrass seedheads (Kageyama, 1989). However, paclobutrazol failed to control flowering at 1.5 kg ha⁻¹ in Britain (Kavanagh, 1986).

Flurprimidol has little efficacy on seedhead inhibition (Freeborg, 1983; McElroy et. al, 1983; Symington et. al, 1982; Hurto, 1981; Watschke, 1981; Wehner, 1980) and has been shown to actually enhance the seedhead production of Kentucky bluegrass after several years of application (Dernoeden, 1984).

Other responses

Flurprimidol at 2.24 kg ha⁻¹ has been reported to reduce photosynthetic rates of annual bluegrass 52% while creeping bentgrass was reduced only 29%. Flurprimidol at 1.68 kg ha⁻¹ did not significantly affect any of measured parameters except for chlorophyll content with treated plants exhibiting significantly higher levels than untreated plants (Gaussoin, et al., 1985). Brueninger et al. (1983) and Freeborg (1983) observed that turf treated with flurprimidol had improved color compared to untreated turf. Sawyer et. al (1983), Dernoeden (1982) and Symington et. al (1982) noticed some phytotoxicity from flurprimidol application but considered it acceptable. Any application of flurprimidol on young seedlings of annual bluegrass and creeping bentgrass showed a marked reduction in growth (Haley & Fermanian, 1985).

Mode of Action

Uptake of paclobutrazol and flurprimidol is primarily through the roots. Foliar absorption of paclobutrazol is practically nonexistent (Barrett & Bartuska, 1982) Flurprimidol has been reported to have some foliar absorption (Batten, 1983; Beard, 1985). Once in the plant, these compounds inhibit GA biosynthesis. Specifically, paclobutrazol blocks the oxidation of kaurene to kaurenoic acid (Dalziel & Lawrence, 1984; Johnston & Faulkner, 1985).

Caution should be used when using PGRs for a renovation program. Paclobutrazol is not recommended in the use of situations that have more than 70% annual bluegrass

(DiPaola & Lewis, 1989). Flurprimidol at rates greater than 0.56 kg ha⁻¹ can reduce germination of annual bluegrass seed as well as bentgrass, therefore should only be applied to established putting greens (Gaussion & Branham, 1987).

Type II Late (Trinexapac-ethyl)

Trinexapac-ethyl (TE) : [4 (cyclopropyl - alpha - hydroxy - methylene) - 3,5 dioxocyclohexanecarboxylic acid ethyl ester] is a new PGR that offers vegetative suppression in turfgrasses, but does not provide complete suppression of seedhead development (CIBA, Agric. Div., Greensboro, NC). TE is labeled for use on monocotyledonous and dicotyledonous plants, including growth inhibition of cool and warm season turfgrasses. It is taken up by the foliage and translocated to the growing shoot where it primarily influences internode elongation (Kerber et. al, 1989). Under greenhouse conditions, Kerber et. al, (1989) studied leaf uptake on wheat. Leaves were sprayed at 400 g a.i. ha⁻¹. Experiment results indicate that 50% penetration of the compound was achieved 6 h after application. In addition, root absorption was compared with foliar activity. When trinexapac-ethyl was applied as a soil drench results were inferior to foliar absorption by a factor of 10 or more in growth regulation. Root growth on wheat was studied under greenhouse conditions in soil cylinders. Rates of 0.5 to 2.0 kg a.i. ha⁻¹ were applied at the 3 leaf stage and root and shoot measurements were made at 30 DAT. Trinexapac-ethyl clearly had a distinct effect on shoot elongation and no effect was observed on root length (Kerber et. al, 1989). Photosynthesis of wheat was

studied under field conditions, using 0.2 m² cuvettes. Trinexapac-ethyl applied at rates up to 500 g a.i. ha⁻¹ resulted in growth inhibition of up to 30%, but no reduction of net photosynthesis occurred when compared with untreated plants (Kerber et. al, 1989). Trinexapac-ethyl application to 'Tifway' bermudagrass at 0.2 kg ha⁻¹ and followed with 0.1 kg ha⁻¹ at 4 wk and 8 wk intervals reduced mowing of bermudagrass by 70 and 67% in 1992 and 1993 respectively. However, reduced bermudagrass quality was observed in both years (Johnson, 1994).

Triazole Fungicides

Some systemic triazole fungicides have been determined to possess nontarget regulatory activity such as increasing photosynthetic rates, stimulating root and shoot initiation and development, and delaying leaf senescence (Kane and Smiley, 1983; Ballard et. al., 1984; Davies et. al., 1984; Goatley & Schmidt, 1990a; Goatley & Schmidt, 1990b). Generally, triazoles have been reported to act like inhibitors of GA biosynthesis in plants (Sisler et al., 1984; Rademacher et al., 1984; Koller, 1987; Buchenauer & Rohner, 1981). Kane and Smiley (1983) reported that the triazole fungicides at levels of 300-600 mg a.i./m² suppressed Kentucky bluegrass root and shoot growth in a manner similar to growth regulator chemicals that behave as GA biosynthesis inhibitors. Gibberellins are important growth substances that control many physiological processes such as cell elongation and expansion, cell differentiation and synthesis of cell membrane phospholipids (Brock and Kaufman, 1991).

Propiconazole : (1 - ((2 - (2, 4 - dichlorophenyl) - 4 - propyl - 1, 3 - dioxolan-2yl) methyl) 1H - 1, 2, 4 - triazole) is a frequently used fungicide for the control of many diseases of turfgrass excluding the *Pythium* species. Some of the triazole chemicals are strong fungicides, while others are effective plant growth regulators. Some have both properties, depending upon the mixture of triazole isomers (Koller, 1987).

Mode of action

Propiconazole (PPC) inhibits fungal sterol biosynthesis. All known triazole fungicides are demethylation inhibitors which have an sp^2 -nitrogen atom with a free electron pair. This free electron pair can bind to the center of the ferric porphyrin system of cytochrome P-450 and prevent formation of the first oxygenated complex (Vanden Bossche, 1985.) Specifically, the triazole fungicides inhibit C-14 demethylation of 24-methylenedihydrolanosterol by binding cytochrome P-450 mixed-function oxygenase, and therefore inhibiting the biosynthesis of ergosterols (Kato, 1986, Sisler & Ragsdale, 1984). The PPC inhibits fungal growth and reproduction, since the biosynthesis of ergosterol is required for reproduction and membrane function (Koller, 1987).

The demethylation of sterols at the 14-C position is not restricted to fungi. It also occurs in some higher plants (Benveniste, 1986,; Rahier & Taton, 1986). Most plants treated with a triazole fungicide, such as PPC, exhibit "side-effects", such as reduced shoot and leaf growth, reduced transpiration and increased yield under water stress conditions, enhanced protection from injuries caused by chilling or heat (Fletcher &

Hofstra, 1985; 1988; Davies et al., 1988; Fletcher, 1985), improved anti-senescence properties, enlarged chloroplasts (Gao et al., 1988), enhanced chlorophyll content (Fletcher et al., 1986; Izumi et al., 1988), and decreased gibberellin concentration (Davies et al., 1988; Fletcher & Hofstra, 1988). These side effects are viewed as beneficial rather than phytotoxic, therefore these fungicides are often classified with PGRs.

Propiconazole responses

Luo (1991) reported propiconazole treated Kentucky bluegrass seed at 0.0, 0.5, 0.9, 1.9 g a.i. kg⁻¹ seed did not affect total germination although germination was delayed. It was also observed that plumule and radicle lengths of seedlings were inhibited with increasing propiconazole rates. Using radish cotyledons as indicator plants, Yan (1993) reported that PPC treated plants displayed an inhibition of cell expansion.

Mature plant root and shoot growth responses to the triazole fungicides have been observed to be primarily positive. PPC at 42 mg m⁻² significantly increased seedling leaf number six weeks after treatment when applied in the fall (Goatley & Schmidt, 1990b). PPC also enhanced post transplant rooting and sod strength of Kentucky bluegrass (Goatley & Schmidt, 1990a). Greater nutrient uptake efficiency was observed in Kentucky Bluegrass treated with PPC in addition to a greater utilization efficiency of some major nutrients (Yan, 1993). Luo (1991) reported reduced crabgrass, in a creeping bentgrass turf maintained under low nitrogen and treated with PPC. This response was likely a result of a more competitive, disease free creeping bentgrass turf.

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Chapter 1

Interseeding Establishment of Creeping Bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) Into an Annual Bluegrass (*Poa annua* L.) Turf as Influenced by Seeding Rate and Plant Growth Regulator Application

INTRODUCTION

Golf putting greens represent one of the most highly specialized uses of grass known (Grau & Noer, 1948). Creeping bentgrass (*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw.) is the most widely used cool-season turfgrass for golf greens in the United States (Beard, 1982). While, golf greens are initially planted to creeping bentgrass in three to five years greens often become infested with a persistent weed, annual bluegrass (*Poa annua* L.). Annual bluegrass is generally discouraged, since its presence disrupts surface uniformity and it is difficult to maintain in the summer (Lush, 1989). It has a slightly upright growth habit and is paler green in color than many of its closely clipped companion species. Irregularities in aesthetics and ball roll are particularly undesirable in putting greens. Annual bluegrass infestations can be attributed to environmental or physical stress, soil compaction, or errors in the cultural program (Beard, et. al, 1978). Once annual bluegrass is introduced it successfully becomes a major portion of the turfgrass stand due to its rapid growth rate and prolific seed production. It produces most

of its seedheads during the late spring. Seed is the primary means of propagation for the plant, although some plants have been observed to be stoloniferous (Beard, 1970). Renney (1964) observed that a single annual bluegrass plant growing in western British Columbia, Canada produced more than 360 seeds during a four-month period from May to August. He estimated that where annual bluegrass had been growing, the surface layer of soil might contain as many as 12 million seeds per hectare. Therefore, over time natural overseeding leads to annual bluegrass perpetuation.

In addition, annual bluegrass germination can be enhanced by the cultural practice of core cultivation on golf greens. This practice disseminates existing annual bluegrass seeds and creates a desirable environment for their germination. The frequent irrigation and fertilization of golf greens enhance annual bluegrass seedling development. Lush (1988a) suggests that turfgrass managers would be well advised to overseed their turfs with the desired turfgrass species (e.g. creeping bentgrass), to create a competitive seedbank. If creeping bentgrass stand density declines or bare areas occur as a result of, divoting, from golf balls impacting the surface, or core cultivation, the managed species would have as equal an opportunity to germinate as annual bluegrass seed.

Information on success rates from creeping bentgrass overseeding on putting greens would be useful to golf course superintendents. Furthermore, information pertaining to the use of plant growth regulators (PGRs) to enhance seedling establishment by reducing annual bluegrass competition is also important. The use of PGRs in conjunction with overseeding is termed "passive overseeding". This is due to the reduced competition

from the existing turfgrass. In theory the ensuing seedlings should have a better opportunity to establish themselves among the existing regulated turfgrass.

OBJECTIVES

The objectives of this study were to:

1. Determine the influence of seeding rate and season (spring versus late summer) on the interseeding establishment of creeping bentgrass into existing annual bluegrass.
2. Determine the impacts of plant growth regulators on annual bluegrass competition and the interseeding establishment of creeping bentgrass.

MATERIALS AND METHODS

In September 1993 an existing creeping bentgrass / annual bluegrass mixed stand was selected at the Virginia Tech Turfgrass Research Center, in Blacksburg, Virginia. The site over previous years had little or no supplemental fertilizer or irrigation and was mowed three times weekly at 1.8 cm with clippings returned. Two applications (September 15 and September 25) of glyphosate (2.8 kg ha^{-1}) a non-selective herbicide were used to eradicate the existing vegetation. The area treated was heavily aerified and vertical mowed two directions penetrating the soil 2.5 cm. Following seedbed preparation the area was seeded 4 October 1993 to *Poa annua* var. *annua* L. seed (Thompsons Valley Seed Service of Oregon) at rate of 98 kg ha^{-1} . The area was covered with a 4 mil thick

polyethylene tarp to enhance germination and annual bluegrass establishment. The tarp was vented by 2.5 cm diameter holes approximately 30 cm apart.

