Creeping Bentgrass, Kentucky Bluegrass and Tall Fescue Responses to Plant Growth Stimulants Under Deficit Irrigation

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CREEPING BENTGRASS, KENTUCKY BLUEGRASS AND TALL FESCUE RESPONSES TO PLANT GROWTH STIMULANTS UNDER DEFICIT IRRIGATION

by

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Crop and Soil Environmental Sciences

Abstract

A four-year drought, increasing population and shifting climate has spurred water conservation practices within Virginia. Creeping bentgrass (*Agrostis palustris* 'L93'), Kentucky bluegrass (*Poa pratensis* 'Midnight'), and tall fescue (*Festuca arundinacea*) Dominion blend were evaluated under deficit irrigation and upon exogenous application of plant growth stimulants (PGS), seaweed extract (SWE) + humic acid (HA), glycinebetaine (GB) and a commercial SWE product (PP). The objectives were to determine crop coefficients (K_c) for creeping bentgrass fairways and tall fescue home lawns, to determine if PGS application allowed for more water conservation, and to determine if they impacted physiological function and/or root morphology.

A preliminary greenhouse experiment was conducted with creeping bentgrass and Kentucky bluegrass irrigated with 100%, 85% and 70% of evapotranspiration (ET). The study determined that an additional deficit irrigation level should be included for the field study and that GB application and 100% and 85% ET irrigation level produced the greatest creeping bentgrass root mass.

The two –year field study evaluated creeping bentgrass and tall fescue. Tall fescue home lawns could be irrigated every five days with a K_c of 0.55 or once a week with a K_c of 0.70. Creeping bentgrass fairways could be irrigated every four days with a K_c of 0.85. Glycinebetaine application increased bentgrass rooting after planting and showed osmoprotectant properties.

Another greenhouse study evaluated five GB rates on bentgrass and tall fescue. No differences were found between the five rates and concluded that the rate utilized in the field study may be appropriate for turfgrass application.

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Chapter 1
Introduction and Objectives

Virginia turfgrass managers are responsible for maintaining 1.4 million acres of functional, safe, and aesthetically pleasing turfgrass surfaces, and most depend on customer satisfaction to determine their success. It is expected that these surfaces always be maintained at high quality while efficiently utilizing finite natural resources and minimizing environmental impact. In 1998, it was estimated that Virginians spent almost $120 million on turfgrass irrigation and another $190 million to establish or re-establish turfgrass in areas that may have been damaged by drought or excessive use (VASS, 2000). Some turf managers choose to use plant growth stimulants (PGS) in attempts to increase turfgrass resistance to a variety of environmental stresses such as water deficit.

Most of the commercially available PGS contain seaweed extracts (SWE) and/or humic acids (HA) as their main ingredients. Researchers at Virginia Tech have made significant contributions in assessing the benefits of treating turfgrass with PGS containing SWE and HA. These researchers have reported increased drought resistance of cool season turfgrasses upon application of a SWE and HA mixture (Zhang, 1997; Schmidt and Zhang, 2001; Zhang and Ervin, 2004). In these studies, drought resistance was associated with increased antioxidant activity, rooting capabilities and maintenance of photosynthetic efficiency.

Foliar application of glycinebetaine (GB), a by-product of sugar beet processing, has been studied extensively on field crops as a way to enhance drought resistance by osmoregulation. Plants that maintain turgidity under low soil water potentials are able to continue photosynthesis, thus fueling metabolic processes. Glycinebetaine also functions as an osmoprotectant to buffer membranes from dehydrative stress. Many researchers have documented maintenance of such physiological functions under water stress (Makela et al., 1996a; 1997c; Agboma et al., 1997a; 1997b; 1998b; 1998a; Xing and Rajashekar, 1999).

Virginia experienced a four-year drought from 1999 to 2002, which resulted in mandatory water restrictions for most of the state. The governor assembled a Drought Task Force to compile regulatory actions that would be enforced if Virginia was to experience another drought (Warner, 2002). The turfgrass industry has often been a subject of criticism concerning their water consumption and dependency. This project addresses the public concern for water conservation by developing turfgrass specific crop coefficients. Crop coefficients adjust reference evapotranspiration and allow turfgrass managers to utilize less water while maintaining acceptable turfgrass health.

While previous research has concluded that SWE, HA and GB have the capabilities to enhance physiological processes when water is limited, none have determined if the use of these products allow managers to reduce irrigation inputs.

Two greenhouse studies were conducted upon which to develop treatments for and amplify the results of the field study. The objectives of the first greenhouse study (February-June 2003) were:

i) to determine if the deficit irrigation study is feasible to continue in the field setting.

ii) to examine if the application of SWE + HA, GB or a SWE and Fe product affect turfgrass physiological function (photochemical efficiency, antioxidant activity, cytokinin content) and/or root morphology for creeping bentgrass and Kentucky bluegrass (*Poa pratensis* 'Midnight') under deficit irrigation.

The objectives of the second greenhouse study (November, 2004 – February, 2005) were:

i) to determine which GB concentration has the most effect on enhancing drought resistance characteristics in creeping bentgrass and tall fescue.

ii) to examine which turfgrass physiological functions (photochemical efficiency, antioxidant activity, electrolyte leakage) are altered upon the application of GB under deficit irrigation.

The objectives of the two-year field study (July – September, 2003 and July-September, 2004) were:

i) to develop water conserving crop coefficients for creeping bentgrass (*Agrostis stolonifera* 'L93') fairways and tall fescue (*Festuca arundinacea* Shreb.) blend 'Dominion' home lawns.

ii) to determine if the application of SWE + HA or GB allow for a further reduction in irrigation while maintaining quality.

iii) to determine if the application of SWE + HA or GB have an impact on turfgrass physiological function (photochemical efficiency, antioxidant activity, cytokinin content) and/or root morphology.

Chapter 2
Literature Review

Turfgrass drought resistance

Drought resistance as defined by Passioura (1981) is “the ability of a plant to complete its life cycle even though its growth is limited by an inadequate supply of water or by an inability to conduct water to its leaves quickly enough to satisfy high evaporative demand.” Turfgrasses have many adaptive mechanisms to survive drought whether it is to produce progeny prior to deadly droughty conditions or to adapt their physical characteristics. Younger (1985) and Kneebone et al. (1992) have delineated three types of drought resistance. Plants that mature prior to drought conditions or after significant rainfalls are considered to escape drought. An example prominent in the turfgrass industry is *Poa annua*’s ability to produce seeds prior to dry summer conditions. Drought avoiders are capable of producing growth when subjected to limited soil water. Their avoidance capabilities are expressed in the development of deep root systems, leaf rolling, stomatal regulation and even presence of hairs and wax on the leaf surface. Finally, drought tolerators are capable of maintaining turgor and surviving low water potentials. The distinction between drought tolerators and avoiders is the ability of drought avoiders to produce tissue mass, while drought tolerators are solely capable of surviving. Drought avoiders are of interest for this paper because some level of sustained growth and color are required by turfgrass users. The enhancements of certain morphological characteristics allow some species to resist drought better and longer. Ideally, a healthy turfgrass surface could be achieved with as little water input as possible. As a result, there has been a significant amount of research conducted to characterize drought resistant turfgrass qualities.

Rooting

Drought resistant plants are capable of producing high root to shoot ratios by consuming as few metabolites as possible and by collecting water at a rate that is suitable for survival in its environment (Passioura, 1981). High root to shoot ratios are key for survival as observed in desert plants where considerable amounts of total mass is in the form of deeply penetrating and dense root systems (Jones et al., 1981; Nguyen et al., 1997). The theory behind deep extensive root systems is that they allow the plant to uptake water from more surface area and deeper within the soil profile than more shallow root systems. Qian et al. (1997) found that the deeper root system of tall fescue allowed it to avoid drought conditions better than the shallower rooted 'Meyer' zoysiagrass (*Zoysia japonica* Steud.). Under well-watered conditions, water uptake occurred more in the 0- to 20-cm depth than the 40- to 60-cm depth. The opposite was true under surface soil drying (Nguyen et al., 1997; Huang and Gao, 2000). An increase in root length within deeper soil depths was observed under surface soil drying for tall fescue (Huang et al., 1997a; Huang and Gao, 2000), Emerald zoysiagrass (*Zoysia japonica* Steudel x *Z. tenuifolia* 'Emerald') and seashore paspalum (*Paspalum vaginatum* Swartz) (Huang et al., 1997a). Similarly, stress tolerant Kentucky bluegrass (*Poa pratensis* L.) varieties extracted water from deeper soil depths (15- to 30-cm) due to their increased rooting and activity (Bonos and Murphy, 1999). Poor performing Kentucky bluegrasses studied in Colorado maintained 80% of their root systems within the top 2.5- to 15-cm, while the better performing cultivars had higher proportions of roots in the 15- to 30-cm and 30- to 45-cm depths. The deeper rooted cultivars exhibited better drought resistance even though there were no differences in total root mass between the cultivars (Keeley, 1996).

In turfgrass culture, it is common practice to withhold water for a period of time before either a significant rainfall or irrigation occurs. It is important to note the effects that rewatering has on turfgrass grown in drought conditions. Root dry weight decreased for warm-season grasses undergoing soil drying, but an increase in root dry weight beyond that of the control was noted upon rewatering (Huang et al., 1997a). A similar phenomena was reported in Texas when creeping bentgrass greens, irrigated at a four day interval, compared to a one or two-day interval, produced greater root length density and exhibited improved quality (Jordan et al., 2003). Under short-term drought conditions (less than 14 days), tall fescue root hairs were longer than those in well-watered soils (Huang and Fry, 1998). Root hairs increase surface area and are responsible for a large portion of water and mineral uptake (Passioura, 1981; Kramer and Boyer, 1995). As the drought conditions continued, root hairs died and were sloughed (Huang and Fry, 1998).

Root viability measurements may be more related to shoot survivability, not total root length (Huang et al., 1997b). Root viability can be measured numerous ways, carbohydrate content being one. Total nonstructural carbohydrate content was not affected in tall fescue under surface soil drying and photosynthesized ^{14}C was higher in the roots of the more drought resistant cultivars (Huang and Gao, 2000). Carbohydrate allocation to roots may restrict aboveground biomass; however, turfgrass survivability overrides production, especially under drought. Another root viability measurement is electrolyte leakage (EL) as it indicates cell membrane integrity. An increase in root EL occurred in drought-stressed tall fescue (Huang and Gao, 2000) and continued to increase as drought severity increased (Huang and Fry, 1998). However, less EL was measured in those roots surviving deeper within the soil as the soil surface was drying (Huang et al., 1997a).

Stomatal resistance

Stomatal resistance is regulated by the opening or closing of stomata to control transpiration (Taiz and Zeiger, 1998). Greater stomatal resistance (closed stomates) allows plants to maintain turgor by decreasing the amount of water lost from a plant growing in a drying soil. Regulation of stomatal conductance mainly effects survivability by balancing water loss, rather than carbon gain for growth production (Jones et al., 1981). Stomatal closing commonly occurs during midday, when evaporative demand is highest as a means to conserve water, and reopening often occurs in late afternoon as evaporative demand decreases (Nilsen and Orcutt, 1996). This occurrence is mimicked when plants are subjected to limited soil water to prevent the likelihood of lethal dehydration (Taiz and Zeiger, 1998). Changes in stomatal conductance can occur before there is a measurable change in leaf water content as signals are sent from the root system (Smirnoff, 1993). Stress-tolerant Kentucky bluegrass cultivars maintained transpiration rates, while stress-intolerant cultivars experienced a decrease in transpiration, thus increasing stomatal resistance (Bonos and Murphy, 1999).

An indirect way to gauge stomatal resistance is to measure canopy temperature compared to air temperature (ΔT). Small differences between the two indicate that stomates are open and the plant is actively transpiring, and large differences indicate that stomates are closed to control water loss (Throssell et al., 1987). After irrigation water was withheld for 7 days, Utah grown Kentucky bluegrass ΔT increased and quality decreased. However, nearly a month passed before buffalograss quality declined in response to water stress (Stewart et al., 2004). Similarly, Throssell et al. (1987) reported well-watered (-0.04 MPa) 'Sydsport' Kentucky bluegrass maintained lower ΔT than slightly (-0.07 MPa) and moderately (-0.40 MPa) stressed treatments. Greenhouse studies conducted in Rhode Island reported ΔT readings as low as –2.78°C and as high as 25.83°C for non-stressed and stressed turfgrass, respectively (Wojcik, 1993). Tall fescue in Colorado maintained lower ΔT than Kentucky bluegrass stands, which could be explained by the water scavenging capabilities of the deep rooting tall fescue (Ervin, 1995). Tall fescue's ability to explore deeper soil depths allows for more water uptake for the plant to maintain metabolic processes and transpire actively.

Antioxidant activity

Active oxygen species (AOS) like peroxide (OOH^-), singlet oxygen ($O^·$), superoxide (O_2^-) and hydrogen peroxide (H_2O_2) are formed in the electron transport systems when electrons are leaked and accepted by molecular oxygen (Srivastava, 2002a). Active oxygen species are destructive once excessive levels are reached. A healthy plant is able to scavenge and utilize the AOS produced in photosynthesis reactions, but a severely stressed plant is not capable of doing so, affecting membrane function (Nilsen and Orcutt, 1996). Active oxygen formation often occurs when stomatal openings are closed in response to drought and photosynthesis is inhibited (Smirnoff, 1993). Under water stress, mitochondria and peroxisomes are especially susceptible to oxidative damage by AOS (Bartoli et al., 2004). Antioxidant enzymes serve to scavenge excessive AOS and ultimately convert them to harmless water molecules upon the consumption of NADPH (Nilsen and Orcutt, 1996). The three antioxidants of interest to this paper are superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (CAT). All three react with AOS to maintain levels that are metabolically non-damaging. According to Smirnoff (1993), SOD is located in many subcellular compartments and is responsible for the dismutation of O_2^- to H_2O_2 and O_2. Both APX, which occurs within chloroplasts, and CAT, which occurs within peroxisomes, function to degrade H_2O_2 to H_2O.

Many researchers have measured an increase of plant antioxidant activity in response to stresses like drought. One study conducted with 3-week old pea shoots exposed to drought and then rewatering conditions measured antioxidant activity of APX, SOD and CAT. All three antioxidants were found to increase during drought, but only APX and SOD remained high upon recovery as CAT activity returned to normal. Therefore, CAT appears to be primarily responsible for removing H_2O_2. Ascorbate peroxidase activity was four times higher during drought and 15 times higher during recovery compared to the control unstressed plants. The researchers also found that the initial increase of APX activity coincided with stomatal closure during drought (Mittler and Zilinska, 1994).

A frequent occurrence during summer months is substantial surface soil drying between irrigation or rainfall events. One experiment with Kentucky bluegrass and tall fescue explored the effect of surface soil drying on antioxidant activity. Although SOD activity increased upon initial surface drying, SOD activity decreased as soil was allowed to dry fully (Fu and Huang, 2001). The decrease in activity indicates that the environmental stress was more severe than the capabilities of the protective antioxidants. However, APX activity was not affected when full soil or surface soil drying occurred, compared to the well-watered controls. Catalase levels were not affected by surface drying but like SOD, declined after continued full drying conditions occurred for both cool season grasses (Fu and Huang, 2001). The CAT findings were consistent with Smirnoff (1993), who stated that changes in CAT activity are not often observed. Zhang and Kirkham (1996) likewise determined that CAT was unaffected when sorghum (*Sorghum bicolor*) and sunflower (*Heliantuhus annuus* L.) seedlings were subjected to six days of drought.

Water stress is typically coupled with heat stress during summer months. Jiang and Huang (2001) measured an increase in SOD activity under drought and heat + drought stresses of Kentucky bluegrass and tall fescue. Antioxidant activity did not change during heat stress when leaf water content was maintained above 65%, but decreased when water content dropped below 20%. Under heat, drought, and heat +

drought, CAT activity decreased. Ascorbate peroxidase activity peaked at six days after initiation of heat + drought stress then decreased with time. Despite the natural defense mechanisms plants possess, severe stresses disrupt the balance between the production of AOS and scavenging capabilities of antioxidants. Plant decline and eventual death occur if the stress continues unabated.

Cytokinin synthesis

Cytokinins are considered phytohormones because their site of synthesis and action differ (Haberer and Kieber, 2002). Synthesis occurs in young meristematic tissue like root apices and then cytokinins are transported through the xylem to subsequent leaf tissue (Arteca, 1996; Haberer and Kieber, 2002). Cytokinins are responsible for many plant functions like apical dominance and lateral root formation (Srivastava, 2002a). High cytokinin levels in relation to auxin levels initiate shoot formation over root formation (Taiz and Zeiger, 1998). Cytokinins also counteract the affect of aging by delaying senescence and chlorophyll degradation in stressed plants (Haberer and Kieber, 2002; Srivastava, 2002a). It is thought that cytokinins have an opposite effect on plant growth than abscisic acid (ABA) as cytokinins increase transpiration and ABA stimulates stomatal closure (Nilsen and Orcutt, 1996; Hansen and Dorffling, 2003). The most common and most biologically active cytokinin species are *trans*-zeatin isomers while the *cis*-zeation isomers are less active (Haberer and Kieber, 2002).

A study conducted in Israel on lychee (*Litchi chinensis* Sonn.), a fruit bearing small tree native to China (CRFG, 1996), explored the use of deficit irrigation and the affects of cytokinin synthesis on flower abundance. The researchers found zeatin-riboside (ZR) and dihyrozeatin-riboside xylem sap levels increased under moderate drought stress imposed in the fall (Stern et al., 2003). Zeatin riboside and dihydrozeatin riboside are the most common forms of cytokinins (Mok and Mok, 1994), furthermore both *trans*- and *cis*- zeatin isomers are active (Nilsen and Orcutt, 1996). The increase in cytokinin concentration was linked to increased fruit production the following spring (Stern et al., 2003). Zeatin-riboside was the predominant cytokinin measured in sunflower xylem sap when plants were subjected to drought. Concentration spiked initially and then decreased quickly as drought continued. Upon rewatering, ZR concentration peaked five hours after irrigation and then declined slowly to a concentration not different from the original, non-stressed concentration (Hansen and Dorffling, 2003).

While Hansen and Dorffling (2003) did not measure any isopentenyladenosine-type cytokinins in sunflower xylem sap, other scientists working with different plants have. Wheat (*Triticum aestivum* L.) subjected to partial and full root drought had increased isopentenyl adenosine (IPA) in shoots but decreased amounts in roots. The increase in cytokinins did not correlate with the decrease in roots, therefore it is hypothesized that the leaves synthesized cytokinins independent of roots (Nan et al., 2002). Cytokinin synthesis likely occurs in shoot apexes and lateral buds since they are sites of actively dividing cells (Mok and Mok, 1994). Another study conducted on water stressed grapevines (*Vitis vinifera* L. 'Cabernet Sauvignon') found both zeatin and isopentenyladenosine-type cytokinins in shoot tips. The zeatin cytokinins were consistently present at higher concentrations in non-stressed and water-stressed plants. An interaction was found between xylem sap cytokinin concentration and rootstock varieties. The drought resistant rootstocks had higher concentrations of cytokinins and greater root densities (Nikolauou et al., 2003).

Since cytokinin concentration measurements can be altered due to dilution affects, Shashidhar et al. (1996) measured cytokinin delivery rates in sunflower xylem sap when exposed to drought. They measured a decrease in xylem sap delivery rate from 5.28 to 0.08 pmol h^{-1} as soil potentials decreased from –0.3 to –1.2 MPa, respectively. Cytokinin concentration did not decrease until water stress was severe. These differences are due to the fact that xylem sap flow decreased in decreasing soil water, thus decreasing the cytokinin delivery rate (Shashidhar et al., 1996). Nonetheless, this study reported similar findings to those described above. Cytokinin transport from roots to shoots was negatively affected as soil water stress was imposed.

Numerous researchers have determined that cytokinin concentration and delivery rate decreases as drought increases. A next step in cytokinin research would be to determine mechanisms that maintain cytokinin concentrations while plants are subjected to drought as a means to maintain turfgrass quality by delaying senescence and ultimately protecting chlorophyll stability mechanisms. Some researchers have approached this topic by studying the effects of exogenous cytokinin application on stressed plants. Cytokinins are typically applied as a plant growth stimulator product. Some of those products are discussed in the following sections. Focus will be placed on the cytokinin content and effects of certain plant growth stimulants within this thesis.

Seaweed extracts (SWE) are the most widely used plant growth stimulant that naturally contain cytokinins. When soil was allowed to dry, Zhang and Ervin (2004) found increased ZR levels in creeping bentgrass leaf tissue when treated with a SWE and humic acid (HA) mixture prior to soil drying. The SWE alone and the SWE + HA applications resulted in higher turf quality ratings under drought. However, only the SWE + HA application maintained quality above the minimum acceptable level. Another study applied ZR directly to root zones prior to heat stress. Endogenous levels of ZR were higher for those plants treated with the 1 and 10 μmol concentrations. Also, root mortality, electrolyte leakage, turf quality, photosynthetic rate and photochemical efficiency were all improved, compared to the heat-stressed control, with the higher ZR concentration application (Liu et al., 2002). The same 10 μmol ZR application to creeping bentgrass root zones also decreased leaf senescence under heat stress (Liu and Huang, 2002).

Evapotranspiration

Evapotranspiration (ET) is a measure of the combined processes of soil evaporation and plant transpiration. It is synonymous with water demand because it is an estimate of total water lost from a system and thus is the amount of water needed to be replaced to maintain plant health (Brown, 1996; McCarty, 2001). Beard (1973; 1994) noted that 'water use rate' is used interchangeably with 'evapotranspiration' because the amount of water needed for total plant growth and physiological processes is only slightly larger than evapotranspiration. One to three percent of water absorbed by the plant is used for metabolic processes like photosynthesis (Huang and Fry, 1999). The remaining water is utilized in transpirational cooling.

Potential ET (ET_o) can be estimated by climate data such as air and soil temperature, relative humidity, solar radiation, and wind speed gathered by a weather station. Climate data can then be entered into a computer program like REF-ET (Allen, 2000). There are several ET equations available for use throughout the plant sciences. However, the Penman-Monteith (PM) equation is the most widely used and most consistent ET equation since it incorporates plant height as surface resistance to vapor transfer in the equation, which is missing from the original Penman equation (Allen et al., 1989), that calculate ET_o. The PM equation is suitable for use in various climatic regions and for various crops when computing ET_o (Itenfisu et al., 2003; Ortega-Farias et al., 2004; Stockle et al., 2004). Contrarily, Qian et al. (1996) concluded that the use of atmometers, a less expensive alternative to a weather station, provided more accurate ET_o measurements for warm and cool season grasses than the PM model. More turf managers have weather stations on site or have access to local weather station climate data, than have atmometers. Coupled with an ET computer program, managers can efficiently irrigate based on ET demand (Brown, 1996; Waltz and McCarty, 2000). Evapotranspiration-based irrigation scheduling aids to conserve water because only the estimated amount of water lost from the system is replaced. A study conducted by the Irvine Ranch Water District found that prior to ET-based scheduling, irrigation was applied at up to three times more than ET estimates (Slack, 2000).

Potential ET is an estimate that is calculated via climate data, but actual ET (ET_a) is influenced by turfgrass physiological characteristics. Stomatal and rooting properties, growth habits, and cuticle thickness are among a few of the characteristics that affect water loss through plant transpiration. While reducing transpiration may seem beneficial for water conservation, transpiration is necessary to cool the leaf surface and maintain turf health (Beard, 1973; Salisbury and Ross, 1992; Taiz and Zeiger, 1998; McCarty, 2001). Both warm season (C_4) and cool season (C_3) turfgrasses have the ability to close their stomates during the parts of the day when evaporative demand is highest to prevent water loss (McCarty, 2001). Only the C_4 grasses are able to undergo the occurrence without a reduction in photosynthesis since they can concentrate CO_2 in bundle sheath cells, which suppresses photorespiration (Salisbury and Ross, 1992; Taiz and Zeiger, 1998). Bermudagrass (C*ynodon dactylon* L.) is a deeply rooted turfgrass, which allows it to explore deeper soil volumes for water. This increase in water uptake would theoretically coincide with higher ET rates. However, tall fescue, another deep rooting turfgrass, typically has higher ET_a rates than bermudagrass (Huang and Fry, 1999).

Beard (1994) reported warm season grasses to have ET_a rates between 2 and 6 mm d^{-1}, while C_3 grass ET rates range from 3 to 8 mm d^{-1}. This difference could be explained based on the C_4 versus C_3 stomatal regulation characteristics. Some turfgrasses like tall fescue and Kentucky bluegrass have the ability to roll or fold their leaves to reduce leaf surface area, thus reducing evaporative surface area and ET demand (McCarty, 2001). Native to arid climates, C_4 grasses have thicker cuticles to prevent the loss of water and increase survivability and are capable of concentrating CO_2 in bundle sheath cells (Taiz and Zeiger, 1998).

Evapotranspirational rates not only differ between cool and warm season turfgrasses but also between species within warm and cool season groupings. Carrow (1995) found warm season bermudagrass, St. Augustine (*Stenotaphrum secundatum* [Walt.] Kuntze), and zoysiagrass had ET_a rates of 3.1, 3.3, 3.5 mm d^{-1}, respectively, compared to 3.6 mm d^{-1} for turf type tall fescue. Similarly, McCarty (2001) noted ranges for warm season grasses from 3.1 to 9.6 mm d^{-1} and 3.7 to 12.6 mm d^{-1} for cool season grasses during the summer months. Cool season grasses, Kentucky bluegrass ('Baron' and 'Enmundi'), perennial ryegrass (*Lolium perenne* L. 'Yorktown II'), chewings red fescue (*Festuca rubra* var. *commutata* Guad. "Jamestown') and hard fescue (*Festuca ovina* var. *duriuscula* (L.) Koch 'Tournament'), in southern New England used an average of 3.5 mm d^{-1} from July to September (Aronson et al., 1987). Whereas Kentucky bluegrass and tall fescue grown in Kansas used 5.6 mm d^{-1} from June to September (Fry and Fu, 2003). However, in the arid Arizona desert bermudagrass used 7.2 mm d^{-1} during summer months (Brown et al., 2001). In Nebraska, turf type tall fescue used 6.3 mm d^{-1} from July to September (Kopec et al., 1988). Similarly, peak water consumption rates for cool season exceeded warm season grasses at 5.6 and 4.8 mm d^{-1}, respectively (Smeal, 2000). As Aronson et al. (1987) stated, when soil water is not limiting climate affects ET rates more than turf species.

Crop coefficients

The use of crop coefficients (K_c) allows ET_o to be adjusted for particular climatic conditions and turfgrass species. Crop coefficients are multiplied by ET_o to attain estimated ET_a (Marsh and Strohman, 1980; ASCE, 1990; Carrow, 1995; Brown, 1996;

NMSU, 1996; Brown et al., 2001; McCarty, 2001). The intent of actual ET-based (versus ET_o) irrigation scheduling is conservation of water without unduly impacting turfgrass quality.

A majority of K_c research has been conducted in the arid southwest since potable water is scarce and there is more need for water conservation. Devitt et al. (1992) in southern Nevada determined crop coefficients based on season and level of turfgrass minimum quality. During the spring and fall, fairway height bermudagrass could be irrigated at a K_c of 0.77, while during the summer a K_c of 0.89 was needed. Conversely, during the spring through fall months lawn-height bermudagrass could be irrigated at a K_c of 0.55. A K_c of 0.8 was suitable for bermudagrass grown during the summer months in Arizona and a K_c of 0.83 maintained ryegrass overseeded bermudagrass quality during the winter (Brown et al., 2001). New Mexico fairway warm season grasses maintain quality at a K_c level of 0.75 (NMSU, 1996). Based on quality desired, Kentucky bluegrass and tall fescue could be irrigated with K_cs from 0.6 to 0.8 and 0.5 to 0.8, respectively in Colorado (Ervin and Koski, 1998). Turf type tall fescue in Nebraska could be irrigated at 15 to 20% deficit irrigation (Kopec et al., 1988). Whereas, tall fescue grown in Kansas could safely be irrigated at a K_c of 0.8 but Kentucky bluegrass needed a K_c of 1.0 to maintain quality (Fry and Fu, 2003; Fu et al., 2004).

Some research has been conducted to determine appropriate K_cs in the more humid regions of the country. Aronson et al. (1987) noted a K_c of 1.0 would suffice for all cool season grasses in Rhode Island. Carrow (1995) determined a K_c of 0.75 for warm season grasses and 0.8 for cool season grasses grown in Georgia. It is apparent that K_cs are species and region specific, and that they are useful for conserving water on irrigated surfaces.

Policy affecting turfgrass irrigation

Many states have developed governmental policies that attempt to ensure that adequate amounts of water are available for years to come. In Arizona, the governor proposed a “Water University Initiative” that would work in cooperation with Arizona State University, University of Arizona and Northern Arizona University to further research the drought issues occurring within the state (McKinnon, 2004). The governor also stressed the need for long range water plans and water conservation tactics that could also be immediately be utilized. Similarly, Washington's governor addressed the public's concern over adequate water supplies in a legislative session held in May of 2003 (Hahn and First, 2003).

Colorado is another state that has reacted to the water supply issues plaguing the West. In 2002, Colorado cities issued mandatory restrictions on landscape irrigation. A study was conducted to quantify the amount of water that can be conserved under mandatory landscape irrigation restrictions compared to voluntary restrictions. An 18 to 56% water savings resulted when the 1.85 million customers were only allowed to irrigate their Kentucky bluegrass lawns every third day (Kenney et al., 2004). Colorado's example is one where a science based initiative was implemented. If the Kentucky bluegrass lawns were not irrigated every third day they would enter drought induced dormancy and would be unable to provide the cooling effect that all turfgrasses offer.

While Virginia is an eastern state and usually has adequate water supplies, it experienced a four-year drought from 1999 through 2002 according to the National Oceanic and Atmospheric Association Palmer Drought Severity Index (NOAA, 2005). In response to continuous drought conditions, Governor Mark Warner issued Executive Order #39, titled the Virginia Water Supply Initiative (Warner, 2002). This initiative's aim was, like the above mentioned states' goals, to ensure an adequate water supply for ensuing years. Certain members of the Virginia Turfgrass Council like the Virginia Golf Course Superintendent's Association, Virginia Sports Turf Manager's Association, and the Virginia Irrigation Association joined other Virginia professionals involved in water management to form the Drought Management Task Force. The task force categorized drought severity levels and actions that would be implemented during those times. Home lawn, golf course and athletic field irrigation is not restricted until the state designates that it is under a Drought Emergency, the most severe drought level (DRTAC, 2003).

Continuing research that aids water policy decisions imperative for both western and eastern states. While landscape irrigation uses only 2.9% and golf courses only 1.5% of the country's potable water supplies, both are very visible and are often judged by the public to be water wasters (Barrett, 2004). The turfgrass industry has developed technologically advanced equipment that has great potential to ensure water use efficiency. A recent article in *Golf Course Management* discussed the water and budget savings that can be achieved by simply upgrading irrigation nozzles (Zoldoske, 2004). Gross (2004) discussed steps golf course superintendents can take to ensure they achieve irrigation efficiency in response to drought conditions. Some cities like San Antonio, El Paso, Albuquerque, and Las Vegas have implemented rebate incentives for those who meet set standards for irrigation efficiency (Fender, 2004; Addink, 2005).

Plant growth stimulants

The use of plant growth stimulants (PGS) is gaining popularity for turf managers wishing to increase stress tolerance. Most PGS contain a mixture of seaweed extract (SWE) and humic acid (HA) since research has determined that these compounds work best when combined (Zhang and Schmidt, 1997; Zhang and Schmidt, 1999; Zhang and Schmidt, 2000; Zhang et al., 2003a; Zhang and Ervin, 2004). Another PGS of recent interest for use on turfgrass is glycinebetaine (GB), a by-product of sugar beet processing. Research has shown that GB is does have osmoprotectant and osmoregaultory effects on field crops, which allow the crops to increase production under limited water conditions. Research reports on the use of GB to increase stress tolerance of turfgrass are very sparse but the beneficial properties may be expressed upon application on turfgrass. Discussed below are the characteristics associated with each PGS and their documented affects on plant health and survivability during stress.

Humic acid

Humate is highly decomposed plant and animal matter, typically several million years old. Humic substances are neutrally charged molecules whose exact structure is unknown because of its complex heterogeneous mixture (MacCarthy et al., 1990). Humic acid and fulvic acid (FA) are extracted from humic substances using an alkali reagent (Parsons, 1988; Aitken et al., 1993; Jackson, 1993). The difference between HA and FA is hypothesized to be the number of carboxyl and hydroxyl groups, thus, depending on the extraction process different proportions of HA and FA may be attained (Aitken et al., 1993). Humic acids have a higher molecular weight than FAs and are hypothesized to consist of amino acids, sugars, peptides and aliphatic compounds

(Jackson, 1993; Anonymous, 2003). Fulvic acids remain in solution after HA are precipitated through acidification (Stevenson, 1982; Anonymous, 2003).

