

ROOT DEPTH DEVELOPMENT AND TRANSPIRATIONAL RESPONSE TO SOIL
DRYING OF WARM-SEASON TURFGRASS SPECIES

By

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To Pablo, Pablito and Santiago

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LIST OF ABBREVIATIONS

BP	Break point
ET	Evapotranspiration
FTSW	Fraction of transpirable soil water
NTR	Normalized transpiration rate
RLD	Root length density
RRDD	Rate of root depth development
RUE	Radiation use efficiency
RWC	Relative water content
TR	Transpiration rate
TSW	Total transpirable soil water

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DRYING OF WARM-SEASON TURFGRASS SPECIES

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Water, over the previous two decades, has become a valuable commodity and limitations have been imposed for irrigating landscapes. The use of drought-resistance turfgrasses would help to maintain aesthetically pleasing and economically viable landscapes. Our objectives were to determine the variation in root depth development and root distribution (volume and length) among warm-season turfgrass species and/or genotypes within species (1st experiment) and to determine the changes in the transpiration rate of these species during soil drying (2nd experiment). The species evaluated were: *Zoysia* spp., *Cynodon* spp., *Axonopus fissifolius*, *Eremochloa ophiuroides* and *Stenotaphrum secundatum*.

In the first experiment plants were grown in clear acrylic tubes and watered to sustain growth. Root depth measurements were recorded. Sixty days after planting species differed for their root depth. Regression analysis was used to estimate the rate of root depth development (RRDD). Common bermudagrass had the highest RRDD. The roots were then sectioned into 30 cm horizons; horizon A, B, C and D (0-30; 30-60; 60 to 90 and 90 to 120 cm), and they were analyzed with root scanning software to

estimate root length (cm) and volume (cm³). These analyses showed difference in volume and RLD between species and genotypes.

In the second experiment transpiration response to drying soil was tested using clonally propagated plugs grown in pots. Transpiration rate was recorded by weighing each pot each day. The fraction of transpirable soil water (FTSW), number of days to complete a drydown and total water used were determined for individual genotypes, within species and across species. Break points indicated that some genotypes respond to soil drying by decreasing their transpiration rate early in the drydown, while other genotypes maintain their transpiration rate longer into cycle. Zoysiagrasses exhibited the greatest range for BPs, days to endpoint and TSW indicating that significant amount of variation exists for transpirational and drydown responses in zoysiagrasses. Bermudagrasses were grouped together for their BPs, days to endpoint and TSW; and were moderate among all genotypes. Floratam, St. Augustinegrass, had an early breakpoint and extracted more water than any other genotype.

CHAPTER 1 INTRODUCTION

Water

Water is one of the most common and important substances on Earth. It is essential for the existence of life, and the kinds and amounts of vegetation occurring on the various parts of the earth's surface depend more on the quantity of water available than on any other single environmental factor. Water is as important quantitatively as it is qualitatively and constitutes 80-90% of the fresh weight of most herbaceous plant parts and over 50% of the fresh weight of woody plants (Kramer and Boyer, 1995).

Water availability is becoming increasingly limited for irrigating landscapes, particularly in urbanized areas where water use restrictions are often imposed. Historically, water has been treated as an unlimited resource in the U.S. In the last decade this approach has changed (Hanks et al., 2005). Areas with low water-holding capacities, predominantly sandy soils and high water use requirements associated with high summer temperatures, cause droughts to be much more damaging than similar rainfall deficits on heavier soils (Burton et al., 1957). In Florida, the deterioration of drinking supplies has resulted in the adoption of ordinances that limit available water for use in landscapes or restrict the use of St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) (DEP, 2007).

The utilization of turfgrasses that require less water, fertilizers, and pesticides continues to be a prudent goal. Several warm-season grass species are potentially best suited for low-maintenance situations in some regions (Dernoeden et al., 1994). A low-maintenance grass should be slow growing and provide a functional purpose, as well as acceptable aesthetic quality with limited inputs of water and fertilizer (Biran et al., 1981).