Soil Testing

The existing soil was a Frederick silt loam (clayey, mixed, mesic Typic Paleudult). The soil of the experimental area was sampled and was analyzed by the Virginia Tech soil testing laboratory. Soil test results indicated the following: pH = 5.7, P = 39 ppm, K = 113 ppm, Ca = 1176 ppm, Mg = 209 ppm. A particle size analysis was also performed. The soil separates were: sand = 31.9 % silt = 53.2 % clay = 14.9 %. The site was located mostly in full sun and was without thatch. One half of the test area was shaded for about an hour in the morning. This was the area that used for the fall treatments.

Experimental Area Management Practices

Throughout the study the test plots were managed as putting green turf. Actively growing turf (April through October) was walk mowed five times per week with a reel mower (Toro, Greensmaster 1000). The cutting height was 4-mm and clippings were removed. Irrigation was applied as needed to promote growth and prevent stress. Fungicides and insecticides were applied to control disease and insect problems as they

occurred. Fertility was supplied as 49, 11, 27 kg ha⁻¹ of nitrogen, phosphate, and potash respectively per growing month (April through October). Siduron was applied on 12 April, at 4.9 kg a.i. ha⁻¹. Five applications of 16 % Disodium methanearsonate (DSMA) (10.2 L ha⁻¹) in 375 L ha⁻¹ of water seven to ten days apart beginning June 20, 1994 were applied for post-emergent smooth crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.) and goosegrass (*Eleusine indica* (L.) Gaertn.) control.

Spring Treatments

Test plots measuring 1.8 m by 1.8 m were established March 29, 1994 on one half of the experimental area. The experiment included fourteen treatments comprised of three components and replicated three times (Table 1.1). These components included: plant growth regulator (PGR); (Trinexapac-ethyl, Flurprimidol, and Glyphosate), frequency of PGR application (Once or Twice), and creeping bentgrass seeding rate (49, 98 and 147 kg ha⁻¹). The test plots were arranged in a randomized complete block design.

Table 1.1 Spring and late summer / fall (S/F) 1994 plant growth regulator treatments and creeping bentgrass seeding rates.

Treatment #		Plant growth regulator			Seeding rate
Spring	S/F	Chemical	Rate	Frequency	
			kg ha ⁻¹		kg ha ⁻¹
1	1	None	-	-	0
2	2	None	-	-	49
3	3	None	-	-	98
4	4	None	-	-	147
5	5	Trinexapac-ethyl	0.19	Once	49
6	6	Trinexapac-ethyl	0.19	Twice	49
7	7	Trinexapac-ethyl	0.19	Once	98
8	8	Trinexapac-ethyl	0.19	Twice	98
9	9	Flurprimidol	0.28	Once	49
10	10	Flurprimidol	0.28	Twice	49
11	11	Flurprimidol	0.28	Once	98
12	12	Flurprimidol	0.28	Twice	98
13†		Glyphosate	2.8	Once	49
14	15	Glyphosate	2.8	Once	98
	13‡	Mefluidide	0.14	Once	98
	14‡	Mefluidide	0.14	Twice	98

† Spring treatments only.

‡ Late summer / fall treatments only.

On April 1, 1994 all PGRs were applied from a compressed air sprayer. The compressed air sprayer was calibrated to deliver 750 L ha⁻¹ at 276 kPa. Following a short drying time (6 hr) the plots were irrigated with 1.8 cm water ha⁻¹ . This was necessary for complete activation of the flurprimidol treatment.

On 3 April the area was core cultivated once. The cultivator was equipped with 0.95 cm tines on 5 cm spacing. Following core cultivation the area was vertical mowed twice in perpendicular directions. This procedure broke up the soil cores and penetrated the soil 2.5 cm deep. The test area was drug with a steel mat filtering the soil back into the turfgrass canopy.

Test plots, to receive seed, were then overseeded with creeping bentgrass (*Agrostis stolonifera* L.var. *palustris* (Huds.) Farw. 'Southshore') Lot #2775-5. Seeding was broadcast using a Scotts 0.9 m width drop spreader. This cultivar was selected based on 1991-1993 performance data from the 1989 NTEP creeping bentgrass trial at Blacksburg, Virginia (Appendix 1). 'Southshore' creeping bentgrass is a lower growing cultivar capable of producing an attractive, persistent, moderately aggressive turf with medium-fine texture, upright growth habit, high tiller density, and medium-dark green leaf color. Southshore is recommended for use on golf course greens, fairways, and tees in climactic regions where bentgrasses are adapted (Hurley et. al, 1994). Following seeding, plots were lightly raked to ensure seed soil contact. At the time of seeding the soil temperature recorded at a depth of 5 cm was 8 C. A granular fertilizer was applied at 49, 98, and 49

kg ha⁻¹ of actual nitrogen, phosphate and potash respectively, at planting. On 10 May 1994 treatments receiving a second application of PGRs were applied. Again following a drying time of 6 hours the plots were irrigated with 1.8 cm water ha⁻¹.

Data recorded

Data was recorded throughout the 1994 season for the spring study. Visual turfgrass quality ratings were based on the scale 1 to 9 (1 = brown or dead turfgrass, and 9 = a dense, dark green, uniform turf) A rating of 5 would be indicative of acceptable putting green turf. Visual estimates of percentage green ground cover used a scale of 0 to 100 percent.

A destructive method of sampling was used to determine actual plant tiller populations. Those species of specific interest were creeping bentgrass and annual bluegrass. This method involved sampling four 5.0 cm diameter by 5.0 cm deep plugs from each experimental plot. Sampling occurred on 5 November 1994. The plots were visually divided into four sections. One plug from the center of each quarter section of the plot was removed. The removed plugs were placed in a greenhouse at the Turfgrass Research Center and maintained unclipped for 21 days. After removing all vegetation from each plug, all species tillers were identified, counted and recorded. Identifiable tillers in each plug were counted provided they had at least one expanded leaf. Species identified were: creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.);

annual bluegrass (*Poa annua* L.); perennial ryegrass (*Lolium perenne* L.); white clover (*Trifolium repens* L.); and roughstalk bluegrass (*Poa trivialis* L.). Creeping bentgrass and annual bluegrass data were used for analysis and all remaining species tillers were classified as "other". Based on total tiller populations, percentage creeping bentgrass, and annual bluegrass was calculated.

Late Summer / Fall Treatments

Directly adjacent to the spring treatments, in the remaining experimental area, a separate study with test plots measuring 1.2 m by 1.8 m was established 12 August 1994. The study included fifteen treatments comprised of combinations of three components (Table 1.1): plant growth regulators (PGRs); (Trinexapac-ethyl, Flurprimidol, Mefluidide, and Glyphosate), frequency of PGR application (Once or Twice), and creeping bentgrass seeding rates (49, 98 and 147 kg ha⁻¹). The test plots were replicated four times and arranged in a randomized complete block design.

All PGRs were applied on 29 August 1994 using the compressed air sprayer. Following a 6 hour drying time the plots were irrigated with 1.8 cm water ha⁻¹. On 1 September the area was cultivated as stated for the spring treatments. Creeping bentgrass ('Southshore') was broadcast seeded using a Scotts 0.9 m wide drop spreader on 2 September. Following seeding the plots were lightly raked, and a starter fertilizer was

applied at 49, 98, and 49 kg ha⁻¹ of actual nitrogen, phosphate, and potash respectively. At the time of seeding the soil temperature recorded at 5 cm was 25 C. On 4 October plots receiving a second PGR application were treated.

Data recorded for the late summer / fall study included: Turfgrass visual quality ratings based on the following scale 1 to 9 (1 = brown or dead turfgrass and 9 = a dense, dark green, uniform turf) A rating of 5 would be indicative of acceptable putting green turf. Visual estimates of percentage green ground cover were based on the scale 0 to 100 percent. Visual color ratings were based on a 1 to 9 scale (1 = chlorotic turf, 9 = dark green turf). Visual phytotoxicity ratings were based on a scale of 0 to 5 (0= no injury, 5 = brown, dead turf).

Fresh clipping weights were taken from a 0.58 m² area of each plot on 12 and 17 October 1994. Prior to harvest, plots were unmowed for a period of four to six days. Clippings were placed in paper bags and fresh weights were recorded. Following the clipping harvest the entire plot area was mowed twice to reestablish the 4 mm canopy height.

The method used to count tiller populations was the same as stated for the spring treatments. Samples were taken on 29 November 1994. Based on total tiller numbers, the percentage creeping bentgrass, and annual bluegrass tillers were calculated.

All data was subjected to statistical analysis on the SAS (SAS, 1985) system. Treatment means were compared using Fishers protected LSD (Fisher, 1966). This

procedure performs pairwise t-tests. Percentage data was subjected to the arc-sine transformation (Zar, 1974) and statistical analysis was run on the transformed numbers.

RESULTS AND DISCUSSION

Spring Treatments

Annual bluegrass was observed to produce seedheads throughout the late spring months. Turfgrass quality declined during mid-summer months (July and August) for all treatments, primarily due to a decline in annual bluegrass stand density (Table 1.2). All plots were below an acceptable level of quality in July and August for putting green turf. In September and October there was a period of dramatic recovery. By November, no differences between treatments were observed. Plot quality ratings of all spring treated plots was acceptable (mean values greater than 5) only on the 22 November observation date. On all other observation dates at least one treatment was less than acceptable for putting green turf.

All spring treatments, except the glyphosate treatment had reduced summer stand density (Table 1.3). As has been documented (Bogart, 1972; Beard et. al, 1978) the annual bluegrass stand failed, losing green ground cover density in July and August. However, ground cover in all plots recovered from September to November. The restoration of ground cover could be attributed to fall germination of annual bluegrass

Table 1.2 Turfgrass quality ratings as influenced by spring interseeding of creeping bentgrass and plant growth regulator application.

Treatment	Chemical	Frequency	Seed rate kg ha ⁻¹	Turf quality ‡						
				10 June	27 June	12 July	8 Aug.	26 Sept.	21 Oct.	22 Nov.
1	None	-	0	5.7 ab*	5.0 a	3.7 abc	3.7 ab	4.3 abc	4.3 ab	6.0
2	None	-	49	5.7 ab	5.0 a	3.0 bcd	3.0 ab	3.7 bc	4.7 ab	5.7
3	None	-	98	6.0 ab	5.3 a	3.3 abcd	3.7 ab	4.3 abc	4.7 ab	5.3
4	None	-	147	5.0 ab	5.0 a	2.3 d	2.7 b	3.3 c	3.7 b	5.3
5	TE	Once	49	6.3 a	5.7 a	4.3 a	4.0 a	5.0 a	5.3 a	6.0
6	TE	Twice	49	5.3 ab	4.7 a	3.7 abc	3.7 ab	4.3 abc	4.7 ab	5.3
7	TE	Once	98	6.3 a	5.0 a	3.7 abc	4.0 a	4.7 ab	5.3 a	6.3
8	TE	Twice	98	5.7 ab	5.0 a	3.7 abc	3.7 ab	4.7 ab	5.0 ab	5.7
9	FL	Once	49	5.7 ab	4.7 a	2.7 cd	3.7 ab	4.3 abc	4.7 ab	5.3
10	FL	Twice	49	4.7 bc	4.3 ab	3.7 abc	3.7 ab	3.7 bc	4.3 ab	5.3
11	FL	Once	98	5.3 ab	4.7 a	3.7 abc	3.3 ab	4.0 abc	4.7 ab	5.7
12	FL	Twice	98	4.7 bc	4.3 ab	3.7 abc	3.7 ab	3.7 bc	4.7 ab	5.3
13	G	Once	98	2.7 d	3.0 b	4.0 ab	4.0 a	4.0 abc	4.0 ab	5.7
14	G	Once	98	3.3 cd	3.0 b	4.0 ab	4.0 a	4.3 abc	5.3 a	6.3

*Means followed in the same column followed by the same letter are not significantly different according to Fishers LSD.

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide(0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Visual quality ratings are based on a numerical scale of 1 to 9, where 1 is bare soil, 5 acceptable putting green turf, and 9 is ideal turf.

Table 1.3 Percentage green ground cover as influenced by spring interseeding of creeping bentgrass and plant growth regulator application.