The HA used in these experiments is specified as leonardite extracted HA. An experiment with 'Crenshaw' creeping bentgrass compared granular and foliar applications of various humates. Leonardite based HA showed the most significant effect on bentgrass root mass. Leonardite HA foliar application increased root growth by 375% within 20-cm from the soil surface compared to other HA sources (Cooper et al., 1998). Leonardite is undesirable as fuel due to the high oxygen content (Fowkes and Frost, 1993) so it is utilized as a source of agricultural HA. It is formed of naturally oxidized lignite that contains HA and FA (Fowkes and Frost, 1993). Humic acids are strong chelating agents, (Jackson, 1993), allowing them to bind to ions, making them more available to plants. Complexes are formed with phosphorus and micronutrients, which may increase fertilizer efficiency (Levinsky, 1996) by increasing nutrient uptake. Due to the versatile characteristics of HA, it can be applied to supplement plant growth in various forms.

Some researchers looked at HA effects when plants were grown hydroponically. A study in Spain incorporated HA extracted from leonardite into a hydroponic nutrient solution to measure varying concentrations of C affects on barley (*Hordeum vulgare*) nutrient uptake. Macronutrient absorption increased with the application of HA from leonardite and several other organic sources (Ayuso et al., 1996). Another hydroponic study found that a 400 mg L^{-1} HA solution improved creeping bentgrass photosynthesis and root mass (Liu et al., 1998).

Leonardite used as a soil amendment in the correct proportions to prevent phytotoxic effects has proven to enhance plant growth. Pertuit et al. (2001) found that equal parts leonardite humate and sand was detrimental to tomato (*Lycopersicon esculentum* (L.) Mill. 'Mountain Pride') growth and production. However, they did conclude that a mixture of 1/3 leonardite and 2/3 sand positively affected plant health. Soils amended with HA resulted in increased plant height, leaf production and area, shoot fresh and dry weight, and root fresh and dry weight (Reynolds et al., 1995; Pertuit et al., 2001). Reynolds et al. (1995) also determined that amended soils increased Fe in grapevine petioles, and P, K, and Fe in the lamina. The referenced studies amended soils in a greenhouse setting. Amending soils in the field can be timely and costly.

Humic acids can also be used as a foliar spray by placing HA in a suspension as they are not soluble in water (Jackson, 1993; Levinsky, 1996). Foliar application is more common due to the ease of application, particularly in a field setting. Foliar applications of 0.5% and 1% HA on greenhouse and field grown olive (*Olea europaea*) trees improved plant growth. Fruit set increased for one field grown cultivar when no supplemental irrigation was applied. Due to HA's ability to increase nutrient uptake, an increase in K, B, Mg, Ca and Fe were measured in leaf tissue (Fernandez-Escobar et al., 1996). Container grown maize (*Zea mays* L. Kissan) was subjected to varying levels of foliar HA and Sharif et al. (2002) concluded the lowest application rate, 50 mg kg^{-1}, was sufficient to impact plant growth. Shoot and root dry weights were increased by 20% and 39%, respectively, compared to no HA applied. Nitrogen accumulation in the maize leaves increased by 36% when HA was applied at the lowest rate. Chen and Aviad (1990) documented that foliar sprays of humic substances from leonardite humate increased shoot and root growth of tomatoes, which was attributed to the enhanced uptake of macronutrients due to their chelating capabilities.

Researchers have spent countless years experimenting with HA applications on fruit crops and limited time on turfgrass response to HA. The difference between fruit crops and turfgrass is the amount of stress each are allowed to withstand. Producers would prefer fruit crops to not undergo stress because it will affect fruit quality, while turfgrass managers are continually subjecting their turfgrass to environmental stresses. Zhang and Schmidt (2000) found that foliarly applied leonardite based HA increased root growth for tall fescue and creeping bentgrass, even when growing in water deficit conditions. Enhanced growth was not attributed to nutrient availability, but on the HA having a hormonal affect on the turf. Through enzyme-linked immunosorbent assays and bioassays, it has been determined that HA contains auxins (Cacco and Dell'Agnola, 1984; Muscolo et al., 1998). The increased rooting reported by Zhang and Schmidt (Zhang and Schmidt, 2000) and Liu et al. (Liu et al., 1998) could be a response to auxins.

Seaweed extract

Like humate, there are many variations of seaweed harvested for agricultural use. The seaweed utilized in this experiment is *Ascophyllum nodosum* harvested in the cool waters off the coast of Canada and Norway. It is comprised of naturally occurring hormones like abscisic acid, auxins, betaines, cytokinins, and gibberellins (Senn, 1987; Crouch and van Staden, 1993). It has been stated that seaweed sprays have the capability to suppress disease, reduce insect feeding, increase shelf life of fruit and protect plants from frost (Mattern, 1997). Increased shelf life is thought to be a result of antioxidants destroying AOS before they can degrade the fruit (Norrie and Hiltz, 1999). Mannitol, alginic acid, and laminarin are all carbohydrates that have been found in SWE. Mannitol is a chelating agent and has been shown to stimulate root growth (Booth, 1969) and levels of eight to 10 g per 100 g of dry matter have been measured in *Ascophyllum nodosum* (Moen et al., 1997). Seaweed extracts also contain trace amounts of macronutrients such as N, P, K and larger amounts of micronutrients like Ca, Mg, S, Zn, Fe, Cu, Mn and B. Like leonardite humate, SWE are dark in color because of the 50 to 55% organic matter content (Senn, 1987).

The cytokinins, ZR, dihydrozeatin, isopentenyladenine and IPA, were detected by gas chromatography-mass spectrometry in *Ascophyllum nodosum* (Sanderson and Jameson, 1986). Also, the test proved that the sample contained auxins in the form of indole acetic acid.

Seaweed extracts have been applied on forage crops containing an endophyte. Endophytes form a symbiosis with grasses such as tall fescue and produce a toxin against certain insects and aid in drought resistance (MacCarthy et al., 1990). While endophytes do protect the plant, they also negatively affect vitamin levels in the grazing animals. The application of SWE increased SOD antioxidant activity in the endophyte plant and grazing animal (Fike et al., 2001). The benefits of SWE application on pastures was also present due to increases in antioxidants, α-tocopherol, ascorbic acid, β-carotene, glutathione reductase and APX activity level (Allen et al., 2001). The increase in antioxidant activity allowed the plant and grazing animal to mitigate oxidative stresses.

Seaweed extract applied to Kentucky bluegrass improved plant uptake of macronutrients and some micronutrients at low fertility levels with improved turfgrass quality (Yan et al., 1993). Increased nutrient uptake may be due to the mannitol found in SWE, which serves as a chelator (Norrie and Hiltz, 1999). However, the increased turf quality was thought to be cytokinin driven. Xylem conducted cytokinins inhibit the translocation of N from shoot to root. Therefore, the SWE treated plants were able to prevent translocation of N and maintain leaf quality despite the low fertility levels. Furthermore, cytokinins serve as a signal from root to shoot concerning nitrogen availability and regulate nitrogen absorption (Mok and Mok, 1994; Haberer and Kieber, 2002).

Lettuce yield, weight and cauliflower floret diameter increased with a SWE treatment. There was an interaction between side dressing with N-P-K and SWE and crop productivity (Abetz and Young, 1983). The interaction indicated that SWE is best suited as an additive to proper plant cultural practices not a replacement for failing management practices.

Betaines have been isolated from SWE by utilizing a proton magnetic resonance spectroscopic assay. Glycinebetaine, γ-aminobutyric acid betaine and δ-aminovaleric betaine were all found in SWE (Blunden et al., 1986). However, different levels of betaines were measured for different products containing *Ascophyllum nodosum*. Betaines are regulators that protect cells from dehydrative environmental conditions like freezing, salinity, and drought (Srivastava, 2002b). Some researchers have found that betaines found in SWE are successful in deterring pest damage. Wu et al. (1998) determined that applications of betaines found in SWE reduced the number of females and eggs of the root-knot nematode, *Meloidogyne javanica*, in *Arabidopsis thaliana*. Bioassays were used to determine whether cytokinins or betaines found in SWE were responsible for increasing chlorophyll levels. When increasing SWE concentrations were graphed in relation to chlorophyll levels, a linear relationship did not occur. Chlorophyll levels were not directly related to SWE concentration, however chlorophyll level and cytokinin concentration did have a linear relationship. When betaines were graphed in relation to chlorophyll levels, a series of peaks and valleys similar to the SWE results was attained (Whapham et al., 1993). Therefore, the authors concluded that chlorophyll enhancing effects of SWE are betaine related rather than cytokinin. A follow up study was conducted on wheat, barley, tomato and dwarf French bean that resulted in increased leaf chlorophyll levels when betaines and a product containing *A. nodosum* were applied as a soil drench (Blunden et al., 1997). This effect was again explained by a dependency of betaine activity.

Growth promoting effects of SWE are evident when plants are subjected to stress and are thought to be a result of the hormones and/or betaines naturally present rather than a nutrient effect. Growth stimulation has been observed due to SWE application when plants were grown in non-nutrient limiting soils. Dry root weight improved with SWE application when Kentucky bluegrass was exposed to decreasing soil water contents (Schmidt and Zhang, 1997). Improved ryegrass drought resistance after foliar application of fortified SWE was found. Leaf water potential was higher under drought stressed, SWE treated turf due to higher levels of unsaturated fatty acids, which increase membrane fluidity (Yan et al., 1997). Sun et al. (1997) reported greenhouse grown 'Penncross' creeping bentgrass leaf water status was higher and yellowing, thinning and wilting were reduced when SWE was applied as a soil drench twice a month compared to the control when allowed to dry for 14 days. Seaweed extracts are highly complex in nature. Therefore, determining what property of SWE is responsible for growth effects is complicated.

Seaweed and humate together

Seaweed extracts and HA have the potential to improve plant health when applied separately. However, extensive research has determined that SWE and HA have an increased beneficial effect when applied in conjunction. Photochemical efficiency was enhanced when creeping bentgrass and Kentucky bluegrass were subjected to low fertility and heat stress, respectively (Zhang et al., 2003b; Zhang et al., 2003c; Ervin et al., 2004). While undergoing stress, SWE + HA-treated turfgrass maintained root mass, and had root regrowth, increased shoot growth, increased quality, while maintaining favorable leaf water status. The survivability was thought to be due to the protective mechanisms afforded by the measured increases of antioxidant activity as a result of the PGS applications (Zhang and Schmidt, 1997; Zhang and Schmidt, 1999; Zhang and Schmidt, 2000; Zhang and Ervin, 2004). Increases in SOD, CAT, α-tocopherol and ascorbic acid were all measured.

Finally, endogenous levels of cytokinins were measured following application of PGS like SWE and HA, which naturally contain cytokinins (Zhang and Ervin, 2004).

Glycinebetaine

Glycinebetaine, a type of betaine, is an amino acid derivative (McNeil et al., 1999). It is a naturally occurring compound in animals, algae, fungi, bacteria, and plants (Huang et al., 2000). Wyn Jones and Storey (1981) distinguished between different betaines and their role in mitigating drought. Proline, a betaine of similar structure to GB, accumulation occurs directly after the onset of stress while GB accumulates gradually over time. Salt stressed spinach did not accumulate GB until 20 days after treatment, while increased proline was measured after 10 days (Di Martino et al., 2003).

Betaines regulate osmotic adjustment when plants undergo water stress. Cell turgidity and function is maintained at a water deficit that normally would cause wilt and inhibit cell function (Nilsen and Orcutt, 1996; Abernathy and McManus, 1998; Sakamoto and Murata, 2000). Additionally, betaines have been reported to function as protectants from similar dehydrative stresses like salinity, cold, heat and freezing (Nilsen and Orcutt, 1996; Huang et al., 2000). This occurs because the enzymes are known to be stress-induced (McNeil et al., 1999). Glaasker et al. (1996) measured GB concentration increases when osmotic balances were disturbed and quick declines of GB when the stress subsided.

Glycinebetaine not only serves as an osmoregulator but also as an osmoprotectant. Under the previous discussed stresses, GB protected proteins and membranes from degradation (Sakamoto and Murata, 2000) brought on by environmental conditions not conducive to plant growth. Bean (*Phaseolus vulgaris*) chlorophyll fluorescence was greater for those plants treated with GB when grown in water deficit conditions (Xing and Rajashekar, 1999). Physiological processes were improved because favorable leaf water potentials were maintained longer and recovery was improved. Blunden et al. (1997) applied the equivalent amount of GB that is naturally present in a SWE-diluted solution, 0.34 mg L^{-1}, and measured increased chlorophyll levels for dwarf French bean at 49 days after treatment. Similar results were recorded for the SWE treatment in the study. The chlorophyll increases upon application of SWE were explained as a result of the GB influence. Glycinebetaine has been shown to protect PSII proteins under salinity stress (Papageorgiou et al., 1991). One way to measure PSII activity is through chlorophyll fluorescence since chlorophyll proteins are embedded in PSII (Taiz and Zeiger, 1998).

Some plants like rice (O*ryza sativa*), soybeans (*Glycine max*), potatoes (*Solanum tuberosum*) and tomatoes do not have the ability to produce betaines naturally (Makela et al., 1998a; McNeil et al., 1999). As a result, researchers have studied exogenous application of GB to enhance stress tolerance and some molecular geneticists are interested in engineering GB for drought resistance in these plants (Nguyen et al., 1997). Radiolabeled studies have shown that foliar application of GB does increase GB content within the plants that do not produce GB. Two and a half hours after application to turnip rape (*Bassica rapa* L. ssp. *oleifera*), GB was present in leaves and six hours after application GB was present in roots (Makela et al., 1996b). Soybean cultivars translocated varying concentrations of GB upon its foliar application. Glycinebetaine treatment resulted in higher photosynthesis and nitrogen fixation rates than the control plants when water stressed (Agboma et al., 1997b). Also, seed yield increased upon GB application, independent of moisture stress. Similarly, field and greenhouse studies indicated increases in tomato fruit production with GB additions when the plants were placed under typical stresses like heat, water and salt (Makela et al., 1998a). Glycinebetaine allowed the plants to photosynthesize despite the stresses, which increased assimilates used for fruit production.

Little research has been conducted to evaluate the potential benefits of GB application on stressed turfgrass. The use of GB on other crops has proven to be an effective protectant from detrimental environmental conditions. Application of GB could become a new management practice for turfgrass managers, especially those posed with irrigation restrictions, those who irrigate with reclaimed water or those near the ocean and experience salt sprays.

There is a need to study deficit irrigation on turfgrass in Virginia due to continuing population increase, recent years of drought and policy implemented, and the considerable acreage of cultured turfgrass. Evapotranspiration-based scheduling is an efficient irrigation scheduling process as it replaces the estimated amount of water lost from the system based on empirically based and extensively tested mathematical equations. The utilization of PGS such as SWE, HA, and GB may be beneficial for some managers to reduce irrigation requirements without unduly sacrificing turfgrass quality. This study aims to determine water conserving crop coefficients and to estimate the extent to which plant growth stimulants may increase plant survivability under deficit irrigation.

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Chapter 3

Greenhouse Experiments: Potential of Plant Growth Stimulants to Decrease Irrigation Requirements & Evaluation of Glycinebetaine Rates under Deficit Irrigation

Abstract Study 1

The state of Virginia has experienced drought conditions within the past several years culminating in proposed water conservation legislation. As adequate turfgrass performance is often dependent on supplemental irrigation, such legislation could directly impact irrigation scheduling. The objectives of this greenhouse study were to determine to what extent irrigation could be reduced for creeping bentgrass (*Agrostis paulstris* 'L93') and Kentucky bluegrass (*Poa pratensis* 'Midnight') and if foliar applied plant growth stimulants (PGS) improve turfgrass health at deficit irrigation levels. Seaweed extract (SWE) + humic acid (HA), glycinebetaine (GB), and a commercial 0-3-2 seaweed and iron product (PP) were applied monthly. Evapotranspiration (ET) was determined by the mass balance technique every fifth day. Pots were hand watered to replace 100%, 85% or 70% of measured ET based on the 100% ET control pots. Percentage soil moisture, photochemical efficiency (PE), relative leaf water content and turf quality ratings were taken throughout the study and root samples were taken at the conclusion of the study. Antioxidant activity and cytokinin levels were analyzed when quality ratings were indicative of increased drought resistance. While turfgrass quality differences were detected, levels never fell below the predetermined minimally acceptable threshold due to any treatment. It is therefore concluded that replacing 70% ET every fifth day may often be sufficient to maintain turfgrass health for both turf species under conditions of this study. Glycinebetaine application increased dry root weight, compared to the control, at all irrigation levels. Replacing 100% and 85% ET also resulted in the greatest root mass. Continuing this study in the field will further validate if irrigation can be reduced by 30% and if GB application improves turfgrass drought resistance. However, these data indicate that some modifications are required. An ET rate below 70% should be included to determine if irrigation can be reduced beyond 30% and to attain sufficient separation of treatments, as PGS are most beneficial when turf is subjected to water stress.

Abstract Study 2

Glycinebetaine application has been studied extensively on field crops but no research to date has been conducted on turfgrass. This study was conducted to determine which application rate was ideal for turfgrass application and to determine if GB increased survivability of creeping bentgrass 'L93' and tall fescue (*Festuca arundinacea)* Dominion blend when subjected to deficit irrigation. Evapotranspiration was determined by the mass balance technique. Four GB (28% active ingredient) rates were studied: 3.9 kg ha^{-1}, 7.5 kg ha^{-1}, 11.5 kg ha^{-1}, and 15 kg ha^{-1}. One rate of anhydrous GB that was equivalent to the GB 11.5 kg ha^{-1} rate was used and was applied at 3.2 kg ha^{-1}. Creeping bentgrass pots were hand watered to replace 100% or 70% of measured ET based on the 100% control pots and tall fescue pots were hand watered to replace 100% or 55% ET. Pots were irrigated upon wilt of the 70% and 55% of the creeping bentgrass and tall fescue pots, respectively. Turfgrass quality, wilt, photochemical efficiency, canopy and air temperature difference and soil moisture measurements were made to assess turfgrass health. Roots were ashed in a muffle oven at the conclusion of the study. Creeping bentgrass and tall fescue quality did not differ between GB rates and the control, independent of irrigation level. Irrigation effects for both turfgrass species resulted in higher quality, photochemical efficiency, and root mass for the 100% ET level compared to the deficit irrigation level. While higher GB rates proved beneficial in field crop research, it is hypothesized that lower rates may be suitable for turfgrass production, as fruit production is not desired. Further studies should be conducted to solidify a suitable range of GB rates for increasing turfgrass resistance to drought.

Introduction

There are 1.4 million acres of cultivated turfgrass within the state of Virginia. In 1998, park areas covered 26,000 acres and golf courses covered 34,000 acres (VASS, 2001). Kentucky bluegrass is a predominant turfgrass species grown on Virginia park areas, while creeping bentgrass is a predominant species grown on Virginia golf course fairways (VASS, 2001; Goatley Jr., 2005). Deficit irrigation is more likely to be implemented on fairways, compared to greens or tees, as the stress level is not as severe due to the height of cut difference. Furthermore, there would be more potential impact on water conservation because fairways cover a larger portion of the irrigated surface on golf courses than greens or tees. 'Midnight' Kentucky bluegrass is cultivated due to its desirable dark green foliage and consistent high performance in National Turfgrass Evaluation Program (NTEP) variety trials (Morris, 2000). 'L93' creeping bentgrass is preferred due to its medium to high density and high performance in Virginia NTEP trials (NTEP, 2002). It also is one of the most heat and dollar spot tolerant of the available creeping bentgrass cultivars (Xu and Huang, 2001; Bonos et al., 2004).

Recent legislation to promote water conservation has impacted landscape irrigation practices. Conservation techniques need to be studied to ensure turfgrass health is maintained. Virginia experienced a four-year drought from 1999-2002. During these years, the National Oceanic and Atmospheric Association's Palmer Drought Severity Index categorized 1999 and 2000 as severe drought years, while 2001 and 2002 were categorized as moderate drought years (NOAA, 2005). Between 1993 and 2003 Virginia's population increased by 14%, exceeding the 10.6% national increase (USCB, 2004; USCB, 2005). Drought, coupled with continued population increases, puts excessive strain on natural resources like water. As a result, Governor Mark Warner initiated a Drought Response Task Force to draft a drought plan (Warner, 2002).

Drought was categorized by the Task Force as three stages of severity: Drought Watch, Drought Warning and Drought Emergency. The initiation of a Drought Watch increases public awareness and can result in water savings up to 5% due to public education. Under a Drought Warning, voluntary water conservation activities are encouraged by asking irrigators to use a minimum amount of water required to promote plant survival at each irrigation event. When severity reaches the Drought Emergency stage, mandatory water restrictions are imposed. In a Drought Emergency, golf course fairways and athletic fields are limited to one inch of irrigation per 10 day period and must be monitored to avoid puddling and runoff (DRTAC, 2003). While water levels are specifically addressed under a Drought Emergency, 'minimum amount of water' specified under a Drought Warning is a subjective level that will vary from one turfgrass manager to another. Consequently, water conservation research is needed for Virginia athletic fields and golf course fairways to implement measurable guidelines during a Drought Warning and to refine those recommendations made during a Drought Emergency.

Greenhouses are often utilized to simulate drought conditions due to the accuracy and uniformity with which soil dry down can be achieved. The mass balance technique has proven to be an effective method in estimating evapotranspirational losses (Ray and Sinclair, 1997) as it is assumed the weight difference is water lost through evapotranspiration. A problem associated with greenhouse studies is the tendency for plants to undergo drought conditions quickly due to the ideal environmental conditions and limited rootzones of pot grown plants. Drought conditions should be imposed gradually so plants can acclimate to the drying soil conditions and produce adequate root mass (Pennypacker et al., 1990).

Some researchers have utilized automated irrigation systems connected to mass balances to irrigate whenever soil moisture reaches a certain level (Schwaegerle, 1983; Earl, 2003). This system typically results in frequent irrigation events, resulting in improper water distribution in a rootzone as the surface soil remains wet, while deeper soil is allowed to dry. Such an automated irrigation system is not applicable to field irrigation application. However, it is appropriate for determining physiological factors that are associated when soil moisture reaches a certain level. Such information was not the goal of this greenhouse experiment, but rather simulating field irrigation events to determine its field application potential.

A PGS that may have a future on Virginia grown crops is glycinebetaine (GB). Glycinebetaine, is a form of betaine and is classified as an osmoregulator and osmoprotectant as it regulates osmotic potential and protects membranes when plants are subjected to dehydrative stresses (Nilsen and Orcutt, 1996; Abernathy and McManus, 1998; Sakamoto and Murata, 2000). No documented research has yet been conducted to evaluate turfgrass response to GB application, but researchers have reported increased field crop health when subjected to drought, salinity and chilling (Makela et al., 1996; Agboma et al., 1997c; Xing and Rajashekar, 1999; Chen et al., 2000).

The objectives of the first experiment were to (i) refine treatment levels and methodology prior to field application, (ii) determine deficit irrigation limits for acceptable turfgrass performance, (iii) determine if irrigation can be reduced further upon application of PGS, and (iv) examine if PGS affect turfgrass physiology and/or rooting morphology.

A second greenhouse study explored varying GB rates and their effect on turfgrass health subjected under deficit irrigation. Creeping bentgrass 'L93' and tall fescue Dominion blend were subjected to two irrigation levels and five GB rates. Tall fescue was utilized in the second, study rather than Kentucky bluegrass, as 52% of the turfgrass cultured in Virginia is on home lawns (VASS, 2001). Tall fescue is the most cold tolerant and drought resistant cool season turfgrass grown in Virginia, therefore making it an ideal turfgrass for home lawns (McCarty, 2001). The objectives of the second experiment were to (i) determine which GB concentration has the most effect on enhancing drought resistance characteristics in creeping bentgrass and tall fescue, and (ii) examine if physiological function and/or rooting is affected upon GB application under deficit irrigation.

Materials and Methods

Study 1

This greenhouse study was conducted for four months from February to May of 2003. Creeping bentgrass (*Agrostis stolonifera* 'L93') and Kentucky bluegrass (*Poa pratensis* 'Midnight') were evaluated at golf course fairway (1.3 cm) and athletic field (5.0 cm) heights of cut, respectively.

Three plant growth stimulant treatments were applied monthly with a CO_2 sprayer delivering 785 L ha^{-1} at 290 kPa. Plant growth stimulant treatments consisted of: seaweed extract (SWE) + humic acid (HA) mixture, GB, commercial seaweed product

(PP), and a water control. The SWE was supplied as a dry powder by Acadian Seaplants Ltd. (Dartmouth, Nova Scotia). Leonardite extracted HA (80% active ingredient) was supplied by Plant Wise Biostimulants (Louisville, KY). The SWE + HA mixture was sprayed at a rate of 0.5 kg ha^{-1} + 1.5 kg ha^{-1}, respectively. Glycinebetaine, a byproduct of sugar beet processing with 28% active ingredient (Big Chief Betaine, Monitor Sugar Co., Bay City, MI), was applied at the rate of 3.8 kg ha^{-1}.   The PP 0-3-2 commercial product, manufactured by Emerald Isle (Ann Arbor, MI), was sprayed at 13 kg ha^{-1}. Treatments were arranged in a completely randomized design with four replications.

Irrigation was applied every fifth day to simulate field irrigation schedules. The mass-balance approach was used to compute evapotranspiration (ET) (Bowman and Macaulay, 1991). Pots were irrigated and allowed to drain at the beginning of the study to bring all pots to field capacity. Every fifth day thereafter pots were weighed to measure water lost to ET. Irrigation levels, 100%, 85% or 70% were computed from the mass difference of the 100% ET control pots. Evapotranspiration rate was calculated by the mass difference between the initial field capacity mass and pot mass prior to irrigation events. After irrigation events, pots were rearranged on an open metal bench.

Plugs were taken from mature plots being maintained at fairway height, 1.3 cm, and athletic field height, 5.0 cm, and growing in a silt loam soil (clayey, kaolinitic, mesic Typic hapludult) at the Virginia Tech Turfgrass Research Center in Blacksburg, VA. Roots were washed clean and the plugs were placed in pots (15 cm dia. x 20 cm deep) filled with a medium texture sand meeting United States Golf Association guidelines. Sand was of the same source as the rootzone built for the field portion of the study. The approximate physical properties of this soil were: bulk density 1.68 g cm^{-3}, air-filled porosity 18.6%, and capillary porosity 18. Plugs were placed under a mist system and rooted for three weeks. Soluble fertilizer applications of 20-20-20 (with micronutrients) were applied every two weeks to deliver 12 kg N ha^{-1}. Mowing occurred every third day at 1.3 cm for bentgrass and 5 cm for bluegrass. Greenhouse temperature was set at 21 (± 5) ^{o}C with an average of 550 μmol m^{-2} s^{-1} of photosynthetically active radiation during the experimental period.

Soil moisture readings to the 7.6 cm depth were taken with a Theta probe soil moisture meter (Delta-T Devices Ltd., Cambridge, England) prior to each irrigation event. Quality was rated monthly based on a 1 to 9 scale, where 9 = highest quality and 1 = completely brown turf. A minimum acceptable level of quality was preset at 6.0. Photosynthetic efficiency (PE), as detailed in Zhang et al. (2003b), was measured monthly. Leaf tissue samples for estimation of enzymatic antioxidants (superoxide dismutase, catalase, and ascorbate peroxidase) were taken when overall turf quality differences were visible (Zhang et al., 2003a). Zeatin riboside cytokinin content was measured by enzyme-linked immunoassay based on methods detailed by Zhang and Ervin (2004) when quality differences were detected.

At the conclusion of the study, roots were washed free of sand, exhumed, placed in vials of water and stored at 4°C until analyzed (approximately three months after exhumation). Roots were floated in an acrylic tray filled with distilled deionized water and distributed evenly. Root overlapping was not of concern as the WinRHIZO (Regent Instruments, Inc., Quebec, Canada) root analyzing software compensates for root overlap (Arsenault et al., 1995). Roots were scanned (Epson Expression 1600, Long Beach, CA) in gray scale color and analyzed with WinRHIZO software to determine root morphology including root length density (cm cm^{-3}) and root surface area (cm^2). Scanner resolution was set at 400 dots per inch as recommended by Polomski and Kuhn (2002). Manual threshold was adjusted prior to batch analysis to ensure fine roots were detected. The threshold value is used to separate pixels from the background and scanned root image (WinRHIZO, 2001). Analyzed roots were then oven dried (70 ^{o}C for 24 h) and root dry weight was recorded.

Study 2

This study was conducted from November 2004 through February 2005. Creeping bentgrass (*Agrostis palustris* 'L93') and tall fescue (*Festuca arundinacea)* Dominion blend were evaluated at golf course fairways (1.3 cm) and home lawn height (64 cm) heights of cut, respectively.

Five rates of GB were applied monthly with a CO_2 sprayer delivering 785 L ha^{-1} at 290 kPa. Big Chief Betaine (28% active ingredient) was applied at four rates: 3.9 kg ha^{-1} (GB_1), 7.5 kg ha^{-1} (GB_2), 11.5 kg ha^{-1} (GB_3), and 15 kg ha^{-1} (GB_4) and water control, which is equal to 0.03 M, 0.05 M, 0.07 M and 0.1 M of chemical betaine ($C_5H_{11}NO_2$), respectively. Anhydrous betaine (99% purity) (Sigma-Aldrich Chemical, St. Louis, MO) was applied at 3.2 kg ha^{-1} (GB_5), which is equal to applying 11.5 kg ha^{-1} or of Big Chief Betaine or 0.07 M. Treatments were arranged in a completely randomized design with four replications.

The mass balance technique was used in the second greenhouse study, similar to the first study. Irrigation treatments replaced 100% and 70% for creeping bentgrass and 100% and 55% for tall fescue based on 100% control pots of each turf species. Irrigation occurred upon wilt of the creeping bentgrass 70% ET pots and tall fescue 55% ET pots.

Plugs were taken from field plots utilized for the 03-04 field study at the Virginia Tech Turfgrass Research Center in Blacksburg, VA. Roots were washed clean and plugs were placed in pots containing PROFILE calcined clay (Aimcor Consumer Products, Buffalo Grove, IL). The physical properties of the calcined clay are: bulk density 0.56 g cm^{-3}, air-filled porosity 35%, and capillary porosity 39%. Creeping bentgrass was grown in 10 cm height by 10 cm width pots and tall fescue was grown in 15 cm diameter by 15 cm height pots. Plugs were placed under a mist system and rooted for three weeks. Soluble fertilizer applications of 20-20-20 (with micronutrients) were applied every two weeks to deliver 12 kg N ha^{-1}. Greenhouse temperature was maintained at 27 (± 2) ºC.

Quality and wilt ratings, soil moisture readings at the 0-7.6 cm depth, and canopy and air temperature difference (ΔT) readings were made prior to every irrigation event. An infrared thermometer (Raynger ST, Raytek, Santa Cruz, CA) was utilized to measure canopy temperature. Air temperature was recorded from the thermometer present inside the greenhouse to determine ΔT. The infrared thermometer was held at a 45-degree angle and approximately 31 cm above turf canopy. Photochemical efficiency was measured monthly and tissue samples were collected monthly to measure electrolyte leakage as detailed by Marja-Liisa et al. (1991).

Pots were allowed to dry down and then roots were separated from stems below the thatch layer, at the conclusion of the study. Root weight was recorded prior to and after drying in a muffle furnace (500ºC for 15 h) to assess dry root weight.

Data were subjected to analysis of variance (ANOVA) by the general linear model procedure. Significant main or interactive effects were separated with LSD at the 0.05% level with the SAS version 9.1 computer program (SAS Institute Inc., Cary, NC).

Spearman nonparametric correlations were run with Prism version 4.00 (Graphpad Software Inc., San Diego, CA.) with significance reported at the 0.05% level.

Results and Discusssion

Study 1

Soil Moisture

Kentucky bluegrass soil moisture PGS treatment, irrigation and date main effects and PGS treatment by irrigation and irrigation by date interaction effects were found to be significant (Table 3.1). Creeping bentgrass PGS treatment, irrigation, date main effects and irrigation by date interaction effect were significant (Table 3.2).

Soil moisture increased as irrigation level increased for Kentucky bluegrass (Table 3.3). The creeping bentgrass 100% ET irrigation treatment was still at field capacity (18%) when measured prior to irrigation events, while the 70% ET level was slightly below (13.6%). These data show that an irrigation frequency of every five days was too frequent to attain proper soil moisture deficits. Under field conditions, creeping bentgrass requires more frequent irrigation application than Kentucky bluegrass due to its shallow rooting depth. The opposite was true in this greenhouse experiment. After five days, creeping bentgrass 100% ET soil moisture was still at approximate field capacity. However, after five days without irrigation Kentucky bluegrass soil moisture was depleted to about half field capacity (9.8%).

