# RESPONSE OF ‘CAPTIVA’ ST. AUGUSTINEGRASS TO SHADE AND POTASSIUM (K)

By

XIAOYA CAI

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2010

To my beloved parents, sister and friends

## ACKNOWLEDGMENTS

It is a pleasure to thank my advisor, Dr. Laurie E. Trenholm (chair of my supervisory committee) for her encouragement, guidance and support on my coursework and research project. I would like to offer my regards to my committee members, Dr. Jerry Sartain and Dr. Jason Kruse for their valuable suggestion that make me develop an understanding of the research subject. Financial support is provided by Florida Department of Environmental Protection (FDEP). I am also heartily thankful to Basil Wetherington, Nahid Menhaji, and Jason Haugh for their technical support of my project and those who supported me in any respect during the completion of the project. Lastly, I deeply thank my parents (Mr. Mingzhi Cai, and Mrs. Genmei Zhang) and my sister (Shuya Cai) for their love, encouragement, and support.

TABLE OF CONTENTS

LIST OF TABLES

Table page

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

RESPONSE OF 'CAPTIVA' ST. AUGUSTINEGRASS TO SHADE AND POTASSIUM (K)

By

Xiaoya Cai

August 2010

Chair: Laurie E. Trenholm
Major: Horticultural Science

The effects of potassium (K) on stress tolerance of turfgrass have been documented for many environmental stresses, but not for shade tolerance. 'Captiva' St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) was evaluated in this research to determine if K influenced shade tolerance and how Captiva performed under varying shade levels. The study was conducted at the University of Florida Environtron Turfgrass Research Laboratory in Gainesville, FL. Grasses were planted in 15.2 cm plastic pots in a climate-controlled greenhouse. Two consecutive studies were conducted, the first from May to October 2009 and the second from January to June 2010. Grasses were placed in either full sun or under shade structures covered with woven black shade cloth to provide 30, 50, and 70% shade. Potassium was applied as potassium chloride (KCl) (0-0-62) at four rates (0, 0.125, 0.25 or 0.5 lb 1000 $ft^{-2}$) every 30 days, and nitrogen (N) was applied every 60 days at 1 lb 1000 $ft^{-2}$ as slow release urea (46-0-0). In the first and second trials, turf visual quality and color scores, shoot and root dry weights, and chlorophyll concentration were lowest at 70% shade, and highest at 30% shade. Quality also increased as K rate increased. With increased shade levels, leaf length increased, while leaf width decreased. Total Kjedahl Nitrogen (TKN) and tissue K concentrations in leaves increased as shade levels increased from 0 to 70%. There was no difference in thatch accumulation due to

K rates. Greatest thatch was found at 70% shade, while the lowest was at 30% shade. In the first trial, turf treated with higher K rates had longer leaf length, greater root dry weight and tissue K concentration. Two results from this greenhouse study showed that Captiva could maintain acceptable quality at 30% and up to 50% shade, and turf at 0.5 lb 1000 $ft^{-2}$ K rate had best performance under shade, which indicated that K may help turfgrass growing in a shaded environment by improving turf visual quality scores, root growth, and tissue K concentration. Additional field plot research should be conducted to verify these responses in a landscape environment prior to making an official recommendation of K application to turf in shade.

# CHAPTER 1
# INTRODUCTION

St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) is widely used as a warm-season lawngrass. This species is a perennial that is adapted to tropical and subtropical climates. St. Augustinegrass is one of the most shade tolerant warm-season grasses (Trenholm et al., 2000a). ‘Captiva’ is a new dwarf cultivar of St. Augustingrass that is currently in production. Captiva has improved tolerance to southern chinch bug *(Blissus insularis* Barber*)* and the plant hopper *(Liburnia pseudoseminigra* Muir & Gifford), which could minimize the need for chemical inputs (Trenholm and Kenworthy, 2009).

## Effect of Light Intensity on Plant Growth

Different cultivars of St. Augustinegrass were observed to exhibit different physiological and morphological responses to shade, such as stimulated seedhead formation, and altered chlorophyll concentration and composition (Peacock and Dudeck, 1981). These authors reported that the cultivar ‘Bitterblue’ responded best to shade. Winstead and Ward (1974) reported that St. Augustinegrass growing in shade had decreased leaf longevity, net photosynthesis, respiration, and carbohydrate content of stolons. Trenholm and Nagata (2005) found the best shade tolerance in the dwarf cultivars of St. Augustinegrass. Shading has significant impact on turf performance, and it can deplete carbohydrates by tissue elongation and reduce overall turf health and vigor (Trenholm, 2003). According to one report (Smith and Whiteman, 1983), St. Augustinegrass maintained a greater growth rate than carpetgrass (*Axonopus compressus* Beauv.), signal grass (*Brachiaria decumbens* Stapf.), humidicola (*B. humidicola* Schweick.), green summer grass (*B. miliiformis* J. Presl), and buffalo grass (*Paspalum conjugatum* P.J. Bergius) under heavy shade that provided only 20% light transmission.

In a study of silicon (Si) influence on drought and shade tolerance of St. Augustinegrass, Si was reported to have little effect on St. Augustinegrass under shaded conditions (Trenholm et al., 2004). To determine the shade levels that the various St. Augustinegrass cultivars can tolerate, a study was conducted to rank the relative shade tolerance of cultivars (Trenholm and Nagata, 2005). Each cultivar had best turf performance at 30% shade. At 50% shade, there were no differences in quality between cultivars. Leaf length of each cultivar increased as shade levels increased; however, due to reduced density and shoot count, there was a reduction in clipping weights at 50 and 70% shade (Trenholm and Nagata, 2005).

The responses of ‘Diamond’ zoysiagrass (*Zoysia japonica* Steud.) were evaluated under different light intensities. The best turf performance was at 30 and 60% shade levels in trial 1, and acceptable turf quality was maintained at up to 73% shade in trial 2. In trial 2, turf had higher clipping yields and lower total nonstructural carbohydrate (TNC) content at 47, 73, and 87% shade than under full sun (Qian and Engelke, 2000).

Light intensity is prominent among the environmental factors affecting plant growth rate. Plants grown under different light intensities show different carboxylation efficiencies, light capture potential, rates of net carbon (C) exchange and capacity for nitrogen (N) assimilation (Bethlenfalvay and Phillips, 1977). Because shade is found in many landscapes, maintaining good quality turfgrass can be difficult for many home lawns. Shade stresses can be a major problem in the culture of quality turfgrass in terms of growth, morphological, and anatomical responses (Beard, 1997). An estimated 20 to 25% of the lawns in the United States are grown under some degree of tree or structural shade stress (Beard, 1973). This causes not only a reduction in the incident solar light, but also modifications in a number of other micro-environmental parameters, such as more moderate air and soil temperatures, higher atmospheric relative humidity, and reduced wind velocity (Beard, 1997). Shading from trees may reduce the light below that needed for adequate growth and may also alter the spectral quality of the light received by the grass, resulting in alteration of growth habitat.

Generally, symptoms of turf growth in shade include a less-dense turf sward, fine leaf development, reduced root growth and shoot density, more upright and succulent vertical growth, and long, spindly leaf blade and stem, all of which make turf more susceptible to disease and less tolerant to traffic, heat, cold, and drought (Dudeck and Peacock, 1992). Turfgrass growing in shade generally requires less total N than grass in full sunlight because of the reduced rates of photosynthetic activity. Excess N application on shaded grasses prompts the turf to attempt to produce more shoot tissue, resulting in a depletion of stored carbohydrates and less stress tolerant turf. Disease is often more prevalent in shaded conditions due to increased soil moisture, lack of air movement, and decreased stress tolerance of turf. A study on the response of tall fescue (*Festuca arundinacea* Schreb.) to brown patch (*Rhizoctonia solani* x AG-1IA Kühn) under shaded conditions showed that plants had significantly greater disease severity under shaded conditions compared to full sun, and the brown patch severity was greatly influenced by the morphological and physiological effects of shading (Zarlengo et al., 1994).

Plant physiological responses can be measured by the chlorophyll concentration which is correlated to turf color and plant vitality measurement (Pocklington et al., 1974). Plant pigments absorb wavelengths within the visible spectrum (400-700 nm) and reflect near-infrared (NIR) radiation (700-1300 nm) (Knipling, 1970; Asrar et al., 1984). Total chlorophyll (a and b) increase with decreased irradiance. There are various instruments to measure relative chlorophyll indices. The Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) uses ambient and reflected light at 700 and 840 nm, which could estimate the quantity of leaf chlorophyll (www.specmeters.com).

Barley (*Hordeum vulgare* L. cv. Boone) seedlings under high light intensity (550 mol m$^{-2}$ s$^{-1}$) had greater chlorophyll per leaf area and higher chlorophyll a to b ratios than low light intensity (55 mol m$^{-2}$ s$^{-1}$) (Torre and Burkey, 1990). Four species of Pacific Northwest conifer seedlings were evaluated under shaded conditions. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), douglas-fir (*Pseudotsuga menziesii* Franco), western redcedar (*Thuja plicata* Donn ex D. Donn), and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) all responded similarly to shade. They showed greatest height and chlorophyll concentration under 75% shade. Compared to 0% shade, higher total biomass production and lower shoot to root ratio was found at 75% shade (Khan, et al., 2000). The reduced irradiance levels affected certain plant growth characteristics, including the initiation and outward growth of the indeterminate lateral stems.

In addition to light intensity, light wavelength is also an important parameter in morphogenic changes in plants. Turfgrass growing in shaded conditions receives varied spectral irradiance due to the interception of light by tree canopies (McVey et al., 1969). Near ultraviolet light and blue light regions stimulate or inhibite callus growth and shoot initiation while red and far red light do not appear to affect callus growth or shoot initiation (Seibert et al., 1975). Bermudagrass (*Cynodon dactylon* L. Pers) cultivars of ‘Tifdwarf’, ‘Tifway’, ‘Floraturf’ (FB-137) and ‘Common’ (local sprigs) performed better under shorter wave lengths (<575 nm) (McBee, 1969). Bell et al. (2000) assessed the spectral quality effects of deciduous shade, coniferous shade, building shade and full sun on Kentucky bluegrass (*Poa pratensis* L.). There were more high activity quanta (red [600~700 nm] + blue [400~500 nm]) filtered by deciduous and conifer shade than by building shade. Increased shade density changed blue and red irradiance relative to total irradiance, thus decreasing plant photosynthesis. The changes in light intensity and spectral composition affected tall fescue photomorphogenesis. Low photosysthetic photon flux and high red: far-red ratios led to increased tillering, leaf blade width and thickness, and chlorophyll concentration (Wherley et al., 2005).

A study on response of seashore paspalum (*Paspalum vaginatum* Swartz.) to morning shade (AMS) and afternoon shade (PMS) indicated that AMS had 9% higher color rating, 11% higher density, and 28% less tissue injury than those of PMS 7 days after the grass was subjected to wear injury. Under the stress of wear plus soil compaction at 7 days after treatment (DAT), turf in AMS had 12% higher color rating, 9% higher density, and 4% less tissue injury compared to PMS. As a result, when turf was subjected to wear stress or wear plus soil compaction, turfgrass performance was better in morning shade than that in afternoon shade (Jiang et al., 2003). In another study, seashore paspalum was found to have better tolerance to low light than bermudagrass. There were significant differences between the two species in turf quality, color, density, canopy photosynthetic rate, canopy chlorophyll index, canopy spectral reflectance, and leaf dry weight under 70 and 90% shade (Jiang et al., 2004). A study was conducted in growth chambers with three different light intensities (2.7, 10.8, and 43 klux) to characterize the photosynthetic and respiration responses of ‘Merion’ Kentucky bluegrass and ‘Pennlawn’ red fescue (*Festuca rubra* L.). Under lower light intensity, net photosynthesis, dark respiration, light saturation levels, and light compensation points were reduced in both species (Wilkinson et al., 1975).

Previous studies have addressed the effects of light intensity, N supply, and their combined effects on the growth, leaf area, and shoot to root ratios in species of devil's bit scabious (*Succisa pratensis* Moench), perennial ryegrass (*Lolium perenne* L.), and velvet grass (*Holcus lanatus* L.).

Nutrient solutions supply rates corresponded to total additions of either 10, 40, or 160 mg N per pot twice a week. There were two irradiance treatments of either 130 or 65 W $m^{-2}$. Results indicated that the combination of the higher light level and lowest N caused highest shoot to root ratio (Olff et al., 1990). Similar results were reported in wall-lettuce (*Mycelis muralis* L. Dumort). High irradiance and low N produced significantly greater allocation of shoot mass to root, with lower leaf area ratio and leaf mass ratio due to the interactive effects of light level and N supply on leaf mass per unit area (Clabby and Osborne, 1999). Three heathland sites (barren infertile land) in the Netherlands showed that fertilization with 75 kg N, 25 kg phosphorus (P) and 50 kg potassium (K) $ha^{-1}$ $year^{-1}$ under 50% shade reduced total phenolics and mycorrhizaql colonization in ericaceous plants, compared to full sun (Hofland-Zijlstra and Berendse, 2009). In potted plants of guayule (*Parthenium argentatum* Gray) grown in relatively fertile soil, rubber production decreased by 36%, and dry weight of stems and roots decreased by 14.5% with 25% reduction in light intensity, while plants grown in infertile soil had greatest leaf weight under 75% shade and no significant effect on rubber production and dry weight of stems and roots with moderate shading. Large seed production was also reduced with decreased light intensity, but there was no association between seed quality alternation and light intensity reduction (Mitchell, et al., 1944)

A study of light and nutrient effects on leaf size, carbon dioxide ($CO_2$) exchange, and leaf anatomy in wild strawberry (*Fragaria vesca* L.) showed that leaf size and thickness, net $CO_2$ exchange rate, and mesophyll cell volume increased under high light intensity (21.9 E $m^{-2}$ $d^{-1}$), compared with those at low light intensity (4.3 E $m^{-2}$ $d^{-1}$) (Jurik et al., 1982). Photosynthesis in woodland strawberry was shown to be depressed by high light intensity due to massive starch accumulation in the chloroplasts (Chabot and Chabot, 1977). Hybrid geranium (*Pelargonium* ×

*hortorum* Bailey) growth was evaluated under high (800–1200 mE $m^{-2}$ $s^{-1}$), medium (300–600 mE $m^{-2}$ $s^{-1}$), and low (100–160 mE $m^{-2}$ $s^{-1}$) quantum flux densities. Total leaf area increased by 25% under low light, but dry weight decreased by 25% compared to plants grown under medium or high light. Flower time and maturation were also affected by quantum flux density (Armitage, et al., 1983). Leaves of large leaf pennywort (*Hydrocotyle bonariensis* Lam.) were smaller and thicker under high photosynthetically active radiation (PAR) (48 mol $m^{-2}$ $day^{-1}$) compared to low PAR (4.8 mol $m^{-2}$ $day^{-1}$) (Longstreth et al., 1981). Net assimilation rate of grasses decreased with increased shading due to the stronger dependence of photosynthetic rate on illuminance (Ludlow et al., 1974). Previous work on soybean (*Glycine max*. L. Merr.) has shown lower rate of plant root growth and less response of mycorrhizae at low light intensity (170 µE $m^{-2}$ $s^{-1}$) compared to high light intensity (700 µE $m^{-2}$ $s^{-1}$) (Bethlenfalvay and Pacovsky, 1983).