Treat	Chemical Frequency	Seed rate kg ha ⁻¹	Percentage green ground cover‡									
			2 June	10 June	27 June	11 July	19 July	8 Aug.	26 Sept.	21 Oct.	22 Nov.	
1	None	0	95.0 a*	96.0 ab	86.7 a	45.0 abcd	38.3 bcd	53.3 bcd	81.7 abc	92.7	98.3 a	
2	None	49	92.7 a	96.0 a	86.7 a	33.3 cd	28.3 d	46.7 cd	71.7 bc	90.3	96.0 ab	
3	None	98	91.7 a	97.3 a	88.3 a	45.0 abcd	41.7 bcd	60.0 abcd	74.7 abc	81.0	88.3 b	
4	None	147	88.3 a	92.7 ab	85.0 ab	30.0 d	23.3 d	40.0 d	68.3 c	78.7	95.3 ab	
5	TE	49	92.7 a	94.3 ab	88.3 a	61.7 abc	60.0 abc	68.3 abc	84.3 abc	88.0	98.3 a	
6	TE	49	86.7 a	90.0 ab	83.3 ab	50.0 abcd	43.3 abcd	56.7 abcd	73.0 bc	81.7	91.0 ab	
7	TE	98	91.0 a	95.3 ab	86.7 a	51.7 abcd	46.7 abcd	68.3 abc	93.7 a	97.7	99.7 a	
8	TE	98	88.3 a	94.3 ab	86.7 a	51.7 abcd	50.0 abcd	68.3 abc	82.7 abc	90.0	99.7 a	
9	FL	49	81.0 a	84.0 ab	78.3 abc	38.3 bcd	35.0 cd	55.0 abcd	75.0 abc	86.3	96.0 ab	
10	FL	49	81.0 a	82.7 b	73.3 bc	55.0 abcd	48.3 abcd	58.3 abcd	71.7 bc	80.0	95.0 ab	
11	FL	98	88.3 a	93.7ab	81.7 abc	43.3 bcd	35.0 cd	53.3 bcd	80.0 abc	91.0	97.7 ab	
12	FL	98	81.7 a	85.0 ab	81.7 abc	53.3 abcd	50.0 abcd	56.7 abcd	75.7 abc	91.7	97.3 ab	
13	G	49	31.7 b	53.3 c	76.7 abc	66.7 ab	66.7 ab	73.3 ab	86.3 abc	88.3	98.0 ab	
14	G	98	41.7 b	63.3 c	70.0 c	73.3 a	71.7 a	80.0 a	88.3 ab	95.0	99.0 a	

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Percentage ground cover expressed on a scale of 0 to 100 percent.

seedlings from the soil seedbank (Lush, 1988a). The ability of annual bluegrass to compete with creeping bentgrass is likely the result of several factors: continuous seed production and renewal of growth during cooler seasons in the absence of heat or drought stress (Sprague & Burton, 1937). Observations in this experiment conclude a similar pattern of annual bluegrass behavior. Additionally, evaluation of all treatments does not appear to support the hypothesis that PGR application had an effect on the loss or suppression of annual bluegrass as might be expected. The summer decline of annual bluegrass, supports a hypothesis that overseeding creeping bentgrass at the time (e.g. late summer) of maximum annual bluegrass thinning and minimum vigor may enhance creeping bentgrass seedling survival and subsequent seedling development. It is particularly important to interseed creeping bentgrass into annual bluegrass at this time since it is more adapted to summer conditions. Lush (1989) suggests that annual bluegrass maintains its year-round presence because successive generations overlap in time.

Glyphosate treated plots seeded to creeping bentgrass increased ground cover through June and from September through November. A slight period of decline occurred in mid-July. However, creeping bentgrass germination and development was extremely slow in April and May, and glyphosate treated plots were slow to reach 100 percent cover under close and frequent mowing (Table 1.3). Little difference in establishment rate was observed between 49 and 98 kg ha⁻¹ seeding rates on glyphosate treated plots. Continual mowing (five times per week) at close cutting heights (4 mm) may have reduced seedling

ability to develop and produce stolons. Therefore, where rapid creeping bentgrass ground cover is desired, frequent close clipping appears to be a detrimental practice.

No phytotoxicity on annual bluegrass was observed from spring applications of PGRs. Turfgrass injury symptoms, a slight hazy appearance and bronzing of some leaves, were observed on both fall PGR application dates.

Spring treatment tiller counts in November recorded high tiller populations densities (e.g. 280 000 tillers m⁻²) for all spring treatments (Table 1.4). Lush (1988a) reported similar tiller density (270 000 tillers m⁻²) on a golf green in Southern Australia. Creeping bentgrass tillers were identified in all treatments. Increasing creeping bentgrass tillers were found with increasing rates of creeping bentgrass seed. Treatments without PGRs and seeding rates of 49 and 98 kg ha⁻¹ were similar in numbers of creeping bentgrass tillers. 147 kg ha⁻¹ seed was not statistically different than other treatments. However, there were 50 % more bentgrass tillers in plots receiving 147 kg ha⁻¹ seed.

Plots treated with a PGR were not different than plots not receiving a PGR in numbers of bentgrass tillers present. Trinexapac-ethyl applied once was superior to similar treatments applied with trinexapac-ethyl twice although not statistically significant. A decline in the number of creeping bentgrass tillers with a second application of trinexapac-ethyl was observed. Plots seeded with 49 kg ha⁻¹ creeping bentgrass and treated one time with trinexapac-ethyl had a greater success rate in terms of numbers of bentgrass tillers present than the same seeding rate and trinexapac-ethyl applied twice although again not statistically different.

Table 1.4 Creeping bentgrass and annual bluegrass tiller populations as influenced by spring interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Turfgrass species			Total		
	Chemical	Frequency		A. stolonifera	P. annua	Other			
1	None	-	0	5219	c*	281969 ab	8438 a	295625 abcd	
2	None	-	49	30719	bc	260219 abc	1969 a	292906 abcd	
3	None	-	98	23531	bc	238656 abcd	7281 a	269469 bcd	
4	None	-	147	68844	b	167281	de	8531 a	244688 cd
5	TE	Once	49	32500	bc	264469 abc	5313 a	302281 abc	
6	TE	Twice	49	7500	c	243844 abcd	11656 a	263031 bcd	
7	TE	Once	98	19156	bc	309594 a	10531 a	339281 a	
8	TE	Twice	98	15625	bc	249156 abcd	15313 a	280094 abcd	
9	FL	Once	49	61250	bc	224688 bcd	9156 a	295094 abcd	
10	FL	Twice	49	27094	bc	250531 abcd	14781 a	292406 abcd	
11	FL	Once	98	41344	bc	188531	cde	11969 a	241875 d
12	FL	Twice	98	43750	bc	268344 abc	3031 a	315063 ab	
13	G	Once	49	153531 a		114469	ef	1156 a	269156 bcd
14	G	Once	98	199156 a		70000	f	1656 a	270844 bcd

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

Plugs sampled 5 November 1994.

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

On contrasting plots treated with flurprimidol at 49 kg ha⁻¹ of seed there was observed a 44 % decline in numbers of creeping bentgrass tillers with a second application of flurprimidol. At 98 kg ha⁻¹ seed there was no difference between one and two applications of flurprimidol. Comparing plots seeded with 49 kg ha⁻¹ to 98 kg ha⁻¹, seeding at 49 kg ha⁻¹ and applying flurprimidol once, appeared to be the most successful method on the basis of number of surviving creeping bentgrass tillers. In addition, plots treated with two applications of flurprimidol and seeded to 98 kg ha⁻¹ creeping bentgrass had the greatest tiller populations of all PGR treatments.

The greatest ratio of creeping bentgrass to annual bluegrass tillers occurred in plots treated with glyphosate and seeded to creeping bentgrass. While, the 49 and 98 kg ha⁻¹ seed did not differ significantly in numbers of tillers, they contained significantly more creeping bentgrass tillers than all other treatments. The 98 kg ha⁻¹ seed rate contained 23 % more creeping bentgrass tillers than the 49 kg ha⁻¹ seed rate.

Annual bluegrass response to spring applied plant growth regulators was inconsistent (Table 1.4). Annual bluegrass tillers numbers declined with the second application of trinexapac-ethyl, flurprimidol applied twice resulted in an increase in annual bluegrass tiller numbers. As hypothesized glyphosate treatments had much less annual bluegrass tillers than other treatments and the greatest increase on a percent basis (Table 1.5).

Table 1.5 Percentage of creeping bentgrass and annual bluegrass tillers as influenced by spring interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Percentage tillers‡		
	Chemical	Frequency		Agrostis stolonifera	Poa annua	
1	None	-	0	1.9 d*	95.3 a	
2	None	-	49	10.0 cd	89.2 ab	
3	None	-	98	10.5 cd	86.4 abc	
4	None	-	147	28.1 b	68.3 c	
5	TE	Once	49	12.4 bcd	85.8 abc	
6	TE	Once	49	3.2 d	91.5 a	
7	TE	Twice	98	6.1 d	90.9 ab	
8	TE	Twice	98	5.7 d	88.7 ab	
9	FL	Once	49	24.5 bc	72.4 bc	
10	FL	Twice	49	11.2 cd	82.7 abc	
11	FL	Once	98	17.0 bcd	77.8 abc	
12	FL	Twice	98	15.1 bcd	83.8 abc	
13	G	Once	49	57.1 a	42.4 d	
14	G	Once	98	72.6 a	26.7 d	

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Percentages derived from tiller counts (Table 1.4). Plugs sampled 5 November 1994.

Late summer / fall treatments

Late summer treated plots, except for mefluidide and glyphosate treatments, displayed acceptable (values greater than 5) or better quality throughout the fall months of 1994 (Table 1.6). Plots receiving a second flurprimidol application were initially darker green. Gaussoin et. al, (1985) reported a similar response on flurprimidol treated creeping bentgrass and annual bluegrass. They found that chlorophyll content on plants treated at 1.68 kg ha⁻¹ was significantly higher than untreated plants. However, over time quality of these plots declined giving a light brown appearance. This could be attributed to older leaves naturally senescing, and younger leaves not being able to replace the older ones. This period of prolonged foliar suppression of PGR treated plants prevents foliage replacement to a degree required to sustain sward greenness (Watschke et al, 1992).

Percent green ground cover of the late summer treated plots generally was observed to increase throughout the fall months (Table 1.7). The only exception occurred with one treatment of flurprimidol which resulted in a decline in cover from 84 % on 30 August to 70 % on 20 September. However, recovery occurred by 21 October. This increased ground cover was attributed to more favorable temperatures for annual bluegrass growth and development. The day temperatures were rarely above the optimum for cool-season grasses and the night temperatures were cooler. Thus, allowing the plant to develop in more optimum temperatures for cool season grasses.

Table 1.6 Turfgrass quality ratings as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Turf quality‡				
	Chemical	Frequency		30 Aug.	20 Sept.	21 Oct.	22 Nov.	Mean
1	None	-	0	5.0 a*	5.5 bc	5.5 bc	6.0 a	5.5 abc
2	None	-	49	4.5 ab	5.3 cd	5.3 bc	5.8 ab	5.2 bc
3	None	-	98	4.5 ab	5.0 d	6.3 ab	5.5 ab	5.3 abc
4	None	-	147	4.0 b	5.0 d	6.0 abc	5.5 ab	5.1 c
5	TE	Once	49	4.5 ab	5.0 d	5.8 abc	5.5 ab	5.2 bc
6	TE	Twice	49	4.8 ab	5.5 bc	5.8 abc	5.8 ab	5.4 abc
7	TE	Once	98	4.0 b	5.0 d	6.0 abc	6.0 a	5.3 abc
8	TE	Twice	98	4.3 ab	5.3 cd	5.8 abc	5.5 ab	5.2 bc
9	FL	Once	49	4.5 ab	6.0 a	5.5 bc	5.8 ab	5.4 abc
10	FL	Twice	49	5.0 a	6.0 a	6.5 a	4.8 cd	5.6 ab
11	FL	Once	98	4.5 ab	6.0 a	5.3 cd	5.5 ab	5.3 abc
12	FL	Twice	98	5.0 a	6.0 a	6.3 ab	5.3 bc	5.6 a
13	M	Once	98	4.0 b	5.8 ab	4.5 d	4.5 d	4.7 d
14	M	Twice	98	4.3 ab	6.0 a	3.3 e	3.3 e	4.2 e
15	G	Once	98	4.5 ab	0.0 e	3.0 e	4.5 d	3.0 f

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide (0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Visual quality ratings are based on a numerical scale of 1 to 9, where 1 is bare soil, 5 acceptable putting green turf, and 9 is ideal turf.