The GB and SWE + HA treatments maintained the same soil moisture at the 0-7.6 cm depth for both turf species (Table 3.3). Kentucky bluegrass GB and creeping bentgrass SWE + HA soil moisture were greater than PP and the control. Kentucky bluegrass GB 85% treatment maintained equal moisture to that of SWE + HA 100%, GB 100%, PP 100% and control 100% and greater moisture than any other 85% treatment (Table 3.4). All 70% ET level treatments were grouped together as having the least moisture compared to all 100%. Glycinebetaine was the only treatment where the 85% and 70% ET levels differed in soil moisture. These data could indicate that the GB application could be have increased Kentucky bluegrass water use efficiency. Kramer and Boyer (1995) explained that water use efficiency does not differ for one species when exposed to varying soil moisture levels, but rather among species and climates. In this case, water use efficiency differences may be measured within a species upon PGS application. Further studies should be conducted to assess if water use efficiency is affected upon exogenous application of GB.

Soil moisture declined continuously over the course of the four-month experimental period for both turfgrass species (Fig 3.1). Separation of means first occurred in March for Kentucky bluegrass and April for creeping bentgrass. Soil moisture at the 70% ET level was consistently below that of 100% for Kentucky bluegrass (Fig 3.1A). The creeping bentgrass 100% and 85% ET levels maintained equal moisture, which was greater than the 70% ET level in April and May (Fig 3.1B). The apparent difference between turfgrass species soil moisture as seen in Fig. 3 could be attributed to root area differences and canopy height differences. Creeping bentgrass root surface area ranged from 200 to 300 cm^{-2}, while Kentucky bluegrass surface area ranged from 400 to 500 cm^{-2}. Kentucky bluegrass produced a denser root system than the creeping bentgrass, which depleted the available water faster. The higher canopy height for Kentucky bluegrass resulted in higher ET rate, which depleted soil moisture between irrigation events.

Evapotranspiration Rate

Differences were detected for Kentucky bluegrass ET rate for PGS treatment, irrigation, and date main effects and PGS treatment by irrigation interaction effect (Table 3.1). Creeping bentgrass ANOVA detected ET rate differences due to sampling date and an irrigation by date interaction (Table 3.2).

The Kentucky bluegrass 100% ET level had an average ET of 4.6 mm d^{-1}, which was 10% greater than the 85% ET level and 44% greater than the 70% ET level (Table 3.5). The average ET rate of non-water limiting and untreated (control 100% ET level) Kentucky bluegrass was 4.9 mm d^{-1} and creeping bentgrass was 2.8 mm d^{-1}. Several studies have researched ET rate of Kentucky bluegrass however, only a few were evaluated in non-arid regions of the country. Rhode Island and Kansas grown Kentucky bluegrass lost 3.5 mm d^{-1} and 5.6 mm d^{-1} to ET, respectively (Aronson et al., 1987; Fu et al., 2004). However, Texas grown Kentucky bluegrass and creeping bentgrass ET rate exceeded 10 mm d^{-1} (Beard and Kim, 1989). When irrigation was reduced by 12% and

30%, ET decreased by 10% and 26%, respectively, for a Kentucky bluegrass, perennial ryegrass (*Lolium perenne*) and red fescue (*Festuca rubra*) blended stand (Bastug and Buyuktas, 2003). Similarly, Kentucky bluegrass ET decreased by 8% and 30% when irrigation was reduced by 15% and 30%, respectively.

The SWE + HA and GB treatments had 11% higher ET rate than the control. Ebdon and Kopp (2004) found that high Kentucky bluegrass ET rates were associated with a decrease in leaf firing and low ET rates may not be valuable in drought survival. The SWE + HA and GB treated Kentucky bluegrass plants may be transpiring more than the control plants, which could be affecting drought resistance.

Kentucky bluegrass SWE + HA and GB ET rates did not differ as irrigation was reduced (Table 3.6). The PP 70% treatment was 65% lower than PP 85%. Control 70% ET rate was 35% lower than the 85% ET level. The PP and control treatments experienced significant declines in ET when irrigation was reduced from 70% to 55% ET. The SWE + HA and GB ET rates did not differ as irrigation declined. This may indicate the potential of SWE + HA or GB application to decrease the likelihood of stress as Kentucky bluegrass is grown under deficit irrigation.

Kentucky bluegrass ET rate was highest in April and creeping bentgrass ET rate was highest in April and May (Fig 3.2). Both turf species had the lowest ET rate in February. The Kentucky bluegrass 100% and 85% ET levels consistently maintained the highest ET rate throughout the study. Separation of means did not occur for creeping bentgrass until May when the 70% ET rate exceeded that of the 100% and 85% ET levels.

The trend of increasing ET rate as the study progressed could be speculated as a relationship to root production. The increasing root mass would be capable of extracting more water from the soil, translocating it throughout the plant and finally evapotranspirating it through the stomates. As only one to three percent of absorbed water is utilized in physiological processes, the remaining water is lost through evapotranspiration (Huang and Fry, 1999). Therefore, measuring ET is an accurate assessment of the amount of water absorbed by the roots.

Root Morphology

Roots were analyzed for morphology measurements with the WinRHIZO computer program. This study focused on root biomass production as it has been reported that dense roots are more desirable for overall turfgrass health than sparse deep roots (Beard, 1973). No root length density differences were detected for Kentucky bluegrass, but plant growth stimulant and irrigation treatments were significant for surface area measurements and root dry weight (Table 3.1).

When Kentucky bluegrass was irrigated at the 100% and 85% ET level, root surface area and dry weight was greater than the 70% ET level (Table 3.7). Root morphology was affected upon deficit irrigation treatments, but further analysis is needed to determine if decreased root morphology correlated with decreased turfgrass health. Glycinebetaine application resulted in 40% more root surface area than the SWE + HA treatment. An increase of 35% and 45% root dry weight was recorded for GB when compared to the control and SWE +HA, respectively. The osmoprotectant properties of GB may be apparent for root growth as means to protect the membranes when the roots are growing in soil depleted of water. Naidu et al. (1998) stated that GB treated cotton produced stronger root systems and stems and improved flowering and branching. This effect was explained as GB having a hormone-like activity. Overproduction of proline, a betaine of similar structure to GB, increased transgenic tobacco root length and biomass under drought conditions (Kavi Kosher et al., 1995). Proline accumulates in root apices and serves as membrane osmoprotectants and hydroxyl scavengers (Samaras et al., 1995) to maintain root functionality at low soil water potentials.

Creeping bentgrass irrigation treatment affected root length density and, both PGS and irrigation treatments were significant in affecting root surface area and root dry weight (Table 3.2). The creeping bentgrass 100% and 85% ET levels produced the greatest root length density, root surface area, and root dry weight, compared to the 70% ET level (Table 3.8). The PP treatment produced greater root surface area than the SWE + HA treatment and control. Glycinebetaine foliar application resulted in 63% greater root dry weight, while PP produced 53% greater root dry weight than the control.

Creeping bentgrass and Kentucky bluegrass root growth and soil moisture were positively correlated (Tables 3.9 and 3.10). As soil moisture declined, root surface area and root length density declined.

Turfgrass Quality

Analysis of variance for Kentucky bluegrass quality indicated that PGS treatment, irrigation, and date main effects and irrigation by date and PGS treatment by irrigation interaction effects were significant (Table 3.1). Creeping bentgrass PGS treatment and date main effects and irrigation by date interaction effects were significant (Table 3.2). Kentucky bluegrass SWE + HA treatment resulted in the lowest rating of 7.1 compared to 7.3 of GB and control. The PP treatment had a quality rating of 7.2, which was equal to the highest (GB) and lowest (SWE + HA) rated treatments (data not shown). Creeping bentgrass SWE + HA treatment resulted in higher quality ratings of 7.4 compared to the lower 7.2 rating for the control. Statistically, SWE + HA quality was equivalent to that of GB, but better than that of PP and the control (data not shown).

Separation of means between Kentucky bluegrass irrigation levels were first apparent in March when 100% ET-replacement was greater than that of 85% and 70% (Table 3.11). The 100% ET level remained the highest through April and in May the 85% ET level was equal to that of the 100%. April resulted in the lowest quality ratings, independent of irrigation level. No quality ratings fell below the preset minimum acceptable level of 6.0 for any irrigation level, which indicated that Kentucky bluegrass can be cultured with at least a 30% irrigation reduction without visually detecting a difference in turfgrass health.

Creeping bentgrass took longer than Kentucky bluegrass to respond to deficit irrigation treatments. Means separation was first recorded for creeping bentgrass in May when the 70% ET level was lower than the 100% or 85% levels (Table 3.12). Quality was lowest in February and April, independent of irrigation level. Similar to the Kentucky bluegrass results, quality did not fall below the preset minimum acceptable level during the experimental period, which also indicated that creeping bentgrass health may be unaffected when 30% of irrigation is withheld.

No trend was apparent for Kentucky bluegrass PGS by irrigation quality ratings, therefore no information was extracted from means separation concerning the use of PGS to reduce irrigation. As a result, the interaction data are not shown.

Turfgrass quality was positively correlated with Kentucky bluegrass root morphology measurements (Table 3.10). The 100% and 85% ET levels consistently resulted in better quality relative to the 70% ET level due to the larger root systems to uptake water. Feldhake et al. (1984) measured a 10% quality decrease when Kentucky bluegrass was irrigated at a 27% deficit level. Similarly, this study measured a 9% decrease of Kentucky bluegrass quality when subjected to 30% deficit irrigation. Creeping bentgrass quality was positively correlated with root morphology measurements, which indicated that as quality declined, root length density and root surface area declined (Table 3.10).

Photochemical Efficiency

Sampling month was significantly different for both Kentucky bluegrass and creeping bentgrass PE measurements (Tables 3.1 and 3.2). Photochemical efficiency for both turf species declined as the study continued most likely due to increasing seasonal temperature and light intensity (Table 3.13).

Kentucky bluegrass quality ratings were positively correlated with PE measurements meaning that the plants' inability to utilize light energy efficiently to produce chlorophyll was detected visually (Table 3.10).

Although not included in the PE ANOVA table, Kentucky bluegrass PGS and irrigation main effect differences were detected six days after the last irrigation event in May (one day beyond the regular irrigation schedule). The 100% and 85% ET levels maintained the highest PE compared to the 70% (Table 3.14). The PP photochemical efficiency measurements averaged 12% more than all other PGS treatments. These data organized agree with Zhang and Ervin (2004) who also measured decreasing PE readings with decreasing soil moisture. Photochemical efficiency was measured 21 days after irrigation ceased, while data in Table 3.14 represents readings taken six days after cessation. When plants are grown in long-term water deficit conditions, lower photosynthetic capabilities are typically recorded due to allocation of energy to other physiological functions rather than the photosynthetic apparatus (Smirnoff, 1993). This is often seen in increased root depth of water stressed plants.

Antioxidant Activity and Cytokinin Level

Antioxidant activity was measured at two sampling dates, one in early May and one three days after the final irrigation event. No differences were detected for Kentucky bluegrass ascorbate peroxidase (APX) activity and only date was significant for catalase (CAT) and superoxide dismutase (SOD) activity (Table 3.1). Both CAT and SOD activity was higher in May than in June (the second sampling date) (data not shown). Similarly, creeping bentgrass APX activity was not significant but date was a significant main effect for CAT and SOD activity (Table 3.2). Both CAT and SOD activity was higher in May than in June (data not shown).

We hypothesize that changes in antioxidant activity could be measured if greater water stress occurs. Typically, SOD and APX activity are most responsive to drought conditions as means to scavenge the free radicals present due to the destructive nature of drought (Zhang and Kirkham, 1996; Zhang and Schmidt, 1999b; Fu and Huang, 2001; Pinheiro et al., 2004). Similarly, PGS application is most beneficial to a plant when it is undergoing a stress like limited available soil water. Plant growth stimulants increase antioxidant activity to protect against the populous active oxygen species that leak from the photosynthetic pathway when environmental stresses occur (Zhang and Schmidt, 1999a).

Cytokinin analyses were run only for the May sampling date. Cytokinin levels were unaffected by PGS and irrigation treatments for both turfgrass species (Tables 3.1 and 3.2). As no differences were detected when stress was thought to be the greatest, antioxidant and cytokinin analyses were not run for earlier sampling dates. If irrigation was withheld at a longer irrigation interval, a decline in cytokinin content would be expected (Hansen and Dorffling, 2003).

Table 3.1 Analysis of variance for Kentucky bluegrass response variables when subjected to plant growth stimulants (PGS) and deficit irrigation.

	Soil moisture	ET rate	Root length density	Root surface area	Root dry weight	Quality	PE	APX	CAT	SOD	Cytokinin
						p-value					
PGS treatment	0.0103	0.0697	0.8674	0.0206	0.0007	0.0938	0.2175	0.3030	0.2597	0.5378	0.2135
Irrigation	<.0001	<.0001	0.1447	0.0101	<.0001	<.0001	0.3590	0.5691	0.9863	0.3927	0.3012
Date	<.0001	<.0001	NA	NA	NA	<.0001	<.0001	0.5365	<.0001	<.0001	NA
Rep	0.2104	<.0001	0.7013	0.1796	0.0357	0.0320	0.5009	0.8476	0.3080	0.4667	0.4438
PGS treatment x rep	0.0384	<.0001	0.4247	0.0539	0.0236	0.0138	0.6194	0.6723	0.0681	0.7185	0.5451
PGS treatment x date	0.9882	0.9721	NA	NA	NA	0.5698	0.7351	0.9823	0.2981	0.4808	NA
Irrigation x rep	0.2762	0.0006	0.5425	0.1880	0.0055	0.1574	0.4317	0.2848	0.4683	0.7912	0.3782
Irrigation x date	0.9882	0.6387	NA	NA	NA	<.0001	0.5440	0.3230	0.9177	0.4684	NA
PGS treatment x irrigation	0.0522	0.0240	0.4649	0.4165	0.2690	0.0339	0.9674	0.7179	0.7787	0.7637	0.1436
PGS treatment x irrigation x date	0.8821	0.4273	NA	NA	NA	0.4015	0.7054	0.1474	0.7405	0.6590	NA

Table 3.2 Analysis of variance for creeping bentgrass response variables when subjected to plant growth stimulants (PGS) and deficit irrigation.

	Soil moisture	ET rate	Root length density	Root surface area	Root dry weight	Quality	PE	APX	CAT	SOD	Cytokinin
						p-value					
PGS treatment	0.0513	0.5246	0.3521	0.0810	0.0570	0.0526	0.6798	0.2086	0.6798	0.2701	0.2373
Irrigation	<.0001	0.2476	0.0126	0.0254	0.0034	0.2209	0.9702	0.1783	0.5084	0.4332	0.7483
Date	<.0001	<0.001	NA	NA	NA	<.0001	<.0001	0.9423	<.0001	0.0915	NA
Rep	0.0665	0.4887	0.4428	0.3289	0.1796	0.0037	0.4583	0.6426	0.4840	0.5490	0.5238
PGS treatment x rep	0.0018	0.2286	0.4960	0.6672	0.5917	0.1249	0.2510	0.1237	0.1212	0.5304	0.8343
PGS treatment x date	0.8258	0.9449	NA	NA	NA	0.7217	0.8525	0.5466	0.5491	0.5721	NA
Irrigation x rep	0.6990	<.0001	0.6881	0.8865	0.5830	0.0388	0.2454	0.6225	0.2057	0.5885	0.4755
Irrigation x date	0.0101	<.0001	NA	NA	NA	<.0001	0.1853	0.3719	0.9574	0.6078	NA
PGS treatment x irrigation	0.8637	0.1381	0.9587	0.2879	0.6316	0.1249	0.1736	0.3802	0.4137	0.6697	0.8343
PGS treatment x irrigation x date	0.6309	0.9486	NA	NA	NA	0.1612	0.7521	0.4024	0.4951	0.2445	NA

Table 3.3. Soil moisture at the 0-7.6 cm depth for irrigation and plant growth stimulant (PGS) treatment. Comparisons are made between irrigation levels and PGS treatments separately.

Irrigation and PGS treatment	Soil Moisture (%)	
	Kentucky bluegrass	Creeping bentgrass
100%	9.6 a†	18.4 a
85%	7.7 b	16.9 a
70%	6.8 c	13.6 b
SWE + HA‡	8.1 ab	17.9 a§
GB	8.7 a	16.3 ab
PP	7.8 b	15.0 b
Control	7.6 b	15.9 b

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05

‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.

§ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1

Table 3.4. Plant growth stimulant (PGS) treatment and irrigation interaction of soil moisture at the 0-7.6 cm depth.

PGS treatment and Irrigation	Soil moisture (%)			
	Kentucky bluegrass		Creeping bentgrass	
SWE + HA‡ 100%	9.8	a†	19.8	a
SWE + HA 85%	6.5	cd	18.9	a
SWE + HA 70%	7.1	cd	14.8	a
GB 100%	9.9	a	19.0	a
GB 85%	9.0	a	15.9	a
GB 70%	6.7	cd	13.8	a
PP 100%	8.9	ab	17.7	a
PP 85%	7.5	cb	15.5	a
PP 70%	6.3	cd	12.1	a
Control 100%	9.2	a	17.0	a
Control 85%	7.2	cd	17.3	a
Control 70%	5.8	d	13.5	a

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.

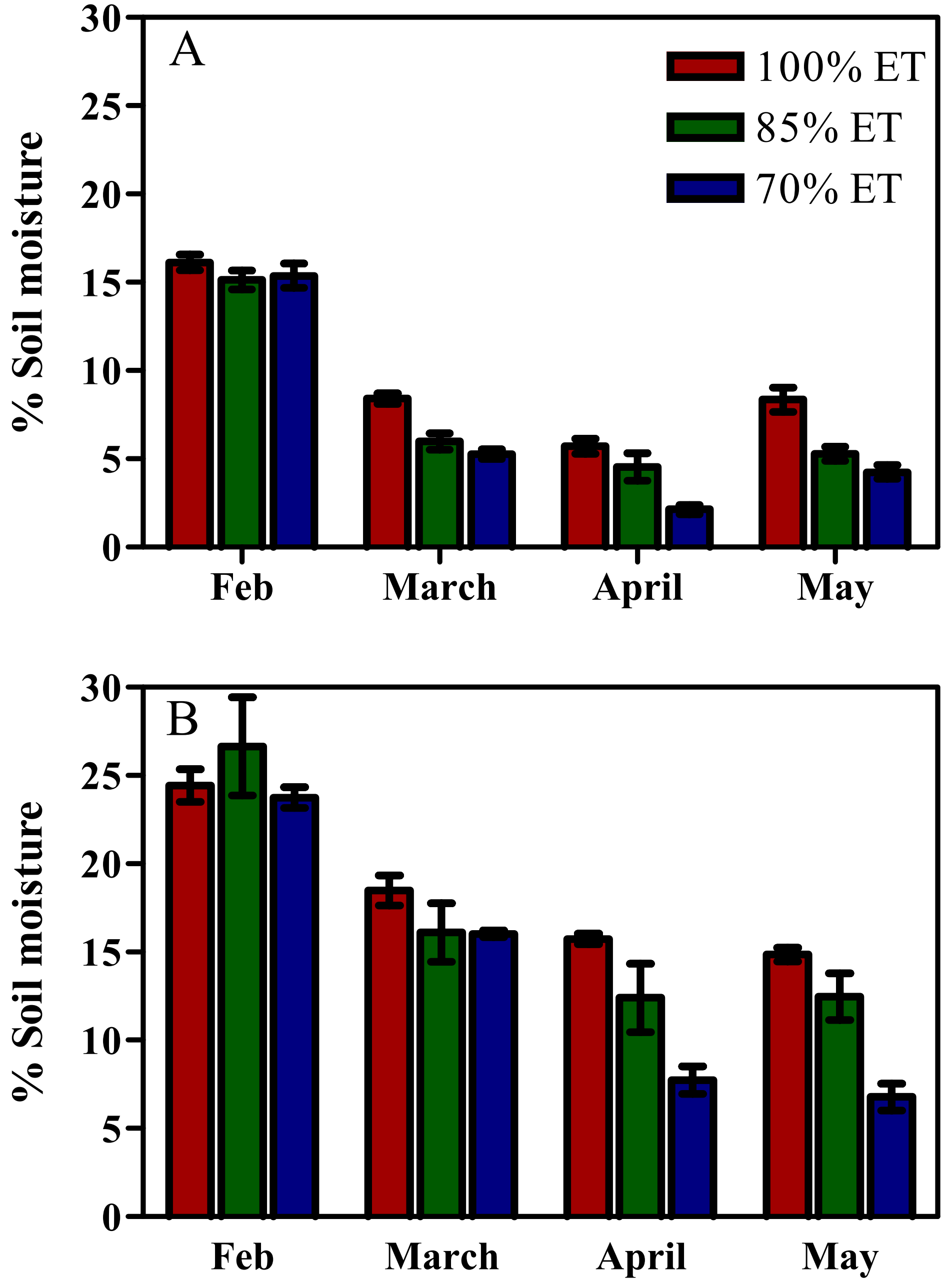


Fig. 3.1 Monthly average percentage soil miosture at the 0-7.6 cm depth trend. Kentucky bluegrass (A) and creeping bentgrass (B) 100%, 85% and 75% evapotranspiration (ET) deficit irrigation. The symbols in A are the same in B. Vertical bars indicate standard error at α=0.05.

Table 3.5. Irrigation and plant growth stimulant (PGS) treatment evapotranspiration (ET) rate for Kentucky bluegrass.

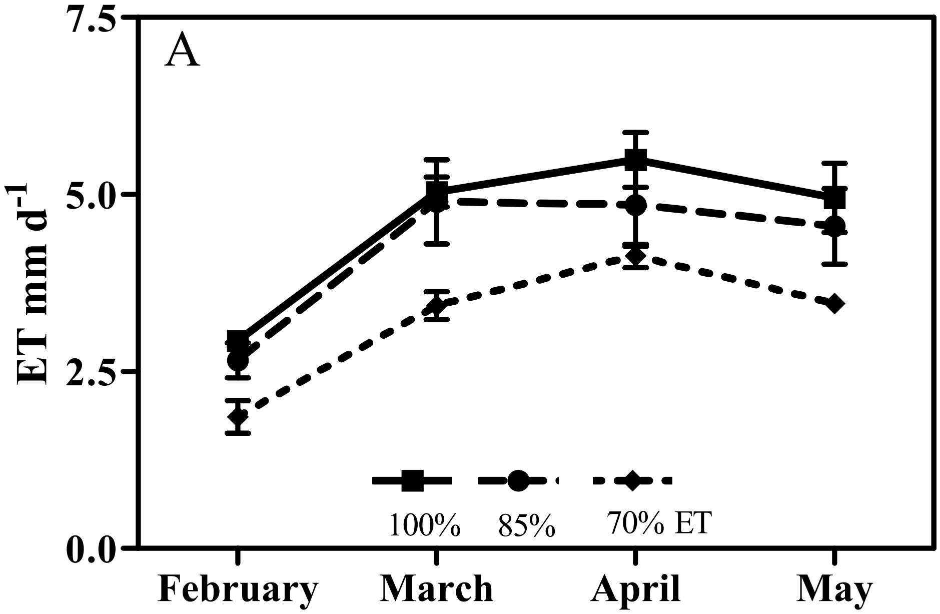
PGS treatment and Irrigation	Evapotranspiration mm d^{-1}	
	Kentucky bluegrass	Creeping bentgrass
100%	4.6 a†	2.6 a
85%	4.2 b	2.7 a
70%	3.2 c	3.0 a
SWE + HA§	4.2 a‡	2.7 a
GB	4.2 a	2.9 a
PP	3.9 ab	2.8 a
Control	3.8 b	2.9 a

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.
§ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.

Table 3.6. Plant growth stimulant (PGS) treatment and irrigation interaction of evapotranspiration (ET) rate for Kentucky bluegrass and creeping bentgrass.

PGS treatment and Irrigation	Evapotranspiration mm d^{-1}			
	Kentucky bluegrass		Creeping bentgrass	
SWE + HA‡ 100%	4.4	abc†	2.2	a
SWE + HA 85%	4.5	abc	2.7	a
SWE + HA 70%	3.7	cd	2.4	a
GB 100%	4.7	ab	2.6	a
GB 85%	4.3	abc	2.6	a
GB 70%	3.6	cd	2.7	a
PP 100%	4.9	a	2.2	a
PP 85%	4.3	abc	2.2	a
PP 70%	2.6	e	2.8	a
Control 100%	4.5	abc	2.6	a
Control 85%	3.9	c	2.2	a
Control 70%	2.9	de	2.6	a

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.001.
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product



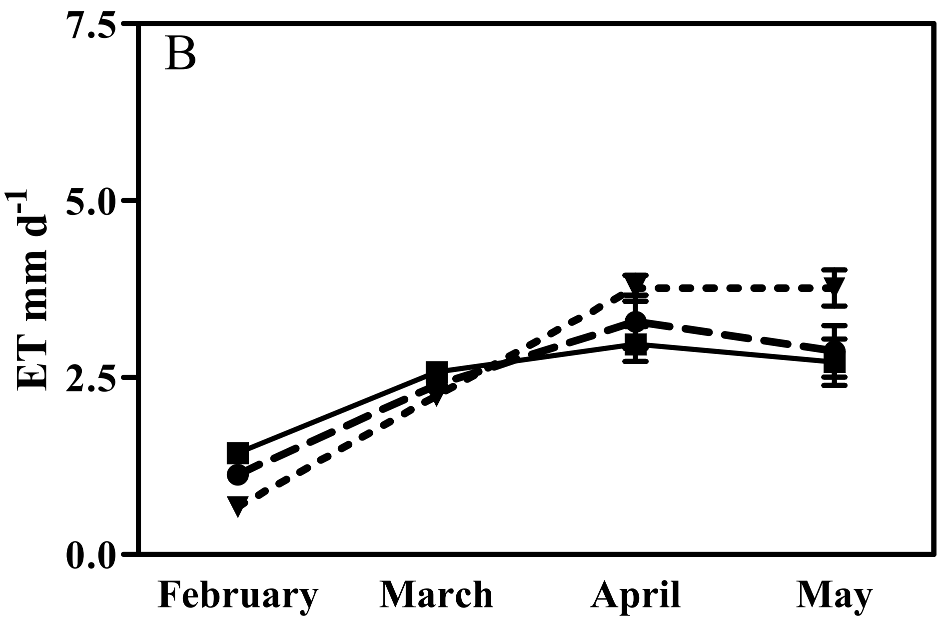


Fig. 3.2 Evapotranspiration (ET) trend over the course of four months. Kentucky bluegrass (A) and creeping bentgrass (B) under 100%, 85% and 70% ET deficit irrigation. The symbols in A are the same in B. Vertical bars indicate standard error. $\alpha=0.05$.

Table 3.7. Root surface area and root dry weight for Kentucky bluegrass.
Comparisons are made between irrigation levels and plant growth stimulant (PGS) treatments separately.

Irrigation and PGS treatments	Root Surface Area cm^2		Root Dry Weight mg	
100%	486.2	a†	401.3	a
85%	468.6	a	358.8	a
70%	370.2	b	262.5	b
SWE + HA‡	368.7	b	284.5	c
GB	515.6	a	411.9	a
PP	449.1	ab	361.1	ab
Control	433.4	ab	305.8	bc

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.

Table 3.8. Root morphology measurements attained through the WinRhizo root scanning program and root dry weight for creeping bentgrass.
Comparisons are made between irrigation levels and plant growth stimulant (PGS) treatments separately.

Irrigation and PGS treatments	Root length density cm cm^{-3}		Root Surface Area cm^2		Root Dry Weight mg	
100%	1.15	a	278.9	a	167.4	a
85%	1.10	a	278.0	a	140.1	a
70%	0.63	b	169.6	b	88.8	b
SWE + HA‡	1.15	NS	211.9	b	119.6	ab
GB	1.02	NS	248.4	ab	159.9	a
PP	0.87	NS	317.7	a	150.8	a
Control	0.81	NS	190.6	b	98.3	b

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.
§ NS = no signifigance

Table 3.9. Creeping bentgrass correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Soil moisture & root length density	0.0035	0.41
Soil moisture & root surface area	0.0022	0.43

α=0.05

Table 3.10. Kentucky bluegrass correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Soil moisture & root surface area	0.0030	0.42
Soil moisture & root length density	0.0012	0.45
Quality & PE †	0.0284	0.32
Quality & ET rate	0.0109	0.36
Quality & root length density	0.0258	0.32
Quality & root surface area	<0.0001	0.57

α=0.05
† PE = photochemical efficiency, ET = evapotranspiration

Table 3.9. Kentucky bluegrass quality as affected by irrigation level over time.

Irrigation level	Quality †			
	February	March	April	May
100%	7.2 a‡	8.1 a	6.9 a	8.1 a
	B§	A	C	A
85%	7.1 a	7.8 b	6.4 b	7.8 a
	B	A	C	A
70%	7.1 a	7.7 b	6.1 b	6.8 b
	B	A	C	B

† Quality ratings were made on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
§ Means followed by the same letter within the row are not significantly different based on LSD at α=0.05.

Table 3.10. Creeping bentgrass quality as affected by irrigation level over time

Irrigation level	Quality †			
	February	March	April	May
100%	6.7 a‡	7.7 b	6.8 a	8.3 a
	C§	B	C	A
85%	6.8 a	7.7 b	6.8 a	8.1 a
	B	A	B	A
70%	6.7 a	8.1 a	6.8 a	7.0 b
	C	A	C	B

† Quality ratings were made on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
§ Means followed by the same letter within the row are not significantly different based on LSD at α=0.05.

Table 3.11. Kentucky bluegrass and creeping bentgrass photochemical efficiency measurements separated by month, across all plant growth stimulant and irrigation treatments.

	Photochemical efficiency			
	February	March	April	May
Kentucky bluegrass	0.79b A†	0.66 B	0.65 B	0.59 C
Creeping bentgrass	0.73 A	0.58 C	0.64 B	0.54 D

† Means followed by the same letter within the row are not significantly different based on LSD at α=0.001.

Table 3.12. Kentucky bluegrass photochemical efficiency (PE) measurements taken six days after last irrigation. Comparisons are made between irrigation levels and plant growth stimulant (PGS) treatments separately.

Irrigation and PGS treatments	PE	
100%	0.645	a†
85%	0.602	a
70%	0.522	b
SWE + HA‡	0.589	b
GB	0.578	b
PP	0.646	a
Control	0.566	b

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.001 for irrigation and α=0.05 for PGS treatments
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine; PP = commercial product.

Conclusions

Study 1

The purpose of this greenhouse study was to obtain preliminary data for developing the field study. Field conditions and maintenance practices were simulated in the greenhouse in an attempt to artificially mimic results that may be attained in a field setting. In doing so, an irrigation frequency of every five days may not have been enough time to allow plants to undergo sufficient soil moisture stress. The preliminary data indicate that an irrigation reduction of 30% could be implemented on creeping bentgrass fairways and Kentucky bluegrass athletic fields without impacting turfgrass quality. The addition of another deficit irrigation level would further validate these claims upon field implementation.

Adjusting the irrigation interval would increase the likelihood of experiencing drought conditions in the field. We speculate that a similar trend of declining photochemical efficiency with declining soil moisture as observed by Zhang and Ervin (2004) would have been achieved in the greenhouse study if the interval between irrigation events was longer. We hypothesize that the beneficial aspects of the PGS would have been measured physiologically and visually upon the implementation of another deficit irrigation treatment and the adjustment of irrigation events.

Data extracted from this study show that GB may be promising in the field setting under lower irrigation levels in aiding the plant to withstand drought. Glycinebetaine application did result in higher soil moisture and root growth for both species, which is promising for turfgrass research as GB application has primarily been studied on field and horticultural crops. The increased root growth may be attributed to the osmoprotectant properties that allow for continued membrane function while subjected to drying soil conditions.

Data from this project exhibit trends that can be expected in the field. Therefore upon some modifications, this study is suitable to continue in the field setting to determine crop coefficients and if the application of PGS have the ability to increase turf survivability under deficit irrigation.

Results and Discussion

Study 2

The analysis of variance (ANOVA) table shown below is a synopsis of all measured variables. Data are shown solely for PGS treatment effects.

Quality and ΔT differences were detected between GB rates on creeping bentgrass, while irrigation differences were detected between quality, wilt, soil moisture, photochemical efficiency, root weight, and ΔT (Table 3.13). Creeping bentgrass treated with GB_2 resulted in an overall quality rating of 7.2, which was better than GB_4 (6.5) and GB_5 (6.6) (Table 3.14). However, all GB rates were rated equal to the control. Glycinebetaine application, independent of rate, did not affect quality when compared to the control. Visual ratings did not indicate an benefit in applying GB from a rate of 3.9 to 15 kg ha^{-1}.