## Turfgrass Shade Tolerance Improvement

Developing good management programs for turf growing in shade is essential. St. Augustinegrass had the best tolerance for shade, while zoysiagrass and centipedegrass (*Eremochloa ophiuroides* [Munro.] Hackel) tolerated moderate shade. Bahiagrass (*Paspalum notatum* Fluegge), seashore paspalum and bermudagrass are not recommended for shaded sites (Trenholm, 2003). Management strategies for improving turf performance under shade include increasing the mowing height to allow for a deeper root system, and a more stress tolerant grass. Reducing N fertilization and irrigation under shade are also important to reduce disease and prevent excess grass growth (Harivandi and Gibeault, 1997). In many cases, grass growth may be improved by trimming tree canopies to allow more light and air (Trenholm, 2003). It is also important to reduce additional stresses such as traffic, Potential Hydrogen (pH) extremes and saline water on turf growing in shade.

Growth regulators have been shown to enhance turf's ability to recover from injury under shade (Qian and Engelke, 1998). Creeping bentgrass (*Agrostis stolonifera* L.) exhibited reduced turf quality and covers under 80% shade. Turf covers increased from 6 to 33%, and tillers increased from 40 to 52% after trinexapac-ethyl (TE) application at 0.042 and 0.070 kg a.i. $ha^{-1}$. Under 80% shade treatment, plots treated with low N (150–185 kg $ha^{-1}$ $season^{-1}$) had greater turf cover than those treated with high N (212–235 kg $ha^{-1}$ $season^{-1}$). In another study, no difference was seen in turf cover of creeping bentgrass after TE applications (0, 0.025, or 0.050 kg a.i. $ha^{-1}$). The authors attributed lack of response to treatment levels being too low to elicit responses (Goss et al., 2002). Trinexapac-ethyl was shown to greatly enhance shade tolerance of Diamond zoysiagrass (Qian and Engelke, 1999), and excessive shade-induced shoot elongation was shown to be effectively suppressed by TE, converting an upright leaf canopy to a more prostrate structure. They found that TE was an effective tool to reduce mowing requirements under heavy shade. Under 85 to 90% shade and traffic free conditions, TE application maintained an acceptable stand of supina bluegrass (*Poa supina* Schrad.) for 4 to 6 months, while Kentucky bluegrass quality became unacceptable within 2 to 4 months. The color of supina bluegrass and chlorophyll levels of both species were enhanced by TE applications under the reduced irradiance of approximately 1 to 5 mol $m^{-2}$ $d^{-1}$ (Stier and Rogers, 2001). Trinexapac-ethyl was also an effective management tool to enhance ‘Meyer’ zyosiagrass performance in shaded conditions, but most zoysiagrass was dead under 89% shade even when treated with TE. The tiller density of Meyer under full sun and 77% shade was increased by monthly TE application of 96 g. a.i. $ha^{-1}$, and turf quality loss under 77% shade was delayed due to monthly TE application (Ervin et al., 2002).

## Effect of Potassium (K) on Plant Growth

Potassium (K) is important for healthy turfgrass growth and development, and helps improve plants' resistance to biotic and environmental stresses, such as drought, wear, disease, and excessive temperature (Turner and Hummel, 1992). It can additionally aid in the production of starches, promote root growth, and assist in stomatal regulation (Wallingford, 1980). Although K is not the constituent of any plant structure and compound, it is essential for regulatory roles to sustain plant growth and reproduction, such as photosynthesis, protein synthesis, ionic balance control, and regulation of plant stomata and water use (Harrewijn, 1979).

There are many factors affecting turf K requirements, including clipping removal, irrigation, and soil texture. In order to maintain satisfactory growth, larger and more frequent applications of K are generally required after removing clippings (Duble, 1992). Nus (1995) found significant correlations between total $K^+$ uptake and root parameters. The longer and denser root hair had stronger affinity for $K^+$ uptake.

Since K is involved in many plant growth processes, its deficiency can cause many problems. These include failure to synthesize carbohydrates into proteins and produce new cells, decreased growth of meristematic tissue that permits replacement of diseased tissues, and thinning cell walls and epidermal tissues (Harrewijn, 1979). Potassium effects on stomatal function can influence plant ability to regulate moisture status (Nus, 1995). In terms of effects on transpiration, K is the major osmoticum to attract water into the guard cells, opening the stomata and initiating transpiration (Nus, 1995). Maximum response to K fertilization was shown to require adequate supplies of other plant nutrients, because there were competing effects on uptake between K and other nutrients (Callahan et al., 1978). When plants were grown under ammonium ($NH_4^+$) as the sole N source, high K levels promoted root growth, dry matter and N accumulation in the shoot (Xu et al., 1992).

Turfgrass has been shown to not respond as readily to K as to N. Meyer zoysiagrass showed increased top and stolon growth during establishment in response to K in one study (Juska, 1959), yet had few differences in establishment in response to K in other research on Meyer (Fry and Dernoeden, 1987). In creeping bentgrass, an interaction between N and K was observed in turf quality. With increased K, less N was required to attain maximum quality, indicating that higher K levels can affect N requirement (Christians et al., 1979). Higher K rates, relative to N, were required for better 'Tifgreen' bermudagrass appearance and growth, but there was no significant increase in tissue K concentration (Snyder et al., 2000). A study on effects of K to N fertilization ratios on Tifway bermudagrass growth and quality showed that increasing K fertilization beyond a K to N fertilization ratio of 1 to 2 had no effect on turfgrass visual quality, root and shoot growth, and tissue K uptake (Sartain, 2002).

The influence of applied nutrients on yield and nutrient accumulation in Tifway bermudagrass and 'Medalist 11' perennial ryegrass were evaluated. Different N fertilization rates affected the P, K, and magnesium (Mg) requirements of both turfgrasses. A high N rate of 20 g $m^{-2}$ every 8 weeks reduced yields of both grasses due to K exclusion (Sartain and Dudeck, 1982). In another study, the growth and color of bermudagrass were extended by late seasonal (October) N (0, 4.9, and 9.8 g $m^{-2}$) and K (0, 4.1, or 8.2 g $m^{-2}$) applications. There were no changes in turfgrass color or TNC levels with any level of K fertilization, while fall or spring turfgrass color ratings increased by N application or combination of N and K application. Nitrogen applications also increased leaf K concentration (Goatley el at., 1994). The effects of applied K in combination with other nutrients have been studied on bermudagrass growth, quality, and thatch accumulation. Potassium application and clipping return did not affect overall mean thatch accumulation. Combination of K and Mg application reduced calcium (Ca) levels and increased bermudagrass clipping yield (Sartain, 1993).

Potassium influences on wear tolerance of hybrid bermudagrass (*Cynodon dactylon* L. x *C. transvaalensis* Burtt-Davy.) and seashore paspalum were evaluated, and both species improved wear tolerance with greater shoot density, shoot moisture, and shoot tissue K concentration. (Trenholm, et al., 2000b). Trenholm et al. (2001) also conducted a study of effects of potassium silicate on wear tolerance of seashore paspalum. Better turf quality correlated with higher leaf tissue K concentration and lower Si concentration, and wear injury was reduced from 35 to 14% with K application or to 20% with Si and K application. Another study evaluated effects of N and K on wear tolerance and recovery of perennial ryegrass. Wear was applied using a differential slip wear (DSW) device and also as grooming brush wear (GBW). Through the visual ratings and a relative chlorophyll index from spectral readings of GBW, wear tolerance was reduced linearly as K rate increased from 49 to 441 kg $ha^{-1}$ $yr^{-1}$ (Hoffman et al., 2010). Dormancy of perennial ryegrass was shown to be delayed by a well-balanced fertility ratio and rate (450 kg $ha^{-1}$ N, 50 kg $ha^{-1}$ P, and 250 kg $ha^{-1}$ K) without causing winter injury. There was no difference in color, density, or growth in response to K rate (50, 150, 250, 350, 450, 550, and 650 kg $ha^{-1}$), but K rates that increased from 50 to 650 kg $ha^{-1}$ were shown to increase cold hardiness of the turf during the winter (Razmjoo and Kaneko, 1993).

Fitzpatrick and Guillard (2004) noted that Kentucky bluegrass showed inconsistent responses to K fertilization. Across varying N rates (0, 98, 196, and 294 kg $ha^{-1}$ $yr^{-1}$) and clipping management, K rates (0, 81, 162, and 243 kg $ha^{-1}$ $yr^{-1}$) had no effect on clipping yields and quality even though soil extractable K levels tested low. Nitrogen recovery and use efficiency increased with higher K rate, and decreased with the highest N rate (294 kg $ha^{-1}$ $yr^{-1}$)

even when the K rate was higher. There were no yield or quality responses to tissue K concentration.

Potassium supply changed the soluble exudates of maize and significantly affected the total amounts of sugars, organic acids, and amino acids exuded $g^{-1}$ root dry matter (Kraffczyk et al., 1984). Potassium deficiency was shown to decrease photosynthesis by increasing mesophyll resistance to $CO_2$ in sugar beet plants (*Beta vulgaris* L.) (Terry and Ulrich, 1973). Cauliflower (*Brassica oleracea* var. botrytis L.) grown with various K rates (0.2, 0.4, 0.8, 2.0 and 4.0 mM) showed different responses of growth, dry matter, and tissue K concentration. Best growth and optimum dry matter were produced with 4 mM K rate. Plants with lower K rates showed decreased stomatal aperture in leaves that associated with increased stomatal resistance, and K deficiency in leaves also showed poor tissue hydration (Singh and Sharma, 1989). The effects of K nutrition on growth of young tomato (*Lycopersicon esculentum* Mill.) plants in sand culture were examined. Potassium concentration in nutrient solution was correlated with the dry mater content, flower number, fruit set, and yield (Besford and Maw, 1975).

The objectives of this research were 1) to determine the shade tolerance of Captiva St. Augustinegrass and 2) to evaluate the effect of K on shade tolerance of Captiva.

# CHAPTER 2
# MATERIALS AND METHODS

Two consecutive experiments were conducted in a climate-controlled greenhouse at the Environtron Turfgrass Research Laboratory at the University of Florida in Gainesville, FL. The first experiment was conducted from May 2009 through October 2009 and the second from January 2010 through June 2010.

In May 2009, St. Augustinegrass cultivar, Captiva, was established in 15.2 cm plastic pots. Media used was 50% Fafard 2 mix (Conrad Fafard, Agawam, MA) and 50% sand (304 T Sand of Florida Rock Industries Keuka Sand Mine, Interlachen, FL). During the establishment stage, grasses were kept in full sunlight under conditions of optimal irrigation until all pots had established uniform cover, density, and shoot growth. There was no fertilization during establishment, and grasses were mowed to 6.4 cm prior to initiation of treatments.

Shade treatments were provided by polyvinyl-chloride (PVC) structures covered with woven black shade cloth to supply shade at 30, 50, or 70% of full sunlight. Structures measured 211.8 cm wide, 173.7 cm tall and 211.8 cm long.

There were four potassium (K) treatments (0, 0.125, 0.25, and 0.5 lb 1000 $ft^{-2}$). Potassium treatments were applied as potassium chloride (KCl) (0-0-62) every 30 days throughout each trial period. The interval between each treatment application was referred to as a Fertilizer Cycle (FC).

Grasses were mowed at 6.4 cm by hand monthly throughout each experiment. Nitrogen (N) was applied to all pots at 1 lb 1000 $ft^{-2}$ as slow release urea (46-0-0) every 60 days. The pots were rotated within shade structures weekly to reduce variability. In the first trial during the summer months, irrigation was applied 5 times a week at 200 ml water each time to four shade levels. In the second trial during the winter months, irrigation was applied 3 times a week at 200 ml water each time to treatments at 0 and 30% shade, and 100 ml water each time to those at 50 and 70% shade. Under the drought stress at 0 shade in trial 1, irrigation was applied 5 times a week at 400 ml water each time for grass recovery.

Greenhouse temperature was monitored using a Hobo temperature data logger (Onset Computer Corporation, Bourne, MA), and light intensity was also measured weekly by LI-189 Quantum/Radiometer/Photometer (LI-Corporation, Lincoln, NE).

Turf was visually rated twice a month for turf quality and color. Turf quality was based on turf vigor, color uniformity, and lack of disease and weed infestations. Visual scores were ranked from 1 to 9, with 1 equaling brown, poor turf and 9 representing optimal grass appearance, color and density. A score of 6 was considered a minimum value for acceptable turf quality. Shoot growth was measured once a month by mowing each pot at 6.4 cm with scissors and collecting all clippings. A Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) was used once a month to measure chlorophyll index (CI). This instrument measures reflected light at 700 and 840 nm to calculate a relative CI, which has been used to quantify turf quality and stress prior to visible symptoms.

The clipped leaves were sampled once a month for Total Kjeldahl Nitrogen (TKN) (Kjeldahl, 1883) and K concentration. Leaves were measured for length from the base of the blade to the apex in centimeters. Tissue samples were dried for 96 hours at 65 ºC, ground in a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO), and analyzed for TKN and tissue K concentration in the Analytical Research Lab (ARL) at the University of Florida.

At the termination of each study, shoots, roots, and thatch were separated and dried for 96 hours at 65 ºC. Shoots were then analyzed for TKN and tissue K concentration as described above, while roots were weighed.

Thatch was separated from green living tissue by hand selection of aboveground dead tissues and organic debris, and dried for 96 hours at 65 ºC. Dried samples were weighed.

The experimental design was a nested design with 4 replications. Potassium treatments were randomized within each shade level for a total of 64 experiment units. Data were analyzed with the SAS analytical program (SAS, 2009) to determine treatment differences at the 0.05 level of significance and means were separated with the Waller-Duncan k-ratio t test. There were numerous significant interactions between the first and second trials, so data were presented separately by trial.

CHAPTER 3
EFFECT OF POTASSIUM (K) ON ‘CAPTIVA’ ST. AUGUSTINEGRASS PERFORMANCE UNDER VARYING SHADE LEVLES

## Introduction

St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) is widely used as a warm-season lawngrass. This is one of the most popular lawngrass species used throughout the southern United States. St. Augustinegrass has better shade tolerance than many other warm-season grasses (Trenholm et al., 2000a). ‘Captiva’ is a new dwarf cultivar of St. Augustingrass, which is characterized by dark green, short, narrow leaf blades and reduced vertical leaf extension. Captiva has improved tolerance to southern chinch bug (*Blissus insularis* Barber) and the plant hopper (*Liburnia pseudoseminigra* Muir & Gifford) (Trenholm and Kenworthy, 2009).

There were many commonly produced cultivars of St. Augustinegrass, such as ‘Palmetto’, ‘Delmar’, ‘Bitterblue’, and ‘Floratam’. They were observed to exhibit different physiological and morphological responses to shade (Peacock and Dudeck, 1981). These authors reported that the cultivar Bitterblue responded best to shade. Trenholm and Nagata (2005) found the best shade tolerance in the dwarf cultivars of St. Augustinegrass, and with best turf performance in all cultivars at 30% shade. They also reported increased leaf length and decreased clipping weights at higher shade levels.

The responses of ‘Diamond’ zoysiagrass (*Zoysia japonica* Steud.) were evaluated under different light intensities. The best turf performance was at 30 and 60% shade levels in trial 1, and acceptable turf quality was maintained up to 73% shade in trial 2. Turf had decreased root mass and number with increasing shade levels. In trial 2, turf had higher clipping yields and lower total nonstructural carbohydrate (TNC) content at 47, 73, and 87% shade than under full sun (Qian and Engelke, 2000). Tegg and Lane (2004) reported that creeping bentgrass (*Agrostis stolonifera* L.), supine bluegrass (*Poa supina* Schrad.), tall fescue (*Festuca arundinacea* Schreb.)

and bermudagrass (*Cynodon dactylon* L. Pers) showed declined quality under high shade levels, which were indicated by increased thin, succulent vertical growth, and a less-dense turf sward. They also found supine bluegrass and tall fescue had acceptable turf quality under 56 and 65% shade. Turfgrass shade tolerance can be determined by vertical shoot elongation rate under shaded conditions.