Drought Stress

Drought stress is one of the most important environmental factors limiting the growth of turfgrasses (Beard, 1973). The selection and development of species and cultivars of turfgrasses that resist drought stress and require minimal inputs of supplemental irrigation is a viable strategy to conserve water (Carrow et al., 1990; Hanks et al., 2005). Knowledge of drought response differences in turfgrasses would accelerate the effectiveness in developing water-use efficient species. Increased water use efficiency is of great interest to growers when yields are maximized for the available water supply in each growing season. Economic benefits from increased water use efficiency under water-limited conditions are usually achieved only if plant performance is maximized for the available water (Sinclair and Muchow, 2001).

Ludlow and Muchow (1990), discussed 16 such traits that concerned production under water-limited conditions, and they recommended that eight of the traits were suited for intermittent stress conditions in modern agriculture. Their top three recommendations in order of priority were to match plant phenology to water supply, osmotic adjustment, and rooting depth. Information of variability in drought-resistance and its mechanisms is very important for the selection of grasses to improve management strategies; and therefore, for developing drought resistant turfgrass cultivars (Huang et al., 1997a). Turfgrasses often concentrate their roots in the upper 30 cm (Beard, 1973). Root characteristics associated with greater drought resistance during surface soil dry down include enhanced water uptake from deeper in the soil profile, root proliferation into deeper soil layers, and persistent root growth or maintenance of root viability in the dry surface soil. These characteristics could be used

as selection criteria in turfgrass breeding programs for improving water use efficiency or drought resistance (Huang et al., 1997b).

Drought Resistance Strategies

Plants have three major drought-resistance strategies: drought escape, drought avoidance and drought tolerance. Drought escape is the ability of a plant to survive drought stress by becoming dormant during drought (perennial species) or by completing the life cycle prior to drought occurrence (annual species). Drought avoidance is the ability of a plant to grow under drought stress by maintaining internal water status through reduction in water use or loss from plant canopy or increasing water uptake of roots from the soil. Plants that possess drought avoidance mechanisms may survive or sustain growth and function during short-term drought until water is depleted in the soil. Drought tolerance can be achieved by maintaining metabolic processes even under decreased cellular water content. This strategy allows for plants to tolerate prolonged periods of drought. The three drought-resistance strategies are not mutually exclusive and the same plant species may utilize more than one strategy when adapting to drought stress (Huang, 2008).

Comparisons among Species

Variations in drought resistance have been found among turfgrass species and cultivars, including bermudagrass (*Cynodon spp.*), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack], creeping bentgrass (*Agrostis palustris* Hudson), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), St. Augustinegrass, tall fescue (*Festuca arundinacea* Schreber), and zoysiagrass [*Zoysia japonica* (Steud) and *Z. matrella* L.] (Aronson et al., 1987; Hays et al., 1991; Salaiz et al., 1991; Marcum et al., 1995; Carrow, 1996a, b). 'Common' bermudagrass [*Cynodon*

dactylon (L.) Pers. var. *dactylon*], and ‘TifBlair’ centipedegrass are considered relatively drought tolerant (Hook et al., 1992; Carrow, 1996b). ‘Emerald’ zoysiagrass is a relatively drought sensitive cultivar (Kim et al., 1988).

In a review of turfgrass drought resistance rankings from several studies, Carrow (1996b) noted that common bermudagrass consistently ranked high to very high relative to other warm-season grasses. Zoysiagrass rankings varied from low to very high with ranking differences explained on the basis of using different cultivars, assessment criteria, and/or duration of drought stress. ‘Common’ centipedegrass was ranked as low in drought resistance by Beard (1973) and Carrow (1996b), but in other studies is ranked as moderate to high. In summary, drought resistance of turfgrasses varied between species and genotypes within a species.

In a study conducted by Huang et al. (1997b), root dry weight was significantly reduced with surface soil drying (the first 20 cm soil layer was allowed to dry down by withholding irrigation while the lower 40 cm was maintained at field capacity) for Emerald zoysiagrass, common bermudagrass, and ‘Adalayd’ seashore paspalum, and under severe stress (the 40 cm soil layer was allowed to dry down by withholding irrigation while the lower 20 cm soil segment was kept at field capacity) for ‘PI 299042’, ‘AP14’ and ‘PI 509018’ seashore paspalum, and TifBlair centipedegrass. Root dry matter production recovered completely for PI 299042, AP14 and PI 509018 and TifBlair, but only partially for Emerald, common bermudagrass, and Adalayd after rewatering and allowed to recover for 14 days.