Table 1.7 Percentage green ground cover as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Percentage green ground cover‡				
	Chemical	Frequency		30 Aug.	20 Sept.	21 Oct.	22 Nov.	
1	None	-	0	91.3 a*	97.0 a	99.3 a	99.8 ab	
2	None	-	49	90.0 ab	95.0 a	98.8 a	94.3 bcd	
3	None	-	98	86.3 ab	93.8 a	99.3 a	95.3 abcd	
4	None	-	147	86.3 ab	96.0 a	99.8 a	99.8 ab	
5	TE	Once	49	90.0 ab	93.5 a	98.0 a	98.5 abc	
6	TE	Twice	49	92.5 a	96.0 a	98.8 a	98.3 abc	
7	TE	Once	98	85.0 ab	94.8 a	99.0 a	99.8 ab	
8	TE	Twice	98	90.0 ab	94.8 a	99.0 a	99.3 ab	
9	FL	Once	49	83.8 ab	69.8 b	98.0 a	99.8 ab	
10	FL	Twice	49	90.0 ab	95.0 a	99.0 a	99.5 ab	
11	FL	Once	98	87.5 ab	94.8 a	99.0 a	100.0 a	
12	FL	Twice	98	91.3 a	97.0 a	99.3 a	99.3 ab	
13	M	Once	98	86.3 ab	85.0 ab	95.8 ab	97.0 abc	
14	M	Twice	98	87.5 ab	90.0 a	92.0 b	90.0 d	
15	G	Once	98	80.0 b	17.5 c	76.3 c	93.5 cd	

*Means followed in the same column followed by the same letter are not significantly different according to Fishers LSD.

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide(0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Percentage ground cover expressed on a scale of 0 to 100 percent.

In comparison to the spring seeded creeping bentgrass the August seeded creeping bentgrass was extremely rapid in the establishment phase. The creeping bentgrass seed was observed to germinate in 4 days at 25 C soil temperature. At 8 C soil temperature spring seeded creeping bentgrass took several weeks. This observation supports that of other researchers that creeping bentgrass does not germinate well under low temperatures (Beard, 1980). Percentage green ground cover of the glyphosate treatment increased by almost 60 % in the one month period from 20 September to 21 October (Table 1.5). Late summer seeding makes creeping bentgrass more competitive on a plant count basis, in relation to existing annual bluegrass seed that is also germinating in the fall. The rapid ground cover is very desirable particularly in establishment situations.

Phytotoxicity after the first application in the fall months was confined to the mefluidide treatments. The second fall PGR application severely injured plots receiving mefluidide and moderately injured flurprimidol and trinexapac-ethyl treated plots (Table 1.8). These phytotoxicity symptoms declined over time and by 22 November no phytotoxic effects were observed on any plots except those treated with two applications of mefluidide or flurprimidol.

Fall applications of PGRs caused a significant enhancement of green color from some treatments (Table 1.9). This was most evident on those plots treated with flurprimidol and is similar to the response reported by other researchers (Brueninger et al., 1983; Freeborg, 1983). This could be perceived as a benefit to PGR application. Mefluidide treatments injured the plots resulting in a more chlorotic appearance.

Table 1.8 Turfgrass phytotoxicity injury ratings as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Phytotoxicity ratings‡	
	Chemical	Frequency		2 Nov.	22 Nov.
1	None	-	0	0.3 de*	0.0 d
2	None	-	49	0.3 de	0.0 d
3	None	-	98	0.8 cd	0.0 d
4	None	-	147	0.3 de	0.0 d
5	TE	Once	49	0.3 de	0.0 d
6	TE	Twice	49	1.0 c	0.0 d
7	TE	Once	98	0.3 de	0.0 d
8	TE	Twice	98	0.8 cd	0.0 d
9	FL	Once	49	0.3 de	0.0 d
10	FL	Twice	49	2.5 b	0.8 bc
11	FL	Once	98	0.0 e	0.0 d
12	FL	Twice	98	2.8 b	1.0 b
13	M	Once	98	0.3 de	0.0 d
14	M	Twice	98	4.0 a	2.0 a
15	G	Once	98	0.0 e	0.0 d

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide (0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Visual phytotoxicity ratings are based on scale of 0 to 5, where 0 is no injury, and 5 is brown turf.

Table 1.9 Turfgrass color ratings as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Color ratings‡							Mean			
	Chemical	Frequency		1 Sept.	12 Sept.	20 Sept.	20 Oct.	30 Nov.						
1	None	-	0	6.0 a*	5.8 bc	5.5	def	5.3 bcd	4.8	e	5.5 bc			
2	None	-	49	5.5 ab	5.0 d	5.3	ef	5.8 b	5.3	de	5.4 cd			
3	None	-	98	5.5 ab	5.0 d	5.0	f	5.0 cd	4.8	e	5.1 de			
4	None	-	147	5.5 ab	5.3 cd	5.0	f	5.3 bcd	5.3	de	5.3 cd			
5	TE	Once	49	4.5 c	5.8 bc	5.0	f	5.8 b	5.0	e	5.2 cde			
6	TE	Twice	49	5.0 bc	5.8 bc	5.5	def	6.8 a	6.0	bcd	5.8 b			
7	TE	Once	98	5.0 bc	6.3 ab	5.0	f	5.5 bc	5.5	cde	5.5 bc			
8	TE	Twice	98	5.0 bc	5.8 bc	5.3	ef	6.5 a	6.3	abc	5.8 b			
9	FL	Once	49	5.3 b	6.5 a	6.8 ab	5.3	bcd	5.0	e	5.8 b			
10	FL	Twice	49	5.5 ab	6.5 a	7.0 a	7.0 a	7.0 a	7.0 a	6.6 a	6.6 a			
11	FL	Once	98	5.3 b	6.8 a	7.0 a	5.0	cd	5.0	e	5.8 b			
12	FL	Twice	98	5.0 bc	6.8 a	6.3 bc	6.8 a	6.8 a	6.5	ab	6.3 a			
13	M	Once	98	4.5 c	4.3	e	5.8	cde	4.8	d	5.0	e	4.9	ef
14	M	Twice	98	4.5 c	4.3	e	6.0	cd	3.0	e	5.3	de	4.6	f
15	G	Once	98	3.0 d	0.0	f	0.0	g	5.0	cd	5.5	cde	2.7	g

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide (0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Visual color ratings are based on a numerical scale of 1 to 9, where 1 is extremely chlorotic turf, 5 acceptable green color, and 9 is dark green.

The color of the mefluidide treated plots improved through September and October. Poor color could be due to initial application of PGRs during August. At a time when annual bluegrass was in a weakened condition. Additionally, the second application of trinexapac-ethyl and flurprimidol improved the color of those plots significantly over all other treatments.

An important reason for using PGRs is to reduce the number of mowings required. This is realized in the amount of clippings produced. Clippings were collected on 12 and 17 October 1994. Those plots receiving a second application of PGRs were treated on 2 October. This was a suitable opportunity to evaluate the influence of PGRs on clipping production and plot vigor (Table 1.10). Clippings were reduced by all repeat PGR applications. The repeat application of mefluidide resulted in the greatest of clipping reduction. What could be interpreted as the relinquishing of PGR effects was recorded on the October harvest dates, on those plots treated with PGRs only once on 29 August. Generally PGR effects last for a period of four to six weeks.

In the late summer treatments, creeping bentgrass tillers were found in all treatments (Table 1.11). Increasing rates of creeping bentgrass seed interseeded into annual bluegrass turf, not treated with a PGR, increased the numbers of bentgrass tillers.

Generally, PGR treatments did not increase creeping bentgrass tiller populations relative to non-PGR treated turf. Trinexapac-ethyl treated turf was not statistically different regardless of number of applications or seed rate comparing all trinexapac-ethyl

Table 1.10 October fresh clipping weights as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Clipping harvest date	
	Chemical	Frequency		12 Oct.	17 Oct.
				-----g / m ² -----	
1	None	-	0	134.0 ab*	64.7 ab
2	None	-	49	114.0 abcde	59.8 ab
3	None	-	98	103.8 cdef	56.2 bc
4	None	-	147	125.3 abcd	61.7 ab
5	TE	Once	49	130.0 abc	75.7 a
6	TE	Twice	49	94.5 efg	39.3 de
7	TE	Once	98	124.7 abcd	69.0 ab
8	TE	Twice	98	79.7 fg	34.0 ef
9	FL	Once	49	137.9 a	66.2 ab
10	FL	Twice	49	98.8 def	37.8 def
11	FL	Once	98	131.6 abc	64.8 ab
12	FL	Twice	98	99.1 def	40.5 cde
13	M	Once	98	104.5 bcdef	65.0 ab
14	M	Twice	98	66.2 g	21.7 f
15	G	Once	98	86.7 efg	53.6 bcd

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluide(0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

Table 1.11 Creeping bentgrass and annual bluegrass tiller populations as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	Chemical	Frequency	Seed rate kg ha ⁻¹	Turfgrass species			Total
				A. stolonifera	P. annua	Other	
				----- tillers / m ² -----			
1	None	-	0	2750	d* 314531	abcd 6969	abcd 324219
2	None	-	49	16656	cd 319688	abc 8531	abc 344844
3	None	-	98	24219	cd 287656	bcde 2031	de 313906
4	None	-	147	26094	cd 339531	ab 3594	bcde 369219
5	TE	Once	49	11875	cd 277656	cde 2438	cde 291969
6	TE	Twice	49	24844	cd 300250	abcde 10156	a 335250
7	TE	Once	98	20313	cd 308438	abcd 6875	abcd 335625
8	TE	Twice	98	24937	cd 300625	abcde 7656	abcd 333219
9	FL	Once	49	12281	cd 328531	abc 3906	abcde 344688
10	FL	Twice	49	17188	cd 245625	e 3375	bcde 266188
11	FL	Once	98	30469	c 288688	bcde 8906	ab 328062
12	FL	Twice	98	14625	cd 282656	bcde 3906	abcde 301188
13	M	Once	98	75938	b 261344	cd 3688	bcde 340938
14	M	Twice	98	26656	cd 347188	a 2656	bcde 376500
15	G	Once	98	187813	a 55781	f 94	e 243687

* Means in the same column followed by the same letter are not significantly different under Fishers least significant difference test (LSD) at 0.05 probability level. Plugs sampled 29 November 1994.

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide (0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

treatments. However, total tiller numbers increased with additional applications of trinexapac-ethyl.

The response of turf treated with flurprimidol was inconsistent. While repeat applications were not significantly different from single applications. The 49 kg ha⁻¹ seed rate and the repeat application of flurprimidol increased creeping bentgrass tiller numbers. At 98 kg ha⁻¹ of seed the repeat application of flurprimidol decreased the number of creeping bentgrass tillers by 52 % over a one time application of flurprimidol.

Turf treated with mefluidide followed a similar pattern associated with PGR application and seedling survival. The second application resulted in a 64 % reduction of creeping bentgrass tillers. Independent of the glyphosate treatment, the greatest significant increase in total creeping bentgrass tiller numbers occurred in turf treated only once with mefluidide and interseeded with creeping bentgrass at 98 kg ha⁻¹.

The most significant increase in creeping bentgrass populations resulted from an application of glyphosate and seeded to with 98 kg ha⁻¹ creeping bentgrass. This method appears to be the most effective method for creeping bentgrass introduction from seed. On a percent basis this resulted in 77 % creeping bentgrass stand (Table 1.12).

Creeping bentgrass seeded at 49 kg ha⁻¹ and one application of flurprimidol had more annual bluegrass tillers than the same treatment with an additional application of flurprimidol. This indicates a possible regulation effect of annual bluegrass by flurprimidol. One application of mefluidide had less annual bluegrass than treatments with a second application of mefluidide. It is plausible that the reduction in creeping

Table 1.12 Percentage of creeping bentgrass and annual bluegrass tillers as influenced by late summer interseeding of creeping bentgrass and plant growth regulator application.