The study of shade effects on tall fescue growth showed decreased plant dry matter production at 70% shade due to fewer tillers per plant (Allard and Nelson, 1991). They reported higher shoot to root ratio and leaf area ratio from plants grown at 70% shade than at full sun. Compared to high irradiance (full sun), turf at low irradiance (70% shade) had 54 or 65% longer leaf blades, 56 or 77% more leaf area, but 12% thinner and 18 or 25% lower specific leaf weight (Allard and Nelson, 1991). Minotta and Pinzauti (1996) reported survival rate, dry weight, leaf area and specific leaf weight of beech (*Fagus sylvatica* L.) increased as light level increased

Shade stresses can be a major problem in the culture of quality turfgrass in terms of growth, morphological, and anatomical responses (Beard, 1997). Winstead and Ward (1974) reported that St. Augustinegrass growing in shade had decreased leaf longevity, net photosynthesis, respiration, and carbohydrate content of stolons. Generally, turf growing in shade has a less-dense turf sward, fine leaf development, reduced root growth and shoot density, and more upright and succulent vertical growth, all of which make turf more susceptible to disease and less tolerant to traffic, heat, cold, and drought (Dudeck and Peacock, 1992). Disease is often more prevalent in shaded conditions, due to modifications in a number of other micro-environmental parameters, such as more moderate air and soil temperatures, higher atmospheric relative humidity, and reduced wind velocity (Beard, 1997). According to one report (Smith and Whiteman, 1983), St. Augustinegrass maintained a greater growth rate than carpetgrass

(*Axonopus compressus* Beauv.), signal grass (*Brachiaria decumbens* Stapf.), humidicola (*B. humidicola* Schweick.), green summer grass (*B. miliiformis* J. Presl), buffalo grass (*Paspalum conjugatum* P.J. Bergius) under heavy shade that provided only 20% light transmission.

Developing good management programs for turf growing in shade is essential. There are many ways to improve turf performance under shade, including increasing mowing height, reducing nitrogen (N) fertilization and irrigation, and application of growth regulators (Qian and Engelke, 1998; Harivandi and Gibeault, 1997). In many cases, grass growth may be improved by trimming tree canopies to allow more light and air (Trenholm, 2003).

Potassium (K) is important in helping to improve plants' resistance to biotic and environmental stresses, such as drought, wear, disease, and excessive temperature (Turner and Hummel, 1992). It can additionally aid in the production of starches, promote root growth, and assist in stomatal regulation (Wallingford, 1980). Potassium was found to be essential for regulatory roles that sustain plant growth and reproduction, such as photosynthesis, protein synthesis, ionic balance control, and regulation of plant stomata and water use. Potassium deficiency was shown to cause failure to synthesize carbohydrates into proteins and produce new cells, decreased growth of meristematic tissue, and thinning cell walls and epidermal tissues (Harrewijn, 1979).

Maximum response to K fertilization was shown to require adequate supplies of other plant nutrients (Callahan and Overton, 1978). The effects of applied K in combination with other nutrients have been studied on bermudagrass growth, quality, and thatch accumulation. Potassium application and clipping return did not affect overall mean thatch accumulation. Combination of K and magnesium (Mg) application reduced calcium (Ca) levels and increased bermudagrass clipping yields (Sartain, 1993).

When plants were grown under ammonium ($NH_4^+$) as the sole N source, higher K levels promoted root growth and shoot dry mater (Xu et al., 1992). With increased K, less N was required to attain maximum quality in 'Merion' Kentucky bluegrass (*Poa pratensis* L.) (Christians et al., 1979). Increasing K fertilization beyond a K to N fertilization ratio of 1 to 2 had no effect on 'Tifway' bermudagrass visual quality, root and shoot growth (Sartain, 2002). Sartain (1993) reported that K application increased clipping yields of Tifway bermudagrass when clippings were removed.

The study of mature, alternate-bearing pistachio (*Pistacia vera* L.) trees was reported to have no relationship between root growth and K uptake from the soil (Rosecrance et al., 1996), while Liang et al. (2007) reported that K humate application promoted the root growth significantly in ginger (*Zingiber officinale* Rosc.). Potassium concentration in nutrient solution was correlated with the dry matter content, flower number, fruit set, and yield of young tomato (*Lycopersicon esculentum* Mill.) plants (Besford and Maw, 1975). In a study of the influences of N and K on the growth and chemical composition of Kentucky bluegrass, clipping weights, weights of underground plant parts (root and rhizomes) and tops, vigor scores, tiller counts, blade widths were increased by K application (Monroe et al., 1969).

Fitzpatrick and Guillard (2004) noted that Kentucky bluegrass showed inconsistent responses to K fertilization. Across varying N rates (0, 98, 196, and 294 kg $ha^{-1}$ $yr^{-1}$) and clipping management, K rates (0, 81, 162, and 243 kg $ha^{-1}$ $yr^{-1}$) had no effect on clipping yields and quality even though soil extractable K levels tested low. Nitrogen recovery and use efficiency increased with higher K rate, and decreased with the highest N rate (294 kg $ha^{-1}$ $yr^{-1}$) even when the K rate was higher. There were no yield or quality responses to tissue K concentration.

Trenholm et al. (2000) reported hybrid bermudagrass (*Cynodon dactylon* L. x *C transvaalensis* Burtt-Davy.) and seashore paspalum (*Paspalum vaginatum* Swartz.) exhibited improved wear tolerance with greater shoot tissue K concentration. Better turf quality and color, shoot density, and wear tolerance of two paspalum ecotypes correlated with K application. However, Johnson et al. (2003) found there was no significant effect of K on creeping bentgrass quality, and tissue K concentration showed a weak correlation with turf quality.

The objective of this study was to evaluate the shade tolerance of Captiva and to determine the effect of K rate on turf visual quality and color scores, shoot and root dry weights, leaf length and width, and thatch accumulation of Captiva St. Augustinegrass under varying shade levels.

## Materials and Methods

Two consecutive experiments were conducted in a climate-controlled greenhouse at the Environtron Turfgrass Research Laboratory at the University of Florida in Gainesville, FL. The first experiment was conducted from May 2009 through October 2009 and the second from January 2010 through June 2010.

In May 2009, St. Augustinegrass cultivar, Captiva, was established in 15.2 cm plastic pots. Media used was 50% Fafard 2 mix (Conrad Fafard, Agawam, MA) and 50% sand (304 T Sand of Florida Rock Industries Keuka Sand Mine, Interlachen, FL). During the establishment stage, grasses were kept in full sunlight under conditions of optimal irrigation until all pots had established uniform cover, density, and shoot growth. There was no fertilization during establishment, and grasses were mowed to 6.4 cm prior to initiation of treatments.

Shade treatments were provided by polyvinyl-chloride (PVC) structures covered with woven black shade cloth to supply shade at 30, 50, or 70% of full sunlight. Structures measured 211.8 cm wide, 173.7 cm tall and 211.8 cm long.

There were four K treatments (0, 0.125, 0.25, and 0.5 lb 1000 $ft^{-2}$). Potassium treatments were applied as potassium chloride (KCl) (0-0-62) every 30 days throughout each study period. The interval between each treatment application was referred to as a Fertilizer Cycle (FC).

Grasses were mowed at 6.4 cm by hand monthly throughout each experiment. Nitrogen was applied to all pots at 1 lb 1000 $ft^{-2}$ as slow release urea (46-0-0) every 60 days. The pots were rotated within shade structures weekly to reduce variability. In the first trial during the summer months, irrigation was applied 5 times a week at 200 ml water each time to four shade levels. In the second trial during the winter months, irrigation was applied 3 times a week at 200 ml water each time to treatments at 0 and 30% shade, and 100 ml water each time to those at 50 and 70% shade. Under the drought stress at 0 shade in trial 1, irrigation was applied 5 times a week at 400 ml water each time for grass recovery.

Greenhouse temperature was monitored using a Hobo temperature data logger (Onset Computer Corporation, Bourne, MA), and light intensity was also measured weekly by LI-189 Quantum/Radiometer/Photometer (LI-Corporation, Lincoln, NE).

Turf was visually rated twice a month for turf quality, color, and density. Turf quality was based on turf vigor, color uniformity, and lack of disease and weed infestations. Visual scores were ranked from 1 to 9, with 1 equaling brown, poor turf and 9 representing optimal grass appearance, color and density. A score of 6 was considered a minimum value for acceptable turf quality. Shoot growth was measured once a month by mowing each pot at 6.4 cm with scissors and collecting all clippings. Leaves were measured for length from the base of the blade to the apex in centimeters, and leaf width was measure every 30 days. At the termination of each study, shoots, roots, and thatch were separated and dried for 96 hours at 65 ℃.

Thatch was separated from green living tissue by hand selection of aboveground dead tissues and organic debris, and dried for 96 hours at 65 ºC. Dried samples were weighed.

The experimental design was a nested design with 4 replications. Potassium treatments were randomized within each shade level for a total of 64 experiment units. Data were analyzed with the SAS analytical program (SAS, 2009) to determine treatment differences at the 0.05 level of significance and means were separated with the Waller-Duncan k-ratio t test. There were numerous significant interactions between the first and second trials, so data were presented separately by trial.

## Results and Discussion

### Turf Visual Quality and Color Scores

In trial 1, turf quality differed due to shade, with the highest visual quality scores at 0 or 50% shade and the lowest at 70% shade in FC1 (Table 3-1). In FC2, 3, and 4 and when scores were averaged over the trial period, turf quality scores were affected by the interaction of K rate and shade (Table 3-1). In FC2, turf visual quality scores increased with increasing K rate at 0, 50, and 70% shade, with no significant differences in quality ratings due to K rate at 30% shade (Table 3-2, Fig 3-1). In FC3 and FC4, turf treated with higher K had higher visual quality scores at 0 and 70% shade, with no significant differences in quality due to K rate at 30 and 50% shade (Table 3-3 and 3-4, Fig 3-2 and 3-3). When averaged over the trial period, at 0 and 70% shade, turf visual quality scores increased as K increased from 0 to 0.5 lb 1000 $ft^{-2}$, indicating that K can increase quality in both sun and shade (Table 3-5, Fig 3-4). There was no difference in quality ratings due to K rate at 30 and 50% shade.

From FC1 to FC4, visual quality scores decreased from 7.2 to 5.3 at 0 shade as a result of drought injury, and from 7.1 to 5.0 at 70% shade (Table 3-1), due to reduced density and shoot count under the increasingly heavy shade. However, turf at 30 and 50% shade maintained acceptable quality from FC1 to FC4.

Trenholm (2005) also found that St. Augustinegrass cultivars maintained acceptable quality up to 50% shade, and they had highest visual quality scores at 30% shade and the lowest at 70% shade. Qian and Engelke (2000) reported that Diamond zoysiagrass had the highest turf visual quality scores at 30 and 60% shade and that acceptable turf quality was obtained at up to 73% shade, while Tegg and Lane (2004) found supine bluegrass and tall fescue had acceptable visual quality score under 56 and 65% shade.

Trenholm et al. (2000) found that seashore paspalum with higher K shoot tissue concentration had enhanced wear tolerance; thereby it had better turf quality after shoot injury from traffic. They also reported turf quality, color, shoot density and wear tolerance of two paspalum ecotypes were enhanced due to K application. Snyder and Cisar (2000) reported that increasing K fertilizer beyond a K to N fertilization ratio of 1 to 2 had no effect on turf quality of Tifgreen bermudagrass. The study of hybrid bermudagrass was shown that the quality scores increased in response to K rate. However, no significant effect of K on turfgrass quality was observed in creeping bentgrass (Johnson et al., 2003).

Turf color scores differed in response to shade in all FCs and when averaged over the trial period, with no differences in color scores due to K rate or the interaction of shade and K rate (Table 3-6). Highest visual color scores were obtained from 30% shade and lowest scores were obtained from 70% shade in all FCs and when averaged over the trial period.

From FC1 to FC4, turf visual color scores increased by 4.4% at 30% shade and 4.2% at 50% shade, and they decreased by 18.2% at 0 shade and 23.5% at 70% shade (Table 3-6). The grasses were in poor condition due to drought injury at 0 shade and reduced density at 70%

shade, therefore turf color scores were decreased at 0 and 70% shade. Because turf had more complete establishment at 30 and 50% shade, visual color scores increased from FC1 to FC4.

Diamond zoysiagrass was reported to have the highest turf visual color scores at 30 and 60% shade (Qian and Engelke, 2000), while 80% shade had a negative effect on turf color in creeping bentgrass (Koh et al., 2003).

In trial 2, turf quality differed in response to shade in all FCs and when averaged over the trial period. Differences due to K rate occurred in FC2, 3, and 4 and when averaged over the trial period (Table 3-7). In FC1, quality was highest at 0 and 30% shade, while in the subsequent periods, highest quality occurred at the 30% shade level. Where there were differences due to K rate, quality was consistently higher at the two highest rates from FC2 until termination of the trial (Table 3-7).

Throughout the trial, turf maintained acceptable visual quality scores at 0, 30, and 50% shade. Acceptable scores were maintained until FC4 at 70% shade due to reduced shoot density (Table 3-7).

Similar results were seen in the research of Trenholm (2005), who reported higher visual quality scores at 0 and 30% shade.

As in trial 1, turf color scores differed in response to shade in all FCs and when averaged over the trial period (Table 3-8). Highest visual color scores were obtained from 30% shade and lowest scores were obtained from 70% shade in all FCs and when averaged over the trial period. Trenholm (2005) also found that most cultivars of St. Augustinegrass had highest turf visual color scores at 30% shade and lowest color scores at 70% shade.

From FC1 to FC4, turf visual color scores increased from 7.5 to 8.2 at 30% shade and decreased from 7.1 to 5.5 at 70% shade (Table 3-4).

## Shoot and Root Growth

### Shoot dry weight (g $m^{-2}$)

In trial 1, shoot dry weight differed in response to shade in all FCs, except for FC3, which had an interaction of shade and K rate, and when averaged over the trial period (Table 3-9). Weights were highest at 30% shade and lowest at 70% shade in all FCs except FC1 and when averaged over the study period. In FC3, weights increased as K rate increased from 0 to 0.5 lbs 1000 $ft^{-2}$ at 0% shade (Table 3-9, Fig 3-5). At 30, 50 and 70% shade, no difference was found in shoot dry weights due to K rate (Table 3-10).

From FC1 to FC4, shoot dry weight increased by 15.6% at 30% shade and decreased by 9.6% at 0 shade, 33.2% at 50% shade, and 67.4% at 70% shade (Table 3-9).

In trial 2, similarly, there were differences in shoot dry weights due to shade in all FCs and when averaged over the trial period (Table 3-11). Turf had greatest shoot dry weight at either 0 or 30% shade and lowest shoot dry weight at 70% shade in all FCs and when averaged over the trial period. There were no differences in shoot dry weight due to K rate (Table 3-11). The interaction between shade and K rate was significant in FC1 (Table 3-11). At 0, 30 and 70% shade, there was no difference in shoot dry weight due to K rate (Table 3-12). At 50% shade, the shoot dry weight increased with increasing K rate (Table 3-12, Fig 3-6).

From FC1 to FC4, shoot dry weight increased by 29.9% at 0 shade, 63.7% at 30% shade, and 60.8% at 50% shade and decreased by 45.8% at 70% shade (Table 3-11; Fig 3-7).