In a comparison of bermudagrass with zoysiagrass, bermudagrass was significantly more drought resistant than zoysiagrass (Sifers and Beard, 1998). The

authors indicated that the differences between the two species have been associated with the environmental conditions under which each evolved: bermudagrass evolved under the hot, dry conditions of southeastern Africa, whereas the center of origin for zoysiagrass is in the humid environment of Southeast Asia. In an evaluation of a 60-day induced summer drought, Steinke et al. (2009) reported that bermudagrass had significantly less leaf firing than St. Augustinegrass and zoysiagrass. This response could be attributed to the ability to pull soil moisture from deeper within the soil profile, as bermudagrass has been documented to be one of the deeper rooting warm-season turfgrass species with mature rooting depths of up to 2.2 m recorded (Steinke et al., 2009).

Hays et al. (1991) conducted a study related to drought avoidance in bermudagrass with seven experimental genotypes and three cultivars, 'Tifgreen', 'U-3' and 'Midiron'. Their results documented differences among bermudagrass genotypes regarding their ability to avoid drought stress at different soil depths (30, 60, 90 and 150 cm). Root weights of horizons were measured for comparisons. The authors indicated that the differences among genotypes may be due to their ability to distribute roots downward in the soil profile. The plants capable of uniformly distributing their roots throughout the soil profile in response to simulated drought were superior in drought avoidance by maintaining high visual quality.

Hook et al. (1992) compared the performance of centipedegrass under differing levels of drought stress. They subjected centipedegrass to three drought regimes: no-stress (watered twice per week), moderate (2 to 3 weeks between watering), and severe (4 to 6 weeks between watering). Soil water was monitored with watermark

sensors (Irrrometer Co., Inc., Riverside, CA). Clipping biomass, relative leaf water content and visual ratings were collected. Under the controlled drydown periods, centipedegrass was affected (all parameters showed decline in turfgrass performance, but the grass was never killed). Recovery after re-watering generally occurred within 10 days in the moderate and severe drought regimes. They concluded that centipedegrass could be a suitable turfgrass for infrequently watered landscapes in the southern U.S.

Root Length Screening Techniques

Lehman and Engelke (1991) and Acuna (2009) have both utilized small diameter clear tubes to assess root lengths of creeping bentgrass (*Agrostis palustris* Huds.) and bahiagrass (*Paspalum notatum* Fluegge) respectively. Lehman and Engelke (1991) used clear polyethylene tubing cut to 65 cm length that was then heat sealed and perforated for drainage. The tubes were filled with a fine, washed sand mixed with 3.6 g of plastic-coated, slow release fertilizer. The cores were then vibrated to form a column 55 cm long. These tubes were placed in PVC pipe for support. Roots of turfgrass plugs were removed to 5 cm below the soil surface and planted in the tubes. Root extension was monitored by marking the outside of the clear tube for the duration of the study. At the end of the study, rooted tillers per core were counted and weighed. The authors concluded that the flexible tube technique adequately predicted field performance of bentgrass genotypes. According to this, the procedure could be applied to other plant root systems.

In a similar study developed by Acuna (2009), the rate of root depth development (RRDD) was monitored by growing bahiagrass in clear acrylic tubes. Tubes 100-cm in length and 3.5-cm or 10-cm diameter were tested. The tubes were used to evaluate the effect of soil volume and plant competition on RRDD. The tubes were filled with sandy

soil or commercial potting mix. These two soils were used to test the potential effect of organic and inorganic soils on RRDD. The result shows that there were no interactions between genotypes and the growing medium or tube size. The RRDD of plants grown in potting mix or soil were similar, indicating that bulk density and other soil attributes had no measurable effect on RRDD. Rates of root depth development were similar when plants were grown in small or large tube diameters indicating that small tubes can be used efficiently to test a large number of genotypes.