Treatment	PGR†		Seed rate kg ha ⁻¹	Percentage tillers‡	
	Chemical	Frequency		Agrostis stolonifera	Poa annua
1	None	-	0	0.8 d*	96.7 a
2	None	-	49	4.8 cd	92.7 ab
3	None	-	98	7.7 cd	91.7 ab
4	None	-	147	7.2 cd	91.8 ab
5	TE	Once	49	4.3 cd	94.8 ab
6	TE	Twice	49	7.4 cd	89.4 ab
7	TE	Once	98	6.1 cd	91.9 ab
8	TE	Twice	98	8.1 c	89.6 ab
9	FL	Once	49	3.6 cd	95.2 ab
10	FL	Twice	49	6.5 cd	92.3 ab
11	FL	Once	98	9.3 c	87.9 b
12	FL	Twice	98	5.0 cd	93.6 ab
13	M	Once	98	21.4 b	77.4 c
14	M	Twice	98	7.1 cd	92.2 ab
15	G	Once	98	77.3 a	22.6 d

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

†FL=Flurprimidol (0.28 kg ha⁻¹), G=Glyphosate (2.8 kg ha⁻¹), M=Mefluidide (0.14 kg ha⁻¹), TE=Trinexapac-ethyl (0.19 kg ha⁻¹)

‡Percentages derived from tiller counts (Table 1.11). Plugs sampled 29 November 1994.

bentgrass tillers with the second application resulted in a space for existing annual bluegrass to tiller. However, this observation is inconsistent with what was observed for the trinexapac-ethyl treatment.

Annual bluegrass response to late summer applied plant growth regulators was very inconsistent (Table 1.11). The trends noted from spring applied PGRs were not evident in the late summer applications of the same PGRs. Trinexapac-ethyl application was inconsistent among number of applications. At the 49 kg ha⁻¹ seed rate subsequent trinexapac-ethyl applications increased annual bluegrass tiller numbers. Creeping bentgrass seeded at 98 kg ha⁻¹ the second application of trinexapac-ethyl resulted in a very slight decline in annual bluegrass tiller numbers. There was significantly more annual bluegrass tillers when flurprimidol was applied with 49 kg ha⁻¹ creeping bentgrass. At both rates of creeping bentgrass seed the second application of flurprimidol resulted in a decline in annual bluegrass tiller numbers. Among mefluidide treatments, mefluidide applied a second time resulted in significantly more annual bluegrass tillers compared to a one time application of mefluidide. As hypothesized glyphosate treatments had significantly less annual bluegrass tillers than all other late summer treatments.

CONCLUSIONS

Creeping bentgrass when seeded into an annual bluegrass under putting green conditions does not become well established, regardless of PGR treatment or season. Any success of overseeding creeping bentgrass into an existing turfgrass was limited to a small percentage of applied seed. Low success rates can be attributed to several factors. These include: stress on seedlings from frequent (5 times a wk) close (4 mm) mowing, allowing little opportunity for a seedling to develop into a mature plant. Interspecific plant competition is also a contributing factor. Creeping bentgrass and annual bluegrass are competing for light, moisture, nutrients, and space. Established plants had an advantage over seedlings. The last and most crucial factor is moisture availability. Adequate moisture must be available for seedling survival. Excess moisture is undesirable in putting green situations. In many cases excess moisture has been referred to as the reason for annual bluegrass invasion and perpetuation (Sprague & Burton, 1937). The ability of creeping bentgrass to vegetatively spread into open areas and create a dense turf is seen as an advantage to maintaining creeping bentgrass. In addition the ability of creeping bentgrass to persist, particularly in the summer months when annual bluegrass ground cover declines is also an advantage. Creeping bentgrass in this study was superior to annual bluegrass losing little or no ground cover in summer months.

The response of PGRs to enhance "passive" overseeding of creeping bentgrass was inconsistent and mostly unsuccessful. Compounds absorbed primarily through the

foliage (e.g. Trinexapac-ethyl, Mefluidide) were hypothesized to perform superior on a one time application basis. The primarily root absorbed compound flurprimidol was hypothesized to be dramatically detrimental to creeping bentgrass seedlings, particularly with a second application on emerged seedlings (Haley & Fermanian, 1985; Gaussoin & Branham, 1987). However, this was not observed. Kageyama et. al (1989) found that a similar root absorbed compound paclobutrazol did not influence the establishment of 'Penncross' creeping bentgrass when slice seeded 15 or 30 days after treatment.

In general, a second application of a PGR after creeping bentgrass seed germination was slightly detrimental to the numbers of surviving tillers. This trend was independent of type of the growth regulator used. It appears in order to realize dramatic increases in creeping bentgrass numbers quickly some turfgrass discoloration, indicative of significant annual bluegrass suppression or injury, must be accepted. This was observed with the late summer and fall mefluidide applications, and glyphosate application regardless of season. This appears to be the only way that annual bluegrass competition can be suppressed sufficiently to allow seedling creeping bentgrass to be competitive. This is valuable information in regard to late summer and late fall applications of PGR in fine turf situations. Discoloration of putting surfaces is particularly undesirable from the standpoint of turfgrass users. Therefore, in situations where high turf quality is desired, PGR applications in late summer or late fall should be carefully considered to avoid discoloration.

Seeding rate is an important consideration. Although inconsistent with some literature (Madison, 1966; Nelson, 1995), seed rates greater than 49 kg ha⁻¹ appear to be necessary to achieve significant increases in creeping bentgrass populations resulting from interseeding. Nelson (1995) reported that seed rates of 25 or 49 kg ha⁻¹ are preferred for overseeding established creeping bentgrass / annual bluegrass putting green turfs. These seed rates were suggested so as not to delay the maturity of the seedlings. This may be more appropriate in situations of initial establishment or renovation where a seedling turfgrass is not immediately subjected to mower stress. In an established putting green community under continuing maintenance creeping bentgrass shoot density appears to be most important. The survival ratio of seeds planted and resultant tiller numbers is anticipated to be low. The degree of creeping bentgrass conversion success should be based on the speed of creeping bentgrass introduction not necessarily plant maturity. Therefore higher seed rates would be beneficial.

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Chapter 2

Creeping Bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) Growth as Influenced by Plant Growth Regulating Materials Under Putting Green Culture

INTRODUCTION

Growth regulators have been used on Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Shreb.), and several other grasses since 1952 (Elkins, 1983). The term 'growth regulator' implies to most turf managers a synthetic chemical that will cause growth reduction. Although partially correct, this term is too restrictive in the sense that certain growth regulators can also stimulate growth. A plant growth regulator (PGR) is an organic compound that, when applied in low concentration, can affect the physiological processes and growth and development in the plant (Danneberger and Street, 1990). Growth regulating compounds can be divided into natural and synthetic products. Natural compounds are hormones produced by the plant. These include abscisic acid, gibberellic acid, ethylene, auxin and others. Commercially produced synthetic plant growth regulating substances are not produced endogenously by plants, but when applied exogenously they induce endogenous processes. Both natural and synthetic growth substances regulate or influence cell division and differentiation, root and shoot growth, germination, flowering, photosynthesis, and sterol synthesis (Danneberger and Street,

1990). The ideal PGR would retard vertical leaf growth but permit active growth of roots, rhizomes, tillers, and horizontal leaf growth. This would permit continued new growth, including new leaves that are essential to maintain a uniformly green, dense turf resistant to damage from traffic, disease and insect pests, and able to overcome environmental stress injury (Elkins, 1983).

Many turfgrass managers have used PGRs to reduce mowing requirements. However, problems associated with PGR applications include; possible phytotoxicity and discoloration, potential to thin or lower density; and the potential to cause damage during periods of inhibited growth with the advent of unexpected environmental stress conditions (i.e. disease or temperature). The most serious concern is associated with root development and function. Stunted roots resulting from PGR use, would be deleterious to the ability of the turf to maintain itself, especially during heat and drought stress (Shearing & Batch, 1982). Retarded root renewal would prevent adequate water and mineral uptake required to sustain grass plants (Field & Whitford, 1982). The relationship between PGRs and their effects on rooting has been inconsistent. Results of studies involving various turfgrass species have shown the following: roots were not affected but resumed growth after the foliage (Wakefield & Fales, 1977); the duration of root suppression mirrored that of the foliage (Wakefield & Dore, 1974) or prolonged root suppression may (Schmidt & Bingham, 1977) or may not (Dernoeden, 1984) be detectable the following year.

OBJECTIVES

1. To determine the influence of the Trinexapac-ethyl (TE) alone, and in conjunction with a triazole fungicide (propiconazole) and a biostimulator, on creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw. 'Southshore') maintained as a putting green.
2. To determine the influence of soil pH on the root production of PGR treated creeping bentgrass as a function of late season PGR application.
3. To evaluate seasonal rootmass production of PGR treated creeping bentgrass.

2.1 Field Study

MATERIALS AND METHODS

On 20 June 1994, plots 1.8 m by 1.5 m (2.7 m²) were established on an eight month old stand of creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw. 'Southshore') located at the Turfgrass Research Center in Blacksburg, Virginia. The location was in full sun and on a modified sand mix. Results of soil test as analyzed by the Virginia Tech soil testing laboratory: pH = 5.9, P = 9 ppm, K = 48 ppm, Ca = 432

ppm, Mg = 65 ppm, Zn = 1.9 ppm, Mn = 13.9 ppm, Organic matter 2.6 %. Results of a particle size analysis: sand = 87.4 % silt = 8.6 % clay = 4.0 %. This classified the soil as a sand.

Treatments were initiated on 22 June 1994. The study involved six treatments comprised of three components replicated four times (Table 2.1). The three components included; a plant growth regulator (trinexapac-ethyl), a fungicide (propiconazole), and a biostimulating material (3-D). The 3D product is a proprietary cold-water seaweed extract, fortified with humic acid and 5% iron (supplied by Plantwise Biostimulant Co., Louisville, Ky.) Each of the treatments consisted of either one of the components alone or in conjunction with one of the other components. The experimental design was a randomized complete block. Plant growth regulators were applied with a compressed air sprayer delivering 375 L ha⁻¹ at 276 kPa.. Treatments were applied on the following dates: 22 June, 3 August, 16 September, 4 November 1994.

Experimental area maintenance practices

Actively growing bentgrass (April through October) was walk-mowed (Toro Greensmaster 1000) five times per week at a height of 4 mm with clippings removed. Fertilizer was applied at 37, 8, and 21 kg ha⁻¹ per month actual nitrogen, phosphate and potash, split in two applications. Irrigation supplemented rainfall as needed.

Table 2.1 Creeping bentgrass plant growth regulating chemical treatments.

Treatment		PGR treatments†		
Field	Greenhouse	TE	PPC	3D
		----- kg ha ⁻¹ -----		L ha ⁻¹
1	1	0.00	0.00	0.0
2	2	0.19	0.00	0.0
3	3	0.00	0.84	0.0
4	4	0.19	0.84	0.0
5	5	0.00	0.00	9.5
6‡		0.19	0.00	4.8

† TE=Trinexapac-ethyl, PPC=Propiconazole, 3D=Biostimulator

‡ Treatment not included in greenhouse pH study.

Data recorded

Data recorded during the study included: *Sclerotinia* dollar spot infestation, visual color ratings, in-situ rootmass production and fall fresh clipping weights.

Sclerotinia dollar spot (Couch, 1995) data was recorded on: 22 June, 25 July, 15 August, 30 August, 19 September, and 10 October 1994. The scale used for rating was 0 to 10 (0 = no visible symptoms, 10 = complete blighting of the turf).

Visual color data was recorded on: 22 June, 27 June, 7 July, 8 August, 22 August, 12 September, 19 September, 26 September, 10 October, and 24 October 1994. The scale used for the ratings was 1 to 9 (1 = extreme chlorosis, 9 = dark green color).