The GB_2 treatment rate had the lowest ΔT than all other GB treatments, which were equal to the control (Table 3.14). While ΔT was lowest for creeping bentgrass treated with GB_2, its quality was rated equal to the control and no other physiological measurements separated it from the other GB treatments. One research reported that bean (*Phaseoulus vulgaris*) treated with 10 mM GB maintained leaf turgidity longer than the untreated plants (Xing and Rajashekar, 1999). This result was due to the osmotic regulation properties of GB even at the low rate. Apparently, bean is more sensitive to GB treatment than creeping bentgrass as no differences were detected between plant health indices under well-watered or water-stressed conditions when GB rates greater than 10 mM were applied.

Creeping bentgrass treatment by irrigation by date interaction is not shown as all GB treatments were ultimately equal to the control. When irrigation level was significant for quality, wilt, soil moisture, photochemical efficiency, electrolyte leakage and root weight, the 70% ET irrigation level consistently performed worse than the 100% (data not shown).

Unlike creeping bentgrass, no differences were detected between GB treatment main effects for tall fescue (Table 3.15). Treatment by irrigation interaction was significant for tall fescue quality. Only the GB_5 100% and 55% irrigation treatments were equal within one GB rate. The GB_5 100% was equal to all other 100% level GB treatments and GB_5 55% was equal to all other 55% level GB treatments (Table 3.16). Other than GB_5, the 100% irrigation level resulted in higher quality ratings than the 55% irrigated turf, independent of GB treatment. Like creeping bentgrass, all differences detected between irrigation levels for quality, wilt, soil moisture, photochemical efficiency, electrolyte leakage and ΔT resulted in the 100% irrigation level performing better than the 55% level (data not shown). Tall fescue root data were not included due to operator error when drying roots in the muffle oven. As no other measurements detected differences between GB rate, it could be speculated that differences in root dry weight would not have been significant.

Date main effects and irrigation by date interactive effects will not be referred to, as the focus of this second greenhouse study was to assess the differences between GB treatment rates and to investigate if irrigation could be reduced upon application of GB.

Previous GB application on field crops has been studied comparing varying rates. Higher rates were studied by Agboma et al. (1997a) when two rates, 0.1M and 0.3M, were foliarly applied on drought stressed tobacco (*Nicotiana tabacum* L.). Increased fresh leaf weight was recorded for those plants treated with GB, especially when drought conditions coincided with rapid leaf growth. However, the 0.3M GB level had phototoxic effects as seen by leaf scorching shortly after application. Makela et al. (1998) tested three GB rates, 0.05, 0.1 and 0.14 M on tomato (*Lycopersicon escilentum* Mill.). The 0.05M rate improved fruit production while the 0.1M rate decreased fruit production when plants were not stressed. The 0.14 M rate was effective at improving fruit yield when tomato plants were grown under salt stress. Soybean (G*lycine max* L. Merrill) treated with 0.1 M of GB survived drought better due its ability to reduce stomatal aperture and conserve water and was capable of maintaining seed production (Agboma et al., 1997b).

Table 3.13. Analysis of variance for response variables when creeping bentgrass was treated with a range of glycinebetaine (GB) rates and subjected to deficit irrigation.

	Quality	Wilt	Soil moisture *p*-value	PE†	EL	ΔT	Root weight
PGS treatment	0.0389	0.1161	0.9658	0.1817	0.7907	0.0181	0.4719
Irrigation	<.0001	<.0001	0.0003	0.0478	0.1320	0.4045	0.0487
Date	<.0001	<.0001	<.0001	0.0168	<.0001	<.0001	NA
Rep	0.0180	0.1843	0.2650	0.7739	0.1365	0.3129	0.9402
PGS treatment x rep	0.0105	0.1184	0.4783	0.0526	0.8170	0.0063	0.1895
PGS treatment x date	0.4416	0.7158	0.7395	0.7296	0.8391	0.8298	NA
Irrigation x rep	0.5555	05102	0.6372	0.3502	0.1354	0.2777	0.1159
Irrigation x date	<.0001	<.0001	0.0073	0.1552	0.2597	0.4736	NA
PGS treatment x irrigation	0.1371	0.2883	0.2301	0.9133	0.6039	0.0065	0.5714
PGS treatment x irrigation x date	0.6404	0.8746	0.8009	0.7825	0.9483	0.0089	NA

† PE = photochemical efficiency, EL = electrolyte leakage, ΔT = canopy temperature minus air temperature.

Table 3.14. Glycinebetaine treatment rate effect on creeping bentgrass quality and canopy minus air temperature difference (ΔT).

PGS treatments	Quality †		ΔT	
GB_1 §	6.9	ab‡	3.0	a
GB_2	7.2	a	0.9	c
GB_3	6.9	ab	2.6	ab
GB_4	6.5	c	1.7	bc
GB_5	6.6	bc	2.6	ab
Control	6.8	abc	2.2	ab

† Quality ratings were made on the 1-9 scale where 1 id dead and 9 is best. Minimum acceptable level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at $\alpha = 0.05$.
§ GB_1 = glycinebetaine 3.9 kg ha^{-1}, GB_2 = glycinebetaine 7.5 kg ha^{-1}, GB_3 = glycinebetaine 11.5 kg ha^{-1}, GB_4 = glycinebetaine 15 kg ha^{-1}, GB_5 = anhydrous glycinebetaine 3.2 kg ha^{-1}.

Table 3.15. Analysis of variance for t response variables when tall fescue was treated with a range of glycinebetaine (GB) rates and subjected to deficit irrigation.

	Quality	Wilt	Soil moisture *p*-value	PE†	EL	ΔT
PGS treatment	0.3392	0.4568	0.4784	0.5104	0.4003	0.7174
Irrigation	<.0001	<.0001	<.0001	0.0002	0.0397	<.0001
Date	<.0001	<.0001	<.0001	0.0131	0.1765	<.0001
Rep	0.0111	0.1863	0.1161	0.3635	0.6838	0.0021
PGS treatment x rep	0.1582	0.1565	0.0057	0.2707	0.5498	0.2657
PGS treatment x date	0.6948	0.7971	0.1782	0.2527	0.0265	0.6525
Irrigation x rep	0.0256	0.6669	0.6515	0.1391	0.5513	0.5807
Irrigation x date	<.0001	<.0001	<.0001	0.5501	0.2769	<.0001
PGS treatment x irrigation	0.0405	0.6092	0.2528	0.9361	0.6297	0.1368
PGS treatment x irrigation x date	0.4762	0.8913	0.5698	0.3856	0.3051	0.7492

† PE = photochemical efficiency, EL = electrolyte leakage, ΔT = canopy temperature minus air temperature

Table 3.16. Plant growth stimulant (PGS) treatment by irrigation interaction of quality for tall fescue.

PGS treatment and irrigation	Quality †
GB_1 100% §	7.2 a‡
GB_1 55%	5.7 c
GB_2 100%	7.3 a
GB_2 55%	5.6 c
GB_3 100%	7.2 a
GB_3 55%	6.1 c
GB_4 100%	7.3 a
GB_4 55%	5.9 c
GB_5 100%	7.1 ab
GB_5 55%	6.1 bc
Control 100%	7.3 a
Control 55%	5.6 c

† Quality ratings were made on the 1-9 scale where 1 id dead and 9 is best. Minimum acceptable level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at $\alpha = 0.05$.
§ GB_1 = glycinebetaine 3.9 kg ha^{-1}, GB_2 = glycinebetaine 7.5 kg ha^{-1}, GB_3 = glycinebetaine 11.5 kg ha^{-1}, GB_4 = glycinebtaine 15 kg ha^{-1}, GB_5 = anhydrous glycinebetaine 3.2 kg ha^{-1}.

Conclusions

Study 2

The 100% ET irrigated creeping bentgrass pots maintained higher quality, photochemical efficiency and produced more root mass than the 70% level. Irrigating at 70% ET upon wilt is not recommended for fairway height creeping bentgrass as turfgrass health was negatively impacted. Similarly, turfgrass health was better for 100% than 55% ET irrigated tall fescue. Therefore, irrigating at 55% ET upon wilt is not recommended for home lawn tall fescue. However, the 55% ET irrigation level may be appropriate with more frequent irrigation events.

As no visual or physiological differences were detected between GB rates of creeping bentgrass and tall fescue, the lower rate may be suitable for turfgrass application. Glycinebetaine rates applied on field crops proved to be beneficial at a wide range of rates, both equal to and exceeding the rates utilized in this study. There may be an interactive effect between fruit production and GB application effect but fruit production is not of concern in turfgrass. Drought resistance, which allows for the plant to continue growing despite the low soil moisture, is more of concern for turfgrass managers. Further research should be conducted on turfgrass response to GB application when subjected to environmental stresses, such as drought, to determine which rate or range of rates is most appropriate.

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Chapter 4

Developing Mid-Atlantic Crop Coefficients and Examining the Impact of Plant Growth Stimulants Applied on Creeping Bentgrass Fairways and Tall Fescue Home Lawns.

Abstract

Due to its temperate, humid climate, water limitations are not typically associated with Virginia grown crops. A balance must be maintained between landscape irrigation water use and human consumption of potable water within Virginia. As a result, water conservation practices are of the utmost importance. Some turfgrass managers have turned to plant growth stimulants (PGS) to increase drought resistant characteristics of their turfgrass. The PGS of interest are a seaweed extract (SWE) + humic acid (HA) mixture and glycinebetaine (GB). Creeping bentgrass (*Agrostis palustris* 'L93') and tall fescue (*Festuca arundinacea*) Dominion blend were grown. Water conserving crop coefficients (K_c) were determined for golf course fairways and home lawns, respectively. Plant growth stimulants were studied for the capability to further reduce, and if they affect physiological function and/or root morphology. A two-year field study was conducted at the Virginia Tech Turfgrass Research Center from July to September in 2003 and 2004. An onsite weather station collected climate data, which was entered into the REFET computer program to determine grass reference evapotranspiration (ET_o). Plots were irrigated at 100%, 85%, 70% or 55% of ET_o and were covered upon the onset of rain. Turfgrass health was assessed by quality and wilt ratings, percentage soil moisture at the 0-7.6 cm depth, photochemical efficiency, canopy and air temperature difference, antioxidant activity, and cytokinin content measurements taken throughout the study. At the end of each study year, roots were sampled to measure morphology with the WinRHIZO computer program. Our results indicate that tall fescue home lawns could be irrigated every five days with a K_c of 0.55 or once a week with a K_c of 0.70 to adjust ET_o. This level is similar to K_cs that have been developed by other researchers throughout the United States. Plant growth stimulants did not affect tall fescue physiological processes, but GB may have an anti-transpirant effect. Creeping bentgrass

was more sensitive to deficit irrigation levels as a K_c of 0.85 is recommended for fairways irrigated every four days. Glycinebetaine did increase root length density, root surface area and root dry weight in 2003. Therefore, it may have utility to increase rooting during the first year after planting. Glycinebetaine application also resulted in lower canopy temperatures in 2004. Therefore, it may protect the plant when subjected to severe drought and heat stress. Further research should be conducted with GB as this is the first documented study to explore the potentials of GB application on turfgrass to increase drought resistance.

Introduction

The Mid-Atlantic region of the United States is not typically associated with drought occurrences and water limitations. Average summer temperature and rainfall in Virginia is 23°C and 326 mm, respectively. Over the past decade there has been an increasing trend in temperature and decreasing trend in precipitation during the summer months of June through August (NOAA, 2005). The combination of increasing evaporative demand and decreasing rainfall occurrences makes Virginia crops dependent on supplemental irrigation water. To ensure ample water supplies for human consumption, irrigation must be applied efficiently. With the continuing population increase, more of the available water supply is allocated for human consumption rather than landscape irrigation. In the arid western U.S., moderate deficit irrigation, a practice where less water is supplied to a system than lost through estimated evapotranspiration, has been shown to allow adequate plant growth while conserving water (Kneebone et al., 1992). States like Nevada, Arizona, California and Colorado have all developed turfgrass crop coefficients (K_c). Climate and species specific K_c's adjust reference evapotranspiration (ET_o) to estimate actual transpiration (ET_a) (ASCE, 1990). Cool season turfgrass K_c's range from 0.7 in Arizona (Brown, 1996) to 1.0 in Rhode Island (Aronson et al., 1987).

At the end of 1999, there were 342 total golf courses in the state of Virginia and due to an average of 4.9 additional golf courses constructed annually from 1982 to 1997, it was expected that this number would continue to rise (VASS, 2001). Creeping bentgrass is often grown on Virginia golf course fairways due to its stoloniferous growth, which allows for quick divot recovery. The 'L93' cultivar has a medium-high density, which does not promote excessive thatch buildup and yet is dense enough to form a uniform stand. In Rutgers University bentgrass trials, 'L93' creeping bentgrass has consistently exhibited good dollar spot resistance (Bonos et al., 2001). The National Turfgrass Evaluation Program (NTEP) trials have reported 'L93' to have high quality and heat tolerance throughout the United States (Morris, 2002).

In Virginia there are an estimated two million home lawns, which is 52% of the state's total turfgrass acreage. Homeowners spend 73% of total turfgrass related expenditures to maintain their lawns (VASS, 2001). As home lawns cover the largest portion of Virginia cultured turfgrass, tall fescue maintained at home lawn height was also studied. Turf type tall fescue is the most heat tolerant of the cool-season grasses and is best suited in the transition zone. Due to its extensive root system, tall fescue is considered drought resistant, which makes it ideal for home lawns (McCarty, 2001).

In a survey conducted by the Golf Course Superintendent's Association of America, improved irrigation techniques and technologies was the second most popular response when asked which management practice had the most positive impact on the environment (Goering, 2004). Water conservation is both an environmental issue and a political issue. Practitioners within the turfgrass industry are often portrayed as water wasters because irrigation practices are necessary to maintain an acceptable product. The turfgrass industry's economic impact is not often considered. In Virginia, there are 1.4 million acres of cultured turfgrass supplying an economic impact of $2.2 billion dollars annually (VASS, 2001). Water consumption is needed for turfgrass production and to continue to positively impact the state's economy.

Many years of research and technology development have been dedicated to exploring irrigation efficiency. As early as the 1960's, researchers were interested in water conservation issues and looking at plant indices to determine irrigation scheduling. Quackenbush and Phelan (1965) determined that soils in the home lawn setting could be depleted to near wilting point prior to irrigating as means to conserve water. Clark and Hiler (1973) determined that leaf water potential measurements were most responsive in determining leaf water content in peas. Delay of tall fescue leaf rolling was a visual indication used in determining drought resistant tall fescue cultivars from the Rutgers breeding program (White et al., 1992).

Drought resistance is partly due to morphological characteristics that allow for survival in water deficit conditions. Deep and extensive root systems are capable of scavenging large soil volumes for available water (Jones et al., 1981). Osmotic adjustment capabilities of tall fescue was correlated with increased survival while grown in limiting soil moisture (White et al., 1992). Canopy temperatures maintained below air temperatures indicate a non-stressed plant as it is actively transpiring (Kneebone et al., 1992). Lower canopy temperatures have been correlated to increased rooting and ability to extract soil moisture (Ervin, 1995).

Due to the aforementioned water issues facing Virginia, some turfgrass managers have implemented the use of plant growth stimulants (PGS) with the goal of enhancing turfgrass drought resistance while irrigating with the least possible water amount. Pathan et al. (2004) determined that irrigation could be reduced by 60% in fly ash amended soil. Amending soils with organic matter is labor intensive and costly so many managers opt for foliar application of PGS. A large portion of the turfgrass PGS products contain seaweed extract (SWE) and/or humic acid (HA) as the main ingredients. Foliar application of a SWE and HA mixture has been reported to increase creeping bentgrass root mass despite drought conditions (Zhang, 1997) which may promote greater water uptake to maintain a cool canopy. Photosynthetic integrity was maintained for water stressed Kentucky bluegrass (*Poa pratensis*) treated with SWE + HA (Schmidt and Zhang, 2001). It has also been proven that SWE + HA enhance plant antioxidant activity to protect the plant from desiccation stresses under low available soil moisture (Zhang, 1997; Zhang and Schmidt, 1997; Zhang and Schmidt, 1999b).

Another PGS of interest is glycinebetaine (GB), a by-product of sugar beet processing. It has been utilized on field crops to enhance drought and salinity tolerance as it is an osmoregulator and osmoprotectant (Abernathy and McManus, 1998; Xing and Rajashekar, 1999; Sakamoto and Murata, 2000). Glycinebetaine application has yet to be researched on turfgrass as a means to cope with deficit irrigation stress.

The objectives of this two year field study were to: (i) develop K_c for the Mid-Atlantic region on creeping bentgrass golf course fairways and tall fescue home lawns, (ii) determine if the application of SWE + HA or GB allow for a further reduction in irrigation while maintaining quality, and (iii) determine if SWE + HA or GB have an impact on turfgrass physiological function and/or root morphology.

Materials and Methods

Establishment, Experimental Design, and Turfgrass Species

A two-year field study was conducted at the Virginia Tech Turfgrass Research Center in Blacksburg, VA from July to September of 2003 and 2004. Research plots were established on April 16, 2003 on a newly constructed medium texture sand rootzone (31 cm depth) meeting United States Golf Association guidelines. The approximate physical properties of this soil were: bulk density 1.68 g cm^{-3}, air-filled porosity 18.6%, and capillary porosity 18%. A sand rootzone was utilized to promote a worst-case scenario and increase the likelihood of developing water-limiting conditions.

Plots were 1 m x 2 m with 0.3 m borders using two cool season grasses. Creeping bentgrass (*Agrostis stolonifera* 'L93') was seeded at the rate of 49 kg ha^{-1}, while tall fescue (*Festuca arundinacea*) Dominion blend was seeded at 195 kg ha^{-1}. Creeping bentgrass seed was from Jacklin Seed (Post Falls, ID), while tall fescue seed was from Landscape Supply (Roanoke, VA). The tall fescue Dominion blend consisted of turfgrass cultivars that were included on the Virginia Crop Improvement Association list of approved cultivars. . Plots were arranged in a randomized complete block design with four replications.

Creeping bentgrass was maintained at golf course fairway height (13 cm), while tall fescue was maintained at home lawn height (64 cm). Biweekly spoon feeding of 20-20-20 (with micronutrients) delivered 12 kg N ha^{-1} at each application in 2003. In May 2004, 24 kg ha^{-1} of a granular 18-4-10 (with micronutrients), 73 kg ha^{-1} of 0-46-0 and 0-0-60 were applied based on soil test report recommendations. The granular 18-4-10 (with micronutrients) delivered 12 kg N ha^{-1} in July and August and 49 kg N ha^{-1} in September.

Treatments: Plant Growth Stimulants

Two PGS treatments were applied monthly with a CO_2 sprayer delivering 785 L ha^{-1} at 290 kPa. Plant growth stimulant treatments consisted of: SWE (*Ascophyllum nodosum)* + HA mixture, GB, and a water control. The SWE was supplied as a dry powder (Acadian Seaplants Ltd., Dartmouth, Nova Scotia). Leonardite extracted HA (80% active ingredient) was supplied by Plant Wise Biostimulants (Louisville, KY). The

SWE + HA mixture was sprayed at a rate of 0.5 kg ha^{-1} + 1.5 kg ha^{-1}, respectively. Glycinebetaine, a byproduct of sugar beet processing with 28% active ingredient (Big Chief Betaine, Monitor Sugar Co., Bay City, MI), was applied at the rate of 3.8 kg ha^{-1}.

Treatments: Irrigation

Climate data was collected in 2003 and 2004 with a Campbell Scientific weather station METData1 (Logan, UT) located 25 m away from plots and was surrounded by a tall fescue stand maintained at 51 cm height of cut. The weather station was located 610 m above sea level and 27 degrees latitude and 80 degrees W longitude. Climate data were entered into the REF-ET computer program to compute evapotranspiration (ET) with adjustments made for mowing height differences (Allen, 2000). The Penman-Monteith equation was utilized as it is considered the most consistent and incorporates mowing height as surface resistance in the equation (Hatfield and Allen, 1996). The Penman-Monteith equation was as follows:

$$ET = \frac{\Delta (R_n - G) + 86400\, \rho C_p [e_a - ed]/r_a}{[\Delta + \gamma (1 + r_c/r_a)]\, \lambda}$$

where ET = evapotranspiration (mm day^{-1}); Δ = slope of saturation vapor pressure curve (kPa $^\circ C^{-1}$); R_n = net radiation flux density to the plant canopy (MJ m^{-2} d^{-1}); G = soil heat flux density (MJ m^{-2} t^{-1}); ρ = density of dry air (kg m^{-3}); C_p = specific heat of air (MJ kg^{-1} $^\circ C^{-1}$); e_a = saturation vapor pressure at the current air temperature (kPa); e_d = saturation vapor pressure at the dewpoint temperature (actual vapor pressure of the air, kPa); r_a = aerodynamic resistance to vapor ad heat diffusion (s m^{-1}); γ = psychrometric constant (kPa $^\circ C^{-1}$); r_c = bulk stomatal (canopy) resistance (s m^{-1}); r_a = aerodynamic resistance to vapor and heat diffusion (s m^{-1}); and λ = latent heat of vaporization (MJ kg^{-1}) (Allen et al., 1989) (Appendix B).

Irrigation treatments were applied to plots individually with a hand-held metered hose (Daniel L. Jerman Co., Hackensack, NJ) to replace 100%, 85%, or 70% of refrence ET (ET_o). In 2003, irrigation was applied every three days for creeping bentgrass and every five days for tall fescue. In 2004, irrigation was applied upon wilt of the untreated 100% ET_o control plots. Plots were covered at the onset of rain during each year of the study. In 2003 a tarp system was constructed from UV and water-resistant tarps attached to PVC pipe at opposing ends for weight. Stakes were inserted through grommet holes and into the soil to keep tarps from blowing away. In 2004 a rainout shelter was constructed out of hollow 31 mm steel pipe. The rainout shelter was in two sections each measuring 6 m x 12 m. Steel pipe was welded to make A-frame trusses. Three trusses, each measuring 1.7 m high, were used for each section and pipe connected the trusses together. At the corners and middle of each truss a castor wheel was bolted. Wheels were made of hard rubber measuring 15 cm in diameter and 5 cm in width. Concrete paths were laid to create a hard, stable surface for the wheels to roll. Ultraviolet resistant plastic, 301M Tufflite™ IV (Tyco International Inc., Princeton, NJ), covered each rainout shelter section.

Summer Climate

Air temperature in 2003 and 2004 was below the 30-year average for the study months (July to September) (Appendix A). The 2003 average summer temperature in Blacksburg, Virginia was 19.6˚C, while the 2004 average summer temperature was 20˚C. The 30-year average temperature in Blacksburg is 22˚C (VSCO, 2000). Rainfall from July to September of 2003 was nearly 30% higher than the 30-year average. A total of 381 mm was recorded for 2003, compared to the 30-year average of 295 mm (VSCO, 2000). Rainfall was slightly less than the 30-year average in 2004 with a total of 244 mm measured.

Quality and Wilt Ratings

Quality and wilt ratings were based on a one to nine scale where one equaled dead and severely wilted turf and nine equaled the highest quality, most turgid turfgrass. Quality was assessed based on three parameters: density, uniformity and color. Minimum acceptability rating level was predetermined as a six for both turf species. Quality and wilt ratings were taken in the afternoon after turfgrass was subjected to the heat of the day and prior to irrigation events to increase the likelihood of visually detecting differences between treatments. Ratings were taken monthly in 2003 and biweekly in 2004, and were reported as average quality per month. Wilt ratings were made by assessing how easily a foot impression could be made in the turfgrass canopy and how quickly it recovered. If turfgrass laid flat upon stepping then it was considered wilted and the quickness it returned upright determined wilt severity. Turfgrass color was also an indication of wilt as turfgrass shows a blue gray color when wilted.

Soil Moisture

Soil moisture was measured at the 0-7.6 cm depth with a Theta soil moisture meter type HH1 and Theta probe type ML2x (Delta-T Devices Ltd., Cambridge, England). Moisture readings were measured as percentage soil moisture in the mineral soil moisture ($m^3\ m^{-3}$) mode. All readings were taken prior to an irrigation event to increase the likelihood of detecting differences between the treatments. In both years of the study, readings were taken weekly and reported as average percentage soil moisture per month.

ΔT

Canopy temperature was measured solely in 2004 with an infrared thermometer with accuracy to 0.2˚C (Raynger ST, Raytek, Santa Cruz, CA). The infrared thermometer senses emitted, reflected and transmitted energy and converts the reading into temperature. Readings were taken biweekly between the hours of 12:00 and 15:00. The infrared thermometer was held at a 45-degree angle and approximately one meter above the turf canopy. Measurement time was recorded and the weather station was consulted for air temperature. The difference between canopy and air temperature (ΔT) gives an indirect measurement of plant stress. As deficit soil water conditions are imposed, evapotranspiration is limited, which causes turfgrass canopy temperatures to rise. This measurement may be an assessment of drought avoidance through stomatal regulation of an unstressed plant (Kneebone et al., 1992).

Photochemical Efficiency

Photochemical efficiency (PE) was measured monthly in both 2003 and 2004. Photochemical efficiency is a measurement of how efficiently the turfgrass is utilizing light energy to photosynthesize. The process of dark adapting the turfgrass and the instrument used is detailed by Zhang et al. (2003b). A healthy plant utilizes 97% of absorbed light energy as photosynthesis. A stressed plant is not capable of absorbing as much light, therefore photosynthesis is hindered (Miles, 1990). Similar to the other measurements for assessing turfgrass stress level, PE readings were taken prior to irrigation events to increase the likelihood of detecting treatment differences.

Antioxidant Activity and Cytokinin Content

Leaf tissue samples were taken monthly to determine antioxidant activity and cytokinin content. Tissue was harvested when turfgrass was wilted due to water stress. Ascorbate peroxidase (APX), catalase (CAT) and superoxide dismutase (SOD) antioxidant activity were measured as detailed by Zhang and Ervin (2003a). Zeatin riboside cytokinin content was analyzed by enzyme-linked immunoassay as detailed by Zhang and Ervin (2004).

Root Morphology

At the conclusion of each study year root samples were taken from the plots as means to measure root morphology. Six plugs of 1.3 cm in diameter and 15 cm in depth and two plugs of 2.5 cm in diameter and 25 cm in depth were randomly sampled from each creeping bentgrass and tall fescue plot, respectively. Roots samples, including soil, were stored in plastic bags at 0˚C until time allowed for root washing (typically four to five months). Roots were washed free from soil and then placed in a number 18 sieve (W.S. Tyler Inc., Mentor, Ohio), separated from soil particles and stems and then stored in plastic vials at 4˚C. Washed root samples taken in 2003 were transferred to a 12% alcohol solution to preserve roots for the several months they were stored prior to analysis (Bohm, 1979). Washed root samples taken in 2004 were analyzed shortly after root washing therefore the alcohol solution was not necessary. Root morphology measurements were made with WinRHIZO software (Regent Instruments, Inc., Quebec, Canada). Roots were distributed evenly in an acrylic tray filled with distilled deionized water. Root overlapping was not of concern as the WinRHIZO root analyzing software compensates for root overlap (Arsenault et al., 1995). Roots were scanned (Epson Expression 1600, Long Beach, CA) in gray scale color and analyzed with WinRHIZO to determine root morphology including root length density (cm cm^{-3}) and root surface area (cm^2). Scanner resolution was set at 400 dots per inch as recommended by Polomski and Kuhn (2002). Manual threshold was adjusted prior to batch analysis to ensure fine roots were detected. The threshold value is used to separate pixels from the background and scanned root image (WinRHIZO, 2001). Analyzed roots were then oven dried (70 ^{o}C for 24 h) and root dry weight was recorded.

Statistical Analyses

Data were subjected to analysis of variance and significant main or interactive effects were separated with LSD at the 0.05% level with the general linear model with SAS version 9.1 (SAS Institute Inc., Cary, NC). Spearman nonparametric correlations were run with Prism version 4.00 (Graphpad Software Inc., San Diego, CA.) with significance reported at the 0.05% level.

Results and Discussion

Data were analyzed for the 2003 and 2004 years separately as differences were detected between years for all measurements.

Tall Fescue

Quality and Wilt

Monthly differences in quality and wilt were detected for both years, while irrigation main effect was solely significant in 2004 (Tables 4.1 and 4.2). Quality was maintained at the same level in July and August and fell to a rating of 6.6 in September of 2003 (Table 4.3). Wilt severity in 2003 increased from none in July (9.0) to 7.3 in September. This relationship is represented in the positive correlation between quality and wilt in 2003 (r=0.41), which means that as quality decreased wilt severity increased (closer to 1.0 rating) (Table 4.4). White et al. (1992) measured positive correlations between wilt and leaf water potential and leaf osmotic potential. Visual determination of wilt severity allows turfgrass managers to easily assess the water status within the leaf without time consuming physiological measurements.

Tall fescue irrigated at the 55% ET_o level in 2004 resulted in lower quality ratings than those irrigated at the 100% and 85% levels (Fig. 4.1A). Huang and Fu (2001)first measured tall fescue quality decline after 15 days of surface soil drying conditions when grown at 24ºC. Water was not withheld longer than five and 15 days in 2003 and 2004, respectively and summer month air temperature did not exceed 22ºC during either year. As a result, quality decline was not as severe in this field study as measured in Huang and Fu's (2001) study. Quality never fell below the preset minimum acceptable level of six in either study years. A linear relationship was significant for 2004 quality (Fig 4.1A), but irrigation would have to be at 20% ET_o to attain an overall quality rating of six.

Wilt was more severe for 55% ET_o deficit irrigated tall fescue compared to the 100% in 2004 (Fig. 4.1B). In the second study year, tall fescue had the highest quality and least wilt in July than in August and September (Table 4.5). Quality increased and wilt severity decreased from August to September, which is a response of mild weather in September as average temperature decreased by 5% and solar radiation decreased by 11%. A correlation between quality and wilt was detected in 2004 (r=0.82) (Table 4.6), therefore as quality decreased in August, wilt severity increased and as quality increased in September, wilt severity decreased (Table 4.5).

Deficit irrigation research to determine K_c is site specific due to varying climatic conditions (Annandale and Stockle, 1994). Fry and Butler (1989) utilized lysimeters to determine that optimum performance of 'Rebel' tall fescue occurred when irrigation was applied every two days at 75% or 100% of potential ET, measured when soil moisture is non-limiting. They were able to maintain acceptable quality when turfgrass was irrigated every two days at 55% potential ET or every four to seven days at 75%. Ervin and Koski (1998) reported that when irrigated every three days, the Kimberly Penman ET equation could be adjusted with a K_c of 0.50 to 0.80, depending on desired quality. Research conducted in California determined tall fescue irrigated twice weekly with a K_c of 0.80 was acceptable (Richie et al., 2002). In the Midwest, Kansas grown tall fescue could be irrigated at a 40% reduction in 2001 and at a 20% reduction in 2002, while maintaining quality above the minimum acceptable level of 6.0 (Fu et al., 2004). In humid Georgia, Carrow (1995) assessed ET_o by utilizing the FAO Penman equation. He reported that 'Rebel II' tall fescue ET_o could be adjusted by a K_c of 0.79. Aronson et al. (1987) also utilized lysimeters and the modified Penman equation to assess ET_a and ET_o, respectively, under non-limiting soil moisture. A K_c of 1.0 was recommended for a mixed stand of Kentucky bluegrass (*Poa pratensis*), perennial ryegrass (*Lolium perenne*), chewings red fescue (*Festuca rubra*) and hard fescue (*Festuca ovina* var. *duriuscula* (L.) Koch, 'Tournament').

As quality never fell below the minimum acceptable level in 2003 or 2004, Mid-Atlantic irrigation may be decreased by 45% if climate is similar to the mild climate present during the two-year study. An irrigation interval of once a week may be more applicable for tall fescue home lawns, rather than the five day interval employed in 2003. Irrigation interval ranged from every seven to 10 days in 2004. This schedule did not allow quality to fall below the minimum preset quality level. Due to the below 30-year average temperatures in the 2004 summer months (Appendix A), a conservative recommendation for a K_c of 0.70 would be suitable for an irrigation interval of once a week.. Also, if irrigation is applied every five days, irrigation can be reduced by 45%. Further analyzed physiological measurements will supplement these recommendations.

Soil Moisture

In 2003, soil moisture differences were detected among sampling months and interactive effects were significant between PGS treatment and irrigation level (Table 4.1). Surface soil moisture declined as the study continued throughout the summer of 2003 as lowest soil moisture measurements were recorded in September, independent of PGS treatment and irrigation level (Table 4.3). Quality and wilt were positively correlated with soil moisture level (r=0.53) (Table 4.4). As surface soil moisture decreased over time, quality decreased and wilt severity increased. Due to the frequent irrigation events in 2003, differences were not detected between irrigation levels or PGS treatments. Although an interaction between irrigation and PGS treatment was detected, large separation of means were not apparent (Table 4.1). The GB 85% and control 100% were equal to all treatments other than control 55% and the GB 100%, SWE + HA 100% and control 100% were equal to all PGS treatments at the 55% level (Table 4.7). There is a possibility that hydraulic lift occurred for the deficit irrigated tall fescue plants, which resulted in equal surface soil moisture readings. Water could have followed the water potential gradiant in to the roots from the higher water potential deep soil into the lower water potential roots. The water would then betranslocated to the surface roots and followed the water potential gradiant to the dry surface soil during the night time, when ET demand was low (Kramer and Boyer, 1995). Therefore, conclusions concerning PGS treatment allowing irrigation to be reduced further can not be assessed based on these data.