Physiological Measures

Evapotranspiration

All plant physiological processes and cell metabolic activity are affected by available water (Kramer and Boyer, 1995). Transpiration is the loss of water from plants in the form of vapor and is a critical component of plant water relations because of the volume of water involved and its role regarding plant water status. It also produces the energy gradient that largely controls absorption and the ascent of sap. In warm sunny weather, transpiration often causes brief midday wilting and as the soil dries it causes permanent wilting and finally death by dehydration if the soil moisture is not replenished by rain or irrigation. The discussion of transpiration has dealt thus far largely with leaves or individual plants, but plants in nature usually occur in stands or communities and water loss occurs both from the transpiring plants and by evaporation from the surface of the soil in which they are growing, which collectively is known as evapotranspiration (ET) (Kramer and Boyer, 1995).

Stomata

Stomata are pores in the epidermis whose aperture is controlled by pairs of specialized epidermal cells known as guard cells. They provide passageways between

the ambient air and the air spaces in photosynthetic tissue essential for the entrance of the CO₂ used in photosynthesis. They also provide pathways for the exit of water vapor, subjecting plants to the danger of excessive dehydration in sunny, dry weather. Thus stomatal aperture plays an important role in controlling both transpiration and the CO₂ supply for photosynthesis. Stomata usually open in the light and close in darkness (Kramer and Boyer, 1995).

Relative Water Content

Determination of the relative water content (RWC) of plants may be useful for characterizing plant drought stress. RWC reflects the dynamic water balance between water flow into and out of plant tissues. An easier way to understand this is considering a simple plant with a single root and a single leaf. The water balance of the plant, and the RWC, is given by the difference between transpiration and root uptake. Normally, RWC must be close to zero or the plant will explode because of excess water or desiccate from water loss. Consequently, RWC will be a moderately stable plant variable, compared to transpiration and root uptake (Sinclair and Ludlow, 1985).

Dehydration Stages

Sinclair and Ludlow (1985) studied the plant water balance of different species during a soil drying cycle and determined that the response of the plants could be designated by three distinct stages of dehydration. Stage I occurs when soil water is abundant and the root uptake rate is similar to the transpiration rate. The transpiration rate is influenced by the environment and the relative water content (RWC) will generally not fall below 75-85%. Stage II occurs when root uptake rate cannot match the demands of transpiration. During this stage, the plant must adjust its conductance to maintain a stable water balance. It is probable that RWC could be lower and decrease

continuously during Stage II, in the range of 80-60%. Stage III begins as the soil dries more, the root water uptake declines, and stomata lose the capability of keeping the transpiration rate approximately equal to the uptake rate. In stage III, the stomata are closed. When the root water uptake rate is considerably lower, the RWC falls and the leaves die.

Fraction of Transpirable Soil Water

Ritchie (1980) suggested that physiological processes such as photosynthesis, transpiration, or leaf growth would show similar responses across a wide range of environmental conditions when compared on the basis of the fraction of total extractable water in the root zone. Subsequent research has shown this to be generally true across a wide range of species and plant processes (Sinclair and Ludlow, 1986).

Johnson et al. (2009) and Miller (2000) in similar studies observed different transpiration rates in turfgrasses during drought stress and their influence on drought stress tolerance. They provided a definition of daily fraction of transpirable soil water (FTSW), noting that it represents the stress level for each treatment expressed as a function of soil water content. A lower FTSW for stomatal closure means that the plant could extract additional soil water before stomatal closure, and thus would exhibit a comparatively higher transpiration rate for a longer period of time. This delayed closure of stomata would appear to be advantageous under drought conditions when the stress is short and intermittent. However, long term drought stress would favor stomata closing early in the drying cycle. This would conserve water and increase the plant's chance of survival (Ray and Sinclair, 1997).

Reduced transpiration rates could allow for soil water conservation and continuous crop growth during dry periods through the growing season (Sadok and Sinclair, 2009).

A high volume of soil water content at which transpiration rate begins to decrease would be a possible mechanism to conserve soil water and maintain turf quality for a longer time as drought conditions persist. Identification of possible genotypic differences is a significant first step in breeding for enhanced performance in response to soil drying (Johnson et al., 2009).