Trenholm (2005) also found reduce clipping weights at 70% shade, while highest weights were reported at 30% shade in St. Augustinegrass. Allard and Nelson (1991) reported that dry matter production of tall fescue was reduced at low irradiance (70% shade), due to fewer tillers per plant. Fitzpatrick and Guillard (2004) reported that K rate had no effect on clipping yields of Kentucky bluegrass.

**Leaf length (mm)**

In trial 1, leaf length differed due to shade level and K rate when averaged over the trial period (Table 3-13). Leaf length increased with increasing shade level and with increasing K rate, which agrees with results of Trenholm and Nagata (2005). Allard and Nelson (1991) found the recently developed leaf blades of tall fescue were 54 or 65% longer at 70% shade than at 0 shade.

In trial 2, leaf length differed only due to shade level when averaged over the trial period, increasing as shade level increased (Table 3-13). There were no differences in leaf length due to K rate.

**Leaf width (mm)**

In trials 1 and 2, leaf width decreased in both trials with increased shade levels when averaged over the trial period (Table 3-13), which has been reported by Trenholm and Nagata (2005). However, blade width of tall fescue was not affected by shade (Allard and Nelson, 1991).

**Root dry weight (g)**

In trial 1, root dry weight differed in response to shade and K rate (Table 3-14). Turf had greatest root dry weight at 30% shade and the lowest at 70% shade, and root dry weight increased as K rate increased from 0 to 0.5 lb 1000 $ft^{-2}$ (Table 3-14).

In trial 2, there was difference in root dry weights due to shade level, but no difference due to K rate (Table 3-14). Highest root dry weight occurred at 30% shade and the lowest at 70% shade (Table 3-14).

Previous research has indicated the effect of K and shade on turf root growth. Qian and Engelke (2000) found that root mass and number decreased with increasing shade levels in Diamond zoysiagrass. Rosecrance et al. (1996) reported that there was no relationship between root growth and the uptake of K from the soil in mature, alternate-bearing pistachio trees, and Watson (1994) also found no increase in root development due to K in honeylocust (*Gleditsia* *triacanthos* var. inermis L.) and pin oak (*Quercus palustris* Muenchh.) trees. However, Liang et al. (2007) reported that K humate application promoted the root growth significantly in ginger.

**Thatch Accumulation (g)**

In trials 1 and 2, thatch accumulation was affected by shade levels, with greatest thatch accumulation at 70% and lowest at 30% shade (Table 3-14). There was no difference in thatch production due to K rate. Similarly, Sartain (1993) reported that K application did not affect overall mean of bermudagrass thatch accumulation.

## Conclusions

From the results of these two trials, we can conclude that K can improve turf performance under shade. In this research, turf at 0.5 lb 1000 $ft^{-2}$ K rate had best turf visual quality, while turf at 0 lb 1000 $ft^{-2}$ K rate had worst turf visual quality. In the first trial, K improved overall turf quality ratings, and turf visual quality scores and shoot dry weight at 50% shade were higher than at 0% shade. Turf treated with higher K rates had longer leaf length and greater root dry weight, which indicated that K may promote leaf length and root growth. The highest turf visual quality and color scores, shoot and root dry weights were obtained from turf at 30% shade, while the lowest ones were at 70% shade. With increased shade levels, leaf length increased, while leaf width decreased. There was no difference in thatch accumulation due to K rates. Greatest thatch was found at 70% shade, while the lowest was at 30% shade, because of the reduced density and shoot count under the heavy shade. In the second trial, turf visual quality scores and shoot dry weight at 0% shade were higher than at 50% shade. Unlike trial 1, there was no difference in leaf length and root dry weight due to K rate. Results of this research show that K can improve turf performance of Captiva St. Augustinegrass under shaded conditions. Additional field plot research should be conducted to verify these responses in the landscape.

Table 3-1. Visual quality score in Captiva St. Augustinegrass in response to shade and potassium (K) rate in a greenhouse experiment by Fertilizer Cycle (FC) and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 7.18a | 6.50 | 5.63 | 5.33 | 6.16 |
| 30 | 7.12ab | 6.93 | 6.98 | 6.98 | 7.03 |
| 50 | 7.16a | 6.68 | 6.89 | 6.88 | 6.96 |
| 70 | 7.05b | 6.27 | 5.52 | 5.23 | 6.02 |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 7.10 | 6.77 | 6.02 | 5.85 | 6.57 |
| 0.125 | 7.16 | 6.82 | 6.24 | 6.14 | 6.76 |
| 0.25 | 7.10 | 6.89 | 6.43 | 6.32 | 6.79 |
| 0.5 | 7.14 | 7.23 | 6.85 | 6.55 | 6.85 |
| Anova | | | | | |
| Shade Level | 0.015 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K-rate | NS | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K-rate × Shade Level | NS | 0.031 | <0.0001 | <0.0001 | <0.0001 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-2. Turf visual quality score in Captiva St. Augustinegrass in response to K rate under each shade level in FC2 in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Turf visual quality | 30% shade: K-rate | Turf visual quality |
|---|---|---|---|
| 0 | 6.24b | 0 | 6.94 |
| 0.125 | 6.34ab | 0.125 | 6.96 |
| 0.25 | 6.36ab | 0.25 | 6.97 |
| 0.5 | 6.83a | 0.5 | 7.00 |
| Anova | | Anova | |
| K-rate | 0.024 | K-rate | NS |
| **50% shade: K-rate** | **Turf visual quality** | **70% shade: K-rate** | **Turf visual quality** |
| 0 | 6.53b | 0 | 5.89b |
| 0.125 | 6.57b | 0.125 | 6.39a |
| 0.25 | 6.93a | 0.25 | 6.42a |
| 0.5 | 6.95a | 0.5 | 6.43a |
| Anova | | Anova | |
| K-rate | 0.0012 | K-rate | <0.0001 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-3. Turf visual quality score in Captiva St. Augustinegrass in response to K rate under each shade level in FC3 in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Turf visual quality | 30% shade: K-rate | Turf visual quality |
|---|---|---|---|
| 0 | 5.53c | 0 | 6.93 |
| 0.125 | 5.93b | 0.125 | 6.95 |
| 0.25 | 6.01b | 0.25 | 6.96 |
| 0.5 | 6.24a | 0.5 | 7.00 |
| Anova | | Anova | |
| K-rate | 0.0031 | K-rate | NS |
| **50% shade: K-rate** | **Turf visual quality** | **70% shade: K-rate** | **Turf visual quality** |
| 0 | 6.86 | 0 | 5.02d |
| 0.125 | 6.88 | 0.125 | 5.15c |
| 0.25 | 6.90 | 0.25 | 5.43b |
| 0.5 | 6.92 | 0.5 | 5.84a |
| Anova | | Anova | |
| K-rate | NS | K-rate | <0.0001 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-4. Turf visual quality score in Captiva St. Augustinegrass in response to K rate under each shade level in FC4 in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Turf visual quality | 30% shade: K-rate | Turf visual quality |
|---|---|---|---|
| 0 | 5.11d | 0 | 6.95 |
| 0.125 | 5.62c | 0.125 | 6.98 |
| 0.25 | 5.83b | 0.25 | 7.01 |
| 0.5 | 6.01a | 0.5 | 7.03 |
| Anova | | Anova | |
| K-rate | <0.0001 | K-rate | NS |
| **50% shade: K-rate** | **Turf visual quality** | **70% shade: K-rate** | **Turf visual quality** |
| 0 | 6.89 | 0 | 5.03d |
| 0.125 | 6.92 | 0.125 | 5.14c |
| 0.25 | 6.94 | 0.25 | 5.22b |
| 0.5 | 6.96 | 0.5 | 5.68a |
| Anova | | Anova | |
| K-rate | NS | K-rate | 0.0015 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-5. Turf visual quality score in Captiva St. Augustinegrass in response to K rate under each shade level when averaged over the trial period in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Turf visual quality | 30% shade: K-rate | Turf visual quality |
|---|---|---|---|
| 0 | 5.93c | 0 | 6.96 |
| 0.125 | 5.96c | 0.125 | 6.99 |
| 0.25 | 6.43b | 0.25 | 7.03 |
| 0.5 | 6.96a | 0.5 | 7.05 |
| Anova | | Anova | |
| K-rate | <0.0001 | K-rate | NS |
| **50% shade: K-rate** | **Turf visual quality** | **70% shade: K-rate** | **Turf visual quality** |
| 0 | 6.93 | 0 | 5.88c |
| 0.125 | 6.95 | 0.125 | 5.87c |
| 0.25 | 6.98 | 0.25 | 6.14b |
| 0.5 | 7.02 | 0.5 | 6.55a |
| Anova | | Anova | |
| K-rate | NS | K-rate | <0.0001 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-6. Visual color score in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 7.10b | 6.43c | 6.12c | 5.86b | 6.55b |
| 30 | 7.21a | 7.43a | 7.45a | 7.53a | 7.36a |
| 50 | 7.18a | 7.31b | 7.34b | 7.48a | 7.32a |
| 70 | 7.01c | 6.21d | 5.86d | 5.36c | 6.06c |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 7.11 | 7.15 | 7.02 | 6.96 | 7.07 |
| 0.125 | 7.13 | 7.16 | 7.04 | 6.99 | 7.11 |
| 0.25 | 7.14 | 7.14 | 7.06 | 7.01 | 7.09 |
| 0.5 | 7.15 | 7.12 | 7.05 | 7.02 | 7.08 |
| Anova | | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-7. Visual quality score in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 2.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 7.58a | 7.66b | 7.73b | 7.24b | 7.51b |
| 30 | 7.62a | 7.83a | 8.21a | 8.16a | 7.86a |
| 50 | 7.45b | 7.53c | 7.65c | 7.03c | 7.38c |
| 70 | 7.12c | 6.43d | 6.12d | 5.57d | 6.26d |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 7.56 | 7.13c | 7.01c | 6.67c | 7.11c |
| 0.125 | 7.50 | 7.78b | 7.49b | 7.36b | 7.49b |
| 0.25 | 7.54 | 7.85a | 7.58a | 7.44a | 7.53a |
| 0.5 | 7.52 | 7.88a | 7.62a | 7.48a | 7.56a |
| Anova | | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K-rate | NS | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K-rate × Shade Level | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-8. Visual color score in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 2.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 7.25b | 7.47c | 7.39c | 7.32c | 7.32c |
| 30 | 7.48a | 7.83a | 8.14a | 8.24a | 7.68a |
| 50 | 7.23b | 7.56b | 7.41b | 7.68b | 7.42b |
| 70 | 7.06c | 6.93d | 6.12d | 5.46d | 6.14d |
| K-rate (lb 1000 ft$^{-2}$) | | | | | |
| 0 | 7.34 | 7.45 | 7.49 | 7.27 | 7.22 |
| 0.125 | 7.35 | 7.47 | 7.52 | 7.28 | 7.25 |
| 0.25 | 7.37 | 7.43 | 7.55 | 7.25 | 7.21 |
| 0.5 | 7.31 | 7.44 | 7.54 | 7.23 | 7.24 |
| Anova | | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-9. Turf shoot weight (g m$^{-2}$) in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 1.14c | 1.80b | 0.98 | 1.03c | 1.20c |
| 30 | 1.67b | 2.10a | 1.79 | 1.93a | 1.69a |
| 50 | 2.05a | 1.99a | 1.45 | 1.37b | 1.54b |
| 70 | 1.29c | 1.00c | 0.35 | 0.42d | 0.78d |
| K-rate (lb 1000 ft$^{-2}$) | | | | | |
| 0 | 1.56 | 1.78 | 1.03 | 1.17 | 1.31 |
| 0.125 | 1.64 | 1.80 | 1.11 | 1.16 | 1.35 |
| 0.25 | 1.42 | 1.67 | 1.22 | 1.26 | 1.28 |
| 0.5 | 1.59 | 1.63 | 1.20 | 1.20 | 1.27 |
| Anova | | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | NS | NS | 0.01 | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-10. Turf shoot weight (g $m^{-2}$) in Captiva St. Augustinegrass in response to K rate under each shade level in FC3 in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Shoot dry weight | 30% shade: K-rate | Shoot dry weight |
|---|---|---|---|
| 0 | 0.60c | 0 | 1.65 |
| 0.125 | 0.73bc | 0.125 | 1.95 |
| 0.25 | 1.23ab | 0.25 | 1.80 |
| 0.5 | 1.34a | 0.5 | 1.77 |
| Anova | | Anova | |
| K-rate | 0.02 | K-rate | NS |
| **50% shade: K-rate** | **Shoot dry weight** | **70% shade: K-rate** | **Shoot dry weight** |
| 0 | 1.46 | 0 | 0.42 |
| 0.125 | 1.33 | 0.125 | 0.45 |
| 0.25 | 1.62 | 0.25 | 0.24 |
| 0.5 | 1.41 | 0.5 | 0.29 |
| Anova | | Anova | |
| K-rate | NS | K-rate | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-11. Turf shoot weight (g $m^{-2}$) in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment in trial 2.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 1.40 | 1.38a | 2.00a | 2.43c | 1.81a |
| 30 | 1.22 | 1.41a | 1.87a | 2.98a | 1.83a |
| 50 | 0.97 | 1.22a | 1.50b | 2.75b | 1.51b |
| 70 | 0.68 | 0.75b | 0.67c | 0.91d | 0.96c |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 0.91 | 1.12 | 1.43 | 2.86 | 1.69 |
| 0.125 | 1.06 | 1.17 | 1.50 | 2.84 | 1.76 |
| 0.25 | 1.12 | 1.19 | 1.63 | 2.91 | 1.71 |
| 0.5 | 1.17 | 1.28 | 1.48 | 2.89 | 1.73 |
| Anova | | | | | |
| Shade Level | <0.0001 | 0.0025 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | 0.0005 | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-12. Turf shoot weight (g $m^{-2}$) in Captiva St. Augustinegrass in response to K rate under each shade level in FC1 in a greenhouse experiment in trial 2.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | Shoot dry weight | 30% shade: K-rate | Shoot dry weight |
|---|---|---|---|
| 0 | 1.10b | 0 | 1.17 |
| 0.125 | 1.60a | 0.125 | 1.15 |
| 0.25 | 1.46ab | 0.25 | 1.37 |
| 0.5 | 1.44ab | 0.5 | 1.18 |
| Anova | | Anova | |
| K-rate | NS | K-rate | NS |
| **50% shade: K-rate** | **Shoot dry weight** | **70% shade: K-rate** | **Shoot dry weight** |
| 0 | 0.75c | 0 | 0.63 |
| 0.125 | 0.79bc | 0.125 | 0.70 |
| 0.25 | 0.94b | 0.25 | 0.70 |
| 0.5 | 1.39a | 0.5 | 0.70 |
| Anova | | Anova | |
| K-rate | 0.0002 | K-rate | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

Table 3-13. Turf leaf length and width (mm) in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment

| Shade Level (%) | Length (Trial 1) | Length (Trial 2) | Width (Trial 1) | Width (Trial 2) |
|---|---|---|---|---|
| 0 | 131.4d | 117.0d | 7.06a | 7.21a |
| 30 | 175.1c | 159.0c | 6.88b | 6.93b |
| 50 | 197.6b | 187.1b | 6.30c | 6.32c |
| 70 | 226.3a | 229.6a | 5.28d | 5.31d |
| K-rate (lb 1000 $ft^{-2}$) | | | | |
| 0 | 174.1c | 168.6 | 6.49 | 6.63 |
| 0.125 | 182.2b | 175.7 | 6.52 | 6.65 |
| 0.25 | 189.4a | 173.6 | 6.55 | 6.67 |
| 0.5 | 191.2a | 174.7 | 6.61 | 6.62 |
| Anova | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | 0.013 | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-14. Turf root weight and thatch accumulation (g) in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment

| Shade Level (%) | Root Wt (1) | Root Wt (2) | Thatch (1) | Thatch (2) |
|---|---|---|---|---|
| 0 | 0.56b | 2.31a | 1.64b | 0.67c |
| 30 | 0.67a | 1.87b | 0.86d | 0.54d |
| 50 | 0.27c | 1.50c | 1.12c | 0.78b |
| 70 | 0.13d | 1.20d | 2.12a | 1.82a |
| K-rate (lb 1000 $ft^{-2}$) | | | | |
| 0 | 0.34b | 1.69 | 1.54 | 1.13 |
| 0.125 | 0.38ab | 1.68 | 1.51 | 1.17 |
| 0.25 | 0.42ab | 1.66 | 1.57 | 1.15 |
| 0.5 | 0.48a | 1.72 | 1.53 | 1.24 |
| Anova | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | 0.05 | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level

.