Differences in surface soil moisture due to irrigation level were detected in 2004 (Table 4.2). Soil moisture was lower for the 70% ET_o level compared to the 100% level but was equal to the 85% and 55% levels (Tables 4.8). Unlike quality and wilt ratings, surface soil moisture was highest in August of 2004 (Table 4.15). This difference may represent the ongoing stress in August and the plants' inability to utilize available soil moisture perhaps because stomates are closed. Ervin and Koski (1998) did not detect differences in gravimetric soil moisture content at the 0-30 cm depth for deficit irrigated tall fescue; however, differences were detected when measured at deeper soil depths. The deep root systems of tall fescue are capable of mining water from lower soil depths. If soil moisture was measured beyond the 7.6 cm depth in this study, it is hypothesized that differences would probably be detected between irrigation levels in both study years.

Photochemical Efficiency

Differences in photochemical efficiency were detected between 2003 and 2004 monthly samplings and between the PGS treatments in 2004 (Tables 4.1 and 4.2). Unlike quality, wilt and soil moisture measurements, photochemical efficiency was highest in September of 2003 and lowest during August (Table 4.3). Temperature and solar radiation were lowest in September and highest in August of 2003. September average temperature was 17˚C and average solar radiation was 190 W m^{-2}, while average temperature in August was 23˚C and average solar radiation was 217 W m^{-2}. Stress relating to evaporative demand was not as high in September (Appendix A). Solar radiation is the driving force of evapotranspiration and is a function of seasonal climate, including air temperature (Kneebone et al., 1992).

Similar to 2003, 2004 PE was highest in September, again when summer stress was least (Table 4.5). September 2004 average temperature was 18˚C with solar radiation of 177 W m^{-2}, while July average temperature was 22˚C with solar radiation at 212 W m^{-2}. August temperature and solar radiation was in between July and September readings at 20˚C and 197 W m^{-2}, respectively (Appendix A). Control tall fescue plots were measured to have a 6% higher PE than the GB treated turfgrass in 2004 (data not shown). These findings do not agree with several researchers who have studied GB application on field crops. Net photosynthesis increases were measured in salt stressed and unstressed GB treated tomatoes (*Lycopersucon esculentum* Mill.) (Makela et al., 1998b). Also, drought stressed soybean (*Glycine max* L. Merrill) improved photosynthesis activity upon GB application (Agboma et al., 1997b). A 22% cotton yield increase when treated with GB was explained as GB increasing water use efficiency or photosynthetic efficiency (Naidu et al., 1998).

ΔT

Differences in canopy and air temperatures (ΔT) were only calculated in 2004, with sampling month and PGS treatment by irrigation effects being significant (Table 4.2). Temperature difference was constant from July to August but increased in September, meaning canopy temperature increased in relation to air temperature, an indirect measure of increasing stress (Table 4.5). As soil moisture decreased, ΔT increased, which correlated with a decrease in quality and increase of wilt severity (Table 4.6). All GB treated plots at the varying deficit irrigation levels maintained equal canopy temperature while control 70% was greatest compared to all other control plots (Table 4.9). No differences were detected between control and GB treated turfgrass at any of the deficit irrigation levels. Bonos and Murphy (1999) found ΔT measurements to be a reliable indicator of water stress for Kentucky bluegrass grown in New Jersey. Agboma et al. (1997b) found exogenous GB application on soybeans to have an anti-transpirant effect, which allowed the plant to conserve water and maintain physiological function for a longer time period when in drought conditions. This anti-transpirant effect would result in increased canopy temperatures, thus higher ΔT. Although, there is very little evidence that differences are due to PGS treatments, independent of irrigation level, average GB ΔT was 0.6ºC higher than average control ΔT . There were no differences between GB irrigation treatments, while the control 100% have lower ΔT than the control 70%

treatment. This may indicate an anti-transpirant effect for the GB treatment. Breeders are interested in turfgrasses that have low ET rates and yet can maintain quality (Carrow and Duncan, 2003). Continued research should explore the possibility of GB having anti-transpirant effects on turfgrass and methods of implementation to improve drought resistance.

Root Morphology

Tall fescue root length density, root surface area and root dry weight, were unaffected in 2003 and 2004 by PGS treatment and deficit irrigation levels (Tables 4.1 and 4.2). Huang and Gao (2000) measured a decline in tall fescue root length and an increase in root mortality at 0-20 cm root depth due to drought, measurements were taken after a 35 day dry down period. Such severe drought stress was not imposed in this study. Ervin and Koski (1998) found that only when irrigation was reduced to 20% ET_o, utilizing alfalfa as the reference crop, differences were evident in tall fescue root dry weight at 0-30 cm depth. Root dry weight was reduced for 65% and 55% ET_o irrigated tall fescue at the 31-60 and 60-90 cm depths. This effect is a result of decreased available soil moisture, especially at the deeper depths. When irrigation decreased to the 20% ET_o, differences were evident in the more shallow rooting depths as soil moisture was not only limiting in the deeper depths, but also in the shallow soil. In this study, the sand rootzone was 31 cm deep, therefore root samples could not be sampled at the depths in which Ervin and Koski (1998) sampled. Differences were not detected, as water was most likely not limiting to such an extent to negatively affect root growth.

Antioxidant Activity

Ascorbate peroxidase and CAT antioxidants were unaffected by PGS treatment and deficit irrigation in both years (Tables 4.1 and 4.2). Sampling month effects were detected for both antioxidants in both years. In 2003 and 2004, APX activity was highest in September, while it was lowest in July of 2003 and equal in July and August of 2004 (Tables 4.3 and 4.5). Catalase activity increased in August from July and maintained its high level in September of both years (Table 4.3 and 4.5).

Superoxide dismutase activity was affected by irrigation and sampling month main effects and PGS treatment by irrigation by sampling month interaction in 2003 and sampling month was significant in 2004 (Tables 4.1 and 4.2). In agreement with Jiang and Huang (2001), SOD peaked upon initial stress in July of 2004 and declined over time (Table 4.5). Plant growth stimulant and irrigation effects were only detected in July and not in August or September of 2003 (Table 4.10). In July, the GB 55% treatment SOD activity was greater than any other GB treatment, which could be an indication of stress. The GB 55% activity was equal to all SWE + HA treatments and all control treatments except the 85% ET_o level. Activity increased from July to September for select treatments like SWE + HA 100%, 70%, and control 85%. The GB 100% SOD activity was lower than both SWE + HA 100% and control 100%. When irrigation was reduced by 30% and GB was applied, SOD activity was equal to that of GB 100% treated tall fescue in July. If tall fescue is treated with GB, irrigation can be reduced by 30% without causing stress. Once summer heat stress is imposed, SOD activity increases independent of irrigation or PGS treatments as means of protection.

An increase in antioxidant activity is typically a defense mechanism when stress is severe as means to scavenge destructive active oxygen species (Smirnoff, 1993). Unlike what was measured in this study, Zhang and Schmidt (1999b) measured an increase in SOD activity when two week old Kentucky bluegrass seedlings were treated with SWE + HA, which provided defense mechanisms for the plants to withstand low soil moisture. The turfgrass in this study was seeded two months prior to treatment. The younger plants in Zhang and Schmidt's (1999b) study may have been more sensitive to imposed drought stress and SWE + HA application. Ervin and Koski (1998) reported that tall fescue avoids drought better than Kentucky bluegrass due to its deeper root system. Applying SWE + HA on tall fescue in this study did not have the effect that Zhang and Schmidt (1999b) measured with Kentucky bluegrass as stress was not as severe for the tall fescue.

Cytokinin Content

Cytokinin content varied with sampling month in both 2003 and 2004 (Tables 4.1 and 4.2). While PGS treatment by irrigation by month interactive effect was significant in 2004, means separation did not offer any valuable information concerning defense mechanisms in deficit irrigation conditions. In 2003, cytokinin content was lower in August than in September and in 2004 cytokinin content was greatest in July (Table 4.3). Cytokinin content decreases in drought stressed plants and affects stomatal aperture on a short-term basis (Nilsen and Orcutt, 1996).

Cytokinin content measured in tall fescue ranged from 17.09 to 58.13 ng g^{-1} FW in 2003 and 1.74 to 135.32 ng g^{-1} FW of zeatin riboside in 2004 (Tables 4.3 and 4.5). Cytokinin levels in 2003 and September of 2004 were similar to levels measured in previous studies (Tables 4.3 and 4.5). Zhang and Ervin (2004) measured a maximum of 28.9 ng g^{-1} DW in bentgrass, while a cytokinin overproducing tobacco mutant contained 73.2 ng g^{-1} FW (Szekacs et al., 2000), and Nikolaou et al. (2003) measured 2.75 to 87.72 ng g^{-1} DW of zeatin riboside in grapevines. However, Kudoyarova et al. (1998) measured a maximum of 149 ng g^{-1} FW of zeatin riboside in wheat shoots prior to root cooling. This level was similar to the highest zeatin riboside content measured in tall fescue prior to water stress in 2004 (135.32 ng g^{-1} FW).

Table 4.1 Analysis of variance of 2003 tall fescue response variables when treated with plant growth stimulants and subjected to deficit irrigation.

	Quality	Wilt	Soil moist.	PE	Root length density	Root surface area *p*-value	Root dry weight	APX	CAT	SOD	CK
PGS treatment	0.9321	0.7059	0.2331	0.8284	0.8073	0.6747	0.8497	0.1785	0.6615	0.7336	0.9336
Irrigation	0.9692	0.3657	0.2732	0.9238	0.2966	0.5001	0.8102	0.4820	0.9907	0.0541	0.1785
Month	<.0001	<.0001	<.0001	<.0001	NA	NA	NA	<.0001	0.0116	<.0001	0.0838
Rep	0.0029	<.0001	<.0001	0.1583	0.2642	0.1189	0.0829	0.5926	0.7581	0.7782	0.6718
PGS x irrigation	0.6081	0.9182	0.0269	0.7336	0.1015	0.1095	0.6355	0.2870	0.7314	0.7004	0.6257
PGS x rep	0.6954	0.5735	0.0431	0.4141	NA	NA	NA	0.4015	0.6213	0.5863	0.4075
PGS x month	0.8175	0.7604	0.8867	0.6796	0.8475	0.5287	0.3546	0.4735	0.5758	0.9454	0.7109
Irrigation x rep	0.9285	0.3516	0.4878	0.9692	NA	NA	NA	0.1207	0.3322	0.5167	0.9298
Irrigation x month	0.9490	0.5735	0.9702	0.1853	0.1094	0.1052	0.0126	0.6388	0.2801	0.6933	0.6333
PGS treatment x irrigation x month	0.3698	0.8923	0.9658	0.8222	NA	NA	NA	0.1059	0.0912	0.0547	0.2021

Table 4.2 Analysis of variance of 2004 tall fescue response variables when treated with plant growth stimulants and subjected to deficit irrigation.

	Quality	Wilt	Soil moist.	PE	$T_c - T_a$	Root length density	Root surface area	Root dry weight	APX	CAT	SOD	CK
						p-value						
PGS treatment	0.7871	0.3722	0.7541	0.0743	0.2833	0.9746	0.5281	0.5213	0.6730	0.4970	0.8549	0.4071
Irrigation	0.0225	0.1034	0.0708	0.5281	0.4023	0.6222	0.5621	0.8298	0.8002	0.4334	0.1713	0.2229
Month	<.0001	<.0001	<.0001	<.0001	<.0001	NA	NA	NA	<.0001	0.0266	<.0001	<.0001
Rep	0.9469	0.0068	0.5241	0.0105	0.1074	0.5582	0.0995	0.2645	0.8520	0.4151	0.1800	0.6643
PGS x irrigation	0.1240	0.1801	0.6068	0.1100	0.0256	0.6388	0.2542	0.4149	0.6504	0.3901	0.5735	0.1026
PGS x rep	0.1383	0.5325	0.4538	0.0183	0.1697	NA	NA	NA	0.8659	0.7327	0.2356	0.7427
PGS x month	0.7230	0.8175	0.5536	0.4062	0.6223	0.2812	0.2830	0.2601	0.8499	0.4261	0.4949	0.6882
Irrigation x rep	0.0564	0.0118	0.2334	0.1653	0.0935	NA	NA	NA	0.0021	0.5261	0.4790	0.6904
Irrigation x month	0.4817	0.6818	0.8775	0.8950	0.5863	0.5467	0.0959	0.2221	0.8785	0.7837	0.3329	0.4063
PGS treatment x irrigation x month	0.8745	0.9823	0.9744	0.6575	0.8121	NA	NA	NA	0.9613	0.5257	0.1973	0.0773

Table 4.3. Tall fescue monthly effects in 2003 when subjected to plant growth stimulants and deficit irrigation.

Month					Antioxidants (units g^{-1} FW)			
	Quality †	Wilt	Soil Moisture (%)	PE§	APX	CAT	SOD	Cytokinin (ng g^{-1} FW)
July	7.7 a‡	9.0 a	7.2 a	0.64 b	167 c	12850 b	1439 b	56.47 ab
August	7.4 a	7.5 b	6.2 a	0.52 c	567 b	19445 a	4638 a	17.09 b
September	6.6 b	7.3 c	3.2 b	0.73 a	739 a	19458 a	5231 a	58.13 a

† Quality and wilt ratings were made on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable quality level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.
§ PE = photochemical efficiency, APX = ascorbate peroxidase, CAT = catalase, SOD = superoxide dismutase, FW = fresh weight.

Table 4.4. Tall fescue 2003 correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Quality & wilt	<.0001	0.41
Quality & soil moisture	<.0001	0.53
Wilt & soil moisture	<.0001	0.63

α=0.05

Table 4.5. Tall fescue monthly effects in 2004.

Month						Antioxidants (units g^{-1} FW)			
	Quality †	Wilt	Soil Moisture (%)	PE	ΔT (˚C)	APX	CAT	SOD	Cytokinin (ng g^{-1} FW)
July	7.3 a	7.3 a	2.9 b	0.58 c	7.7 b	393 b	10602 b	1098 a	135.32 a
August	6.1 c	6.0 c	7.0 a	0.66 b	8.2 b	290 b	15377 a	386 b	1.74 b
September	6.8 b	6.8 b	3.3 b	0.76 a	11.2 a	749 a	15138 a	161 c	12.20 b

† Quality and wilt ratings were made on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable quality level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.
§ PE = photochemical efficiency, ΔT = difference between canopy and air temperature, APX = ascorbate peroxidase, CAT = catalase, SOD = superoxide dismutase, FW = fresh weight

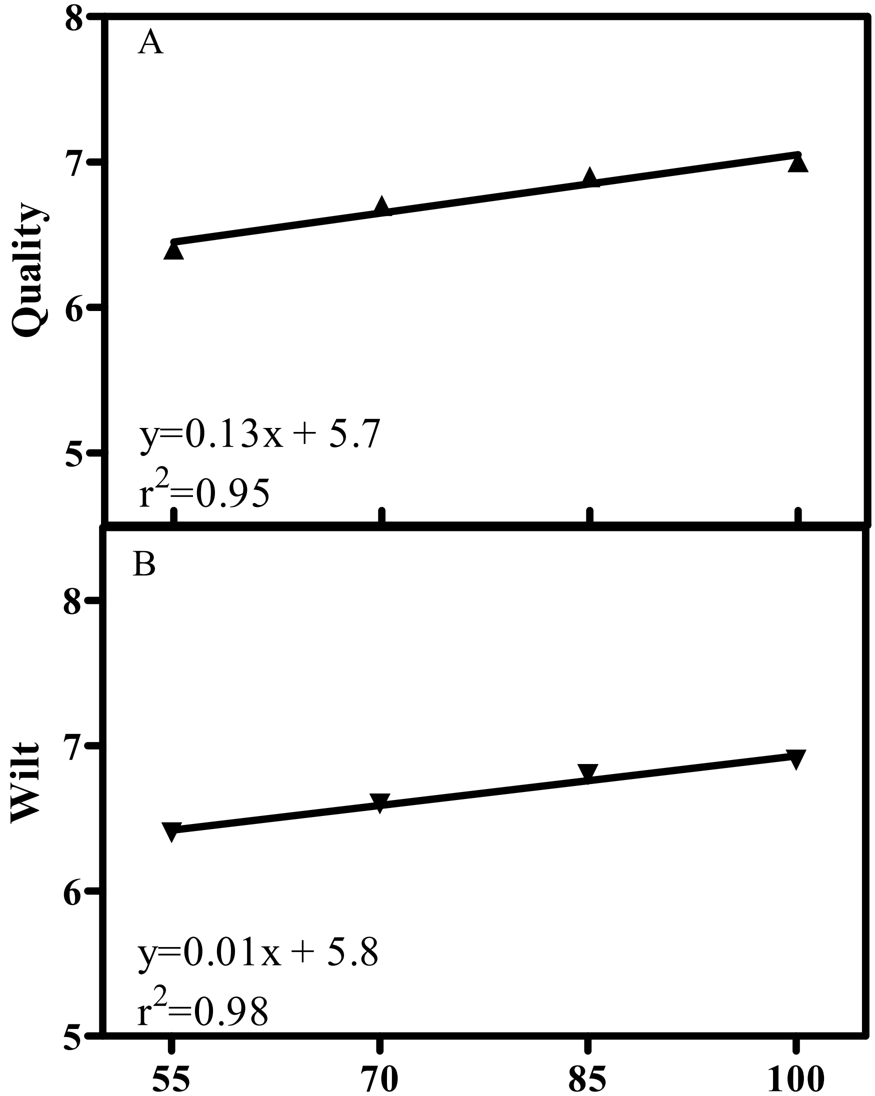
Table 4.6. Tall fescue 2004 correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Quality & wilt	<.0001	0.82
Quality & ΔT †	<.0001	-0.40
Wilt & ΔT	0.0009	-0.33
Soil moisture & ΔT	0.0003	-0.36

α=0.05
† ΔT = difference between canopy and air temperature

.

Fig. 4.1. Tall fescue 2004 overall quality (A) and wilt (B) subjected to



linear regression. Quality and wilt is based on the 1 to 9 scale where 1=dead and 9=best, most turgid leaf. Minimum acceptable quality was preset at 6.0

Table 4.7. Tall fescue 2003 plant growth stimulant (PGS) treatment and irrigation interaction for soil moisture at the 0-7.6 cm depth.

PGS treatment and Irrigation	Soil moisture (%)	
	Tall fescue	
SWE + HA‡ 100%	5.3	ab†
SWE + HA 85%	5.0	ab
SWE + HA 70%	4.9	ab
SWE + HA 55%	5.1	ab
GB 100%	4.8	ab
GB 85%	6.6	a
GB 70%	6.1	ab
GB 55%	5.1	ab
Control 100%	6.6	a
Control 85%	5.1	ab
Control 70%	5.4	ab
Control 55%	4.6	b

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine

Table 4.8. Tall fescue irrigation effect on soil moisture at the 0-7.6 cm depth in 2004 averaged over all sample dates.

Irrigation	Soil moisture (%)	
100%	5.1	a
85%	4.7	ab
70%	3.5	b
55%	4.3	ab

‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.

Table 4.9. Tall Fescue 2004 plant growth stimulant (PGS) treatment and irrigation interaction effect on canopy-air temperature (T_c-T_a)

PGS treatment and Irrigation	T_c-T_a (˚C) Tall fescue	
GB 100%‡	9.3	abc†
GB 85%	9.3	abc
GB 70%	8.5	abc
GB 55%	10.4	ab
Control 100%	7.7	c
Control 85%	8.1	cb
Control 70%	10.9	a
Control 55%	8.3	bc

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ GB = glycinebetaine

Table 4.10. Tall Fescue plant growth stimulant (PGS) treatment and irrigation interaction for July 2003 superoxide dismutase (SOD) antioxidant activity

PGS treatment and Irrigation	SOD activity (units g^{-1} FW)					
	July		August		September	
SWE + HA §100%	2280	ab† B‡	3246	a AB	7612	a A
SWE + HA 85%	1497	abcd B	5458	a A	3743	a AB
SWE + HA 70%	2014	abc B	4169	a B	7294	a A
SWE + HA 55%	2371	a A	5763	a A	4291	a A
GB 100%	794	d B	4846	a B	9708	a A
GB 85%	748	d A	3352	a A	2166	a A
GB 70%	961	cd A	4555	a A	4466	a A
GB 55%	2487	a A	5546	a A	5594	a A
Control 100%	2183	ab A	7806	a A	4051	a A
Control 85%	1192	bcd B	2584	a AB	6002	a A
Control 70%	1613	abcd A	4290	a A	4624	a A
Control 55%	1532	abcd A	4123	a A	5237	a A

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ Means followed by the same letter within the row are not significantly different based on LSD at α=0.1.
§ SWE + HA = seaweed extract + humic acid; GB = glycinebetaine

Results and Discussion

Creeping Bentgrass

Quality and Wilt

In 2003, PGS treatment, irrigation, and month main effects and PGS treatment by irrigation and PGS treatment by month interaction effects were significant (Table 4.11). In 2004, irrigation and month main effects and PGS treatment by irrigation interaction effect were significant (Table 4.12). The difference in irrigation scheduling methods between 2003 and 2004 did affect quality as seen in Fig. 4.2A. In 2003, the 100% irrigation level resulted in the lowest quality rating, while it was greater than the 70% and 55% irrigation levels in 2004. The three-day irrigation interval was too frequent at the 100% ET level in 2003. However, basing irrigation on wilt events, as done in 2004, proved to be more discerning in separating irrigation level effects at the lower ET levels. When irrigating as often as every three days applying 100% ET may in fact be too much, as seen in the decreased quality compared to the deficit irrigation levels.

Irrigation can be reduced by 45% without negatively affecting turfgrass quality when applied every three days as quality never fell below the minimum acceptable quality level of six. When irrigation was based on wilt, quality averaged over the three months was below the minimum acceptable level even when irrigated at the 100% ET level indicating that the interval between irrigation events in 2004 was too wide (Fig. 4.2A). In July and August the average irrigation interval was five days, but the average September irrigation interval was 14.5 days due to the mild weather (Appendix B.3). Despite the fact that linear regression was significant for quality in 2004, analyzing data with regression did not allow for determining the appropriate K_c based on quality. More physiological measurements must be analyzed before confirming an appropriate K_c and irrigation timing for creeping bentgrass fairways. DaCosta and Huang (2004) found creeping bentgrass did not meet minimum quality when irrigated below 60% ET three times a week.

The SWE + HA PGS treated creeping bentgrass was rated the lowest in quality, while the GB and control were equal in 2003 (Table 4.13). In 2004 the SWE + HA treatment was eliminated but the GB and control were again rated as equivalent.

Therefore, foliar application of GB did not improve turfgrass quality ratings independent of irrigation interval and level. While no previous research has been conducted for GB application on turfgrass, these results do not coincide with previous research with field crops. Agboma et al. (1997b) recorded increased photosynthetic activity and leaf area of water stressed soybeans upon exogenous application of 3 kg ha^{-1} of GB. Similarly, increased tobacco (*Nictoanan tabacum* L.) leaf fresh weights resulted after treatment with 0.3M GB when the plants were drought stressed (Agboma et al., 1997a).

Although no differences were detected between PGS treatments at each sampling month in 2003, there was a trend of decreasing quality from July to September for each PGS treatment (Table 4.13). Unlike the SWE + HA and control plots, quality did not differ for GB treated plants from August to September. In 2003, only the SWE + HA 100% plots were rated below the minimum acceptable level of 6.0 (Table 4.14). In 2004, GB 85% and control 100% were the only plots that were rated above 6.0. The GB 85% treatment however was not significantly different from the other GB treatments. The control 100% was rated higher than all other control treatments.

In both years, quality declined from July to September although, in 2003 quality never fell below the minimum acceptable level and in 2004 quality fell below 6.0 after July (Tables 4.15 and 4.16). Quality declined by 8% from July to September in 2003 and by 42% in 2004. As turfgrass was established in April of 2003, turf was not stressed upon the start of the study in July. In July of 2004, when the second year of the study began, quality was much lower than July 2003 ratings. This difference may be explained by the stresses imposed in 2003 and the lack of time and suitable weather conditions to produce as good of a stand in 2004. The greater decline of quality from July to September in 2004 versus 2003 could be explained by the more severe water limiting conditions imposed during 2004 as irrigation occurred upon wilt.

Plant growth stimulant and month main effects were significant in 2003 for wilt, while irrigation and month main effects and PGS treatment by irrigation effects were significant in 2004 (Tables 4.11 and 4.12). Both 2003 and 2004 wilt ratings increased in severity from July to August to September (Tables 4.15 and 4.16). In 2003 wilt severity increased by 36% from July to September while in 2004 wilt severity increased by 44%. Again, the increase in wilt severity in 2004 versus 2003 is a result of the differing irrigation schedules. Irrigation level did not affect wilt ratings in 2003 but in 2004 the 55% irrigation level resulted in more severe wilt than the 100% level (Fig. 4.2B). A trend of decreasing quality over the course of the experiment was correlated with increasing wilt severity for both 2003 (r=0.60) and 2004 (r=0.84) (Tables 4.17 and 4.18).

Similar to quality, increased wilt on the SWE + HA plots was observed relative to the GB plots in 2003 (Table 4.19). With regression, it was determined that wilt severity was least for GB when irrigated at 87% ET_o and for control at 100% (Fig 4.3). This shows the osmoregulator properties of GB as turgor was maintained at deficit irrigation levels. Bentgrass control 100% resulted in less wilt severity than the control 55% treatment in 2004, while the GB 100% and GB 55% treatments did not differ in wilt severity (Fig. 4.3). The lack of SWE + HA treatment effects did not coincide with previous research conducted at Virginia Tech with creeping bentgrass. Creeping bentgrass quality was maintained above that of the control when water was withheld for a minimum of 10 days (Zhang and Ervin, 2004). Zhang and Ervin's study measured one dry down cycle while the author's field study consisted of several dry down events with an irrigation interval that did not exceed 10 days.

Soil Moisture

Analysis of variance for creeping bentgrass surface soil moisture showed that PGS treatment, irrigation and sampling month and PGS treatment by irrigation effect were significant in 2003, while only irrigation and sampling month effects were significant in 2004 (Tables 4.11 and 4.12). In 2003, surface soil moisture was higher in the 70% ET_o level plots than the 100% level but the opposite was true in 2004 (Fig. 4.4). It is speculated that hydraulic lift occurred in the 85% and 70% ET_o level plots. During the night when transpirational demand was least, water was absorbed by deeper roots and transported to the upper roots and then released to the surrounding drier surface soil (Kramer and Boyer, 1995). Water moved to the upper soil layers is then used the next day to facilitate transpiration (Caldwell et al., 1998).

Irrigation scheduling differences are apparent in Table 4.15 and 4.16 when comparing soil moisture between the two years. In 2003, surface soil moisture was at its highest in July at 5.5%, compared to 2.1% in 2004. However, surface soil moisture was depleted from July to September as the study continued in both years. Also detected in both years was a positive correlation between wilt severity and surface soil moisture depletion (r=0.52 and r=0.70) (Tables 4.17 and 4.18). Only in 2004 was quality and surface soil moisture directly correlated (r=0.51) where quality declined with declining surface soil moisture content.

In 2003 the GB and control treated plots maintained higher soil moisture at the 0-7.6 cm depth compared to the SWE + HA (data not shown). This similar trend is apparent in the PGS treatment by irrigation interaction in 2003 when all the SWE + HA treatments except at the 70% irrigation level were recorded to have less soil moisture than the control 85% (Table 4.20). Unlike the data shown in Table 4.20 where the 70% ET level treated plots maintained more soil moisture than the 100% level, the control 85% maintained more surface soil moisture than the control 100%. Surface soil moisture content was consistent throughout all GB treatments.

It is apparent that measuring soil moisture at the 0-7.6 cm depth does not give the whole picture, as much moisture is likely stored at deeper depths. Soil moisture should be measured at various rooting depths to determine soil moisture distribution. Ervin (1995) utilized a hydraulic soil probe to measure gravimetric soil moisture at 0-30.5 cm, 30.5-61 cm, and 61-91.5 cm depths. Ideally, time domain reflectometry probes would need to be installed in every plot to measure volumetric soil moisture over the course of the study. Installing such an extensive system of soil moisture sensors was beyond the means available in this study.

Photochemical Efficiency

Sampling month main effect for PE was significant in 2003, while irrigation level and sampling month main effects were significant in 2004 (Tables 4.11 and 4.12). In both 2003 and 2004 PE was highest in September, which could be attributed to the decreased air temperature and end of the summer heat stress (Tables 4.15 and 4.16). Similar results were measured in 2003 and 2004 for tall fescue (Tables 4..3 and 4.5). Again, the lower PE readings in 2004 versus 2003 could be explained as an effect of irrigation schedule and turfgrass stand. This is also present in Table 4.21 where PE was not affected at the deficit irrigation levels in 2003. However, in 2004 the 100% and 85%

ET_o level irrigated creeping bentgrass had higher PE readings than the 70% and 55% levels meaning the latter irrigation levels imposed stress conditions. Based on these data in 2004, a trend to recommend a K_c of 0.85 for creeping bentgrass fairways arises. As equal PE was measured for the 100% and 85% ET levels, stress did not differ if 15% water was withheld. Regression based on quality level could not be implemented to determine corresponding PE as all creeping bentgrass was rated below the minimum acceptable level in 2004.

The absence of detectable PGS treatment effects does not agree with previous research concerning SWE + HA and GB. Higher leaf chlorophyll concentrations were found in tomato 'Tiny Tim', dwarf French bean (*Phaseolus coccineus* 'Candadian Wonder'), wheat (*Triticum aestivum* L. 'Brigadier') and barley (*Hordeum vulgare* L. 'Chariot') when SWE was foliarly applied (Blunden et al., 1997). Photochemical efficiency was greater for SWE treated bentgrass, independent of fertility level (Schmidt and Zhang, 1997; Zhang and Schmidt, 1999a). When HA was applied without SWE, photosynthetic rate was consistently higher for creeping bentgrass grown hydroponically with HA added to the solution (Liu et al., 1998). Other researchers have proven that HA and SWE promote more plant response than either alone. Creeping bentgrass subjected to drought and treated with SWE + HA maintained higher PE than SWE and HA applied alone (Zhang and Ervin, 2004). Glycinebetaine treated beans 'Tendergreen' maintained lower chlorophyll flourescence when drought conditions were imposed (Xing and Rajashekar, 1999). Differences in net photosynthesis were detected when 0.1M GB was applied to tomatoes subjected to salt stresses (Makela et al., 1998b). It is thought that SWE + HA increases PE due to its antioxidant activity stimulation in stressed plants, while GB protects membranes, thus photosynthetic integrity, from dehydrative stresses (Zhang, 1997; Sakamoto and Murata, 2000).

It is speculated that applied SWE + HA did not affect photochemical efficiency in this study due to lack of stress. In 2003, the frequent irrigation events did not subject creeping bentgrass to sufficient water stress. Previous research, as mentioned above, have found that PGS like SWE and HA are most beneficial when a plant is subjected to environmental stresses, like drought. In 2004, when water stress was severe, the SWE + HA treatment was eliminated due to space constraints. Although GB can maintain turgor pressure in drought conditions, allowing more leaf surface area to be exposed for light absorption, its osmoregulatory property was not observed in this study. It is unknown how well exogenous GB application can affect turfgrass osmoregulation, as this is the first study to research the topic. The GB rate utilized in this study was within the range that previous researchers have used on field crops (Agboma et al., 1997c; Agboma et al., 1997b; Makela et al., 1998b; Makela et al., 1998a; Xing and Rajashekar, 1999). Perhaps a higher rate would be needed for turfgrass to truly benefit from GB's properties. Further research is needed to determine what GB rate is appropriate for turfgrass culture and if rates need to be altered depending on stress level, as done when in field crops depending on reproductive stage.

ΔT

Differences in canopy minus air temperatures proved to be an accurate measurement of turfgrass stress as PGS treatment, irrigation and sampling month effects were significant in 2004 (Table 4.12). As expected, ΔT increased from July to September (Table 4.16), which was correlated with decreasing quality (r= -0.58), increasing wilt severity (r= -0.73), and decreasing soil moisture (r= -0.70) (Table 4.18). Ervin and Koski (1998) also measured a negative correlation between ΔT and leaf wilt severity of tall fescue and Kentucky bluegrass. The 100% and 85% ET_o level treated creeping bentgrass maintained lower ΔT than the 70% and 55% levels in 2004 (Table 4.22). Feldhake et al. (1984) determined that Kentucky bluegrass canopy temperature increased 1.7˚C with every 10% reduction in ET_o irrigation level. This was not the case in our study as ΔT increased by 1˚C when irrigation was decreased by 15% to the 85% ET_o level. However, 3˚C separated the 85% and 70% ET_o irrigation levels.