In a study of radiation use efficiency (RUE), RUE is down-regulated as a soil water deficit develops, which is an expression of stomata closure. This down regulation occurs as a function of the FTSW. The value of the FTSW ranges from 1.0 at field capacity to 0.00 when all of the water available for transpiration has been extracted. Transpiration as a function of the FTSW has been described in many species, and a relatively constant exponential function has been obtained across a range of conditions (Sinclair et al., 1998). Atypical behavior does not usually occur until the FTSW has decreased to a value of about 0.30 to 0.35 (Sinclair and Muchow, 2001).

Typically, as the soil dries under constant environmental conditions, the transpiration rate remains constant until threshold soil-water content is reached, and after that, it declines linearly. With few exceptions, the threshold at which transpiration begins to decline occurs when 0.3–0.4 of the transpirable soil water remains in the soil. This general relationship was fairly stable in a number of experimental conditions and species (Ray and Sinclair, 1998; Sadras and Milroy, 1996). The basis for the consistent responses of transpiration to drying soil may result from a need for plants to balance water loss to the atmosphere and the water supply from the soil. As the soil dries and conductivity in the soil limits water transport to the roots, the decreased water supply rate must be balanced by an inhibition of shoot transpiration rate or the plant quickly

desiccates. Therefore, a decrease in stomatal conductance appears to be a necessity at that soil-water content where water cannot be supplied to equal the transpiration rate allowed with unrestrained stomatal conductance (Ray et al., 2002).

An alternative strategy to the conservative response, in which down regulation is induced earlier in soil drying, is to sustain plant growth by delaying stomata down regulation. In this case, the crop continues to extract water at a high rate until the soil becomes very dry, with a very low FTSW, in anticipation that there will be rain or irrigation before severe water deficits develop. This strategy, therefore, avoids the initial negative consequences of soil drying through continued plant growth. This approach is likely an expression of osmotic adjustment in that the decrease in stomata closure is delayed (Sinclair and Muchow, 2001).

Normalized transpiration rate

To calculate FTSW, it is necessary to calculate the normalized transpiration rate (NTR). The objective of NTR is to remove the variation in transpiration rates between plants. The normalization of the transpiration rate assures that all plants have an average NTR equal to one, when they have abundant available water (Ray and Sinclair, 1997; Sinclair and Ludlow, 1986; Miller, 2000). An NTR value equal to 0.1 to 0.12 is considered an end-point in the drying cycle (Sinclair and Ludlow, 1986; Miller, 2000). The NTR and the days to reach this point are useful measurements to compare species and genotypes. The days required to reach the end-point indicates the differences in absolute water use rates among genotypes, thus a greater number of days to reach this point indicate a slower water use rate or a greater amount of water available to the plant (Ray and Sinclair, 1997).

Total transpirable soil water

Additionally to obtain the FTSW, the transpirable soil water or total transpirable soil water (TSW) must be calculated. By definition, the quantity of TSW represents the amount of soil water consumed during the first stages (I and II) of a drying cycle (Sinclair and Ludlow, 1986). The TSW is normally calculated for each pot by taking the difference between the fully-saturated weight of each pot and the weight when the drying cycle has completed (Sinclair and Ludlow, 1986; Miller, 2000). Crops may differ in their rate of water loss and the amount of water that they are able to extract from the soil (Sinclair and Ludlow, 1986). Ratcliff et al. (1983) indicated that there is little variation in the amount of available soil water among soils except for sand. Therefore, TSW is useful to determine the differences in the amount of water extracted by different crops or plants. The difference in TSW could be due to the rooting behavior of particular plants; for example Lawn (1982) found that soybean (*Glycine max*) was able to extract more water early in the season compared to cowpea (*Vigna unguiculata*) and black gram (*Vigna mungo*) because of greater root depth.