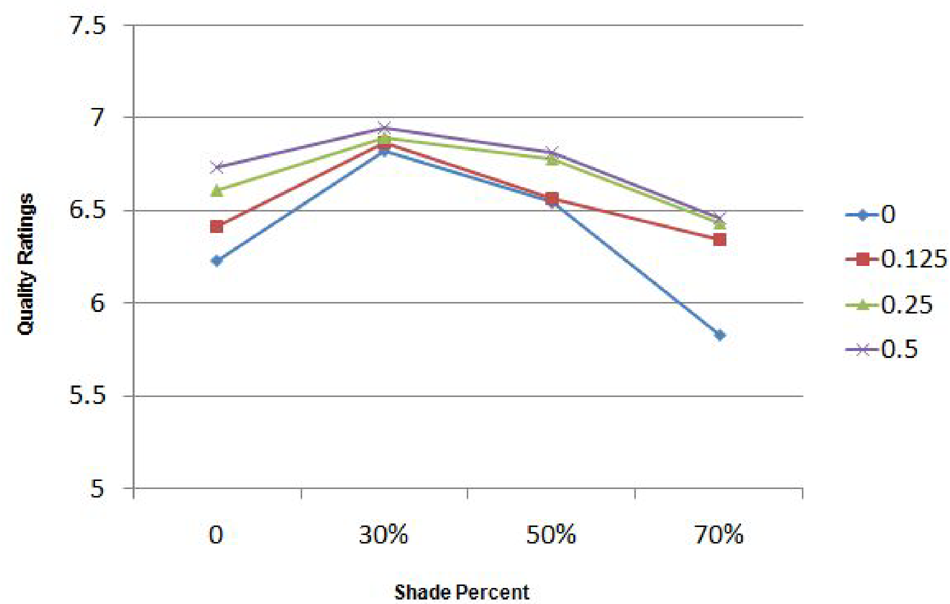


Figure 3-1. Interaction between shade and potassium (K) rate in turf visual quality in Fertilizer Cycle (FC) 2 of trial 1

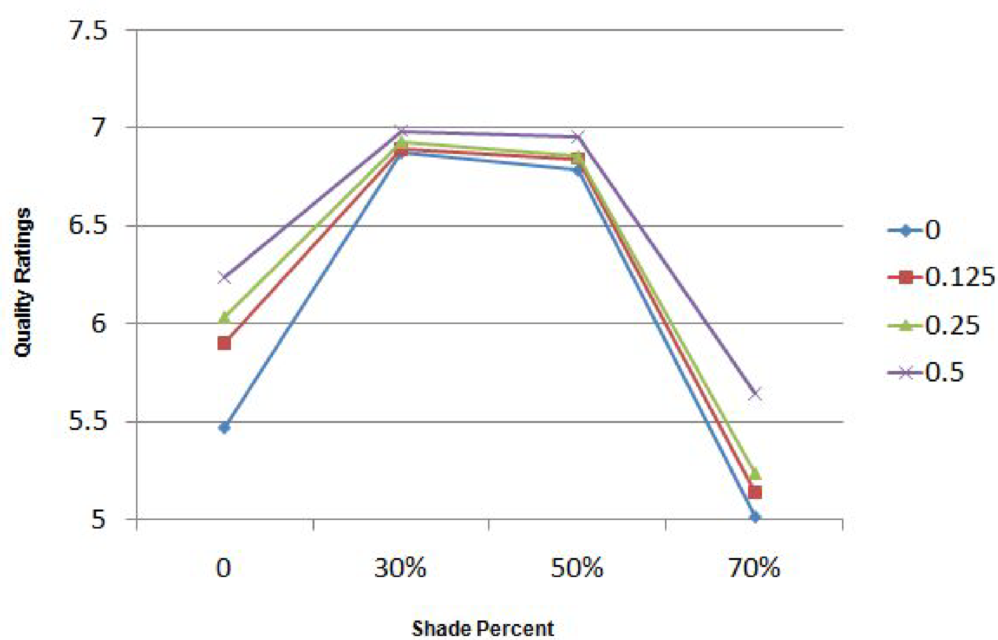


Figure 3-2. Interaction between shade and K rate in turf visual quality in FC3 of trial 1

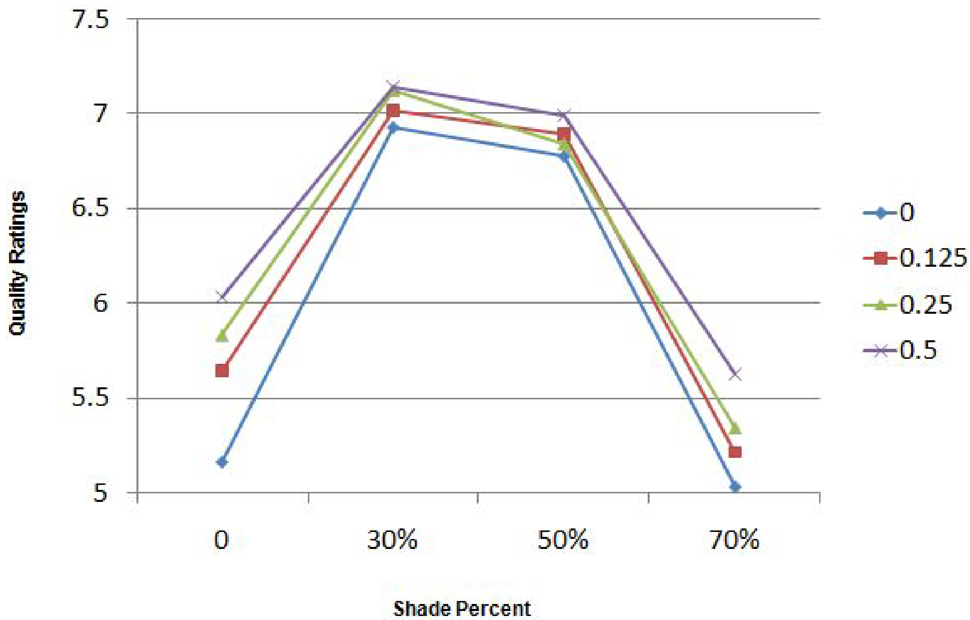


Figure 3-3. Interaction between shade and K rate in turf visual quality in FC4 of trial 1

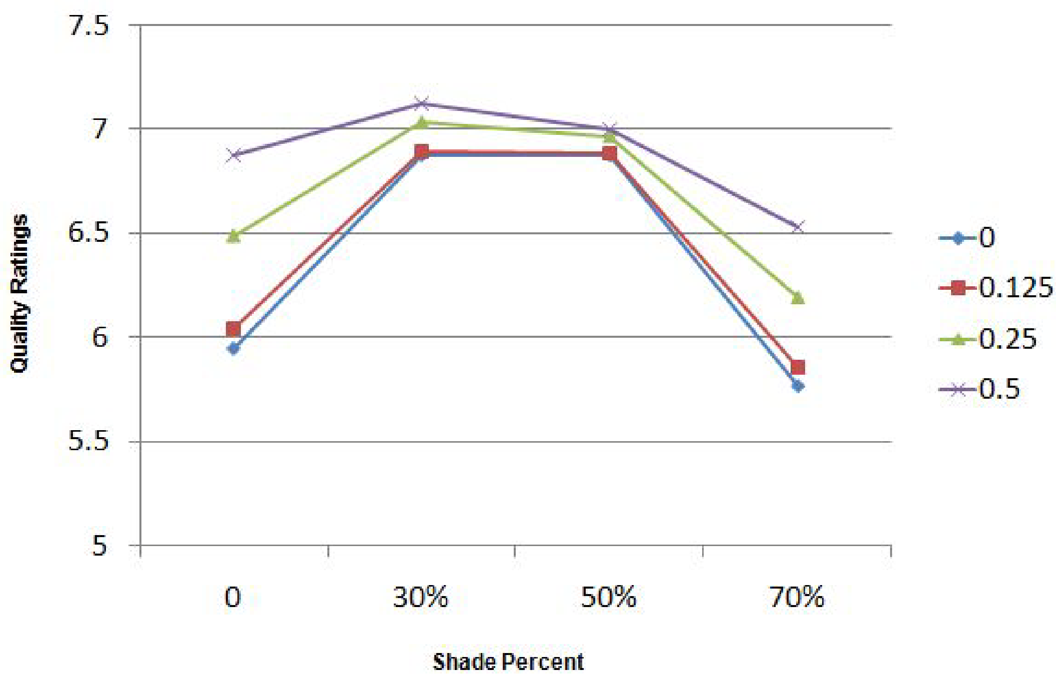


Figure 3-4. Interaction between shade and K rate in turf visual quality averaged over the trial 1 period

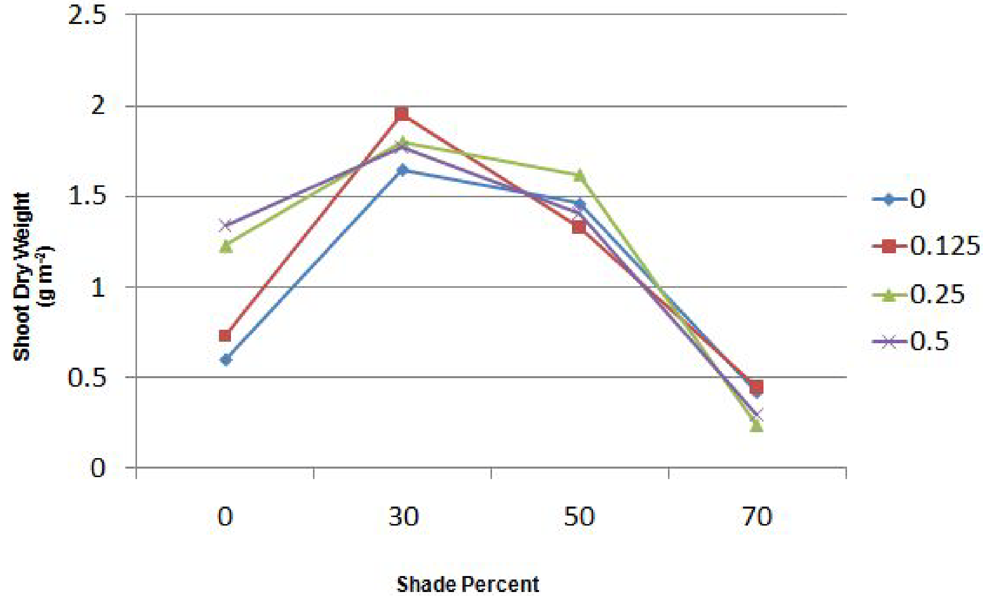


Figure 3-5. Interaction between shade and K rate in shoot dry weight in FC3 of trial 1

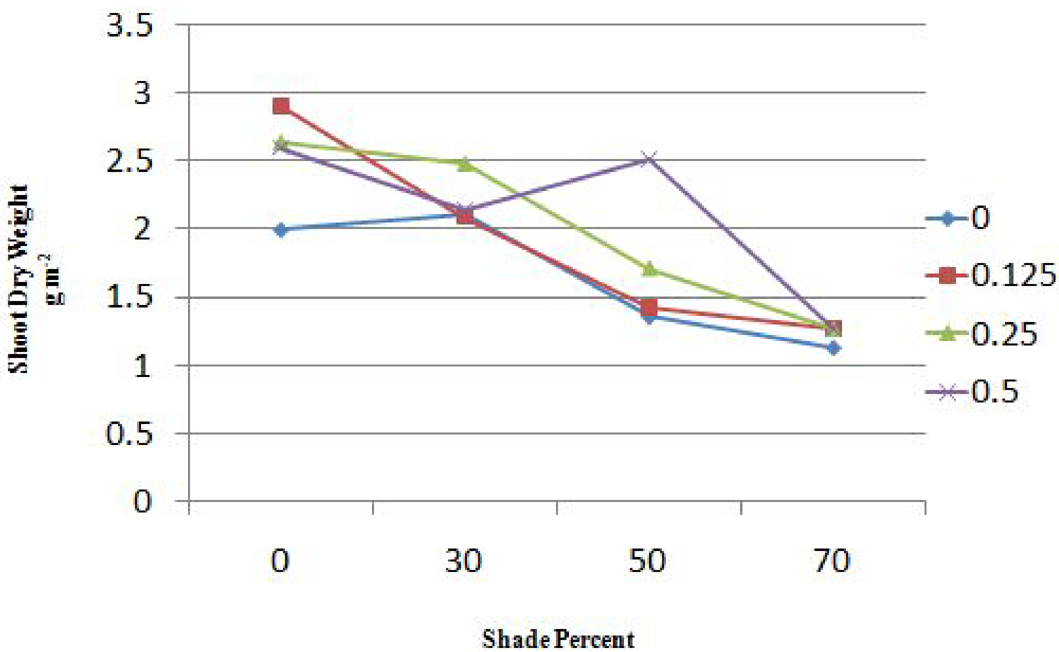


Figure 3-6. Interaction between shade and K rate in shoot dry weight in FC1 of trial 2

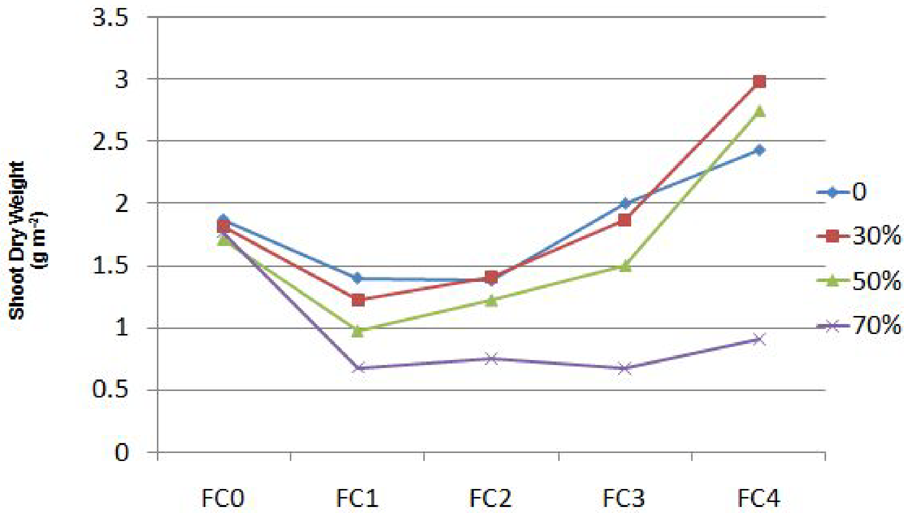


Figure 3-7. Average shoot dry weight under each shade level from the turf at different FCs in trial 2

CHAPTER 4
EFFECT OF SHADE LEVEL AND POTASSIUM (K) ON TISSUE NITROGEN (N), K AND CHLOROPHYLL CONCENTRATIONS OF 'CAPTIVA' ST. AUGUSTINEGRASS

## Introduction

St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) is widely used as a warm-season lawngrass, This is one of the most popular lawngrass species used throughout the southern United States. St. Augustinegrass has better shade tolerance than many other warm-season grasses (Trenholm et al., 2000a). 'Captiva' is a new dwarf cultivar of St. Augustingrass, which is characterized by dark green, short, narrow leaf blades and reduced vertical leaf extension. Captiva has improved tolerance to southern chinch bug (*Blissus insularis* Barber) and the plant hopper (*Liburnia pseudoseminigra* Muir & Gifford) (Trenholm and Kenworthy, 2009).