Treating creeping bentgrass with GB resulted in lower ΔT measurements (Table 4.22). This measurement does not support GB having anti-transpirant effects but does support the claims that it allows plants to continue normal function in water limited conditions.

Results attained from ΔT measurements were similar to those from photochemcial efficiency in that the 85% ET_o level performed equally as well at the 100% level. The 85% ET level also provided higher PE and lower ΔT temperatures compared to the 70%

and 55% ET_o levels. Therefore, a K_c of 0.85 could further be suggested for Mid-Atlantic creeping bentgrass fairways.

Root Morphology

Unlike tall fescue, bentgrass root length density, root surface area and root dry weight were altered upon the application of PGS in 2003(Table 4.11). Glycinebetaine application increased root length density, root surface area and root dry weight compared to the SWE + HA and control treatments (Table 4.23). According to regression, maximum root length density would be attained when irrigating at 80% ET_o, while maximum root surface area and root dry weight would be attained when irrigating at 83% and 88% ET_o, respectively (Fig. 4.5).

Unlike 2003, morphology was not altered by PGS treatment or irrigation level in 2004 (Table 4.12). Quality and wilt were positively correlated with root length density, root surface area and root dry weight in 2004 (Table 4.18). As quality declined and wilt severity increased, root morphology measurements also declined, independent of PGS and irrigation treatments.

Creeping bentgrass root morphology measurements were consistently higher in 2004 than in 2003. It appears that the young root system in 2003 may have been more susceptible to PGS and irrigation treatments. These results suggest that GB may be effective in increasing rooting of newly seeded areas. Further research to validate these findings should be conducted as it may be a useful tool in creeping bentgrass establishment.

Similar to this study, no difference was measured in root weight between SWE + HA (1.5 kg ha^{-1} + 0.5 kg ha^{-1}) treated creeping bentgrass and the control when grown in drought conditions (Zhang and Ervin, 2004). Zhang (1997) measured increased root length and dry weight when creeping bentgrass was treated with SWE + HA (0.3 kg ha^{-1} + 5 L ha^{-1}) and subjected to low soil moisture. Liu et al. (1998) measured increased creeping bentgrass root mass when 400 mg L^{-1} of HA was added to hydroponic solution. The rate used in the latter study is 11 times what was used in this study and in Zhang and Ervin's (2004). It is postulated that HA either stimulates the production of endogenous indole-3-acetic acid (IAA), a type of auxin, or inhibits enzymes which remove IAA

(Cacco and Dell'Agnola, 1984; Muscolo et al., 1998). The auxins in the HA stimulated lateral and adventitious root growth at the higher concentrations (Taiz and Zeiger, 1998).

Glycinebetaine is translocated to all parts of the plant, including roots, where it protects membrane integrity. Makela et al. (1996) measured translocated [^{14}C]GB in turnip rape (*Brassica rapa* L. ssp. *oleifera*) roots two hours after foliar application. Glycinebetaine applied directly on roots increased survivability to chilling, another dehydrative stress, for *Zea mays* L (Chen et al., 2000). Monthly foliar application of GB on creeping bentgrass in this study may have helped maintain membrane integrity and allowed the roots to continue to grow despite the low soil moisture, while the SWE + HA and control creeping bentgrass plots did not.

Antioxidant Activity

Creeping bentgrass APX antioxidant activity analysis of variance showed that sampling month was significant in 2003 while irrigation level and sampling month were significant in 2004 (Tables 4.11 and 4.12). In 2003, APX activity was higher in September than July meaning that the plants were able to produce more defense enzymes in September in response to stress (Table 4.15). Soil moisture and APX were negatively correlated (-0.42) in 2003 (Table 4.17). As soil moisture declined, APX activity increased. Unlike 2003, APX activity in 2004 was higher in August than it was in September which may be attributed to the lack of environmental stress as several hurricanes caused mild temperatures and overcast skies in September (Table 4.16). Antioxidants were produced to protect the turfgrass plants from damaging active oxygen species during summer stress in August. An overall decline in antioxidant activity from 2003 to 2004 could be attributed to the hindered turfgrass health upon the start of the 2004 study season due to the stress imposed in 2003. Regression determined that maximum APX activity would be attained when irrigating at 90% ET_o (Fig. 4.6A). Upon the stress imposed on the deficit irrigated plots, deficit irrigated plots are capable of upregulating antioxidants to scavenge the active oxygen species as protection, while stress would be too severe for creeping bentgrass irrigated at 70% and 55% ET_o.

Catalase antioxidant activity is often not as responsive as APX and SOD (Smirnoff, 1993) as only sampling month was significant for 2003 and 2004 (Tables 4.11

and 4.12). Fu and Huang (2001) did not measure a difference in Kentucky bluegrass and tall fescue CAT activity under short term surface soil drying conditions while APX and SOD were affected.

Like APX, CAT activity was higher in September than July of 2003 and was higher in August than September of 2004 (Tables 4.15 and 4.16). The similar responses to stress and climatic conditions can be explained for CAT activity as were explained for APX activity.

Superoxide dismutase activity was affected by PGS treatment and sampling month main effects in 2003, while irrigation level and sampling month main effects and PGS treatment by sampling month interaction affected activity in 2004 (Tables 4.11 and 4.12). Like APX and CAT, SOD activity was higher in September than July of 2003 (Table 4.15). Soil moisture and SOD activity were negatively correlated (-0.34) in 2003; as soil moisture declined, SOD activity increased (Table 4.17). Higher SOD activity was measured in 2003 for GB treated creeping bentgrass compared to the SWE + HA treated turfgrass but was equal to the control (data not shown). Zhang et al. (2003a) measured higher SOD activity for SWE + HA treated creeping bentgrass compared to the control when grown in low fertility conditions.

In 2004, SOD activity was highest upon the start of the study in July and declined in August and September, unlike APX and CAT (Table 4.16). A similar occurrence was reported for wheat seedlings subjected to dehydrative conditions. Superoxide dismutase activity peaked prior to CAT activity upon onset of stress and then quickly declined (Niedzwiedz-Siegien et al., 2004). Fu and Huang (2001) measured an increase of SOD activity 25 days after surface soil drying conditions were imposed on Kentucky bluegrass and tall fescue. While climatic stress was less in September, the stress in August was severe and as a result several 55% ET_o level treated turfgrass died, which could account for the drastic decline of SOD activity from July to August. Only in July of 2004 were differences detected between irrigation levels (Table 4.23).

Regression determined that the maximum SOD activity was attained when a 81% ET_o irrigation level is employed. Increased activity an indication that the plant is upregulating antioxidant defense mechanisms to protect it from the potentially destructive nature of active oxygen species. Similar to APX measurements, the 70% and 55% ET_o

level treated turfgrass could not produce such defense mechanisms. The 100% ET_o level was not stressed, therefore defense mechanisms were not needed, as seen by the low antioxidant activity levels. When plants were subjected to deficit irrigation, photosynthetic electron transport capacity was limited, as seen in the decrease of photochemical efficiency (Table 4.21). The plants were exposed to an excessive amount of light energy, which resulted in an overabundance of active oxygen species (Smirnoff, 1993). Lower photochemical efficiency measurements for 70% and 55% deficit irrigated plots (Table 4.45) indicated that the combination of drought and light were responsible for the overproduction of active oxygen species. Under severe water deficit, like 70% and 55% ET_o, the scavenging capabilities of the plant are limited and active oxygen species are accumulated. Also, when a plant is not subjected to water deficit conditions, antioxidant activity is low as defense mechanisms are not needed, as seen in the 100% ET_o irrigation level.

Irrigating at the 70% and 55% ET_o levels in 2004 caused stomates to close to conserve water. The closure of stomates is shown in Table 4.22 as an increased ΔT for the 70% and 55% ET_o levels than the 85% and 100% levels. The closed stomates resulted in less CO_2 intake to fuel the photosynthetic pathway. As a result, photochemical efficiency was negatively affected (Table 4.21), which lead to an excess of light energy. The absorption of excessive light energy caused photoinhibition and the production of active oxygen species. Creeping bentgrass plants irrigated at a deficit irrigation level of 85% ET_o were capable of protecting the turfgrass from active oxygen species, while the turfgrass irrigated at the 70% and 55% ET_o levels could not. As a result, a K_c of 0.85 would be suitable for creeping bentgrass fairways.

No previous research has measured antioxidant activities when developing K_c. This research shows that by measuring more detailed physiological responses to deficit irrigation, researchers can base K_c on more than visual determination of health.

Cytokinin Content

In 2003 cytokinin content was unaffected by PGS application and deficit irrigation but in 2004 irrigation and sampling month by irrigation effects were significant in affecting cytokinin content (Tables 4.11 and 4.12). Like SOD activity, cytokinin content was highest in July when stress was present and declined in August and September in 2004 (Table 4.24). Cumulative stress was apparent, as cytokinin level was lower in August and September than July for all deficit irrigation treatments other than the 55% ET_o. In September, the summer stress was decreased as temperatures were cooler and evaporative demand decreased. This is seen in the lack of differences between deficit irrigation levels. In July and August of 2004, the 70% irrigation level cytokinin content was higher than the 100% and 85% levels. Hansen and Dorffling (2003) measured a similar spike in cytokinin content upon the initiation of sunflower (*Heliantus annuus* L.) drought stress. Similarly, Farhutdinov et al. (1998) measured a spike in wheat seedling cytokinin content when temperature was increased, followed by a sharp decline of cytokinin content to that of twice lower than the initial level as temperature stress continues. Cytokinins are responsible for opening stomates, while abscisic acid works to close stomates (Nilsen and Orcutt, 1996). The cytokinin peak shown for the 70% ET_o irrigated plots may indicate an attempt to protect the plant by opening stomates and cooling the turfgrass canopy. However, since ΔT was higher for 70% ET_o plots than the 85% and 100% ET_o irrigated plots, it was unsuccessful. Cytokinins influence stomatal conductance on the short-term basis and may be upregulated upon the initiation of stress as means of protecting by opening stomates.

This study did not detect cytokinin differences between PGS treatments in 2003 or 2004. Zhang and Ervin (2004) were the first to measure increased endogenous cytokinin levels upon the exogenous application of cytokinin-containing SWE + HA on creeping bentgrass. No studies have been conducted to measure cytokinin level of GB treated plants and this study did not show GB having an effect on cytokinin level.

Table 4.11. Analysis of variance of 2003 creeping bentgrass response variables when treated with plant growth stimulants and subjected to deficit irrigation.

	Quality	Wilt	Soil moist.	PE	Root length density	Root surface area *p*-value	Root dry weight	APX	CAT	SOD	CK
PGS treatment	0.0013	0.0404	0.0362	0.2070	0.0040	0.0038	0.0016	0.3557	0.7915	0.0387	0.3491
Irrigation	0.0006	0.2726	0.0720	0.6806	0.2275	0.3501	0.1084	0.4373	0.8529	0.4490	0.3211
Month	<.0001	<.0001	<.0001	<.0001	NA	NA	NA	0.0430	<.0001	<.0001	0.1851
Rep	<.0001	<.0001	<.0001	<.0001	0.0103	0.2359	0.0004	.06086	0.1775	0.0172	0.4458
PGS x irrigation	0.0290	0.7276	0.0434	0.5466	0.7343	0.4093	0.6731	0.3182	0.6351	0.1840	0.2639
PGS x rep	<.0001	0.0637	0.2057	0.9482	NA	NA	NA	0.3775	0.3291	0.0626	0.8710
PGS x month	0.0260	0.4115	0.6572	0.1125	0.4482	0.0438	0.0828	0.4022	0.5934	0.2929	0.2267
Irrigation x rep	0.0234	0.7038	0.0057	0.5605	NA	NA	NA	0.2721	0.4122	0.3346	0.8710
Irrigation x month	0.5575	0.8205	0.1483	0.8124	0.2129	0.0946	0.0074	0.2466	0.6547	0.8342	0.7023
PGS treatment x irrigation x month	0.9581	0.9423	0.9993	0.2980	NA	NA	NA	0.6205	0.0337	0.1913	0.9002

Table 4.12. Analysis of variance of 2003 creeping bentgrass response variables when treated with plant growth stimulants and subjected to deficit irrigation.

	Quality	Wilt	Soil moist.	PE	T_c - T_a	Root length density	Root surface area	Root dry weight	APX	CAT	SOD	CK
						p-value						
PGS treatment	0.7825	0.4639	0.6337	0.6596	0.0358	0.2898	0.2673	0.2363	0.2231	0.3216	0.2027	0.4326
Irrigation	0.0073	0.0098	0.0549	0.0175	< .0001	0.1571	0.2314	0.3173	0.0143	0.7775	0.0118	0.1134
Month	<.0001	<.0001	<.0001	0.0003	< .0001	NA	NA	NA	0.0027	<.0001	<.0001	0.0098
Rep	<.0001	<.0001	0.9366	0.0366	0.0207	0.0010	0.0025	0.0028	0.9207	0.3010	0.2477	0.6638
PGS x irrigation	0.0184	0.1004	0.5947	0.4374	0.1842	0.2578	0.3314	0.3647	0.9705	0.5867	0.6213	0.8324
PGS x rep	0.4787	0.5370	0.3045	0.7499	0.1879	NA	NA	NA	0.9207	0.3215	0.8673	0.2923
PGS x month	0.9243	0.8859	0.7690	0.8247	0.8345	0.6380	0.6052	0.5985	0.4527	0.3229	0.0414	0.6105
Irrigation x rep	0.1511	0.0928	0.6611	0.1032	0.0002	NA	NA	NA	0.6529	0.2443	0.7280	0.6758
Irrigation x month	0.2914	0.2485	0.9325	0.4566	0.1237	0.6263	0.5736	0.4698	0.7076	0.2568	0.0027	0.0684
PGS treatment x irrigation x month	0.1428	0.1709	0.8115	0.5482	0.3115	NA	NA	NA	0.8736	0.4933	0.5110	0.9546

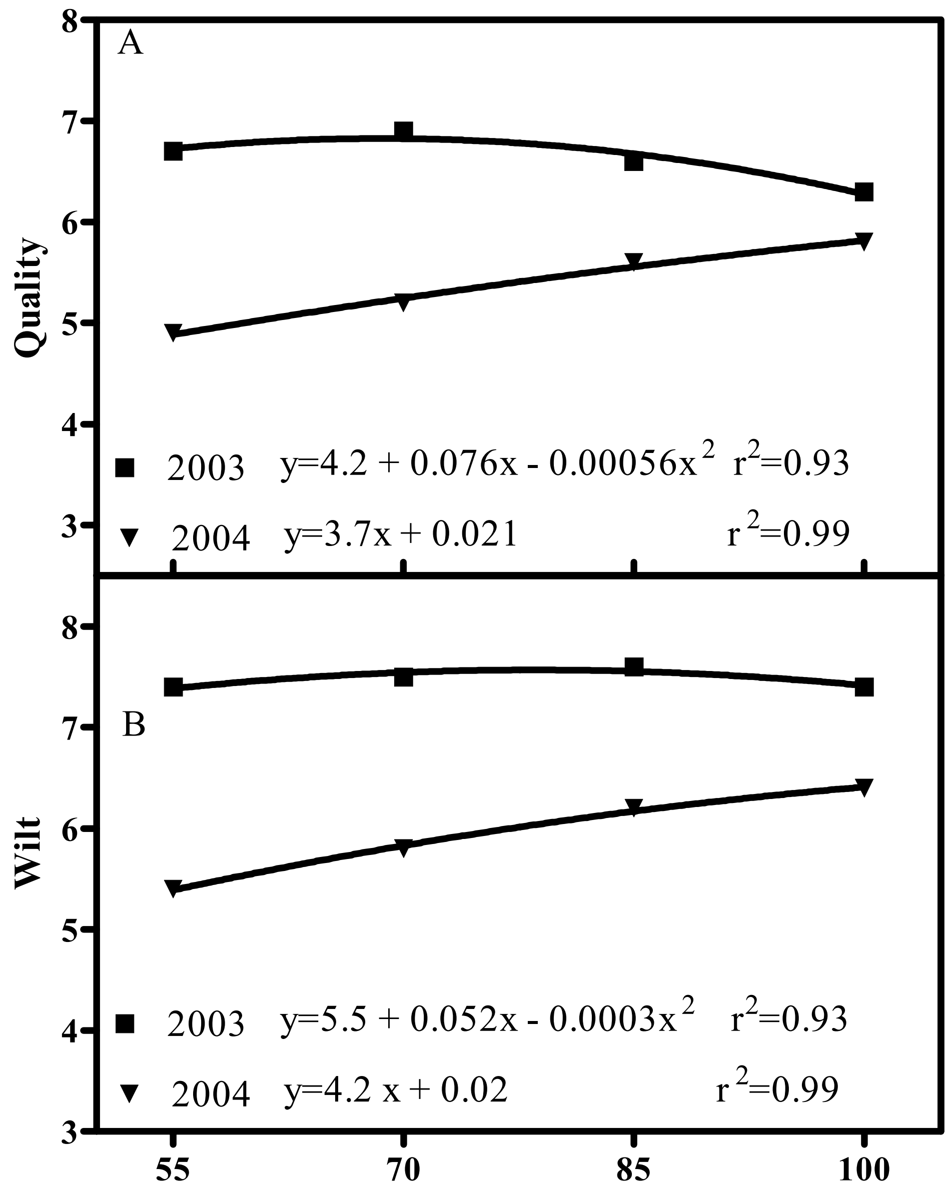


Fig. 4.2 Deficit irrigation treatment effect on creeping bentgrass quality (A) and wilt (B) in 2003 and 2004. Data was subjected to second order polynomial and linear regression for the 2003 and 2004 years, respectively. Quality was based on the 1 to 9 scale where 1=dead and 9=best, most turgid leaves. Minimum acceptable quality level was preset at 6.0.

Table 4.13. Creeping bentgrass quality plant growth stimulant (PGS) treatment and month interaction in 2003.

PGS treatment	Quality † 2003		
	July	August	September
SWE + HA¶	8.5 a‡	7.7 a	7.3 a
	A§	B	C
GB	8.5 a	7.5 a	7.3 a
	A	B	B
Control	8.5 a	7.6 a	7.2 a
	A	B	C

† Quality ratings were made on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable level is 6.0.

‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.

§ Means followed by the same letter within the row are not significantly different based on LSD at α=0.05.

¶ SWE + HA = seaweed + humic acid, GB = glycinebetaine.

Table 4.14. Creeping bentgrass quality plant growth stimulant (PGS) and irrigation interaction in 2003 and 2004

PGS treatment and Irrigation	Quality † 2003		Quality 2004	
SWE + HA § 100%	5.7	b‡	NA	NA
SWE + HA 85%	6.4	a	NA	NA
SWE + HA 70%	6.8	a	NA	NA
SWE + HA 55%	6.3	ab	NA	NA
GB 100%	6.8	a	5.4	abc
GB 85%	6.6	a	6.1	ab
GB 70%	6.9	a	5.1	bc
GB 55%	6.8	a	5.1	bc
Control 100%	6.3	ab	6.3	a
Control 85%	6.6	a	5.2	bc
Control 70%	6.7	a	5.2	bc
Control 55%	6.8	a	4.7	c

† Quality ratings were based on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
§ SWE + HA = seaweed extract + humic acid, GB = glycinebetaine.

Table 4.15. Creeping bentgrass monthly effects in 2003 when subjected to plant growth stimulants and deficit irrigation.

Month					Antioxidants (units g^{-1} FW)		
	Quality †	Wilt	Soil Moisture (%)	PE§	APX	CAT	SOD
July	7.0 a‡	9.0 a	5.5 a	0.65 b	341 b	9317 b	1869 b
August	6.6 b	7.0 b	4.4 b	0.45 c	466 ab	10600 b	7837 a
September	6.5 b	6.6 c	3.2 c	0.73 a	888 a	20345 a	9081 a

† Quality and wilt ratings were based on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable quality level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
§ PE = photosynthetic efficiency, APX = ascorbate peroxidase, CAT = catalase, SOD = superoxide dismutase, FW = fresh weight.

Table 4.16. Creeping bentgrass monthly effects in 2004 when subjected to plant growth stimulants and deficit irrigation.

Month						Antioxidants (units g^{-1} FW)			
	Quality †	Wilt	Soil Moisture (%)	PE §	ΔT (˚C)	APX	CAT	SOD	Cytokinin (ng g^{-1} FW)
July	6.1 a‡	6.9 a	2.1 a	0.49 b	10 c	145 ab	3890 b	2534 a	32.9 a
August	5.6 a	6.1 b	1.7 a	0.43 b	13 b	209 a	9581 a	509 b	0.7 b
September	4.5 b	4.8 c	0.7 b	0.59 a	21 a	91 b	2471 b	336 b	5.9 b

† Quality and wilt ratings were based on the 1-9 scale where 1 is dead and 9 is best. Minimum acceptable quality level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
§ PE = photosynthetic efficiency, ΔT = difference in canopy and air temperature, APX = ascorbate peroxidase, CAT = catalase, SOD = superoxide dismutase, FW = fresh weight.

Table 4.17. Creeping bentgrass 2003 correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Quality & wilt	<.0001	0.60
Wilt & soil moisture	<.0001	0.52
Wilt & SOD †	<.0001	-0.63
Soil moisture & APX	<.0001	-0.42
Soil moisture & SOD	<.0001	-0.34

α=0.05
† SOD = superoxide dismutase, APX = ascorbate peroxidase

Table 4.18. Creeping bentgrass 2004 correlations measured with Spearman's nonparametric correlation.

Correlation	*p*-value	Spearman r
Quality & wilt	<.0001	0.84
Quality & ΔT †	<.0001	-0.58
Quality & soil moisture	<.0001	0.51
Wilt & ΔT	<.0001	-0.73
Wilt & soil moisture	<.0001	0.70
Soil moisture & ΔT	<.0001	-0.70

α=0.05
† ΔT = difference between canopy and air temperature

Table 4.19. Creeping bentgrass plant growth stimulant (PGS) on quality and wilt in 2003 and 2004.

PGS treatment and Irrigation	2003		2004	
	Quality †	Wilt	Quality	Wilt
SWE + HA§	6.4 b	7.3 b	NA	NA
GB	6.8 a	7.6 a	5.4 a	6.0 a
Control	6.7 a	7.5 ab	5.4 a	5.9 a

† Quality and wilt ratings were made on the 1-9 scale where 1 id dead and 9 is best. Minimum acceptable quality level is 6.0.
‡ Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.
§ SWE + HA = seaweed extract + humic acid, GB = glycinebetaine.

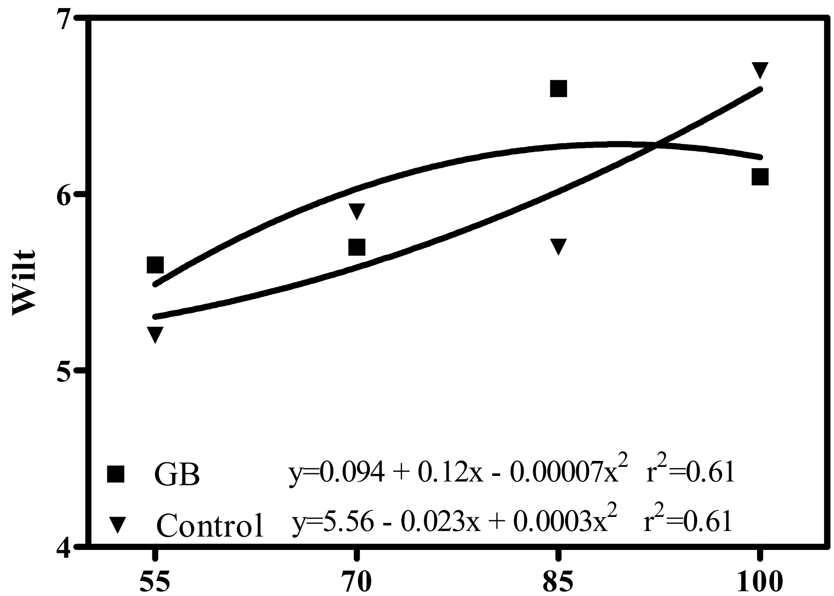


Fig. 4.3 Glycinebetaine (GB) and control treatments effects on creeping bentgrass wilt in 2004 subjected to second order polynomial regression.

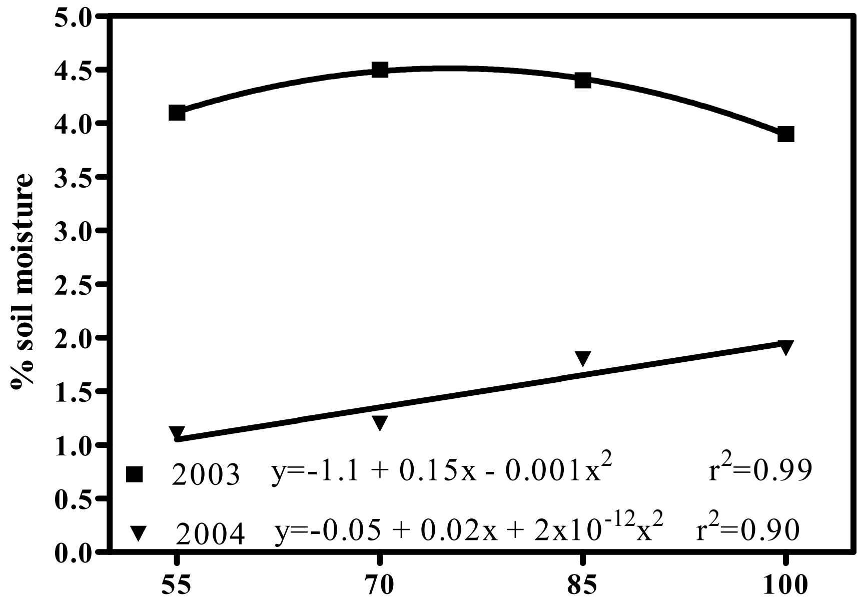


Fig. 4.4. Deficit irrigation treatment effect on soil moisture in 2003 and 2004 subjected to second order polynomial regression

Table 4.20. Creeping bentgrass plant growth stimulant (PGS) by irrigation level interaction for soil moisture in 2003.

PGS treatment and Irrigation	Soil Moisture (%)	
	2003	
SWE + HA ‡ 100%	3.7	b†
SWE + HA 85%	3.7	b
SWE + HA 70%	4.6	ab
SWE + HA 55%	3.7	b
GB 100%	4.5	ab
GB 85%	4.3	ab
GB 70%	4.5	ab
GB 55%	4.2	ab
Control 100%	3.7	b
Control 85%	5.1	a
Control 70%	4.3	ab
Control 55%	4.3	ab

† Means followed by the same letter within the column are not significantly different based on LSD at $\alpha=0.05$.
§ SWE + HA = seaweed extract + humic acid,
GB = glycinebetaine.

Table 4.21. Creeping bentgrass irrigation effect on photochemical efficiency in 2003 and 2004.

Irrigation	Photochemical efficiency	
	2003	2004
100%	0.61 a	0.55 a
85%	0.61 a	0.55 a
70%	0.62 a	0.46 b
55%	0.60 a	0.44 b

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.

Table 4.22. Creeping bentgrass irrigation and plant growth stimulant (PGS) effects on difference between canopy and air temperature (ΔT) in ˚C.

Irrigation	ΔT
100%	12 b†
85%	13 b
70%	16 a
55%	17 a
GB	14 b
Control	15 a

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.

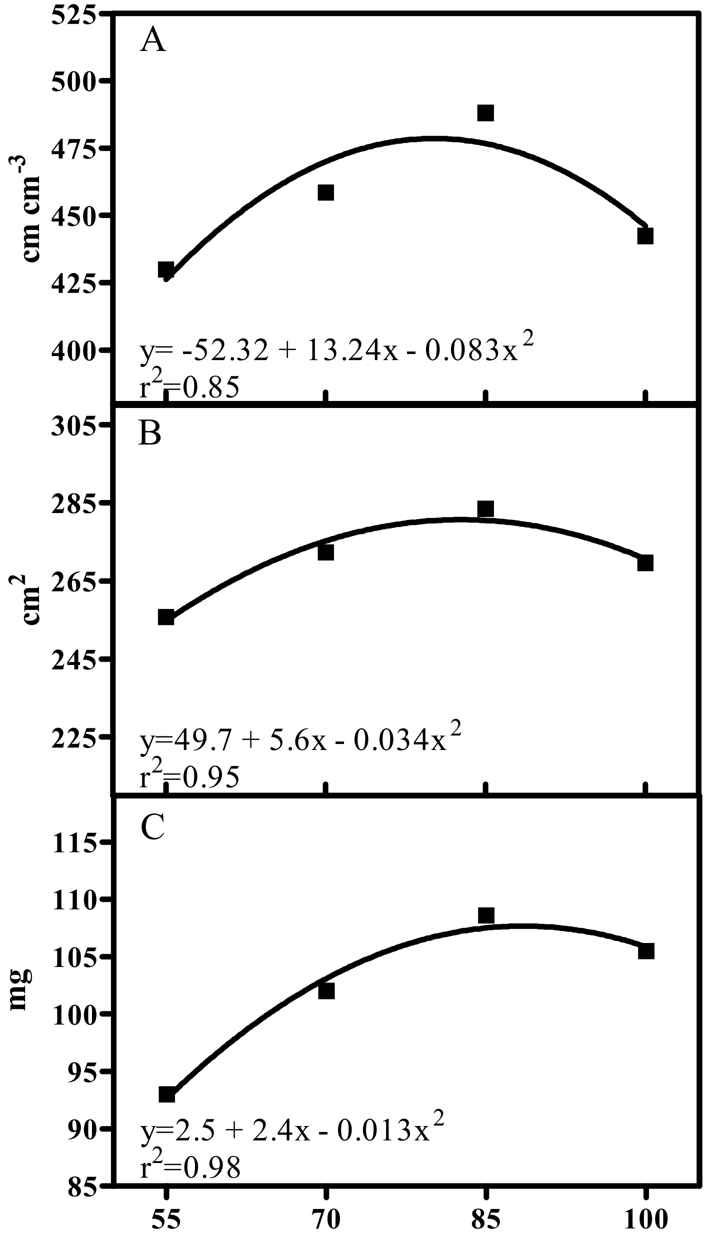


Fig. 4.5. Creeping bentgrass deficit irrigation effect on root length density (A), root surface area (B), and root dry weight (C) in 2003. Data subjected to second order polynomial regression.

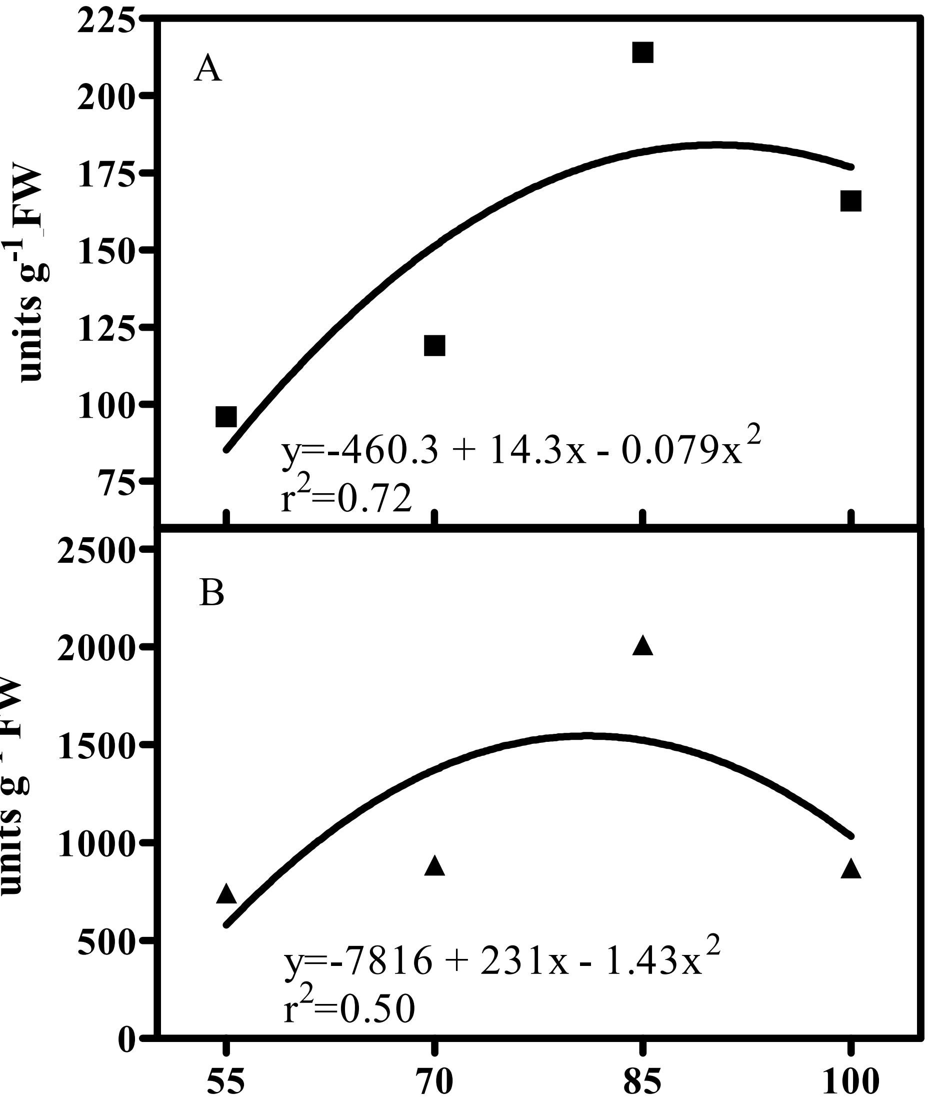


Fig. 4.6. Creeping bentgrass deficit irrigation effect on ascorbate peroxidase (A) and superoxide dismutase (B) antioxidant activity in 2004. Data subjected to second order polynomial regression.