Visual Ratings

Turfgrass evaluation is a subjective process based on visual estimates of characteristics. Turf quality is a measure of aesthetics that encompasses density, uniformity, texture, color, etc. (Morris and Shearman, 2006). Visual turf quality and ET rate have been evaluated as criteria for drought resistance in turfgrasses (Aronson et al., 1987; Carrow, 1996a). During imposed drought, some grasses initially exhibit chlorophyll loss before leaf firing, but others show the reverse order. The genetic variations in leaf response to soil drying could be related to differences in root characteristics (Huang et al., 1997a). Wilting is an initial sign of a water deficit and is

caused by a drop in cell turgor pressure. The internal cell water has been exerted from the cell for transpiration, and the leaves curl (Fuller, 2002). Following wilt, leaf firing can occur as a result of chlorophyll degradation. Estimates of leaf firing are often used to measure drought resistance (Beard, 1973; Kim et al., 1988). The National Turfgrass Evaluation Program (NTEP) indicates in their guidelines that drought stress resistance is evaluated as wilting, leaf firing, dormancy, and recovery. For the wilting parameter, visual rating is used (1 to 9 scale) with 1 being completely wilted and 9 being without wilting (Morris and Shearman, 2006).

Warm Season Turfgrass Species

In the Southern U.S. and lower latitudes little to no effort has occurred to identify and develop turfgrass cultivars that persist and have adequate performance with reductions associated with irrigation, fertilization and mowing. Additionally, the development and utilization of other turfgrass species is warranted because of a near monoculture of St. Augustinegrass, particularly in south Florida (Erickson et al., 2008). There are many warm-season turfgrasses that may be used as an alternative to St. Augustinegrass (Trenholm and Unruh, 2006). These species include: zoysiagrass (*Z. japonica* and *Z. matrella*), carpetgrass (*Axonopus fissifolius* Raddi), centipedegrass, common bermudagrass, and African bermudagrass (*Cynodon transvaalensis* Burtt-Davy). Knowledge of drought-resistance mechanisms in these turfgrass species would improve management strategies and speed progress in the development of drought-resistant cultivars.

Zoysiagrass

Zoysiagrass is a warm-season, perennial turfgrass, native to parts of China, Japan and Korea (Engelke and Anderson, 2003). Two species are of importance to the

turfgrass industry, *Z. japonica* and *Z. matrella* (Hawes, 1979). Both species are tetraploids ($2n=4x=40$); however, they differ morphologically with respect to leaf texture. *Zoysia japonica* can range from medium to coarse textured, while *Z. matrella* plants have a fine texture. They are adapted throughout the southern region of the United States to the northern transition zone. Zoysiagrass forms a dense, uniform turf through the production and spread of rhizomes and stolons (Turgeon, 2008). In the southern U.S., zoysiagrass is considered an alternative species for golf courses, sport fields, and home lawns. Sod production of zoysiagrass in Florida is low, with only 2,125 ha (5% of total Florida sod production) of zoysiagrass in production during 2007. Fifty-eight percent of these acres were harvested for sale in 2007 (Hodges and Satterthwaite, 2009).

Carpetgrass

Carpetgrass is a native of the West Indies and South Central America and is grown in the warmest areas of the southern U.S. (Emmons, 1995; Beard, 1973). Of the 70 species within this genus, only two, common carpetgrass (*Axonopus fissifolius Raddi*) and tropical carpetgrass (*Axonopus compressus* [Swartz] Beauv.) are used as turfgrasses. Common carpetgrass is an octoploid with 80 chromosomes ($2n = 2x = 80$) and tropical carpetgrass is a tetraploid with 40 chromosomes ($2n = 4x = 40$) (Turgeon, 2008).

Common carpetgrass is a stoloniferous grass that forms a dense sod, with light green, coarse textured leaf blades. It grows on wet, low-pH soils where few other grasses persist, thus, it is one of the only turfgrass species recommended for wet sites (Bush, 2000). It has moderate shade tolerance, and it is a low-maintenance grass that does not require excessive amounts of fertilizer. It can easily be established from seed,

sprigs or sod. Comparatively, common carpetgrass has fewer pest problems than most warm-season lawn grasses. Common carpetgrass is not recommended for a high quality lawn; however, it can be used in areas where ease of maintenance is more important than quality (Trenholm, et al., 2000b). Greene et al. (2008) made a germplasm collection of carpetgrass across the southern U.S. and determined that variation exists and that improvement is possible for several turfgrass performance traits.