Peacock and Dudeck (1981) found that different cultivars of St. Augustinegrass were observed to exhibit altered chlorophyll concentration and composition to shade. Plant physiological responses can be measured by the chlorophyll concentration which is correlated to turf color and plant vitality measurement (Pocklington et al., 1974). Plant pigments absorb wavelengths within the visible spectrum (400-700 nm) and reflect near-infrared (NIR) radiation (700-1300 nm) (Knipling, 1970; Asrar et al., 1984). Total chlorophyll (a and b) increase with decreased irradiance. There are various instruments to measure relative chlorophyll indices. The Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) uses ambient and reflected light at 700 and 840 nm, which estimates the quantity of leaf chlorophyll (www.specmeters.com).

A study on chlorophyll concentration in response to light intensity in barley (*Hordeum vulgare* L. cv. Boone) seedlings indicated that seedlings under high light intensity (550 mol $m^{-2}$ $s^{-1}$) had greater chlorophyll per leaf area and higher chlorophyll a to b ratios than low light controls (55 mol $m^{-2}$ $s^{-1}$) (Torre and Burkey, 1990). Four species of Pacific Northwest conifer seedlings were evaluated under shaded conditions. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), douglas-fir (*Pseudotsuga menziesii* Franco), western red cedar (*Thuja plicata* Donn ex D. Donn), and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) all responded similarly to shade. They showed greatest height and chlorophyll concentration under 75% shade (Khan et al., 2000).

Trenholm and Nagata (2005) reported tissue potassium (K) concentration increased from 15.0 to 24.2 g $kg^{-1}$ in 'Floratam' St. Augustinegrass as shade level increased from 0 to 70%, while Travis and Prendergast (2008) found that alfalfa (*Medicago sativa* L.) had increased nitrogen (N) and chlorophyll levels under high light conditions (full sun). However, Minotta and Pinzauti (1996) reported that chlorophyll concentration in beech (*Fagus sylvatica* L.) decreased and that nutrient use efficiency increased as light level increased. A study of light effects on red pine (*Pinus resinosa* Ait.) seedling also showed the highest nutrient use efficiency at high light (Elliott and White, 1994). According to Cruz (1997), there was no effect of shade on the carbon (C) and N influxes into the whole plant in angleton bluestem (*Dichanthium aristatum* [poir] C.E. Hubbard), and C assimilation regulated N absorption. He studied three different levels of irradiance (100, 56, and 33%). Under 33% irradiance, N was preferentially allocated to the laminae, while more N was allocated to the stubble component under 56 and 100% irradiance.

In a study of the influence of photosynthetic irradiance on cotton (*Gossypium hirsutum* L.) growth, development, lint yield and fiber quality, total N and K concentrations in the leaf blades of petioles increased 19 and 22% at 63% shade, respectively, compared with those of plant at full sun. There was decreased carbohydrate accumulation in shaded plants (Zhao and Oosterhuis, 1998). Chirachint and Turner (1988) reported no significant difference in tissue K concentration due to shade (0 and 50% shade) in 'Fuerte' avocado (*Persea americana* Mill.), while Wilson and

Hill (1990) found bahiagrass (*Paspalum notatum* Fluegge.) had greater proportion of green leaf, N and K concentrations, and moisture content under the shade of rose gum (*Eucalyptus grandis* W. Hill ex Maid) than in full sun.

Potassium is important for healthy turfgrass growth and development. It can help improve plants' resistant to drought, wear, disease, and excessive temperature (Turner and Hummel, 1992). Although K is not the constituent of any plant structure or compound, it is essential for regulatory roles that sustain plant growth and reproduction (Harrewijn, 1979).

There are many factors affecting turf K requirements, including clipping removal, irrigation, and soil texture (Duble, 1992). The correlations between total $K^+$ uptake and root parameters were significant, and the longer and denser root hair had stronger affinity for $K^+$ uptake (Nus, 1995)

Potassium influences on wear tolerance of hybrid bermudagrass cultivars (*Cynodon dactylon* L. x *C. transvaalensis* Burtt-Davy.) and seashore paspalum (*Paspalum vaginatum* Swartz.) were evaluated, and both species improved wear tolerance with greater shoot density, shoot moisture, and shoot tissue K concentration (Trenholm, et al., 2000b). Turfgrass has been shown to not respond as readily to K as to N (Juska, 1959; Fry and Dernoeden 1987). Higher K fertilizer rates, relative to N, were required for better 'Tifgreen' bermudagrass appearance and growth, but there was no significant increase in tissue K concentration (Snyder and Cisar, 2000). A study on effects of K to N fertilization ratios on `Tifway' bermudagrass growth and quality showed that increasing K fertilization beyond a K to N fertilization ratio of 1 to 2 had no effect on turfgrass tissue K concentration (Sartain, 2002). He reported effects of K sources (potassium chloride [KCl] and potassium sulfate [$K_2SO4$]) and rate (0, 3.7, 7.4, 9.8, 14.7, 22, 29.4, and 36.8 g $m^{-2}$ 90 $d^{-1}$) on tissue K concentration. As K increased to 7.4 g $m^{-2}$ 90 $d^{-1}$, tissue K concentration was increased, but if K fertilization was above 9.8 g $m^{-2}$ 90 $d^{-1}$ with 4.9 $m^{-2}$ $mo^{-1}$ N rate, there was no effect on tissue K concentration.

A study of the relationship between tissue K concentration and growth response of Tifgreen bermudagrass was investigated (Snyder and Cisar, 2000). They found growth occurred in response to K application when tissue K was below 13 g $kg^{-1}$ dry matter, while there was no increased tissue K concentration or growth rate in response to additional K application when tissue K level was 16 g $kg^{-1}$ dry matter or greater.

In a study of N and K influences on the growth and chemical composition of Kentucky bluegrass (*Poa pratensis* L.), the responses of two N (65 and 130 ppm) and four K (0, 100, 200, and 400 ppm) levels to leaf tissue N and K concentrations were investigated (Monroe et al., 1969). They reported that turf at 130 ppm N application had increased leaf tissue N and K concentrations, and K application also increased leaf tissue K concentration.

Effects of N and K supply on greenhouse tomato (*Lycopersicon esculentum* Mill.) tissue composition were evaluated, and supplemental K increased N and K in leaf and petiole tissue, but it did not affect K in fruit tissue (Gent, 2004). Holm and Nylund (1978) reported K levels of potato (*Solanum tuberosum* L.) petioles were increased with increasing K application rates, but N levels in the petioles were decreased as K rate increased. Bhangoo and Albritton (1972) also reported increased leaf tissue N and K content with N and K application in soybeans (*Glycine Max* L.Merrill).

According to Khayyat et al. (2009), supplementary K fertilization positively influenced leaf chlorophyll concentration in strawberry (*Fragaria* L). Lawanson et al. (1977) reported that transformation rate of protochlorophyll to chlorophyll was retarded by K deficiency in maize

(*Zea mays* L.) seedlings, while the amounts of leaf chlorophyll were not affected by K levels in pineapple (*Ananas comosus* L. Merr.) (Sideris and Young, 1945).

The objective of this research was to determine the effect of shade level and K rate on tissue N, K and chlorophyll concentrations of Captiva St. Augustinegrass.

**Materials and Methods**

Two consecutive experiments were conducted in a climate-controlled greenhouse at the Environtron Turfgrass Research Laboratory at the University of Florida in Gainesville, FL. The first experiment was conducted from May 2009 through October 2009 and the second from January 2010 through June 2010.

In May 2009, St. Augustinegrass cultivar, Captiva, was established in 15.2 cm plastic pots. Media used was 50% Fafard 2 mix (Conrad Fafard, Agawam, MA) and 50% sand (304 T Sand of Florida Rock Industries Keuka Sand Mine, Interlachen, FL). During the establishment stage, grasses were kept in full sunlight under conditions of optimal irrigation until all pots had established uniform cover, density, and shoot growth. There was no fertilization during establishment, and grasses were mowed to 6.4 cm prior to initiation of treatments.

Shade treatments were provided by polyvinyl-chloride (PVC) structures covered with woven black shade cloth to supply shade at 30, 50, or 70% of full sunlight. Structures measured 211.8 cm wide, 173.7 cm tall and 211.8 cm long.

There were four K treatments (0, 0.125, 0.25, and 0.5 lb 1000 $ft^{-2}$). Potassium treatments were applied as KCl (0-0-62) every 30 days throughout each trial period. The interval between each treatment application was referred to as a Fertilizer Cycle (FC).

Grasses were mowed at 6.4 cm by hand monthly throughout each experiment. Nitrogen was applied to all pots at 1 lb 1000 $ft^{-2}$ as slow release urea (46-0-0) every 60 days. The pots were rotated within shade structures weekly to reduce variability. In the first trial during the summer months, irrigation was applied 5 times a week at 200 ml water each time to four shade levels. In the second trial during the winter months, irrigation was applied 3 times a week at 200 ml water each time to treatments at 0 and 30% shade, and 100 ml water each time to those at 50 and 70% shade. Under the drought stress at 0 shade in trial 1, irrigation was applied 5 times a week at 400 ml water each time for grass recovery.

Greenhouse temperature was monitored using a Hobo temperature data logger (Onset Computer Corporation, Bourne, MA), and light intensity was also measured weekly by LI-189 Quantum/Radiometer/Photometer (LI-Corporation, Lincoln, NE).

The clipped leaves were sampled once a month for Total Kjeldahl Nitrogen (TKN) (Kjeldahl, 1883) and K concentration. Tissue samples were dried for 96 hours at 65ºC, ground in a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO), and analyzed for TKN and tissue K concentration in the Analytical Research Lab (ARL) at the University of Florida. Because results were not available at time of writing for TKN and K concentration in trial 2, those results were not reported in this thesis, but they were about to presented in published journal. A Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) was used once a month to measure chlorophyll index (CI). This instrument measures reflected light at 700 and 840 nm to calculate a relative CI, which has been used to quantify turf quality and stress prior to visible symptoms.

At the termination of each study, shoots were dried for 96 hours at 65 ℃ and then analyzed for TKN and tissue K concentration as described above.

The experimental design was a nested design with 4 replications. Potassium treatments were randomized within each shade level for a total of 64 experiment units. Data were analyzed with the SAS analytical program (SAS, 2009) to determine treatment differences at the 0.05 level of significance and means were separated with the Waller-Duncan k-ratio t test. There were numerous significant interactions between the first and second trials, so data were presented separately by trial.

## Results and Discussion

### Total Kjedahl Nitrogen (TKN) Concentration in Leaf Tissue (g $kg^{-1}$)

In trial 1, TKN differed in response to shade in all FCs and when averaged over the trial period (Table 4-1). Where there were differences due to shade, TKN increased as shade increased from 0 to 70%. There was an interaction between shade and K rate in FC2 and when averaged over the trial period (Table 4-1). In FC2, lowest TKN was found in the plots that received no K, while TKN was equal from turf treated with the other three K applications at 0 shade (Table 4-2, Fig 4-1). At 30 and 50% shade, no significant difference was seen in TKN due to K rate. At 70% shade, TKN was lowest from turf treated with 0 and 0.125 lbs 1000 $ft^{-2}$ and highest with 0.5 lbs 1000 $ft^{-2}$.

When averaged over the trial period, lowest TKN was from turf treated with 0 K rate at 0 shade (Table 4-3, Fig 4-2). This agrees with Gent (2004), who reported that the N concentration of leaf and petiole tissues increased with supplemental K application in greenhouse tomato. At 30% shade, greatest TKN was reached at 0 K rate and the lowest was at 0.5 lbs 1000 $ft^{-2}$, which may be due to nutrient competition between K and N. At 50% shade, there was no difference in TKN due to K rate (Table 4-3). At 70% shade, turf had highest TKN at 0.5 lbs 1000 $ft^{-2}$ K rate and lowest at 0 and 0.125 lbs 1000 $ft^{-2}$.

Travis and Prendergast (2008) found the leaf N concentration of alfalfa increased under high light (full sun), compared with that of shaded plant. According to Zhao and Oosterhuis (1998), N concentrations in leaf blades of cotton petioles were 19% higher at 63% shade than at full sun.

Holm and Nylund (1978) reported that N concentration decreased in petioles of potato as K rate increased.

**Tissue K Concentration (g $kg^{-1}$)**

In trial 1, tissue K concentration increased in response to increasing shade in all FCs and when averaged over the trial period. Potassium levels increased from 10.2 to 18.1 g $kg^{-1}$ as shade increased from 0 to 70% when averaged over the trial period (Table 4-4). Trenholm and Nagata (2005) also reported that tissue K concentration increased from 15.0 to 24.2 g $kg^{-1}$ as shade increased from 0 to 70% in Floratam St. Augustinegrass. Increasing K concentration may indicate that more K was required to regulate some physiological processes under stress conditions, such as enzyme activation and stomatal control for photosynthesis. In FC1, 2, 3 and when averaged over the trial period, there were differences in tissue K concentration due to K rate (Table 4-4), with greater tissue K concentration at two higher K rates.

In a study of light effects on cotton growth, total K concentration in leaf blades of petioles were 22% higher at 63% shade than at full sun, which was closely associated with decreased carbohydrate accumulation in shaded plants (Zhao and Oosterhuis, 1998). According to Chirachint and Turner (1998), there was no significant difference in tissue K concentration due to shade (0 and 50% shade) in Fuerte avocado.

Sartain (2002) reported that there was no effect of K application on tissue K concentration when K to N was applied beyond a ratio of 1 to 2 in Tifway bermudagrass. Snyder and Cisar (2000) found no response in tissue K concentration to additional K application while tissue K level was 16 g $kg^{-1}$ dry matter or greater in Tifgreen bermudagrass. They also reported that higher K rates relative to N had no effect on tissue K concentration. According to Gent (2004), supplemental K increased K in leaf or petiole tissue, but did not affect K in fruit tissue in greenhouse tomato. Holm and Nylund (1978) reported increased K levels in potato petioles with increasing K application rates. In a study of the effects of two N (65 and 130 ppm) and four K (0, 100, 200, and 400 ppm) levels on Kentucky bluegrass, K and 130 ppm N applications increased leaf tissue K concentration (Monroe et al., 1969).

**Chlorophyll Index (CI)**

In trials 1 and 2, differences were seen in CI due to shade in all FCs and when averaged over the trial period (Table 4-5, Table 4-6). Highest levels were found in 30% and lowest at 70% shade. There was no difference in CI due to K rate (Table 4-5, Table 4-6).