Table 4.23. Creeping bentgrass irrigation and month interaction effect on superoxide dismutase (SOD) antioxidant activity in 2004.

Irrigation	SOD (ng g^{-1} fresh weight)		
	July	August	September
100%	1588 b†	593 a	430 a
	A‡	B	B
85%	5139 a	453 a	436 a
	A	B	B
70%	1952 b	509 a	193 a
	A	B	B
55%	1455 b	481 a	287 a
	A	B	B

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.05.
‡ Means followed by the same letter within the row are not significantly different based on LSD at α=0.05

Table 4.24. Creeping bentgrass irrigation and month interaction effect on cytokinin content in 2004.

Irrigation	Cytokinin content		
	July	August	September
100%	24.0 b†	0.12 b	3.0 a
	A‡	B	B
85%	14.2 b	0.23 b	6.8 a
	A	B	B
70%	88.0 a	2.0 a	4.5 a
	A	B	B
55%	5.4 b	0.32 b	9.4 a
	A	A	A

† Means followed by the same letter within the column are not significantly different based on LSD at α=0.1.
‡ Means followed by the same letter within the row are not significantly different based on LSD at α=0.1.

Conclusions

Tall fescue physiological and morphological qualities were not altered to the extent of those of creeping bentgrass, indicating that tall fescue is not as responsive to deficit irrigation. Our results indicate that tall fescue irrigation can be adjusted by a K_c of 0.55 when irrigated every five days as seen in the equal PE and antioxidant activity for 100% and 55% ET_o irrigated plots. Quality did not fall below the minimum acceptable level when irrigated at 55% every five days. Fry and Butler (1989) also determined that a K_c of 0.55 was suitable given that an irrigation interval of three to six days be maintained. An irrigation schedule of every five days may be too often for homeowners as lawn care typically occurs on weekends. No differences were detected between 70% and 55% ET_o in 2004, when an average irrigation interval was 12 days (Appendix B.4). Climate in 2004 was mild for a typical Blacksburg, Virginia summer. A K_c of 0.70 is recommended for tall fescue home lawns that are irrigated once a week. This recommendation is similar to K_cs determined for other locations throughout the United States that culture tall fescue (Carrow, 1995; Ervin and Koski, 1998).

The addition of SWE + HA or GB did not alter tall fescue survivability or physiological function when subjected to deficit irrigation. Glycinebetaine did show several promising effects and further studies should be conducted to determine if GB has an anti-transpirant effect on tall fescue.

Creeping bentgrass can not be cultured under the same deficit irrigation levels as tall fescue. Quality and wilt ratings gave visual indication of equal performance for creeping bentgrass irrigated at 100% and 85% ET_o. Photochemical efficiency, ΔT, and antioxidant activity supported visual indices of stress showing that stress was too great if irrigated below 85% ET_o. Irrigation interval can be less often than every three days, but should be more often than every five days, the average irrigation schedule when daily ET demand was high in 2004. Root morphology and antioxidant activity regression determined that a K_c of 0.80 to 0.90 would produce the most root mass and antioxidant defense mechanisms. An irrigation schedule of every four days would suffice with a K_c of 0.85 to adjust ET_o. This level and irrigation interval differs from DaCosta and Huang (2004) who concluded that creeping bentgrass fairways could be irrigated three days a week with a K_c of 0.60. This difference stresses the point that K_cs are site specific and can not be extrapolated from one climate to another.

The SWE + HA treatment did not affect creeping bentgrass health in 2003 and was eliminated in 2004 due to space constraints. Therefore, we have no basis for speculating how health would have been affected if irrigation stress were increased as in 2004. Further studies should be conducted to determine if irrigation level may be decreased beyond the recommended 0.85 K_c with monthly applications of SWE + HA. Glycinebetaine application indicated promise for increasing creeping bentgrass health for the short and long term as rooting was increased in 2003 and ΔT was lower in 2004.

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Appendix A: Climate Data

Fig. A.1. Temperature and rainfall in 2003 and 2004 compared to the 30-year average.

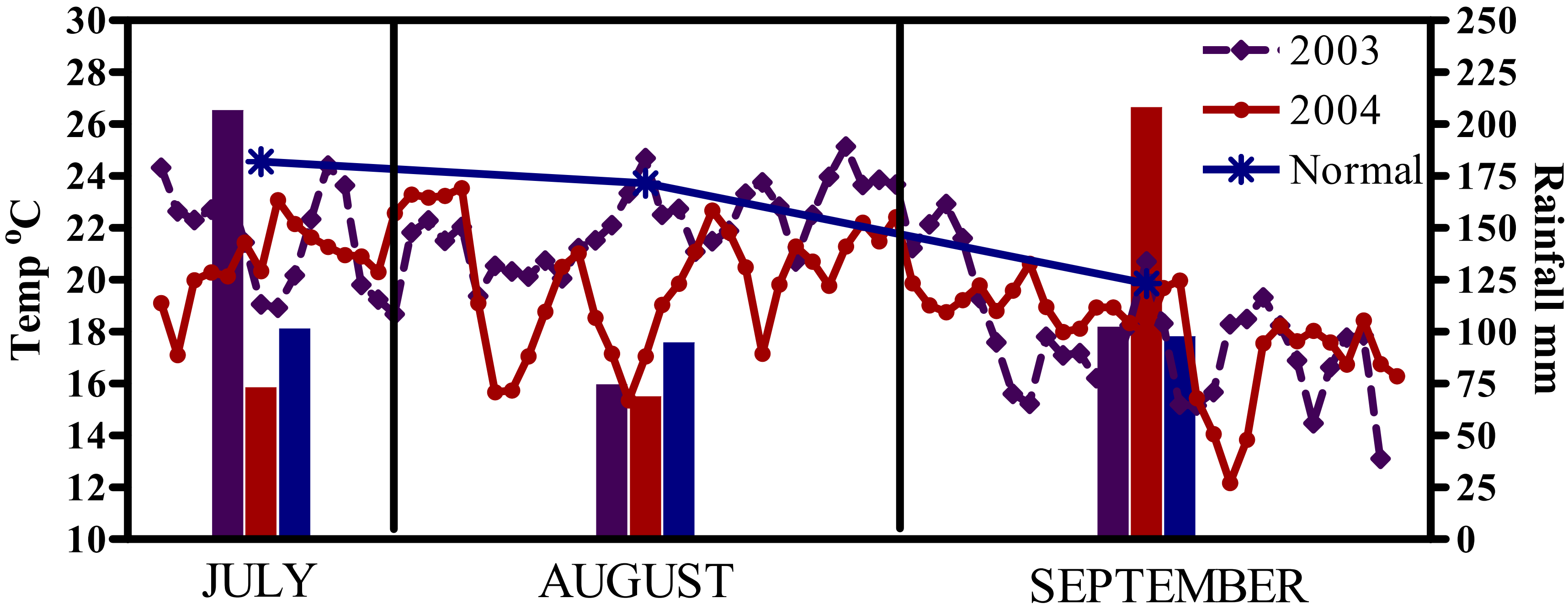

Table A.1. July 2003 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2}\,hr^{-1}$)	Wind speed AVG ($m\,s^{-1}$)	Rain (mm)
16	24.32	25.33	23.34	68.26	55.55	25.09	26.35	274.11	22.57	0.81267	0.92912	0
17	22.65	23.33	21.98	75.79	68.87	24.01	25.03	187.69	18.77	0.67569	0.96114	0
18	22.11	23.00	21.40	81.17	70.31	24.83	25.74	240.05	24.01	0.86422	0.93329	0.116
19	22.34	23.12	21.59	81.00	73.00	25.46	26.41	269.83	26.98	0.97135	0.80067	0
20	23.32	24.06	22.66	77.44	69.81	24.80	26.40	230.75	23.08	0.83071	1.268	0
21	21.35	22.04	20.79	83.76	77.13	23.69	25.21	178.44	17.84	0.64239	1.15146	0.402
22	18.96	19.68	18.32	90.71	81.83	22.54	23.53	136.33	13.63	0.49079	0.8655	0.454
23	18.58	19.35	17.81	80.03	71.39	21.94	23.65	228.27	22.83	0.82176	1.00608	0
24	19.70	20.46	18.91	79.45	70.74	22.93	24.56	260.99	26.10	0.93957	0.79558	0
25	21.93	22.70	21.17	79.11	70.16	24.17	25.16	252.43	25.24	0.90872	0.75033	0
26	23.99	24.72	23.29	77.11	70.79	24.92	25.99	243.00	24.30	0.87479	1.14071	0
27	23.46	24.17	22.80	78.17	70.83	24.54	26.55	202.90	20.29	0.73042	1.18921	0
28	19.87	20.27	19.54	96.32	93.08	23.06	25.38	66.58	6.66	0.23966	0.72325	1.439
29	19.14	19.50	18.80	93.99	90.25	22.79	24.29	100.27	10.03	0.36095	0.76363	0.010
30	18.62	18.86	18.40	97.81	95.99	21.95	23.54	42.57	4.26	0.15327	0.54138	0.391
31	21.56	22.11	21.08	91.20	85.12	23.26	24.13	157.76	15.78	0.56796	0.76471	0.052

Table A.2. August 2003 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2}\,hr^{-1}$)	Wind speed AVG ($m\,s^{-1}$)	Rain (mm)
1	22.30	23.01	21.66	87.00	79.68	25.15	26.07	287.30	28.73	1.034215	1.004583	0
2	21.51	22.10	20.94	90.36	83.87	24.48	25.27	149.28	14.93	0.537399	1.040708	0.095
3	22.04	22.61	21.45	84.63	77.54	24.67	25.74	226.60	22.66	0.815766	0.970458	0
4	19.37	20.24	18.69	91.47	83.80	23.75	24.74	187.98	18.80	0.676739	1.084833	0.6563
5	20.39	21.05	19.76	86.51	78.98	23.78	24.79	212.83	21.28	0.766199	0.64308	0
6	20.33	20.95	19.79	91.03	84.36	24.28	25.76	167.55	16.75	0.603182	0.676583	0.1693
7	20.12	20.76	19.56	94.05	88.41	24.00	26.21	129.50	12.95	0.466225	0.65375	0.560
8	20.74	21.41	20.21	91.23	85.50	24.39	25.27	182.10	18.21	0.655555	0.79125	0.0105
9	20.05	20.69	19.47	92.65	87.05	24.32	25.25	185.32	18.53	0.667157	0.731208	0.095
10	21.23	21.86	20.63	88.09	80.91	25.49	27.39	260.90	26.09	0.939236	0.789667	0.0105
11	21.52	22.31	20.81	89.77	82.53	24.80	27.75	161.32	16.13	0.580767	0.607375	0.0105
12	22.11	22.71	21.61	91.78	86.00	24.80	27.08	141.33	14.13	0.508817	0.529958	0
13	23.35	24.20	22.65	90.64	82.97	25.96	27.39	192.12	19.21	0.69161	0.536292	0.2116
14	24.70	25.35	24.06	81.96	73.30	26.81	28.36	239.76	23.98	0.863107	0.692208	0
15	22.51	23.14	21.87	90.01	84.85	25.50	26.49	171.72	17.17	0.618172	0.954417	1.1958
16	22.75	23.51	21.94	82.84	74.63	24.94	25.83	212.57	21.26	0.765247	1.075958	0.031
17	21.09	21.88	20.34	82.07	72.90	24.54	25.64	261.27	26.13	0.940599	0.715375	0
18	21.49	22.18	20.83	86.06	79.14	25.03	26.10	214.31	21.43	0.771541	0.784583	0
19	21.89	22.54	21.25	86.83	81.00	25.31	26.42	241.77	24.18	0.870384	0.753917	0
20	23.32	24.03	22.66	85.30	78.77	26.00	28.43	241.01	24.10	0.867611	0.761583	0
21	23.75	24.37	23.17	81.60	75.39	25.76	28.24	226.93	22.69	0.816936	1.188042	0
22	22.83	23.65	21.93	78.86	70.20	25.04	26.28	207.27	20.73	0.746186	0.988333	0
23	20.71	21.46	20.02	76.07	67.08	24.47	25.68	231.93	23.19	0.834934	0.829667	0
24	22.52	23.18	21.83	75.00	67.52	24.20	26.45	250.07	25.01	0.900249	0.92925	0
25	23.98	24.75	23.21	76.67	68.20	24.64	27.39	240.53	24.05	0.865929	0.947083	0

Table A. 2. August 2003 climate data continued

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
26	25.13	25.81	24.44	78.98	71.46	25.53	28.26	227.86	22.79	0.820289	1.079292	0
27	23.66	24.43	23.02	80.91	73.75	25.66	27.37	183.33	18.33	0.659965	0.664333	0
28	23.86	24.63	23.11	84.05	76.38	25.50	27.63	202.75	20.28	0.729905	0.9385	0
29	23.68	24.38	23.02	82.79	77.13	24.89	27.91	164.01	16.40	0.590479	1.029917	0
30	21.22	21.70	20.84	93.30	89.42	24.42	27.28	104.30	10.43	0.375481	0.789458	0.0423
31	22.14	22.79	21.46	91.14	85.07	24.80	27.48	161.41	16.14	0.581079	0.98225	0.0211

Table A.3. September 2003 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
1	22.92	23.70	22.24	83.77	76.99	24.63	26.77	211.49	21.15	0.761354	0.835542	0
2	21.61	22.24	21.07	91.89	86.27	24.17	25.48	111.95	11.19	0.403013	0.624708	0.296
3	19.29	19.81	18.79	95.47	91.24	22.69	23.79	78.74	7.87	0.283494	0.728792	0.624
4	17.59	18.39	16.82	83.04	73.46	21.86	23.19	232.47	23.25	0.836876	0.726125	0
5	15.62	16.37	15.01	89.18	82.84	20.81	21.85	126.54	12.65	0.455531	0.561333	0
6	15.23	15.84	14.64	91.68	87.01	19.94	21.04	131.52	13.15	0.473506	0.512375	0
7	17.81	18.54	17.10	84.98	77.12	21.42	22.72	222.73	22.27	0.801844	0.661125	0
8	17.09	18.09	16.27	87.61	79.78	21.10	22.37	193.31	19.33	0.695936	0.727292	0
9	17.17	17.86	16.54	81.04	73.01	21.51	23.37	217.66	21.77	0.783607	0.823917	0
10	16.20	17.06	15.42	77.90	68.60	20.53	22.65	232.74	23.27	0.837895	0.724875	0
11	16.20	17.02	15.52	81.85	74.82	19.86	21.74	141.38	14.14	0.508978	0.756417	0
12	18.24	18.70	17.83	92.01	87.58	20.81	22.92	103.68	10.37	0.37323	0.617208	0.063
13	20.71	21.29	20.17	88.05	81.50	22.40	24.71	207.73	20.77	0.747829	1.067333	0
14	18.32	18.78	17.88	93.03	88.85	21.70	24.02	85.27	8.53	0.306969	0.937917	0.0211
15	15.20	16.10	14.33	81.21	72.58	19.50	21.81	223.71	22.37	0.805325	0.707292	0
16	15.16	16.06	14.34	81.66	73.77	19.18	21.90	201.00	0.85	0.47601	0.682667	0
17	15.54	15.96	15.19	87.32	82.31	17.76	19.73	41.32	0.15	0.611299	1.978357	0.894
18	18.18	18.85	17.54	82.23	74.06	18.93	20.24	187.13	0.67	0.548466	1.777	56.868
19	18.49	19.28	17.75	86.09	79.46	20.30	21.50	196.13	0.71	0.545258	0.877786	57.240
20	19.33	20.05	18.69	87.51	81.64	21.18	22.42	168.98	0.61	0.620041	1.058714	35.844
21	18.25	18.54	17.93	94.17	90.54	20.03	21.33	36.07	0.13	0.580411	1.650214	36.395
22	16.89	17.63	16.12	76.42	67.93	18.91	21.06	169.27	0.61	0.581903	2.104643	47.685
23	14.48	15.35	13.73	84.51	76.86	17.78	20.45	213.12	2.13	0.82628	0.894458	0
24	16.63	17.45	15.80	86.51	79.83	18.65	21.47	206.27	2.06	0.742583	0.646917	0
25	17.78	18.71	16.97	87.29	80.52	19.66	21.78	180.49	1.80	0.649737	0.915333	0

Table A.3. September 2003 climate data continued

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2}\,hr^{-1}$)	Wind speed AVG ($m\,s^{-1}$)	Rain (mm)
26	17.86	18.67	17.00	89.99	82.68	19.01	20.21	122.66	1.23	0.441577	0.970458	0.656
27	13.10	13.92	12.38	79.74	71.28	17.36	18.49	144.05	1.44	0.518571	1.415208	0.127
28	9.29	9.90	8.72	74.38	66.98	14.58	16.49	161.60	1.62	0.581769	1.630708	0
29	8.50	9.25	7.78	80.13	71.69	13.61	16.22	216.59	2.17	0.779725	0.771875	0
30	8.78	9.48	8.18	85.37	78.24	13.99	16.65	141.02	1.41	0.507666	1.066375	0

Table A.4. July 2004 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2}\ hr^{-1}$)	Wind speed AVG ($m\ s^{-1}$)	Rain (mm)
1	21.24	21.90	20.64	85.55	79.72	23.77	24.18	258.90	25.89	0.93203	1.34477	0
2	22.16	22.95	21.40	88.68	81.76	24.25	24.61	177.65	17.77	0.63954	0.56792	1.778
3	21.72	22.55	20.92	92.51	86.66	23.81	24.16	158.89	15.89	0.57197	0.4945	2.286
4	21.83	22.75	21.15	91.80	85.04	24.25	24.64	187.62	18.76	0.67538	0.62779	11.434
5	23.72	24.41	23.07	79.93	73.57	24.58	24.94	257.12	25.71	0.92566	1.32225	0
6	23.55	24.30	22.86	76.27	68.33	24.57	24.97	270.59	27.06	0.97415	1.18383	0
7	23.02	23.73	22.35	78.44	71.61	24.93	25.28	274.38	27.44	0.98771	1.1305	0
8	22.18	22.89	21.46	74.46	67.14	24.16	24.53	280.35	28.03	1.00923	1.191	0
9	22.68	23.42	21.97	75.84	68.69	23.95	24.34	261.10	26.11	0.93992	0.89596	0
10	22.36	23.19	21.68	87.61	81.51	24.16	24.53	165.02	16.50	0.59411	0.86946	6.096
11	22.67	23.31	22.05	86.51	80.74	24.51	24.86	215.94	21.59	0.77746	0.73271	7.874
12	22.73	23.47	21.99	88.25	82.02	24.87	25.20	220.37	22.04	0.79335	0.97721	0
13	24.07	24.72	23.50	78.34	72.01	25.32	25.68	266.69	26.67	0.96013	1.28592	0
14	23.24	23.89	22.67	74.79	69.03	24.56	24.89	244.22	24.42	0.87916	1.83213	0
15	20.45	21.09	19.74	67.04	60.35	22.80	23.15	252.26	25.23	0.90819	1.87146	0
16	19.13	19.92	18.31	70.97	62.29	21.75	22.15	271.34	27.13	0.97681	1.09975	0
17	17.08	17.75	16.48	91.33	85.51	20.39	20.71	104.60	10.46	0.37653	0.40063	15.496
18	19.96	20.59	19.38	87.73	81.08	22.36	22.66	197.32	19.73	0.71034	0.65463	0.254
19	20.30	20.99	19.59	78.85	71.85	23.24	23.65	273.19	27.32	0.98347	0.97008	0
20	20.09	21.01	19.27	79.58	70.56	22.60	23.01	206.00	20.60	0.74157	0.55163	0
21	21.38	22.25	20.64	77.80	70.01	23.37	23.79	265.26	26.53	0.95493	0.66813	0
22	20.37	20.76	19.94	92.58	89.28	22.22	22.49	70.63	7.06	0.25427	0.751	10.414
23	23.02	23.63	22.50	87.02	81.66	22.97	23.27	160.04	16.00	0.57617	0.93329	2.032
24	22.12	22.90	21.41	84.02	76.42	24.17	24.56	239.35	23.94	0.86166	0.7275	0
25	21.66	22.30	20.99	85.06	78.05	25.19	25.56	227.90	22.79	0.82045	0.83488	0.254

Table A.4. July 2004 climate data continued

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
26	21.27	21.73	20.84	93.36	89.28	24.61	24.90	129.91	12.99	0.4677	0.66942	5.334
27	20.93	21.29	20.62	92.47	89.08	23.54	23.79	107.59	10.76	0.3873	0.67692	5.334
28	20.86	21.45	20.36	79.00	71.89	23.89	24.25	285.22	28.52	1.02681	0.93117	0
29	20.27	21.06	19.56	86.66	80.70	23.65	24.01	211.14	19.73	0.76011	0.82304	0
30	22.59	23.15	21.99	88.22	80.88	24.41	24.68	142.39	14.24	0.51263	1.25038	4.572

Table A.5. August 2004 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
1	23.26	24.08	22.51	87.23	80.14	25.27	25.68	257.20	24.54	0.883465	0.738083	3.81
2	23.12	23.80	22.55	86.51	79.11	26.34	26.73	241.23	25.72	0.925946	0.821917	0.508
3	23.23	23.94	22.54	78.59	71.88	25.77	26.13	249.18	24.12	0.868401	1.298458	0
4	23.56	24.32	22.74	76.88	69.47	25.05	25.44	50.10	24.92	0.897053	1.00725	0
5	19.12	19.54	18.68	93.53	89.32	22.81	23.10	235.61	5.01	0.18038	0.795333	14.986
6	15.63	16.48	14.86	74.92	65.16	20.50	20.81	215.45	23.56	0.848202	1.489208	0
7	15.71	16.60	14.88	74.14	65.09	19.06	19.41	257.15	21.54	0.775603	1.260833	0
8	17.06	17.89	16.24	79.25	70.99	20.22	20.63	245.45	25.72	0.925742	0.65	0
9	18.72	19.60	17.97	80.89	73.32	21.49	21.90	216.84	24.55	0.883644	0.668667	0
10	20.47	21.23	19.78	78.31	71.65	22.09	22.44	220.73	21.68	0.780596	0.854458	0
11	21.05	21.79	20.27	79.58	72.01	22.28	22.66	55.76	22.07	0.794649	0.888417	0
12	18.52	18.90	18.19	94.11	90.99	21.05	21.28	173.41	5.58	0.200766	0.3895	16.01
13	17.13	17.71	16.61	83.71	78.40	20.79	21.08	132.95	17.34	0.624249	1.180292	0
14	15.36	16.06	14.67	88.00	81.49	19.69	19.99	206.52	13.30	0.478594	0.603583	0
15	17.03	17.85	16.27	87.88	81.96	20.31	20.69	260.12	20.65	0.743486	0.742375	0
16	19.00	19.68	18.39	82.89	76.03	22.12	22.51	246.24	26.01	0.936427	0.803625	0
17	19.86	20.60	19.12	82.18	75.15	22.80	23.18	228.35	24.62	0.886498	0.687	0.254
18	21.13	21.75	20.43	83.18	76.60	23.22	23.56	241.68	22.83	0.822035	0.76975	0
19	22.67	23.51	21.85	79.02	71.57	23.48	23.88	179.07	24.17	0.87004	0.877875	0
20	21.95	22.66	21.03	87.44	80.30	23.15	23.49	114.83	17.91	0.644664	0.923125	9.656
21	20.46	21.11	19.85	93.17	87.48	22.79	23.08	163.12	11.48	0.413379	0.894292	16.002
22	17.14	17.79	16.53	89.18	84.03	20.79	21.14	250.14	16.31	0.587166	0.658542	0.254
23	19.74	20.60	19.05	86.51	79.98	22.41	22.82	170.65	25.01	0.900494	0.662	0
24	21.24	21.97	20.62	84.95	79.31	23.72	24.08	204.73	17.07	0.614354	0.760875	0
25	20.67	21.42	19.99	82.11	75.35	23.69	24.05	208.69	20.47	0.736999	0.837042	0

Table A.5. August 2004 climate data continued

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
26	19.71	20.52	19.04	85.03	78.89	22.91	23.34	189.42	20.87	0.75127	0.808167	0
27	21.28	22.09	20.51	89.44	82.05	23.51	23.87	203.69	18.94	0.681884	0.533333	7.366
28	22.15	23.01	21.42	90.47	84.53	24.43	24.80	129.85	20.37	0.733283	0.562958	0
29	21.51	22.03	20.96	87.38	81.88	23.75	24.07	157.10	12.98	0.467469	0.575917	0
30	22.39	22.97	21.89	84.72	78.52	23.77	24.05	210.97	15.71	0.565539	1.046833	0

Table A.6. September 2004 climate data

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
1	19.84	20.52	19.22	81.83	76.01	22.85	23.62	214.55	21.46	0.77239	1.13454	0
2	18.98	19.70	18.37	86.29	81.08	21.32	22.04	143.34	14.33	0.51602	0.71517	0
3	18.66	19.61	17.92	84.51	78.42	21.02	21.52	176.72	17.67	0.63616	0.64954	0
4	19.13	20.08	18.38	82.77	75.44	21.48	22.04	177.29	17.73	0.6382	0.56925	0
5	19.78	20.54	19.05	80.99	73.33	22.21	22.83	229.07	22.91	0.82467	0.93342	0
6	18.79	19.04	18.57	96.34	94.28	21.76	22.05	68.41	6.84	0.24629	0.71692	2.794
7	19.60	19.89	19.29	97.40	96.00	21.35	21.63	56.49	5.65	0.20334	0.52433	20.83
8	20.61	20.90	20.34	96.45	94.24	21.03	21.29	40.26	4.03	0.1449	1.4865	43.178
9	18.90	19.38	18.53	85.50	81.01	20.88	21.19	103.75	10.37	0.3735	1.51488	0
10	17.97	18.84	17.13	85.45	78.37	20.61	21.22	195.47	19.55	0.7037	0.50021	0
11	18.15	19.03	17.21	87.26	80.76	20.73	21.34	195.52	19.55	0.70388	0.60796	0
12	18.89	19.71	18.16	86.01	80.45	21.25	21.79	178.82	17.88	0.64371	0.52458	0
13	18.92	19.63	18.26	87.81	82.78	21.48	21.99	172.72	17.27	0.62181	0.66542	0
14	18.32	18.85	17.82	89.10	84.05	21.11	21.55	118.94	11.89	0.42821	0.49121	0
15	17.84	18.59	17.23	88.93	84.06	20.49	21.02	146.57	14.66	0.52768	0.67975	0
16	19.67	20.02	19.36	91.84	88.88	21.15	21.53	87.12	8.71	0.31363	0.54979	1.016
17	19.93	20.32	19.62	94.99	91.61	20.88	21.20	49.60	4.96	0.17855	1.88171	32.766
18	15.44	15.98	14.90	77.71	70.72	18.53	18.99	169.53	16.95	0.61031	2.12367	0.762
19	14.00	15.08	13.03	73.20	60.11	17.17	17.81	218.47	21.85	0.7865	0.68433	0
20	12.12	13.05	11.28	78.70	69.46	16.53	17.15	212.91	21.29	0.7665	0.69617	0
21	13.77	14.78	12.89	80.17	71.23	17.22	17.89	222.22	22.22	0.79996	0.451	0
22	17.56	18.50	16.61	81.29	74.59	18.75	19.45	201.09	20.11	0.72399	0.52408	0
23	18.23	19.26	17.24	82.56	74.27	19.39	20.05	205.62	20.56	0.74021	0.54992	0
24	17.64	18.53	16.76	86.29	79.61	19.56	20.15	184.12	18.41	0.66289	0.51279	0
25	18.04	18.89	17.19	88.22	82.25	20.41	20.97	174.29	17.43	0.62749	0.53513	0

Table A.6. September 2004 climate data continued

Day	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
26	17.57	18.45	16.75	87.87	81.65	19.63	20.16	174.61	17.46	0.62857	0.526	0
27	16.74	16.97	16.50	93.35	91.16	18.52	18.79	44.52	4.45	0.16026	0.78404	4.318
28	18.45	18.77	18.13	92.64	89.54	18.49	18.76	47.72	4.77	0.17184	1.60458	102.61
29	16.81	17.52	16.01	82.61	74.88	18.31	18.93	196.39	19.64	0.70696	0.86025	0
30	16.27	16.98	15.59	85.63	79.22	18.78	19.33	161.19	16.12	0.58027	0.48163	0

Appendix B: Evapotranspiration Data

Table B.1. Example: climate data input and REF ET output for creeping bentgrass 1.3 cm mowing height from July 25-28, 2003

Day	Time (h)	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2}\ hr^{-1}$)	Wind speed AVG ($m\ s^{-1}$)	Rain (mm)
207	800	15.52	16.59	14.85	98.7	94.9	19.93	20.41	17.6	1.76	0.06337	0.023	0
207	900	18	19.19	16.69	94.6	83.5	19.8	20.44	30.87	3.087	0.11112	0.556	0
207	1000	20.37	21.56	19.23	84.6	76.2	19.97	20.47	44.15	4.415	0.15895	0.808	0
207	1100	22.63	23.65	21.46	78.3	70.5	20.3	21.09	102.3	10.23	0.36832	1.093	0
207	1200	24.82	26.61	23.12	72.3	50	21.69	23.01	434.3	43.43	1.5633	1.321	0
207	1300	26.48	27.4	25.57	63.7	38.01	23.78	25.26	572.8	57.28	2.0622	1.698	0
207	1400	27.53	28.16	26.83	54.96	42.55	25.96	27.51	589.8	58.98	2.1234	1.641	0
207	1500	28.33	29.09	26.82	51.2	41.44	27.41	28.78	543	54.3	1.9546	1.478	0
207	1600	28.85	29.62	28.05	52.07	39.54	28.58	29.78	501.6	50.16	1.8058	1.31	0
207	1700	29.24	30.15	28.28	50.43	37.8	29.47	30.68	421.8	42.18	1.5184	1.142	0
207	1800	28.76	29.51	28.37	48.92	40.74	29.58	30.67	313.3	31.33	1.1277	1.472	0
207	1900	27.91	28.45	27.38	57.02	46.89	28.99	30.26	164.3	16.43	0.59147	1.436	0
207	2000	26.25	27.55	24.59	73.6	52.04	28.17	29.56	44.14	4.414	0.15891	0.701	0
207	2100	23.97	24.59	23.22	78.4	69.37	27.22	28.3	3.08	0.308	0.01109	0.556	0
207	2200	23.29	23.97	22.84	79	71.9	26.33	27.38	0	0	0	1.02	0
207	2300	21.55	22.67	20.74	88.4	78.5	25.55	26.83	0	0	0	0.59	0
207	2400	20.23	20.67	19.84	92.4	88	24.82	25.81	0	0	0	0.224	0
208	100	19.57	20.44	19.11	95.5	88.7	24.25	25.04	0	0	0	0.132	0
208	200	19.3	19.85	18.95	95.9	91.5	23.68	24.56	0	0	0	0.21	0
208	300	18.62	19.12	18.25	97.7	94.5	23.34	23.97	0	0	0	0	0
208	400	18.28	18.51	18.01	98.7	97.5	22.81	23.45	0	0	0	0.162	0
208	500	18.13	18.45	17.78	99.1	97.9	22.36	23.24	0	0	0	0.369	0
208	600	18.08	18.41	17.81	98.9	97.5	22.04	22.68	0	0	0	0.4	0

Table B.1. Example: climate data input and REF ET output for creeping bentgrass 1.3 cm mowing height from July 25-28, 2003 cont.