Seasonal in situ rootmass production was measured on three separate dates; 6 September, 1 November 1994 and 8 March 1995 by removing a 10 cm diameter plug each from each field plot and cutting roots at a depth of 2.5 cm. PVC pipe was installed just below the soil surface in the hole from which plugs were taken. These holes were backfilled with a sandy soil (sand = 95.1 % silt = 4.9 %) which produced the following soil test results: pH 5.1; P = 12 ppm, K = 17 ppm, Ca = 540 ppm, Mg = 31 ppm, Zn = 1.6 ppm, Mn = 2.0 ppm, and organic matter = 3.0 %. The removed plug was fitted with a wire mesh screen then replaced in the hole flush with the surface. Plugs were hand watered frequently the first several days to prevent desiccation. Plugs were removed from the rooting chambers and roots were washed free of soil. Roots were severed from the plugs and dried at 60 C for 24 hours and weighed and ashed at 600 C to determine the

actual carbon content. Rootmass on 6 September were not ashed.

Root sampling periods (date in-situ plug inserted and date sampled) were: 13 July - 6 September 1994, 12 September - 1 November 1994, and 7 November 1994 - 8 March 1995. Each date a new plug from an unsampled area of the field plots was used. The removed root mass was then dried at 60 C for 24 hours

Winter root production was measured by the same procedure: This study compared rootmass production of turf last treated with PGRs 4 November with turf last treated 16 September 1994. The plugs from the 1 November sample date were replaced in the hole from which they came. Plugs were removed on 8 March 1995. The roots were washed free of the sandy soil and severed from plug. The removed rootmass was dried at 60 C for 24 hours and ashed at 600 C to determine actual carbon content.

Fall clipping weights were taken from plots that were unmowed for a period several days prior to harvesting. Clippings were harvested from a 0.58 m² section from the center of each plot with the walk behind greens mower. Clippings were placed in paper bags and fresh weights were recorded. Following clipping removal all plots were mowed twice to reestablish the 4 mm height. Clipping weights were recorded on: 4 October, 12 October, 9 November, and 22 November 1994.

RESULTS AND DISCUSSION

Disease severity increased throughout the growing season (Table 2.2). As of

Table 2.2 1994 *Sclerotinia* dollar spot ratings as influenced by plant growth regulator applications.

Plant Growth Regulator†	Dollar spot ratings‡						Mean
	22 June	25 July	15 Aug.	30 Aug.	19 Sep.	10 Oct.	
Untreated	1.8 a*	2.3 b	3.0 ab	3.3 b	4.8 b	5.0 a	3.3 b
TE	2.3 a	3.5 a	4.0 a	5.0 a	6.5 a	5.8 a	4.5 a
PPC	2.3 a	1.0 c	0.3 d	0.0 d	0.0 d	0.0 c	0.6 d
TE and PPC	2.3 a	1.0 c	0.0 d	0.0 d	0.0 d	0.0 c	0.5 d
3D	2.3 a	2.3 b	2.3 bc	2.3 bc	3.3 c	3.3 b	2.6 b
TE and 3D	0.5 b	1.8 bc	1.8 c	1.3 cd	2.8 c	2.5 b	1.8 c

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

‡Dollar spot ratings based on a scale of 0 to 10, (0 = no disease present, 10 = complete turf blighting).

18 September 1994 all untreated plots had severe *Sclerotinia* dollar spot infestations as well as the plots treated with TE only. On three of five observation dates TE treatments had more disease than all other treatments. PPC treatments had the least amount of disease. Biostimulator treated plots had less disease than the control or those treated with TE alone. However, these plots had more disease than those treated with PPC. This could indicate that the turf treated with the biostimulator was more healthy and less prone to fungal attack. Although there was less disease in relation to the untreated control the disease levels present were unacceptable (ratings greater than 2) for fine quality putting green turf.

Generally, treatments containing the biostimulator material had a darker green appearance (Table 2.3). A value of greater than 5 was determined to be an improvement over the natural color of the turf. This response was attributed to the 5 % iron contained in the product. Turf treated with the PPC and TE combination was more green than untreated turf. The untreated control had the poorest color throughout the study.

Clipping production was greatest in the plots treated with PPC alone at all sampling dates (Table 2.4). Untreated plots were next in clipping amounts. This reduction in clippings could be attributed to numerous disease lesions present. Therefore, reducing the amount of harvestable turfgrass. PPC treated turf had no disease and therefore the amount of harvestable turfgrass was greater. Another plausible explanation could be that PPC treated creeping bentgrass had greater leaf numbers per plant. Goatley et. al, (1990) found this to be the case on seedling Kentucky bluegrass treated with

Table 2.3 Creeping bentgrass seasonal visual color ratings as influenced by plant growth regulator application.

Plant Growth Regulator†	Visual Color Ratings‡									
	22 June	27 June	7 July	8 Aug.	22 Aug.	12 Sept.	19 Sept.	26 Sept.	10 Oct.	Mean
Untreated	5.8	4.5 bc*	5.0	d 5.8 bc	4.0 b	4.5	c 4.8 bc	4.5 b	5.8	4.9 c
TE	6.0	4.0	c 6.0 bc	5.3 c	6.3 a	5.0 bc	4.8 bc	4.3 b	5.8	5.2 abc
PPC	6.0	5.5 ab	5.3	cd 5.8 bc	4.5 ab	5.3 b	4.8 bc	4.3 b	5.8	5.2 bc
TE and PPC	6.0	4.0	c 7.5 a	4.3	d 4.5 ab	6.0 a	4.3	c 6.0 a	6.3	5.4 ab
3D	6.0	6.5 a	5.0	d 7.3 a	5.5 ab	4.5	c 6.0 a	4.5 b	5.8	5.7 a
TE and 3D	6.0	4.5 bc	6.8 ab	6.3 b	6.0 ab	5.3 b	5.3 b	4.3 b	6.0	5.6 abc

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

‡Visual color ratings based on a scale of 1 to 9, 1 is extremely chlorotic turf and 9 is dark green.

Table 2.4 Creeping bentgrass clipping yields as influenced by plant growth regulator applications.

Plant Growth Regulator†	Harvest date				Sum
	4 Oct.	12 Oct.	9 Nov.	22 Nov.	
	-----g / m ² -----				
Untreated	28.4 a*	10.2 ab	16.4 b	21.7 b	76.6 b
TE	11.9 b	7.3 b	15.1 b	12.2 c	46.5 c
PPC	29.7 a	10.9 a	21.2 a	27.9 a	89.7 a
TE and PPC	10.1 b	7.7 b	17.7 ab	13.2 c	48.7 c
3D	28.6 a	8.0 ab	18.0 ab	21.6 b	76.2 b
TE and 3D	10.8 b	7.5 b	17.7 ab	16.6 c	52.5 c

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

0.93 kg ha⁻¹ PPC. PPC significantly increased seedling leaf number six weeks after treatment. TE reduced the amount of cumulative clippings by 39 % relative to the control. TE in conjunction with PPC reduced clippings 48 % in relation to PPC only treated turf. The addition of the biostimulator material with TE application slightly negated the TE induced growth reduction.

In situ rootmass production results were inconsistent. Rootmass production at all sampling dates was not significant (Table 2.5). At the 6 September sampling date plots treated with plant growth regulators increased in rootmass over untreated creeping bentgrass. The greatest increase in rootmass was with TE treated turf and TE with 3D combination, these treatments increased rootmass 21 % and 23 % respectively. At the 1 November sampling date the greatest rootmass production was from turf treated with the combinations of TE with PPC or 3D. These treatments had equal rootmass and increased rootmass 33 % over untreated creeping bentgrass. At the 8 March sampling date results were similar to the 1 November date. The TE with PPC or 3D combinations again yielded the most rootmass production with 23 % and 10 % more rootmass respectively, than untreated turf. All other treatments at this sampling date had less rootmass than the untreated turf.

Beard and Daniel, (1965) observed that individual roots of creeping bentgrass had a specific pattern of growth. Initially the rate of growth was rapid with a peak between the 8th and 10th days. After this peak, regardless of temperature, there was a gradual decline until eventually all root growth ceased. Beard and Daniel (1965) also reported that

Table 2.5 Seasonal creeping bentgrass rootmass production as influenced by plant growth regulator applications.

Plant Growth Regulator †	Sampling date			Sum
	6 Sept.	1 Nov.	8 Mar.	
	----- g / 75 cm ² -----			
Untreated	0.59	0.22	0.61	1.42
TE	0.74	0.18	0.47	1.39
PPC	0.61	0.28	0.44	1.33
TE and PPC	0.62	0.33	0.79	1.74
3D	0.70	0.24	0.52	1.46
TE and 3D	0.76	0.33	0.68	1.77
LSD(0.05)	NS*	NS	NS	NS

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

16 C was the most desirable temperature for creeping bentgrass root production maintained at 6 mm.

Creeping bentgrass root production was active through the winter period. However, no difference in rootmass was observed between all plant growth regulators applied in September compared with those applied in November (Table 2.6). Results were also inconsistent. Creeping bentgrass treated with TE and PPC alone saw a small decline in 4 November rootmass. However, TE combined with PPC or 3D resulted in increased rootmass, although not significant. Beard and Daniel, (1966) observed that new creeping bentgrass roots formed only after very sharp drops in temperatures. This observation suggests that cooler temperatures are important in promoting root elongation or as a prerequisite condition for root production. Schmidt and Blaser (1967) reported that the most creeping bentgrass root development and highest levels of carbohydrate accumulation occurred at low temperatures where there was little respiration and net photosynthesis. Hanson and Juska (1961) showed that Kentucky bluegrass produced a substantial gain in root growth during low temperature periods and that applications of nitrogen prior to low temperature periods favors roots without the corresponding large gain in top growth. Powell et. al, (1967) found similar results on creeping bentgrass. They stated that if nitrogen applications are too high available carbohydrates are used for N metabolism, if N is too low the plants become brown, photosynthesis is reduced and therefore carbohydrates will not be available for root growth. Additionally, late season fertilization of creeping bentgrass will result in a larger energy supply and a greater ability

Table 2.6 Creeping bentgrass root production as influenced by late fall plant growth regulator application.

Plant Growth Regulator†	Date PGR Last Applied	
	16 Sept.	4 Nov.
	-----g / 75 cm ² -----	
Untreated	0.45	0.61
PPC	0.58	0.44
TE	0.53	0.48
TE and PPC	0.53	0.79
TE and 3D	0.59	0.69
3D	0.52	0.52
LSD(0.05)	NS*	NS

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

to remove water and nutrients during later stress periods. The subsequent greater root growth during early spring improves the competitive ability of cool season turf over undesirable annual species such as annual bluegrass.

Cumulative rootmass production; although not statistically significant the TE with PPC or 3D combinations resulted in the most rootmass 19 % and 20 % increases respectively over untreated creeping bentgrass. This information on TE root impacts is similar to what other researchers have found with other foliarly absorbed materials on turfgrass roots. Cooper et. al, (1987) reported an increase in root length and root elongation of mefluidide treated annual bluegrass. All of these observations suggest that healthy creeping bentgrass, whether it be fertilizer induced or through the use of PGR substances, going into winter months with minimal top growth will result in increased root production the following spring and make it more competitive with weedy grasses.

Lastly, a slight phytotoxic response was noticed on plots treated with the TE plus PPC treatment. This could possibly be attributed to the result of mixing two emulsifiable concentrates. This response was primarily confined to the edges of the plots where the sprayer started and stopped. The phytotoxic response from the 4 November application date was observed to remain until mid-March 1995, when mowing resumed. This knowledge is particularly important for high quality putting greens, where a phytotoxic response is very undesirable.

2.2 pH study

MATERIALS AND METHODS

On 10 January 1995 forty plugs, 10 cm diameter by 2.5 cm deep were removed from the creeping bentgrass plots treated in the field. The plugs were placed in 10 cm diameter by 20 cm deep (780 cm³) PVC rooting cylinders. These cylinders were filled with two sandy soils that differed only in pH 5.1 and 6.2, respectively. Cylinders were placed in a glass greenhouse under an overhead mist system for six weeks. Temperatures maintained in the greenhouse were similar to a summer climate (26 C day and 22 C night). Plug leaf canopy was clipped weekly to maintain 6 mm of foliage. The cylinders were periodically randomly rearranged to minimize the potential irregularities associated with overhead mist irrigation. This study involved all treatments used in the field study except the TE with 3D combination (Table 2.1).