Torre and Burkey (1990) reported the greater chlorophyll per leaf area and higher chlorophyll a to b ratio at high light intensity (550 mol $m^{-2}$ $s^{-1}$) than at low light intensity (55 mol $m^{-2}$ $s^{-1}$) in barley seedlings, while Khan et al. (2000) found ponderosa pine, douglas-fir, western red cedar, and western hemlock had greatest chlorophyll concentration under 75% shade.

According to Khayyat et al. (2009), supplementary K fertilization positively influenced leaf chlorophyll concentration in strawberry. Lawanson et al. (1977) reported that transformation rate of protochlorophyll to chlorophyll was retarded by K deficiency in maize seedlings, while the amounts of leaf chlorophyll were not affected by K levels in pineapple (Sideris and Young, 1945).

## Conclusions

Shading had some effects on Captiva leaf nutrient content, such as TKN and tissue K concentrations, which could provide an indication of the physiological functioning of the turfgrass. Turf at lower light intensity had higher TKN and tissue K concentrations. Tissue K concentration can be useful in determining turfgrass wear tolerance, while tissue TKN concentration was used to determine N requirement of turfgrass under heavy shade. Chlorophyll index was correlated with turf color and quality, which has ability to indicate stress or healthy in a turfgrass system.

Additional field plot research should be conducted to verify these responses in the landscape.

Table 4-1. Total Kjedahl Nitrogen (TKN) (g $kg^{-1}$) concentration in leaf tissue of Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 14.4c | 10.4 | 8.6d | 7.8d | 11.5 |
| 30 | 15.0bc | 13.6 | 10.2c | 9.6c | 13.3 |
| 50 | 15.5b | 15.1 | 12.2b | 11.3b | 14.5 |
| 70 | 16.6a | 16.3 | 13.4a | 12.4a | 17.1 |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 14.8 | 14.2 | 11.6 | 11.3 | 13.8 |
| 0.125 | 15.9 | 14.8 | 11.0 | 11.1 | 14.2 |
| 0.25 | 15.6 | 15.7 | 11.7 | 10.9 | 14.6 |
| 0.5 | 15.3 | 16.4 | 10.6 | 11.2 | 14.3 |
| Anova | | | | | |
| Shade Level | 0.032 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | 0.035 | NS | NS | NS |
| Shade× K rate | NS | <0.0001 | NS | NS | 0.01 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4-2. TKN ($g\ kg^{-1}$) concentration in leaf tissue of Captiva St. Augustinegrass in response to K rate under each shade level in FC2 in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | TKN | 30% shade: K-rate | TKN |
|---|---|---|---|
| 0 | 8.4b | 0 | 14.5a |
| 0.125 | 11.0a | 0.125 | 14.5a |
| 0.25 | 11.2a | 0.25 | 12.8b |
| 0.5 | 11.2a | 0.5 | 12.8b |
| Anova | | Anova | |
| K-rate | 0.0061 | K-rate | NS |
| **50% shade: K-rate** | **TKN** | **70% shade: K-rate** | **TKN** |
| 0 | 15.2 | 0 | 18.8c |
| 0.125 | 15.5 | 0.125 | 18.3c |
| 0.25 | 15.0 | 0.25 | 22.8b |
| 0.5 | 14.8 | 0.5 | 25.5a |
| Anova | | Anova | |
| K-rate | NS | K-rate | <0.0001 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4-3. TKN (g $kg^{-1}$) concentration in leaf tissue of Captiva St. Augustinegrass in response to K rate under each shade level when averaged over the trial period in a greenhouse experiment in trial 1.

| 0 shade: K-rate (lb 1000 $ft^{-2}$) | TKN | 30 shade: K-rate | TKN |
|---|---|---|---|
| 0 | 10.5b | 0 | 14.0a |
| 0.125 | 12.1a | 0.125 | 13.2ab |
| 0.25 | 11.8a | 0.25 | 13.3ab |
| 0.5 | 11.8a | 0.5 | 12.6b |
| Anova | | Anova | |
| K-rate | 0.01 | K-rate | 0.05 |
| 50% shade: K-rate | TKN | 70% shade: K-rate | TKN |
| 0 | 14.5 | 0 | 16.3b |
| 0.125 | 14.8 | 0.125 | 16.5b |
| 0.25 | 14.8 | 0.25 | 17.6ab |
| 0.5 | 14.0 | 0.5 | 18.2a |
| Anova | | Anova | |
| K-rate | NS | K-rate | 0.05 |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4-4. Tissue K concentration (g $kg^{-1}$) in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 13.9d | 8.2c | 11.1d | 7.7c | 10.2d |
| 30 | 15.7c | 11.9b | 13.3c | 10.0b | 12.7c |
| 50 | 18.3b | 13.9a | 15.6b | 11.3ab | 14.8b |
| 70 | 22.1a | 13.8a | 16.6a | 11.7a | 18.1a |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 16.8b | 12.3c | 14.1b | 9.4 | 13.2b |
| 0.125 | 17.3ab | 13.0b | 14.5b | 9.9 | 13.6b |
| 0.25 | 18.7a | 13.9a | 15.7ab | 10.7 | 14.7a |
| 0.5 | 17.8ab | 13.8a | 16.6a | 11.2 | 14.8a |
| Anova | | | | | |
| Shade Level | <0.0001 | <0.0001 | <0.0001 | 0.0090 | <0.0001 |
| K rate | 0.05 | 0.0057 | 0.04 | NS | 0.03 |
| Shade× K rate | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4-5. Chlorophyll reading in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 1.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 287.43b | 164.00b | 183.43c | 160.07c | 198.71c |
| 30 | 394.94a | 242.88a | 292.50a | 308.63a | 309.34a |
| 50 | 294.31b | 204.44a | 223.88b | 246.44b | 240.25b |
| 70 | 273.19b | 174.69b | 141.56d | 130.38c | 179.96c |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 341.13 | 184.75 | 216.50 | 218.94 | 247.46 |
| 0.125 | 289.25 | 195.38 | 198.88 | 204.56 | 228.73 |
| 0.25 | 314.73 | 198.73 | 215.73 | 210.20 | 238.99 |
| 0.5 | 307.73 | 212.33 | 214.20 | 218.60 | 248.19 |
| Anova | | | | | |
| Shade Level | 0.0039 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4-6. Chlorophyll reading in Captiva St. Augustinegrass in response to shade and K rate in a greenhouse experiment by FC and averaged over the trial period in trial 2.

| Shade Level (%) | FC1 | FC2 | FC3 | FC4 | Average |
|---|---|---|---|---|---|
| 0 | 469.56ab | 313.56b | 390.38b | 374.06b | 367.09b |
| 30 | 482.88a | 408.94a | 507.50a | 492.50a | 434.13a |
| 50 | 473.06ab | 447.75a | 437.06b | 501.75a | 426.20a |
| 70 | 439.00b | 323.06b | 216.38c | 188.50c | 284.75c |
| K-rate (lb 1000 $ft^{-2}$) | | | | | |
| 0 | 472.38 | 368.94 | 364.38 | 380.13 | 368.55 |
| 0.125 | 462.19 | 348.63 | 402.19 | 406.63 | 376.54 |
| 0.25 | 466.19 | 390.06 | 388.50 | 398.69 | 384.96 |
| 0.5 | 463.75 | 385.69 | 396.25 | 371.38 | 382.11 |
| Anova | | | | | |
| Shade Level | 0.0237 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| K rate | NS | NS | NS | NS | NS |
| Shade× K rate | NS | NS | NS | NS | NS |

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

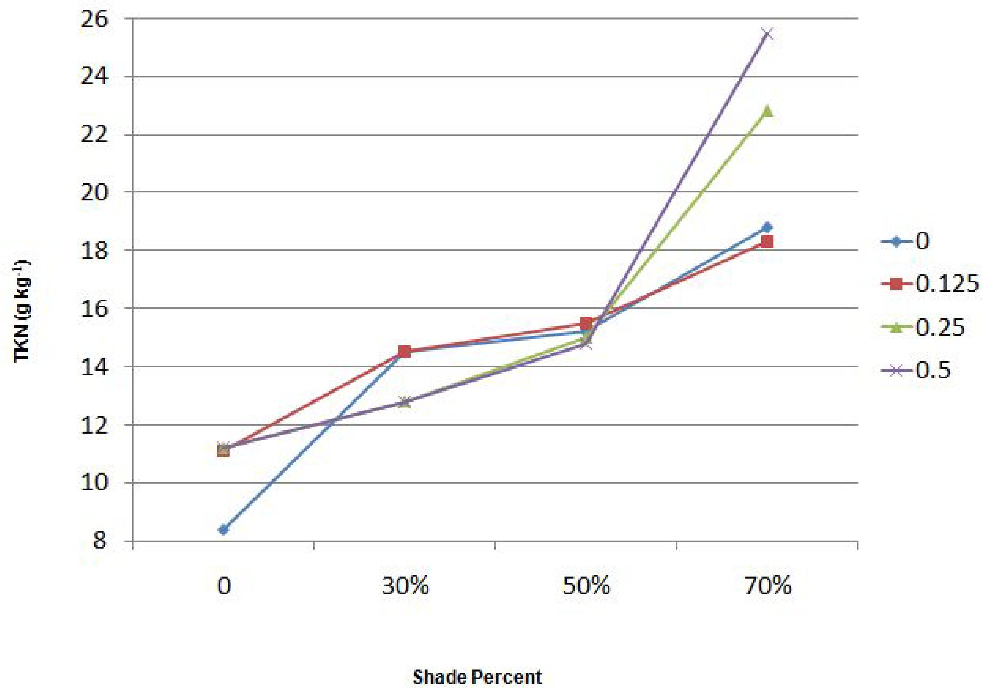


Figure 4-1. Interaction between shade and K rate in Total Kjedahl Nitrogen (TKN) in FC2 of trial 1

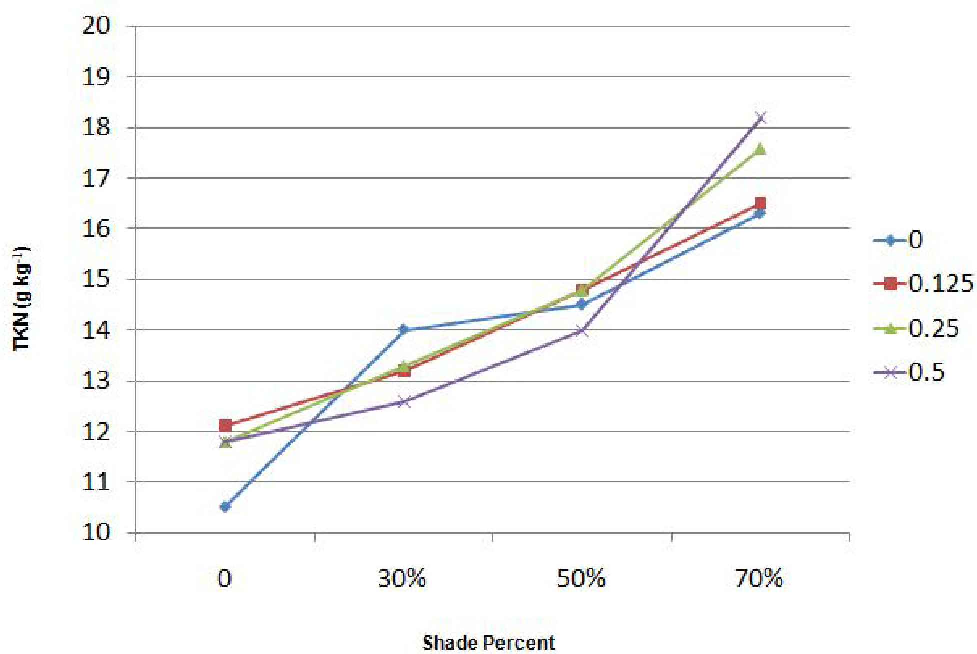


Figure 4-2. Interaction between shade and K rate in TKN when averaged over the trial 1 period

# CHAPTER 5
# CONCLUSIONS

Two trials were conducted under greenhouse conditions. Four shade levels and four potassium (K) rates were studied for their effects on turf visual color and quality, shoot and root growth, thatch accumulation, Total Kjedahl Nitrogen (TKN) concentration, tissue K concentration, and chlorophyll index (CI) in 'Captiva' St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze). Potassium can improve turf performance of Captiva under shaded conditions. Turf at 30% shade had highest turf visual quality and color scores, shoot and root dry weights, and CI. The higher the K rate, the better the turf visual quality. When turf was in poor condition and injured by drought stress at 0 shade in the first trial, higher K rate improved overall turf performance, such as turf visual quality, leaf length, and root growth.

Grasses grown at a higher shade level had higher TKN and tissue K concentrations. Higher K rates had higher leaf tissue K concentration, but there was little effect on TKN concentration due to K rates, because of nutrients competition and physiological process in turfgrass. These grasses could maintain acceptable quality at 30% shade and up to 50% shade. Thatch accumulation was highest at 70% shade and lowest at 30% shade due to reduced density under the heavy shade.

Results of this greenhouse experiment indicated that K may help turfgrass growing in a shaded environment by improving turf visual quality scores, leaf length, root growth, and tissue K concentration. Additional field research should be conducted to verify these responses in a landscape environment prior to making an official recommendation of K application to turf in shade.

# LIST OF REFERENCES


Allard, G., and C.J. Nelson. 1991. Shade effects on growth of tall fescue: I. Leaf anatomy and dry matter partitioning. Crop Sci. 31:163-167.

Armitage, A.M., C.E. Sams, R.M. Miranda, W.H. Carlson, and J.A. Flore. 1983. The effect of quantum flux density and net photosynthetic rate on morphology and time to flower of hybrid geraniums Sci. Hort. 21(3):273-282.

Asrar, G., M. Fuchs, E.T. Kanemaru, and J.L. Hatfield. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. J. 76:300-306.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs, N.J.

Beard, J.B. 1997. Shade stress and adaptation mechanisms of turfgrass. Int. Turfgrass Soc. Res. J. 8:1186-1195.

Bell, G.E., T.K. Danneberger, and M.J. McMahon. 2000. Spectral irradiance available for turfgrass growth in sun and shade. Crop Sci. 40:189-195.

Besford, R.T., and G.A. Maw. 1975. Effect of potassium nutrition on tomato plant growth and fruit development. Plant and Soil. 42(2):395-412.

Bethlenfalvay, G.J., and D.A. Phillips 1977. Effect of light intensity on efficiency of carbon dioxide and nitrogen reduction in *Pisum sativum* L. Plant Physiol. 60:868-871.

Bethlenfalvay, G.J., and R.S. Pacovsky. 1983. Light effects in mycorrhizal soybeans. Plant Physiol. 73:969-972.

Bhangoo, M.S., and D.J. Albritton. 1972. Effect of fertilizer nitrogen, phosphorus, and potassium on yield and nutrient content of lee soybeans. Agron J. 64:743-746.

Callahan, L.M., and J.R. Overton. 1978. Effects of lawn management practices in a bermudagrass turf. Tenn. Farm Home Sci. 108:37-40.

Chabot, B.F., and J.F. Chabot. 1977. Effects of light and temperature on leaf anatomy and photosynthesis in *Fragaria vesca*. Oecologia. 26:363-377.

Christians, N.E., D.P. Martin, and J. F. Wilkinson. 1979. Nitrogen, phosphorus, and potassium effects on quality and growth of Kentucky bluegrass and creeping bentgrass. Agron. J. 71:564-567.

Chirachint, W., and D.W. Turner. 1988. Shade reduces the foliar symptoms of ‘Fuerte’ avocado affected by salt, without significantly changing the concentration of Na, K or Cl in the leave. Sci. Hort. 36:1-15.