Day	Time (h)	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
208	700	18.01	18.28	17.78	98.8	97.9	21.51	22.23	2.816	0.2816	0.01014	0.5	0
208	800	18.66	19.25	18.25	98.1	95.8	21.23	21.83	17.56	1.756	0.06322	0.685	0
208	900	20.06	20.89	19.22	95.8	88.4	21.13	21.8	30.78	3.078	0.1108	1.106	0
208	1000	22.15	23.09	20.86	88.9	77.7	21.31	22.01	40.08	4.008	0.14427	1.177	0
208	1100	24.45	26.05	23.12	78.9	67.22	21.64	22.59	135.5	13.55	0.48775	1.402	0
208	1200	26.97	28.14	26.02	68.52	58.74	23.23	24.74	501.9	50.19	1.8068	1.697	0
208	1300	28.13	28.73	27.36	65.95	54.02	25.29	26.58	499.4	49.94	1.7977	1.875	0
208	1400	28.56	30.02	27.45	58.79	48.23	26.87	28.17	505.2	50.52	1.8187	1.97	0
208	1500	30.25	30.76	29.55	52.14	44.59	28.09	29.59	551.1	55.11	1.9838	1.678	0
208	1600	30.22	30.79	29.41	51	44.25	28.91	30.29	457.7	45.77	1.6477	1.972	0
208	1700	30.65	31.21	29.75	51.13	43.41	29.62	30.76	421.5	42.15	1.5173	1.767	0
208	1800	30.37	30.91	29.44	51.29	43.01	29.42	30.49	304.9	30.49	1.0977	1.554	0
208	1900	29.42	30.81	28.38	53.68	46.58	28.98	30.64	129.6	12.96	0.46671	1.48	0
208	2000	27.64	28.78	26.68	63.48	52.67	28.19	29.4	44.93	4.493	0.16174	1.51	0
208	2100	26.09	26.69	25.46	67.9	63.44	27.42	28.64	2.107	0.2107	0.00759	1.52	0
208	2200	25.08	25.46	24.76	69.41	66.97	26.31	27.39	0	0	0	1.623	0
208	2300	24.29	24.86	23.77	71.5	67.5	25.57	27.17	0	0	0	1.589	0
208	2400	22.82	23.87	21.84	79.5	70.9	24.89	26.52	0	0	0	0.999	0
209	100	21.82	22.34	21.4	78.8	74.6	24.27	25.15	0	0	0	0.895	0
209	200	21	21.44	20.64	82.3	76.9	23.87	24.5	0	0	0	0.573	0
209	300	20.36	20.91	20.04	83.9	80.1	23.41	24.13	0	0	0	0.842	0
209	400	19.83	20.31	19.58	85.6	82.3	22.98	23.79	0	0	0	1.398	0
209	500	19.78	20.01	19.58	85.8	83.8	22.69	23.26	0	0	0	0.79	0
209	600	19.84	20.04	19.68	85.3	82.9	22.43	23.06	0	0	0	0.659	0
209	700	19.75	20.12	19.41	86.9	81.9	22.05	22.88	4.061	0.4061	0.01462	0.374	0

Table B.1. Example: climate data input and REF ET output for creeping bentgrass 1.3 cm mowing height from July 25-28, 2003 cont.

Day	Time (h)	Air AVG (ºC)	Air MAX (ºC)	Air MIN (ºC)	RH MAX (%)	RH MIN (%)	Soil temp AVG (ºC)	Soil temp MAX (ºC)	Solar Rad. (Wm^{-2})	Soil heat flux (Wm^{-2})	Net Rad. ($MJm^{-2} hr^{-1}$)	Wind speed AVG ($m s^{-1}$)	Rain (mm)
209	800	20.14	20.41	19.85	85.2	82.6	21.81	22.57	28.78	2.878	0.10361	0.756	0
209	900	21.5	23.09	20.35	83.8	73.4	21.75	22.74	58.87	5.887	0.21195	1.095	0
209	1000	23.6	24.38	23.12	74.3	70.5	21.96	23.65	81.8	8.18	0.29455	1.515	0
209	1100	25.44	26.64	24.35	72.2	62.09	22.28	24.37	168.9	16.89	0.60789	1.756	0
209	1200	26.5	27.3	25.83	67.03	60.32	23.5	25.25	268.2	26.82	0.96538	2.065	0
209	1300	27.56	28.5	26.67	63.69	57.03	24.47	28.38	511.2	51.12	1.8402	2.357	0
209	1400	28.82	29.62	28.03	62.44	52.87	26.31	29.07	527	52.7	1.8971	1.929	0
209	1500	29.5	29.92	28.95	57.95	51.07	27.37	29.83	486.2	48.62	1.7503	2.052	0
209	1600	28.93	30.25	26.34	68.18	47.69	28.17	31.97	365	36.5	1.3139	2.828	0
209	1700	26.21	27.18	24.75	80	57.82	28.13	31.98	186.3	18.63	0.67056	1.744	0
209	1800	25.51	26.4	24.78	79.8	68.13	27.51	30.47	197.5	19.75	0.7111	1.411	0
209	1900	25.33	25.73	25.03	73.3	69.34	27.1	31.03	116	11.6	0.4177	1.197	0
209	2000	24.83	25.8	24.29	75.6	68.54	26.7	30.47	40.6	4.06	0.14617	0.773	0
209	2100	23.49	24.26	22.53	78.9	72.2	26.06	29.72	3.114	0.3114	0.01121	0.641	0
209	2200	21.98	22.5	21.57	82.8	79.1	25.2	27	0	0	0	0.451	0
209	2300	20.79	21.71	20.17	91	80.7	24.71	25.89	0	0	0	0.338	0
209	2400	20.51	21.25	20.21	91.2	84	24.23	26.04	0	0	0	0.102	0
210	100	20.98	21.45	20.44	91.7	85.4	23.89	26.94	0	0	0	0.521	0.254
210	200	20.14	20.78	19.71	97.6	91.7	23.35	24.65	0	0	0	0.535	3.81
210	300	19.72	19.84	19.61	98.8	97.5	23.04	24.92	0	0	0	0.48	2.032
210	400	19.66	19.78	19.58	99.1	98.6	22.88	26.4	0	0	0	0.791	3.302
210	500	19.59	19.71	19.51	99.3	99.1	22.63	23.47	0	0	0	0.58	3.556
210	600	19.49	19.61	19.34	99.3	99	22.28	23.21	0	0	0	0.913	2.032
210	700	19.33	19.58	19.04	99.4	99	21.87	24.16	0.131	0.0131	0.00047	0.68	8.13
210	800	19.29	19.54	19.21	99.5	99.3	21.66	24.31	6.647	0.6647	0.02393	0.696	3.556

Table B.2. REF-ET output for July 25-28, 2003 data at 1.3 cm height of cut

REF-ET REFERENCE EVAPOTRANSPIRATION CALCULATOR Ver. 2 Windows
Computer Program Supplement to ASCE Manual 70
EVAPOTRANSPIRATION AND IRRIGATION WATER REQUIREMENTS
M.E. Jensen, R.D. Burman and R.G. Allen, Editors, 1990
and FAO Irrigation and Drainage Paper No. 56
CROP EVAPOTRANSPIRATION Guidelines for Computing Crop Water Req.
R.G., Allen, L.S. Pereira, D. Raes, M. Smith. 1998

Day	Time	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	ASCE **stPM ETo mm h^{-1}**
207	800	2003	16.6	14.9	18	0	15.2	**0.02**
207	859	2003	19.2	16.7	31	0.6	16.1	**0.03**
207	950	2003	21.6	19.2	44	0.8	16.9	**0.05**
207	1057	2003	23.7	21.5	102	1.1	17.7	**0.12**
207	1147	2003	26.6	23.1	434	1.3	16.6	**0.45**
207	1243	2003	27.4	25.6	573	1.7	15.3	**0.61**
207	1359	2003	28.2	26.8	590	1.6	15.7	**0.63**
207	1438	2003	29.1	26.8	543	1.5	15.3	**0.6**
207	1533	2003	29.6	28.1	501	1.3	15.9	**0.56**
207	1643	2003	30.2	28.3	422	1.1	15.6	**0.48**
207	1701	2003	29.5	28.4	313	1.5	15.7	**0.38**
207	1808	2003	28.5	27.4	164	1.4	17.1	**0.22**
207	1903	2003	27.6	24.6	44	0.7	18.2	**0.07**
207	2018	2003	24.6	23.2	3	0.6	18.9	**0.02**
207	2101	2003	24	22.8	0	1	18.8	**0.02**
207	2208	2003	22.7	20.7	0	0.6	18.7	**0.01**
207	2303	2003	20.7	19.8	0	0.2	18.6	**0**
208	3	2003	20.4	19.1	0	0.1	18.4	**0**
208	128	2003	19.9	19	0	0.2	18.4	**0**
208	202	2003	19.1	18.3	0	0	18	**0**
208	301	2003	18.5	18	0	0.2	18	**0**
208	401	2003	18.5	17.8	0	0.4	17.9	**0**
208	544	2003	18.4	17.8	0	0.4	17.8	**0**
208	604	2003	18.3	17.8	3	0.5	17.8	**0**
208	756	2003	19.3	18.3	18	0.7	18.3	**0.02**
208	858	2003	20.9	19.2	31	1.1	18.7	**0.03**
208	952	2003	23.1	20.9	40	1.2	19	**0.05**
208	1058	2003	26.1	23.1	135	1.4	19.4	**0.16**
208	1152	2003	28.1	26	502	1.7	19.5	**0.53**

Table B.2. REF-ET output for July 25-28, 2003 data at 1.3 cm height of cut continued

Day	Time	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	**ASCE stPM ETo mm h^{-1}**
208	1242	2003	28.7	27.4	499	1.9	19.5	**0.54**
208	1351	2003	30	27.5	505	2	18.3	**0.56**
208	1456	2003	30.8	29.6	551	1.7	18	**0.62**
208	1515	2003	30.8	29.4	458	2	17.7	**0.54**
208	1630	2003	31.2	29.8	421	1.8	17.9	**0.5**
208	1716	2003	30.9	29.4	305	1.6	17.6	**0.38**
208	1805	2003	30.8	28.4	130	1.5	18.1	**0.2**
208	1901	2003	28.8	26.7	45	1.5	18.7	**0.1**
208	2004	2003	26.7	25.5	2	1.5	19.1	**0.05**
208	2130	2003	25.5	24.8	0	1.6	18.8	**0.05**
208	2204	2003	24.9	23.8	0	1.6	18.4	**0.04**
208	2302	2003	23.9	21.8	0	1	18.2	**0.02**
209	2	2003	22.3	21.4	0	0.9	17.6	**0.02**
209	110	2003	21.4	20.6	0	0.6	17.4	**0.01**
209	201	2003	20.9	20	0	0.8	17.3	**0.01**
209	301	2003	20.3	19.6	0	1.4	17.1	**0.02**
209	413	2003	20	19.6	0	0.8	17.2	**0.01**
209	559	2003	20	19.7	0	0.7	17.1	**0.01**
209	637	2003	20.1	19.4	4	0.4	17	**0.01**
209	729	2003	20.4	19.9	29	0.8	17.3	**0.04**
209	858	2003	23.1	20.4	59	1.1	17.8	**0.07**
209	954	2003	24.4	23.1	82	1.5	18.5	**0.11**
209	1058	2003	26.6	24.4	169	1.8	18.9	**0.21**
209	1112	2003	27.3	25.8	268	2.1	19.1	**0.31**
209	1252	2003	28.5	26.7	511	2.4	19.2	**0.55**
209	1357	2003	29.6	28	527	1.9	19.6	**0.58**
209	1457	2003	29.9	29	486	2.1	19.3	**0.55**
209	1534	2003	30.3	26.3	365	2.8	19	**0.44**
209	1626	2003	27.2	24.8	186	1.7	19.7	**0.22**
209	1716	2003	26.4	24.8	197	1.4	20.6	**0.22**
209	1816	2003	25.7	25	116	1.2	19.8	**0.14**
209	1906	2003	25.8	24.3	41	0.8	19.6	**0.06**
209	2032	2003	24.3	22.5	3	0.6	18.8	**0.02**
209	2150	2003	22.5	21.6	0	0.5	18.6	**0.01**
209	2202	2003	21.7	20.2	0	0.3	18.4	**0**
209	2305	2003	21.3	20.2	0	0.1	18.6	**0**
210	30	2003	21.5	20.4	0	0.5	19	**0.01**
210	104	2003	20.8	19.7	0	0.5	19.3	**0**
210	202	2003	19.8	19.6	0	0.5	19.4	**0**
210	305	2003	19.8	19.6	0	0.8	19.5	**0**
210	401	2003	19.7	19.5	0	0.6	19.5	**0**

Table B.2. REF-ET output for July 25-28, 2003 data at 1.3 cm height of cut continued

Day	Time	Year	T max	T min	Solar Rad.	Wind	Dew Pt.	ASCE **stPM ETo**
			C	C	W m^{-2}	m s^{-1}	C	**mm h^{-1}**
210	546	2003	19.6	19.3	0	0.9	19.3	**0**
210	604	2003	19.6	19	0	0.7	19.2	**0**
210	711	2003	19.5	19.2	7	0.7	19.3	**0.01**
							SUM	**12.3 mm**

ET (mm) conversion to gallons 18ft^{-2}

ET mm x 10 = mm^3 ha^{-1} x 0.04417 = gal plot $^{-1}$

<u>Conversions:</u>

1 ha = 10000 m^2

1 mm^3 = 264.2 gallons ha^{-1}

Plot size =18 ft^{-2}

12.3 mm x 10 = 123 mm ha^{-1}

123 mm ha^{-1} x 0.04417 = 5.4 gal plot^{-1} 100% ET

5.4 x 0.85 = 4.6 gal plot $^{-1}$ 85% ET

5.4 x 0.70 = 3.9 gal plot^{-1} 70% ET

5.4 x 0.55 = 3.0 gal plot^{-1} 55% ET

Table B.3. Creeping bentgrass irrigation events

			Gallons			
Year	Date	ET (mm)	100%	85%	70%	55%
2003	7/20	11.77	5.2	4.4	3.6	2.9
2003	7/23	11.77	5.2	4.4	3.6	2.9
2003	7/26	9.96	4.4	3.7	3.1	2.4
2003	7/29	12.23	5.4	4.6	3.8	3.0
2003	8/2	5.43	2.4	2.0	1.7	1.3
2003	8/4	6.79	3	2.6	2.1	1.7
2003	8/7	9.06	4	3.4	2.8	2.2
2003	8/10	6.79	3	2.6	2.1	1.7
2003	8/13	8.60	3.8	3.2	2.7	2.1
2003	8/16	8.60	3.8	3.2	2.7	2.1
2003	8/19	9.96	4.4	3.7	3.1	2.4
2003	8/22	10.41	4.6	3.9	3.2	2.5
2003	8/25	10.87	4.8	4.1	3.4	2.6
2003	8/28	12.23	5.4	4.6	3.8	3.0
2003	8/31	9.06	4	3.4	2.8	2.2
2003	9/3	7.02	3.1	2.6	2.2	1.7
2003	9/6	6.11	2.7	2.3	1.9	1.5
2003	9/10	9.28	4.1	3.5	2.9	2.3
2003	9/14	11.77	5.2	4.4	3.6	2.9
2004	7/2	14.04	6.2	5.3	4.3	3.4
2004	7/9	18.11	8	6.8	5.6	4.4
2004	7/13	8.83	3.9	3.3	2.7	2.1
2004	7/16	13.36	5.9	5.0	4.1	3.2
2004	7/21	16.98	7.5	6.4	5.3	4.1
2004	7/29	19.70	8.7	7.4	6.1	4.8
2004	8/4	17.89	7.9	6.7	5.5	4.3
2004	8/9	16.75	7.4	6.3	5.2	4.1
2004	8/13	10.64	4.7	4.0	3.3	2.6
2004	8/18	14.04	6.2	5.3	4.3	3.4
2004	8/23	16.98	7.5	6.4	5.3	4.1
2004	8/27	9.74	4.3	3.7	3.0	2.4
2004	9/15	24.90	11	9.4	7.7	6.1
2004	9/26	27.17	12	10.2	8.4	6.6

Table B.4. Tall fescue irrigation events.

			Gallons			
Year	Date	ET (mm)	100%	85%	70%	55%
2003	7/22	21.51	9.5	8.1	6.7	5.2
2003	7/27	18.11	8	6.8	5.6	4.4
2003	8/2	14.04	6.2	5.3	4.3	3.4
2003	8/6	12.90	5.7	4.8	4.0	3.1
2003	8/11	12.68	5.6	4.8	3.9	3.1
2003	8/16	14.94	6.6	5.6	4.6	3.6
2003	8/21	17.24	7.6	6.5	5.3	4.2
2003	8/26	19.92	8.8	7.5	6.2	4.8
2003	8/31	17.89	7.9	6.7	5.5	4.3
2003	9/5	10.19	4.5	3.8	3.2	2.5
2003	9/11	16.07	7.1	6.0	5.0	3.9
2004	7/16	54.79	24.2	20.6	16.9	13.3
2004	7/22	18.79	8.3	7.1	5.8	4.6
2004	8/6	43.92	19.4	16.5	13.6	10.7
2004	8/18	36.90	16.3	13.9	11.4	9.0
2004	9/3	45.73	20.2	17.2	14.1	11.1

Table B.5. July 2003 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max	T min	Solar Rad.	Wind	Dew Pt.	Creeping bentgrass ASCE stPM ETo	Tall Fescue ASCE stPM ETo
		C	C	W m^{-2}	m s^{-1}	C	mm h^{-1}	mm h^{-1}
198	2003	25.33	23.36	225.65	0.94	16.51	4.31	4.51
199	2003	22.92	21.63	117.25	0.89	17.03	3.31	3.54
200	2003	23.02	21.40	149.96	0.93	17.80	3.89	4.02
201	2003	23.13	21.60	168.63	0.80	17.64	4.37	4.49
202	2003	23.69	22.22	159.74	1.04	17.85	8.57	8.96
203	2003	23.21	21.79	145.49	1.09	17.81	11.60	12.17
204	2003	19.68	18.31	85.04	0.87	16.70	2.06	2.10
205	2003	19.35	17.83	142.58	1.00	13.87	3.61	3.76
206	2003	20.47	18.93	163.00	0.79	14.63	4.27	4.43
207	2003	22.72	21.18	157.71	0.75	16.86	4.20	4.37
208	2003	24.73	23.31	151.88	1.15	18.51	4.37	4.65
209	2003	24.17	22.80	126.79	1.20	18.65	3.57	3.76
210	2003	20.27	19.53	41.63	0.72	18.91	0.99	1.00
211	2003	19.50	18.82	62.71	0.76	17.79	1.46	1.48
212	2003	18.86	18.41	26.58	0.55	18.05	0.58	0.58
213	2003	22.15	21.10	102.87	0.76	19.47	2.46	2.49
						SUM	63.62	66.31

Table B.6. August 2003 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	Creeping bentgrass ASCE stPM ETo mm h^{-1}	Tall Fescue ASCE stPM ETo mm h^{-1}
214	2003	23.02	21.66	155.71	1.00	19.15	3.98	4.08
215	2003	22.09	20.95	87.04	1.04	19.21	2.23	2.32
216	2003	22.60	21.45	132.25	0.97	18.45	3.46	3.59
217	2003	20.25	18.70	109.67	1.09	17.14	2.69	2.75
218	2003	21.07	19.76	124.29	0.67	17.11	3.04	3.11
219	2003	21.04	19.84	97.75	0.67	18.21	2.36	2.42
220	2003	20.76	19.55	75.67	0.65	18.53	1.78	1.81
221	2003	21.48	20.27	106.13	0.79	18.68	2.61	2.65
222	2003	20.64	19.41	108.08	0.73	18.08	2.59	2.61
223	2003	21.85	20.63	152.17	0.80	18.42	3.73	3.77
224	2003	22.24	20.74	94.13	0.59	18.90	2.35	2.39
225	2003	22.73	21.59	82.38	0.56	20.12	2.03	2.05
226	2003	24.20	22.65	111.96	0.53	20.90	2.78	2.82
227	2003	25.28	24.01	139.79	0.68	20.37	3.76	3.9
228	2003	23.26	22.00	100.00	0.95	20.13	2.57	2.61
229	2003	23.59	22.04	123.92	1.08	18.78	3.35	3.5
230	2003	21.86	20.32	152.33	0.73	16.66	3.9	4.03
231	2003	22.18	20.85	124.96	0.78	18.18	3.17	3.27
232	2003	22.50	21.18	140.96	0.77	18.68	3.57	3.68
233	2003	24.00	22.65	140.54	0.74	19.73	3.68	3.82
234	2003	24.39	23.20	132.33	1.18	19.57	3.7	3.91
235	2003	23.75	22.06	120.88	1.02	17.93	3.49	3.69
236	2003	21.51	20.04	135.29	0.83	15.38	3.51	3.71
237	2003	23.08	21.70	145.88	0.92	16.28	4.15	4.41
238	2003	24.74	23.19	140.33	0.96	18.28	4.03	4.29
239	2003	25.82	24.43	132.83	1.08	20.25	3.8	3.99
240	2003	24.47	23.04	106.96	0.66	19.29	2.94	3.12
241	2003	24.59	23.12	118.25	0.94	20.04	3.26	3.42
242	2003	24.43	23.03	95.63	1.03	19.67	2.75	2.98
243	2003	21.77	20.92	60.88	0.78	19.73	1.48	1.56
244	2003	22.68	21.38	90.28	0.97	19.83	2.45	2.56
						SUM	95.19	98.82

Table B.7. September 2003 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	Creeping bentgrass ASCE stPM ETo mm h^{-1}	Tall Fescue ASCE stPM ETo mm h^{-1}
245	2003	23.70	22.25	114.50	0.84	19.03	3.13	3.27
246	2003	22.25	21.07	65.25	0.61	19.63	1.66	1.69
247	2003	19.81	18.80	45.92	0.73	18.03	1.07	1.1
248	2003	18.39	16.83	135.54	0.73	13.55	3.31	3.4
249	2003	16.38	15.02	73.83	0.56	13.13	1.71	1.76
250	2003	15.83	14.65	76.71	0.51	13.18	1.7	1.72
251	2003	18.55	17.12	129.88	0.67	14.23	3.13	3.21
252	2003	18.10	16.27	112.75	0.73	14.01	2.74	2.81
253	2003	17.88	16.56	126.92	0.83	13.03	3.04	3.12
254	2003	17.06	15.42	135.71	0.72	11.09	3.36	3.49
255	2003	17.03	15.53	82.33	0.75	12.35	2.04	2.16
256	2003	18.71	17.83	60.46	0.61	16.49	1.41	1.44
257	2003	21.31	20.18	121.13	1.06	17.86	3.12	3.23
258	2003	18.80	17.90	49.67	0.94	16.70	1.21	1.28
259	2003	16.10	14.34	130.42	0.70	10.47	3.24	3.38
260	2003	16.06	14.33	168.50	0.68	10.79	4.3	4.36
261	2003	15.96	15.18	496.83	1.79	13.02	9.88	9.27
262	2003	18.86	17.58	468.50	1.69	14.23	10.21	9.81
263	2003	19.29	17.75	169.92	0.61	15.03	4.34	4.37
264	2003	20.05	18.70	187.63	0.68	16.37	4.83	4.85
265	2003	18.55	17.95	341.42	1.24	16.96	7.44	7.12
266	2003	17.64	16.11	480.67	1.72	11.55	10.79	10.55
267	2003	15.35	13.74	155.96	0.90	10.71	3.89	4
268	2003	17.46	15.82	120.21	0.65	13.10	3.25	3.33
269	2003	18.71	16.98	105.17	0.92	14.57	2.93	3.06
270	2003	18.68	17.02	71.58	0.96	15.16	2.08	2.17
271	2003	13.93	12.39	83.96	1.42	8.75	2.38	2.56
272	2003	9.92	8.72	94.17	1.63	4.12	2.42	2.58
273	2003	9.26	7.78	126.21	0.77	3.86	2.87	2.95
274	2003	9.49	8.18	82.21	1.07	5.76	1.82	1.88
						SUM	109.3	109.92

Table B.8. July 2004 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max	T min	Solar Rad.	Wind	Dew Pt.	Creeping bentgrass ASCE stPM ETo	Tall Fescue ASCE stPM ETo
		C	C	W m^{-2}	m s^{-1}	C	mm h^{-1}	mm h^{-1}
183	2003	21.92	20.64	141.04	0.85	17.87	3.59	3.68
184	2003	22.95	21.41	103.67	0.57	19.28	2.66	2.72
185	2003	22.56	20.92	92.63	0.49	19.77	2.29	2.34
186	2003	22.75	21.15	109.92	0.63	19.69	2.77	2.84
187	2003	24.41	23.06	150.08	1.33	18.80	4.32	4.6
188	2003	24.29	22.85	157.96	1.18	17.75	4.48	4.75
189	2003	23.73	22.35	160.08	1.13	17.89	4.36	4.62
190	2003	22.89	21.48	163.67	1.19	15.78	4.59	4.9
191	2003	23.43	21.97	152.42	0.89	16.67	4.28	4.55
192	2003	23.19	21.68	96.25	0.87	19.36	2.64	2.8
193	2003	23.31	22.06	125.92	0.74	19.39	3.25	3.35
194	2003	23.48	22.00	128.71	0.98	19.84	3.32	3.41
195	2003	25.05	23.81	176.79	1.35	18.88	4.95	5.22
196	2003	23.89	22.64	142.42	1.75	17.72	4.25	4.6
197	2003	21.30	20.02	147.29	1.96	13.09	4.43	4.83
198	2003	20.35	18.69	182.58	1.21	11.54	5.02	5.35
199	2003	17.63	16.30	61.08	0.36	14.63	1.42	1.47
200	2003	20.60	19.41	115.21	0.64	17.01	2.79	2.84
201	2003	20.91	19.61	159.46	1.01	15.24	4.14	4.33
202	2003	21.10	19.29	120.33	0.57	14.70	3.15	3.32
203	2003	21.93	20.37	154.75	0.65	15.54	4.12	4.29
204	2003	20.77	19.93	41.13	0.73	18.55	1.07	1.13
205	2003	23.67	22.55	93.33	0.95	20.04	2.58	2.73
206	2003	22.89	21.43	139.63	0.69	18.28	3.63	3.75
207	2003	22.33	21.02	132.83	0.82	18.05	3.36	3.46
208	2003	21.70	20.78	75.79	0.70	19.60	1.87	1.91
209	2003	21.34	20.70	62.83	0.66	19.39	1.53	1.54
210	2003	21.72	20.68	166.42	0.95	16.15	4.25	4.45
211	2003	20.71	19.18	123.21	0.77	16.86	3.09	3.18
212	2003	23.10	21.97	83.08	1.23	19.71	2.25	2.42
213	2003	23.76	22.54	118.84	1.24	19.32	3.43	3.65
						SUM	103.88	109.03

Table B.9. August 2004 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	Creeping bentgrass ASCE stPM ETo mm h^{-1}	Tall Fescue ASCE stPM ETo mm h^{-1}
214	2003	23.02	21.66	155.71	1.00	19.15	3.98	4.08
215	2003	22.09	20.95	87.04	1.04	19.21	2.23	2.32
216	2003	22.60	21.45	132.25	0.97	18.45	3.46	3.59
217	2003	20.25	18.70	109.67	1.09	17.14	2.69	2.75
218	2003	21.07	19.76	124.29	0.67	17.11	3.04	3.11
219	2003	21.04	19.84	97.75	0.67	18.21	2.36	2.42
220	2003	20.76	19.55	75.67	0.65	18.53	1.78	1.81
221	2003	21.48	20.27	106.13	0.79	18.68	2.61	2.65
222	2003	20.64	19.41	108.08	0.73	18.08	2.59	2.61
223	2003	21.85	20.63	152.17	0.80	18.42	3.73	3.77
224	2003	22.24	20.74	94.13	0.59	18.90	2.35	2.39
225	2003	22.73	21.59	82.38	0.56	20.12	2.03	2.05
226	2003	24.20	22.65	111.96	0.53	20.90	2.78	2.82
227	2003	25.28	24.01	139.79	0.68	20.37	3.76	3.9
228	2003	23.26	22.00	100.00	0.95	20.13	2.57	2.61
229	2003	23.59	22.04	123.92	1.08	18.78	3.35	3.5
230	2003	21.86	20.32	152.33	0.73	16.66	3.9	4.03
231	2003	22.18	20.85	124.96	0.78	18.18	3.17	3.27
232	2003	22.50	21.18	140.96	0.77	18.68	3.57	3.68
233	2003	24.00	22.65	140.54	0.74	19.73	3.68	3.82
234	2003	24.39	23.20	132.33	1.18	19.57	3.7	3.91
235	2003	23.75	22.06	120.88	1.02	17.93	3.49	3.69
236	2003	21.51	20.04	135.29	0.83	15.38	3.51	3.71
237	2003	23.08	21.70	145.88	0.92	16.28	4.15	4.41
238	2003	24.74	23.19	140.33	0.96	18.28	4.03	4.29
239	2003	25.82	24.43	132.83	1.08	20.25	3.8	3.99
240	2003	24.47	23.04	106.96	0.66	19.29	2.94	3.12
241	2003	24.59	23.12	118.25	0.94	20.04	3.26	3.42
242	2003	24.43	23.03	95.63	1.03	19.67	2.75	2.98
243	2003	21.77	20.92	60.88	0.78	19.73	1.48	1.56
244	2003	22.68	21.38	90.28	0.97	19.83	2.45	2.56
						SUM	95.19	98.82

Table B.10. September 2004 ET data for creeping bentgrass and tall fescue from REF-ET computer program.

Day	Year	T max C	T min C	Solar Rad. W m^{-2}	Wind m s^{-1}	Dew Pt. C	Creeping bentgrass ASCE stPM ETo mm h^{-1}	Tall Fescue ASCE stPM ETo mm h^{-1}
245	2003	20.52	19.22	116.21	0.68	15.61	3.04	3.2
246	2003	19.70	18.38	83.58	0.70	15.91	2.18	2.28
247	2003	19.61	17.91	103.08	0.65	15.10	2.63	2.73
248	2003	20.09	18.38	103.33	0.57	14.91	2.71	2.86
249	2003	20.54	19.05	133.58	0.94	14.99	3.61	3.81
250	2003	19.04	18.58	39.88	0.73	18.03	0.88	0.91
251	2003	19.89	19.31	32.96	0.53	19.04	0.74	0.74
252	2003	20.91	20.35	23.50	1.50	19.82	0.63	0.7
253	2003	19.38	18.53	60.50	1.52	15.95	1.71	1.88
254	2003	18.85	17.14	114.00	0.50	14.20	2.86	2.94
255	2003	19.03	17.21	114.08	0.60	14.95	2.88	2.95
256	2003	19.71	18.17	104.29	0.52	15.59	2.63	2.74
257	2003	19.63	18.27	100.67	0.67	16.07	2.54	2.65
258	2003	18.85	17.83	69.38	0.50	15.85	1.71	1.76
259	2003	18.60	17.23	85.46	0.69	15.42	2.06	2.13
260	2003	20.03	19.36	50.79	0.55	18.00	1.21	1.26
261	2003	20.33	19.63	28.96	1.88	18.84	0.85	0.89
262	2003	15.99	14.91	98.88	2.13	10.68	2.64	2.87
263	2003	15.09	13.04	127.42	0.69	6.81	3.24	3.4
264	2003	13.06	11.29	124.21	0.69	7.11	2.85	2.95
265	2003	14.79	12.89	129.54	0.45	8.07	3.17	3.29
266	2003	18.49	16.61	117.29	0.52	12.79	3.09	3.22
267	2003	19.24	17.25	119.92	0.55	13.44	3.13	3.25
268	2003	18.52	16.76	107.42	0.52	14.25	2.67	2.75
269	2003	18.88	17.20	101.63	0.53	15.21	2.48	2.56
270	2003	18.45	16.75	101.83	0.53	14.62	2.47	2.54
271	2003	16.97	16.50	26.00	0.78	15.48	0.63	0.65
272	2003	18.77	18.14	27.83	1.61	16.89	0.86	0.98
273	2003	17.52	16.00	114.54	0.87	12.59	2.86	2.98
274	2003	16.98	15.58	94.04	0.48	12.92	2.25	2.32
						SUM	67.21	70.19

Vita

Adrienne Janel LaBranche was born in September 10, 1979 in Providence, Rhode Island to Janet Lee LaBranche and Paul Donat LaBranche. She lived in Coventry, Rhode Island with her parents, two older brothers, Timothy and Matthew, and younger sister, Danielle. Adrienne graduated from Coventry High School in 1997 and then moved to South Carolina for college. She graduated from Clemson University in 2001 with a Bachelor of Science degree in ornamental horticulture. While enrolled at Clemson University, Adrienne worked for Dr. T. L. Senn, who introduced her to plant growth stimulants. She was also made an honorary member of the Clemson College Class of 1939. After a year of graduate studies at Clemson University, Adrienne entered the Masters program in 2003 to study turfgrass science at Virginia Polytechnic Institute and State University. At Virginia Polytechnic Institute and State University, she was a member of the graduate student association, CSES recycling committee, and served as chair for the CSES graduate committee.