On 21 February 1995 roots were removed from the cylinders and washed free of sandy soil. The roots were severed from the plug and dried at 60 C for 24 hours. Oven dried roots were ashed at 600 C for 24 hours to determine total carbon content.

RESULTS AND DISCUSSION

Creeping bentgrass rootmass at the two levels of pH (5.1 and 6.2) was not

different. The overall rootmass only increased slightly at pH 6.2. The actual rootmass production comparing all treatments means was 0.28, 0.27 grams per cylinder at pH 6.2 and 5.1 respectively. At both pH levels creeping bentgrass treated with PPC produced the most roots. Comparing all treatments, PPC treated creeping bentgrass grown at pH 6.2 (Table 2.7) produced the most rootmass, 0.30 grams. Soil pH did not influence rootmass production of TE treated creeping bentgrass or the TE with PPC combination. Creeping bentgrass treated with PPC in conjunction with TE increased rootmass at both levels of soil pH. The biostimulant was not different from any treatment at any pH. However, the biostimulant increased rootmass relative to untreated creeping bentgrass.

CONCLUSIONS

A high quality creeping bentgrass putting green turf was maintained with plant growth regulating substances. TE reduced the amount of foliar production on creeping bentgrass. Additionally, it was not detrimental to rootmass production. The addition of PPC to creeping bentgrass was effective in reducing *Sclerontinia* dollarspot infestations. PPC had an impact on the rootmass and foliar production of creeping bentgrass. Total harvested clippings were significantly greater than all other treatments. PPC treated creeping bentgrass grown under greenhouse conditions resulted in greater rootmass than untreated or creeping bentgrass treated with TE although in most cases not statistically different. The biostimulator material enhanced the green color of treated field plots and

Table 2.7 Creeping bentgrass root production as influenced by plant growth regulator and pH under greenhouse conditions.

Plant Growth Regulator†	Rootmass	
	pH 5.1	pH 6.2
	-----g / 75 cm ² -----	
Untreated	0.22 d*	0.26 bcd
PPC	0.31 abc	0.34 a
TE	0.24 cd	0.24 bcd
TE and PPC	0.32 ab	0.32 ab
3D	0.28 abcd	0.27 abcd

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

†TE=Trinexapac-ethyl, PPC=Propiconazole, 3D = Biostimulator material.

an increase in rootmass was observed. The disease severity of *Sclerotinia homeocarpa* on creeping bentgrass treated with PPC was negligible and, biostimulant treated turf had less disease than untreated turf.

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Chapter 3

Seedling Growth Responses of Creeping Bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) and Annual Bluegrass (*Poa annua* var. *annua* L.) to Plant Growth Regulators Under Controlled Environments

INTRODUCTION

Annual bluegrass (*Poa annua* L.) invades close-cut, irrigated, intensively managed cool season turfs and within 3 to 5 years may dominate the stand (Beard et. al, 1978). To reduce annual bluegrass invasion and to favor the existing creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Farw.) golf course superintendents will overseed golf course fairways and putting greens with creeping bentgrass in order to maintain a competitive seedbank and minimize annual bluegrass ingress. Generally, the majority of annual bluegrass seed in the soil seed bank germinates in late summer and fall months. At this time of year a pre-emergence herbicide (i.e. bensulide) can be applied to reduce annual bluegrass germination (Goss et. al, 1980). An alternative to fall pre-emergent application is to use a plant growth regulator (PGR) to inhibit annual bluegrass seedling development. PGRs were first introduced to reduce the number of necessary mowings on turfgrass systems. It was later noticed that seedlings were more sensitive to these materials. Kageyama, et. al, (1989) reported that annual bluegrass was more sensitive to

the PGR paclobutrazol than creeping bentgrass. They attributed this response to a preferential uptake of the xylem mobile compound by the shallower rooted annual bluegrass plants. In situations where annual bluegrass or creeping bentgrass seedlings are present the application of a primarily root absorbed PGR (i.e. flurprimidol, paclobutrazol) could be detrimental to seedling establishment and development. This same response could be perceived as beneficial in managing annual bluegrass particularly at the seedling stage.

3.1 Growth Chamber Experiment

OBJECTIVE: To quantify the effects of plant growth regulators (PGRs) on creeping bentgrass and annual bluegrass, in the early seedling stage, in a controlled environment.

MATERIALS AND METHODS

On 2 August 1994 eighty plastic pots 11.5 cm diameter 71.8 cm³ were filled with sandy soil. The composition of the sandy soil media was analyzed by the Virginia Tech Soil Testing Laboratory with the following results: pH = 5.1; P = 12 ppm, K = 17 ppm, Ca = 540 ppm, Mg = 31 ppm, Zn = 1.6 ppm, Mn = 2.0 ppm. The percent organic matter was 3.0 %. The pots were irrigated and allowed to drain to provide for soil settling. After which they were again filled to the surface with sandy soil and irrigated. Forty pots were

seeded to 49 kg ha⁻¹ creeping bentgrass (*Agrostis stolonifera* var. *palustris* (Huds.) Faw. 'Southshore'), seed lot M20-M100-2BN3A (lab germination 96%). The remaining forty pots were seeded to 49 kg ha⁻¹ of annual bluegrass (*Poa annua* var. *annua*) seed of Oregon origin (lab germination 85%) supplied by Thompson Valley Seed Service.

The pots were placed in an airp 12 in an air-conditioned green house at the Virginia T Turfgrass Research Center and maintained at 20 C during germination. On 12 August all pots were fertilized with a liquid solution containing 9.8 kg ha⁻¹ of nitrogen, phosphate, and potash, respectively. On 28 August all pots were uniformly clipped to 1.8 cm and a foliar application of fertilizer was again applied at 4.9 kg ha⁻¹ nitrogen, phosphate, and potash, respectively.

On 6 September 1994 all pots were uniformly clipped to 1.8 cm and then visually grouped by density into five blocks. These blocks were designated as replications for the treatments. Block 1 consisted of pots with the most plant density, Block 5 = least plant density. Following blocking, PGR treatments were applied foliarly from a compressed air sprayer. The sprayer was calibrated to deliver 750 L ha⁻¹ at 276 kPa. Pots treated with flurprimidol were irrigated with 1.8 cm ha⁻¹ water.

The study comprised of eight treatments with two components (Table 3.1). The components were PGR (flurprimidol, propiconazole and trinexapac-ethyl) and rate (one rate of propiconazole and three rates for each flurprimidol and trinexapac-ethyl). Each treatment was replicated five times. Treatments were completely randomized.

Table 3.1 Plant growth regulator treatments applied to creeping bentgrass and annual bluegrass seedlings.

Treatment	Plant growth regulator	
	Chemical	Rate
		kg ha ⁻¹
1	None	NA
2	Trinexapac-ethyl	0.10
3	Trinexapac-ethyl	0.19
4	Trinexapac-ethyl	0.38
5	Flurprimidol	0.14
6	Flurprimidol	0.28
7	Flurprimidol	0.56
8	Propiconazole	0.84

NA = Not applicable

On 6 September 1994, pots were placed in a Sherer Controlled Environment Growth Chamber (Model CEL 37-14). The chamber provided the following environmental conditions: irradiance 16/8 h day/night; and temperatures of 27 C / 18 C (day/night). The pots were foliarly fertilized on 21 September and 29 September with 9.8 kg ha⁻¹ of nitrogen, phosphate, and potash, respectively. The pots were kept moist through capillary action to prevent plant desiccation. Pots were rearranged weekly to reduce any variation in temperature or light inside of the chamber. The experiment was terminated on 12 October, 1994.

Data was recorded for fresh clipping weights and rootmass. Pots were clipped and the fresh clipping weights were recorded on; 18 September and 12 October 1994. Rootmass was also measured. On 12 October, immediately following clipping, plant roots were washed free of sandy soil and dried at 60 C for 24 hours. Total carbon content was determined by ashing dried roots at 600 C for 24 hours.

Creeping bentgrass and annual bluegrass were analyzed independently. Treatment means were compared using Fishers protected LSD (Fisher, 1966). This procedure performs pairwise t-tests. All data was subjected to statistical analysis on the SAS (SAS, 1985) system.

RESULTS AND DISCUSSION

The untreated creeping bentgrass seedlings and those treated with 0.84 kg ha⁻¹

propiconazole resulted in the most significant amount of foliage produced (Table 3.2). flurprimidol applied at 0.56 kg ha⁻¹ resulted in the greatest amount of foliage growth regulation. No treatment was different from untreated seedlings in rootmass (Table 3.2). The greatest rootmass resulted from 0.14 kg ha⁻¹ flurprimidol. There was no difference between the highest rates of flurprimidol or trinexapac-ethyl.

The greatest annual bluegrass clipping yield occurred from untreated plants and plants treated with 0.84 kg ha⁻¹ propiconazole (Table 3.3). The greatest foliage growth regulation resulted from 0.56 kg ha⁻¹ flurprimidol and 0.19 kg ha⁻¹ trinexapac-ethyl. However, only the 0.56 kg ha⁻¹ flurprimidol differed from the untreated control in rootmass production. This treatment had 21 % less rootmass than the untreated plants. A decline in rootmass was noticed with increasing levels of PGR treatments although this was not significant.

Comparisons between creeping bentgrass and annual bluegrass treatments in this study are inappropriate. Each species was planted on an equal weight basis. However, creeping bentgrass has far more seeds per unit area. If they had been planted on a Pure Live Seed basis this would have enabled valid comparisons between the two species.

This study demonstrates the ability to apply plant growth regulating chemicals at four weeks after seeding and not damage rootmass production. This could reduce the number of required mowings for an establishment planting. In addition the benefits of applying propiconazole at the seedling stage was realized. This treatment had the highest

Table 3.2 Creeping bentgrass seedling response to Plant Growth Regulators (PGR) grown in a controlled environment chamber.

PGR†	Rate	Clipping yields		
		24 Sept.	10 Oct.	Sum
	kg ha ⁻¹	----- g / pot -----		
None	0.00	0.16 ab*	0.72 a	0.88 a
TE	0.10	0.13 ab	0.51 b	0.64 b
TE	0.19	0.11 ab	0.44 bc	0.55 bc
TE	0.38	0.14 ab	0.37 bc	0.51 bc
FL	0.14	0.11 b	0.43 bc	0.54 bc
FL	0.28	0.13 ab	0.37 bc	0.50 bc
FL	0.56	0.10 b	0.32 c	0.42 c
PPC	0.84	0.18 a	0.70 a	0.88 a
			Rootmass	1.25 ab
				1.12 b
				1.12 b
				1.08 b
				1.45 a
				1.15 b
				1.19 b
				1.26 ab

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

†FL = Flurprimidol, PPC = Propiconazole, TE = Trinexapac-ethyl

Table 3.3 Annual bluegrass seedling response to Plant Growth Regulators (PGR) grown in a controlled environment chamber.

PGR†	Rate	Clipping yields			Rootmass
		24 Sept.	10 Oct.	Sum	
	kg ha ⁻¹	----- g / pot -----			
None	0.00	0.25 a*	0.54 ab	0.79 a	1.12 a
TE	0.10	0.22 ab	0.38 cd	0.60 b	1.04 ab
TE	0.19	0.19 bcd	0.35 de	0.54 bc	1.00 ab
TE	0.38	0.19 bcd	0.37 cd	0.56 b	0.97 ab
FL	0.14	0.15 d	0.41 cd	0.56 b	1.06 ab
FL	0.28	0.16 cd	0.48 bc	0.64 b	0.99 ab
FL	0.56	0.17 bcd	0.24 e	0.41 c	0.88 b
PPC	0.84	0.21 abc	0.63 a	0.84 a	1.06 ab

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

†FL = Flurprimidol, PPC = Propiconazole, TE = Trinexapac-ethyl

amount of clippings produced and in turn resulted in the most number of leaves produced. Goatley and Schmidt (1990) found similar results when propiconazole was applied at 0.93 kg ha⁻¹ to Kentucky bluegrass. They found that propiconazole significantly increased seedling leaf numbers six weeks after treatment when applied to a fall seeding.

The treatment of 0.14 kg ha⁻¹ flurprimidol produced more rootmass than untreated plants. This result is interesting since this treatment yielded significantly less clippings than the control or seedlings treated with propiconazole. Therefore, it may be possible to use this product to maximize rootmass production without excessive clipping production.