Clabby, G., and B.G.Osborne.1997. Irradiance and nitrate-dependent variation in growth and biomass allocation of *Mycelis muralis*. An analysis of its significance for a functional categorization of ‘sun’ and ‘shade’ plants. New Phytol. 135:539-547.

Cruz, P. 1997. Effect of shade on the carbon and nitrogen allocation in a perennial tropical grass, Dichanthium aristatum. J. Exp. Biol. 48:15-24.

Duble, R.L. 1992. Turf Management in the 21st Century. Texas Turfgrass. 45:6-9.

Dudeck, A.E., and C.H. Peacock. 1992. Shade and turfgrass culture. Agron. J. 32:269-284.

Elliott, K.J., and A.S. White. 1994. Effects of light nitrogen, and phosphorus on red pine seedling growth and nutrient use efficiency. Forest Sci. 40: 47-58.

Ervin, E.H., C.H. Ok, B.S. Fresenburg, and J.H. Dunn. 2002. Trinexapac-ethyl restricts shoot growth and prolongs stand density of 'Meyer' zoysiagrass fairway under shade. Hort. Sci. 37(3): 502-505.

Fitzpatrick, J.M., and K.Guillard. 2004. Kentucky bluegrass response to potassium and nitrogen fertilizer. Crop Sci. 44: 1721-1728.

Fry, J.O., and P.H. Dernoeden. 1987. Growth of zoysiagrass from vegetative plugs in response to fertilizers. J. Am. Soc. Hortic. Sci. 112:285-289.

Gent, M.P.N. 2004. Effect of nitrogen and potassium supply on yield and tissue composition of greenhouse tomato. Acta Hort. 644:369-375.

Goatley, J.M., V. Maddox, D.J. Lang, and K.K. Crouse. 1994. ‘Tifgreen’ bermudagrass response to late-season application of nitrogen and potassium. Agron J. 86:7-10.

Goss, R.M., J.H. Baird, S.L. Kelm, and R.N. Calhoun. 2002. Trinexapac-Ethyl and nitrogen effects on Creeping Bentgrass grown under reduced light conditions. Crop Sci. 42:472-479.

Harivandi, M.A. and V.A. Gibeault. 1997. Turfgrass management in shade. Calif. Turfgrass Cult. 47:1-3.

Harrewijn, P. 1979. Potassium and plant health. Eur. J. Plant Pathol. 85:82.

Hoffman, L., J.S. Ebdon, W.M. Dest and M. DaCosta. 2010. Effects of nitrogen and potassium on wear mechanisms in perennial ryegrass: I. Wear tolerance and recovery. Crop Sci. 50:357-366.

Hofland-Zijlstra, J.D., and F. Berendse. 2009. The effect of nutrient supply and light intensity on tannins and mycorrhizal colonisation in Dutch heathland ecosystems. Plant Ecol. 201(2):661-675.

Holm, D.G., and R.E. Nylund. 1978. The influence of potassium fertilizer application on tuber yield and mineral element content of potato petioles during the growing season. Amer. J. Potato Res. 55:265-273.

Jiang, Y. W., R.N. Carrow, and R.R. Duncan. 2003. Effects of morning and afternoon shade in combination with traffic stress on seashore paspalum. Hort. Sci. 38:1218-1222.

Jiang, Y. W., R.N. Carrow, and R.R. Duncan. 2004. Assessment of low light tolerance of seashore paspalm and bermudagrass. Crop Sci. 44:587-594.

Johnson, P.G., R.T. Koenig, and K.L. Kopp. 2003. Nitrogen, phosphorus, and potassium responses and requirements in calcareous sand greens. Agron. J. 95:697-702.

Jurik, T.W., J.F. Chabot, and B.F. Chabot. 1982. Effects of light and nutrients on leaf size, $CO_2$ exchange, and anatomy in wild strawberry (*Fragaria virginiana*). Plant Physiol. 70:1044-1048.

Juska, F.V. 1959. Response of 'Meyer' zoysia to lime and fertilizer treatments. Agron. J. 51:81-83.

Kjeldahl, J. 1883. A new method for the determination of nitrogen in organic matter. Z. Anal. Chem. 22:366.

Khan, S.R., R. Rose, D.L. Haase, and T.E. Sabin. 2000. Effects of shade on morphology, chlorophyll concentration, and chlorophyll fluorescence of four Pacific Northwest conifer species. New Forests. 19:171-186.

Khayyat, M., M.R. Vazifeshenas, S. Rajaee, and S. Jamalian. 2009. Potassium effect on ion leakage, water usage, fruit yield and biomass production by strawberry plants grown under NaCl stress. J. Fruit Ornam. Plant Res. 17:79-88.

Knipling, E.B. 1970. Physical and physiological basis for the reflectance of visible and nearinfrared radiation from vegetation. Rem. Sens. Environ. 1:155-159.

Koh, K.J., G.E. Bell, D.L. Martin, and N.R. Walker. 2003. Shade and airflow restriction effects on creeping bentgrass golf greens. Crop Sci. 43:2182-2188.

Kraffczyk, I., G. Trolldenier, and H. Beringer. 1984. Soluble root exudates of maize: Influence of potassium suppy and rhizosphere microorganisms. Soil Biol. Biochem. 16(4):315-322.

Lawanson, A.O., O.O. Otusanya, and D.A. Akomolede. 1977. Mechanism of potassium deficiency-induced retardation of chlorophyll biosynthesis in *Zea Mays*. Cell. Mol. Life Sci. 33(9):1145-1146.

Liang T.B., Z.L.Wang, R.J. Wang, L.L. Liu, and C.Y. Shi. 2007. Effects of potassium humate on ginger root growth and its active oxygen metabolism. Chin. J. Appl. Ecol. 18(4):813-817.

Longstreth, D.J., T.L. Hartsock, and P.S. Nobel. 1981. Light effects on leaf development and photosynthetic capacity of *Hydrocotyle bonariensis* Lam. Photosynth. Res. 2(2):95-104.

Ludlow, M.M., G.L. Wilson, and M.R. Heslehurst. 1974. Studies on the productivity of tropical pasture plants. V.* Effect of shading on growth, photosynthesis and respiration in two grasses and two legumes. Aust. J. Agric. Res. 25:425-433.

McBee, G.G. 1969. Association of certain variations in light quality with the performance of selected turfgrasses. Crop Sci. 9:14-17.

McVey, G.R., E.W. Mayer, and J.A. Simmons. 1969. Responses of various turgrasses to certain light spectra modifications, p. 264-272. In: R.R. Davis (ed.). Proc. 1st Intl. Turfgrass Res. Conf., Harrogate, England. 15-18 July 1969. Sports Turf Res. Inst., Bingley, UK.

Mikkelsen, R.L., H.M. Williams, and A.D. Behel, Jr. 1994. Nitrogen leaching and plant uptake from controlled-release fertilizers. Fert. Res. 37:43-50.

Minotta, G., and S. Pinzauti. 1996. Effects of light and soil fertility on growth, leaf chlorophyll content and nutrient use efficiency of beech (*Fagus sylvatica* L.) seedlings. For. Ecol. Manage. 86:61-71.

Mitchell, J.W., A.G. Whiting, and H.M. Benedict. 1944. Effect of light Intensity and nutrient supply on growth and production of rubber and seeds by guayule. Bot. Gaz. 106:83-95.

Monroe, C.A., G.D. Coorts, and C.R. Skogley. 1969. Effects of nitrogen-potassium levels on the growth and chemical composition of Kentucky bluegrass. Agron. J. 61:294-296.

Nus, J.L 1995. Potassium. Golf Course Management. 63(1):55-58.

Olff, H., J. Andel, and J.P. Bakker. 1990. Biomass and shoot:root allocation of five species from a grassland succession series at different combinations of light and nutrient supply. Funct. Ecol. 4: 193–200.

Peacock, C.H., and A.E. Dudeck. 1981. Effects of shade on morphological and physiological parameters of St. Augustinegrass cultivars, p. 493-500. In: R.W. Sheard (ed.). Proc. 4th Intl. Turfgrass Res. Conf., 19-23 July. Guelph, Ont., Canada.

Pocklington, T.E., J.D. Butler, and T.K. Hodges. 1974. Color evaluation of *Poa pratensis* cultivars. J. Sports Turf Res. Inst. 66:134-140.

Qian, Y., and M.C. Engelke. 1998. Growth regulator boosts zoysia's shade tolerance. Golf Course Management. 66(7):54-57.

Qian, Y.L., and M.C. Engelke. 1999. Influence of Trinexapac-Ethyl on ‘Diamond’ zoysiagrass in a shade environment. Crop Sci. 39:202-208.

Qian, Y.L., and M.C. Engelke. 2000. ‘Diamond’ zoysiagrass as affected by light intensity. J. Turfgrass Manage. 3(2):1-13.

Razmjoo, K., and S. Kaneko. 1993. Effect of fertility ratios on growth and turf quality of perennial ryegrass (*Lolium prenne* L.) in winter. Plant Nutr. 16(8):1531-1538.

Rosecrance, R.C., S.A. Weinbaum, and P.H. Brown. 1996. Assessment of nitrogen, phosphorus, and potassium uptake capacity and root growth in mature alternate-bearing pistachio (*Pistacia vera*) trees. Tree Physiol. 16:949-956.

Sartain, J.B., and A.E. Dudeck. 1982. Yield and nutrient accumulation of 'Tifway' bermudagrass and overseeded ryegrass as influenced by applied nutrients. Agron. J. 74:488-491.

Sartain.J.B. 1993. Interraltionships among turfgrasses. clipping recycling, thatch, and applied calcium, magnesium and potassium. Agron. J. 85:40-43.

Sartain, J.B. 2002. Tifway bermudagrass response to potassium fertilization. Crop Sci. 42:507-512.

SAS Institute. 2009. SAS user's guide: Statistics. Vers. 9.2. SAS Inst., Cary, N.C.

Seibert, M., P.J. Wetherbee, and D.J. Donald. 1975. The effects of light intensity and spectral quality on growth and shoot initiation in tobacco callus. Plant Physiol. 56:130-139.

Sideris, C.P., and H.Y. Young. 1945. Effects of potassium on chlorophyll, acidity, ascorbic acid, and carbohydrates of *Ananas cosmosus* (L.) Merr. Plant Physiol. 20:649-670.

Singh, S., and C.P. Sharma. 1989. Potassium effect on tissue hydration and transpiration in cauliflower. Plant Sci. 99(4):313-317.

Smith, M.A., and P.C. Whiteman. 1983. Evaluation of tropical grasses in increasing shade under coconut canopies. Exp. Agric. 19(2):153-161.

Snyder, G.H. and J.L Cisar. 2000. Nitrogen/Potassium fertilization ratios for bermudagrass turf. Crop Sci. 40:1719-1723.

Stier, J.C., and J.N. Rogers. 2001. Trinexapac-Ethyl and iron effects on supina and Kentucky bluegrasses under low irradiance. Crop Sci. 41:457-465.

Tegg, R.S., and P.A. Lane. 2004. A comparison of the performance and growth of a range of turfgrass species under shade. J. Exp. Agric. 44(3):353-358.

Terry, N., and A. Ulrich. 1973. Effects of potassium deficiency on the photosynthesis and respiration of leaves of sugar beet. Plant Physiol. 51(4):783-786.

Torre, W.R., and K.O. Burkey. 1990. Acclimation of barley to changes in light intensity: chlorophyll organization. Photosynth. Res. 24(2):117-125.

Travis, R.L., and J. Prendergast. 1987. Effect of leaf sugar and starch concentration on apparent photosynthesis in alfalfa. J. Agron. Crop Sci. 159(1):51-58.

Trenholm, L. E., J.L. Cisar, and J.B. Unruh. 2000a. St. Augustinegrass for Florida lawns. Univ. of Fla. Coop.Ext. Serv., ENH 5. Univ. of Florida, Gainesville, FL.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000b. Mechanisms of wear tolerance in seashore paspalum and bermudagrass. Crop Sci. 40:1350-1357.

Trenholm, L.E., R.R. Duncan, R.N. Carrow, and G.G. Snyder. 2001. Influence of silica on growth, quality, and wear tolerance of seashore paspalum. Plant Nutr. 24(2):245-259.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2001. Potassium for enhancement of turfgrass wear tolerance. Better Crops. 85:14-17.

Trenholm, L.E. 2003. Growing turfgrass in the shade. Electronic Data Info. Source(EDIS) Coop. Ext. Serv. Fact Sheet ENG 151, Univ. of Florida Inst. Of Food and Agr. Sci., Gainesville.

Trenholm, L.E., L.E. Datnoff, and R.T. Nagata. 2004. The influence of silicon on drought and shade tolerance of St. Augustinegrass. Hort. Tech. 14(4):487-490.

Trenholm, L.E., and R.T. Nagata. 2005. Shade tolerance of St. Augustinegrass cultivars. Hort. Tech. 15(2):267-272.

Trenholm, L.E. and K. Kenworthy. 2009. ‘Captiva’ St. Augustinegrass. Electronic Data Info. Source (EDIS) Coop. Ext. Serv. Fact Sheet ENH1137, Univ. of Florida Inst. Of Food and Agr. Sci., Gainesville.

Turner, T.R., and N.W. Hummel. 1992. Nutritional requirements and fertilization. p. 385–439. In: D.V. Waddington, R.N. Carrow, and R.C. Shearman (ed.). Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Wallingford, W. 1980. Function of potassium in plants. p.10-27. In: Potassium for Agriculture. Potash and Phosphate Inst., Atlanta, Georgia.

Watson, G.W. 1994. Root growth response to fertilizers. Arboriculture. 20(1):4-8.

Wherley, B.G., D.S. Gardner, and J.D. Metzger. 2005. Tall Fescue photomorphogenesis as influenced by changes in the spectral composition and light intensity. Crop Sci. 45:562-568.

Wilkinson, J.F., J.B. Beard, and J.V. Krans. 1975. Photosynthetic-respiratory responses of 'Merion' Kentucky bluegrass and 'Pennlawn' red fescue at reduced light intensities. Crop Sci. 15:165-168.

Wilson, J.R., and K. Hill. 1990. The growth of *Paspalum notatum* under the shade of a *Eucalyptus grandis* plantation canopy or in full sun. Trop. Grasslands. 24:24-28.

Winstead, C.W., and C.Y. Ward. 1974. Persistence of southern turfgrasses in a shade environmental, p.221-230. In: E.C.Roberts (ed.). Proc 2nd Intl. Turfgrass Res. Conf., 19-21 June 1973. Blackburg, Va.

Xu, Q.F., C.I. Tsai, and C.Y. Tsai. 1992. Interaction of potassium with the form and amount of nitrogen nutrition on growth and nitrogen uptake of maize. Plant Nutr. 15(1):23-33.

Zarlengo, P.J.,C.S. Rothrock, and J.W. King. 1994. Influence of shading on the response of tall fescue cultivars to rhizoctonia solani AG-l IA. Plant Dis. 78:126-129.

Zhao, D., and D.M. Oosterhuis. 1998. Influence of shade on mineral nutrient status of field-grown cotton. Plant Nutr. 21(8):1681-1695.

# BIOGRAPHICAL SKETCH

Xiaoya Cai was born in 1984 in Zhejiang, China. She got her bachelor's degree of horticulture science from Soochow University, China in 2007. In fall 2008, she was accepted as a master student by the Environmental Horticulture Department at the University of Florida and got her master's degree in summer 2010. After graduating, she plans to pursue doctorate degree in the Horticulture Science Department at Texas A&M University.