3.2 Germination Studies

INTRODUCTION

Propiconazole is an important fungicide for use in turfgrass disease control. Ciba Geigy currently markets two formulations of the fungicide propiconazole. Their trade names are Alamo and Banner. Alamo is a 1.24 MeC (Micro-encapsulated Concentrate) water based formulation that contains a wetting agent and blue dye. Banner is a 1.1 EC (Emulsifiable Concentrate) organic solvent based formulation.

OBJECTIVE: To observe the germination response of creeping bentgrass (*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw.) and annual bluegrass (*Poa annua* var. *annua* L.) to two formulations of propiconazole under laboratory conditions.

MATERIALS AND METHODS

A logarithmic series of solutions (0, 1, 10, 100, 1000 ppm) of Alamo and Banner formulations of propiconazole (Table 3.4) were mixed on 10 February 1994 with distilled deionized water.

Germination tests for creeping bentgrass and annual bluegrass were run according to the protocol established by the Association of Official Seed Analysts (Anonymous, 1981). Creeping bentgrass seed (*Agrostis stolonifera* L. var. *palustris* (Huds.) Farw 'Southshore'.) was supplied from Loft's Seed Company. Annual bluegrass (*Poa annua* var. *annua* L.) was supplied by Thompson's Valley Seed Company of Oregon. 100 seeds of each species were placed on two sheets of 7.0 cm Watmans 541 hardened ashless filter paper within a plastic germination (petri) dish. Four replicates of 100 seeds each were used per treatment. 10 ml of the appropriate test solution was initially added to each dish. Additional distilled water was added over time as needed to prevent desiccation.

The dishes were placed in a germinator and was maintained at 30 C/15 C, 8/16 h (light/dark). All germination dishes were placed in large clear plastic boxes containing moistened towels in order to maintain humidity.

Table 3.4 Creeping bentgrass and annual bluegrass germination study treatments.

Treatment	Formulation	Concentration
		ppm
1	distilled deionized H ₂ O	NA
2	Alamo	1
3	Alamo	10
4	Alamo	100
5	Alamo	1000
6	Banner	1
7	Banner	10
8	Banner	100
9	Banner	1000

NA = Not Applicable

The number of germinated seeds were removed and recorded at 7, 14, 21, and 28 days after treatment. A seed was considered to have germinated when the first root penetrated the seed coat and had visibly extended outward. Treatment means were analyzed Fisher's protected Least Significant Difference (LSD) test at the 5% error level.

RESULTS AND DISCUSSION

Untreated annual bluegrass germination was less than untreated creeping bentgrass, 91 % and 98 %, respectively. Banner had less impact on germination relative to Alamo for both species (Table 3.5 and 3.6). Seven days after treatment propiconazole concentrations of 100 ppm or greater in both species had significantly less germination percentage than the untreated control or the 1 and 10 ppm solutions of both formulations. At 100 ppm propiconazole there was significantly less germination of seeds treated with Alamo when compared to seeds treated with Banner. At concentrations of 1000 ppm both formulations almost inhibit seed germination. These tests illustrate that the Alamo formulation seems to be more effective in penetrating seed coats. This might be attributed to a wetting agent that is contained in this propiconazole formulation. Luo (1991) found similar results with the Banner formulation on Kentucky bluegrass seeds. Banner concentrations of 0, 0.5, 0.9 and 1.9 g kg⁻¹ seed (0, 20,000, 36,000, and 380,000 ppm) delayed Kentucky bluegrass germination but did not completely inhibited the process. Luo also found that plumule and radicle lengths at the termination of the experiment (21 days)

were inhibited.

Propiconazole is an important fungicide in the maintenance of fine quality turfgrass and ornamental plants. In addition, these tests demonstrate that high concentrations of propiconazole could be potentially harmful to overseeded grasses or very young plants.

Table 3.5 Creeping bentgrass germination response to propiconazole formulations and rate.

Formulation	Conc	Days After Treatment					Total
		7	14	21	28		
	ppm	-----number of germinated seeds -----					
Control	-	96.0 a*	1.8 d	0.0 d	0.0		97.8 a
Alamo	1	95.0 a	1.5 d	0.0 d	0.0		96.5 ab
Alamo	10	96.5 a	0.8 d	0.0 d	0.0		97.3 a
Alamo	100	58.0 c	17.5 a	2.0 bc	0.0		77.5 c
Alamo	1000	3.8 e	0.3 d	2.8 b	0.0		6.9 e
Banner	1	95.5 a	1.0 d	0.8 cd	0.0		97.3 a
Banner	10	95.0 a	1.5 d	0.3 d	0.0		96.8 ab
Banner	100	82.5 b	8.5 c	0.5 cd	0.0		91.5 b
Banner	1000	9.0 d	12.3 b	4.5 a	0.0		25.8 d

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

Table 3.6 Annual bluegrass germination response to propiconazole formulations and rate.

Formulation	Conc	Days After Treatment					Total
		7	14	21	28		
	ppm	-----number of germinated seeds -----					
Control	-	85.0 a*	6.3 cd	0.0 b	0.0		91.3 a
Alamo	1	83.8 a	9.3 c	0.0 b	0.0		93.1 a
Alamo	10	71.3 b	15.3 b	0.0 b	0.0		86.6 ab
Alamo	100	53.8 c	25.3 a	1.3 a	0.0		80.4 b
Alamo	1000	0.8 d	1.3 e	1.5 a	0.0		3.6 d
Banner	1	84.3 a	6.5 cd	0.8 b	0.0		91.6 a
Banner	10	80.3 a	5.3 cde	1.3 ab	0.0		86.9 ab
Banner	100	65.3 b	22.0 a	0.0 b	0.0		87.3 a
Banner	1000	6.5 d	4.0 de	0.5 ab	0.0		11.0 c

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

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Conclusions

Chapter 1

Creeping bentgrass does not become well established when interseeded into annual bluegrass under putting green management. It was hypothesized that the use of a plant growth regulator (PGR) would enhance interseeding success and create a "passive" situation where annual bluegrass would be less competitive. It was also hypothesized that high seeding rates (98 kg ha^{-1}) would increase creeping bentgrass introduction. In addition the use of a foliarly absorbed PGR (i.e. trinexapac-ethyl) just prior to interseeding was thought to have an advantage over a root absorbed PGR (i.e. flurprimidol). Finally, it was believed that a late summer seeding of creeping bentgrass would be superior to a spring seeding.

Results established that generally higher seeding rates did increase creeping bentgrass tiller numbers and that the use of a PGR was not necessary for creeping bentgrass introduction. In addition, if a PGR was used and a subsequent application was made following creeping bentgrass emergence tended to be deleterious to the survival of those seedlings. This was based on comparison to those treatments only receiving a PGR prior to seeding. Seed emergence was considerably more rapid in late summer, as a result of more favorable soil temperature for creeping bentgrass germination. However, success of interseeding was not increased with a late summer seeding, except when

comparing total renovation treatments where creeping bentgrass was interseeded following an application of glyphosate. Creeping bentgrass that was spring seeded took several months to achieve 100 % cover, whereas late summer seeded creeping bentgrass increased ground cover 60 % in a one month period from September to October. This is particularly remarkable considering the plots were mowed five times per week at 4 mm throughout that establishment period.

Lastly, phytotoxicity was not observed from spring applications of PGRs. However, phytotoxicity was observed on mefluidide treated turf and late fall applications of PGRs. Those PGRs were flurprimidol, mefluidide, and trinexapac-ethyl. Mefluidide was not used in the spring treatments. Future research needs to quantify the impacts of soil media and possibly different types of seedbed preparation equipment. Concern is expressed for the practice of interseeding creeping bentgrass into high sand content putting greens. The limited success in this study was on a native soil situation where seedlings had a better opportunity for adequate available moisture. Sand-based greens could possibly be even more unsuccessful due to the limited moisture holding capacity. Compounding this is that many golf courses are not encouraged to keep putting greens moist. Additional research regarding shallow tine core cultivation or the use of equipment with more narrow tine spacing should be evaluated for creeping bentgrass seed establishment into existing putting greens.

Chapter 2

This study examined the influence of plant growth regulating substances on a creeping bentgrass putting green turf. It was originally hypothesized that the PGR trinexapac-ethyl would reduce the amount of clipping harvested and could be detrimental to creeping bentgrass root production. Trinexapac-ethyl reduced clipping production and on some sampling dates increased rootmass relative to untreated turf. It was also hypothesized that the PGR propiconazole would effectively control turfgrass diseases, particularly *Sclerotinia* dollar spot, but the impact on creeping bentgrass roots was unclear. Propiconazole was very effective at controlling *Sclerotinia* dollar spot and its use increased rootmass production relative to untreated creeping bentgrass. Additionally, propiconazole applications resulted in the highest amount of clippings at all sampling dates. The use of the biostimulator material (3D) was hypothesized to enhance the green color of the turf and to have a positive impact on creeping bentgrass root production. Both of these suppositions were validated throughout the study. In addition the biostimulant had less disease than untreated creeping bentgrass.

Chapter 3

It was hypothesized that the application of a PGR, particularly flurprimidol a root

absorbed compound, during the seedling stage of creeping bentgrass or annual bluegrass would be detrimental to rootmass production. This was not necessarily the case since rootmass, in some instances, was observed to be greater than untreated seedlings while top growth was reduced. Additionally, the application of propiconazole was hypothesized to have a positive influence on root and top growth. Propiconazole application increased clipping production throughout this study while rootmass production of both species was unaffected.

In addition, creeping bentgrass and annual bluegrass germination response to Alamo and Banner formulations of propiconazole was evaluated. It was hypothesized that seed germination in solutions of propiconazole would decline as concentrations were increased. Additionally, it was hypothesized that seed germination in response to Banner treatments would be less than the Alamo since Banner contains an organic solvent as the propiconazole carrier. The results of this study showed that increasing concentrations of propiconazole reduced germination of both species. It was also observed that 1000 ppm concentrations of both formulations almost completely inhibited germination. Lastly, it was observed that seed germination in the Alamo formulation was less than seed germination in the Banner formulation. This response might be attributed to a wetting agent included in the Alamo formulation or possibly the blue dye included in the formulation.

Appendix 1. Creeping bentgrass visual quality ratings. 1989 NTEP Creeping Bentgrass Trial. Blacksburg, Virginia.

Cultivar	1991	1992	1991-1993
	Visual quality ratings†		
Southshore	5.3	5.2	5.2
Egmont	4.9	5.0	5.1
Regent	5.2	4.7	5.1
Penncross	4.7	5.3	5.1
Cobra	5.2	4.9	5.0
Pennlinks	4.9	4.9	4.9
Providence	5.1	4.6	4.9
88.CBL	5.1	4.6	4.7
88.CBE	5.1	4.4	4.7
Penneagle	4.8	4.6	4.7
Putter	4.9	4.2	4.6
PRO/CUP	4.8	4.4	4.6
Lopez	4.6	4.3	4.5
Bardot	4.3	4.9	4.5
National	4.4	4.4	4.4
Carmen	5.6	3.6	4.3
LSD (0.05)	NA‡	0.7	0.3

† Quality ratings based on a 1 to 9 scale (1=poor quality, 5= acceptable putting green turf, 9 = best).

‡NA = Not Available

VITA

Cale Andrew Bigelow was born November 1, 1971 in Harrisonburg, Pennsylvania to Margaret Ann Bigelow and Frankie Lee Bigelow. He graduated from Paul VI High School in Fairfax, Virginia in June 1989. In the fall of 1989 he entered Virginia Polytechnic Institute and State University. In May 1993, he graduated from the department of Crop and Soil Environmental Sciences with an emphasis on turfgrass management. He began graduate work at Virginia Polytechnic Institute and State University in the fall of 1993. Cale was married to Ashley Howard Hanchey on August 20, 1994. They are the proud owners of a very happy Black / Chocolate labrador retriever named "Links". Upon completing the requirements for the Master of Science degree Cale accepted a position as Assistant Golf Course Superintendent at the Robert Trent Jones Golf Club in Lake Manassas, Virginia.

A handwritten signature in black ink that reads "Cale Bigelow". The signature is written in a cursive, flowing style with a long horizontal line extending to the right from the end of the name.