Centipedegrass

Centipedegrass is a perennial stoloniferous grass native to Southeast Asia (Hanson et al., 1969) with a center of origin located in south to central China (Hanna, 1995). It is a low-maintenance grass widely used throughout the southeastern United States (Johnson and Carrow, 1988). It is a diploid species ($2n=2x=18$) available as seed or sod and it is the most common lawn grass in the panhandle of Florida.

Centipedegrass is slow growing with low fertility requirements, it grows close to the ground, is medium textured and has a pale green color (Trenholm et al., 2000a). Over-fertilizing to obtain dark green color reduces its cold tolerance, increases long-term maintenance problems, and is believed to contribute to “centipedegrass decline” (Trenholm et al., 2000a). Centipedegrass decline is a term used to describe centipedegrass that exhibits slow spring green-up or becomes chlorotic and suddenly dies after initial growth (Johnson and Carrow, 1988).

Centipedegrass performs very well in acidic and infertile soils. It has fair to good shade and good drought tolerance. Stolons from centipedegrass have high lignin content and contribute to a heavy thatch layer, particularly under high fertility rates (Trenholm et al., 2000a). Centipedegrass that is actively growing should be mowed

every 7 to 14 days at 3.8 to 5.0 cm in height. Mowing at this height promotes a deeper, more extensive root system that enables the grass to better withstand drought and nematode stress (Trenholm et al., 2000a). Centipedegrass sod production occurs on 1,315 ha in Florida compared to 21,408 ha for St. Augustinegrass. Less than 50% of the centipedegrass grown for sod is harvested on an annual basis (Hodges and Satterthwaite, 2009).

Bermudagrasses

Bermudagrass is one of the most important and widely adapted turfgrass species. Bermudagrass is found throughout most of the warm, humid, tropical, and subtropical regions of the world (Beard, 1973). There are nine species in the genus *Cynodon*, and *Cynodon dactylon* (L.) Pers. var. *dactylon* is the most widely utilized (Taliaferro, 1995). This species is known in United States as common bermudagrass (Christians, 2007). The other important bermudagrass species for turf purposes is *Cynodon transvaalensis* Burt-Davy, known as African bermudagrass (Taliaferro, 1995).

Common bermudagrass

Cynodon dactylon (L.) Pers. var. *dactylon* is a cross-pollinated tetraploid ($2n = 4x = 36$). It was one of the first bermudagrass species widely utilized for turfgrass purposes (Beard, 1973). It is adapted to a wide range of soil conditions. Although it is generally not very cold tolerant, the colder limits of adaptation have been extended with the development of several new cultivars (Turgeon, 2008).

Common bermudagrass is well-suited for golf course roughs, home lawns, and industrial parks, as well as for soil stabilization. It responds well to moderate fertilization, frequent mowing, and adequate moisture (Christians, 2007); and it has a medium to coarse leaf texture and medium green color. Its growth habit is quite prostrate with

intergradations of stolons and rhizomes that form a very tight sod. It is propagated through seed, sprigs, plugs, or sod (Beard, 1973).

African bermudagrass

Cynodon transvaalensis, a diploid ($2n=2x=18$), commonly referred to as African bermudagrass, is endemic to South Africa. It has a very small range of natural distribution, and is found in moist areas within the southwestern Transvaal area, Orange Free State, and northern part of the central Cape Province of South Africa (Harlan et al., 1970a; Harlan et al., 1970c). African bermudagrass can usually be found growing in damp areas around surface water and stream banks (Harlan et al., 1970b).

African bermudagrass is adapted to much cooler climates and is more winter hardy than is implied by its natural distribution (Harlan et al., 1970a). 'Uganda' and 'Florida' are among the earliest of the African cultivars and have been widely distributed around the world. They are adapted for cold tolerance to approximately 39°N latitude in the United States (Taliaferro, 1992; Taliaferro, 2003). Use of the species has been limited due to the following: increased use of water and nutrients, tendency to thatch, lack of a dark green color, purpling under cooler temperatures, and a decline in turf quality as a result of chronic heat stress. It is not known if these limitations are characteristics of the species as a whole or just the relatively few available varieties (Taliaferro, 1992).

Plants of African bermudagrass are characterized as a low-growing, turf type bermudagrasses (Hanna, 1986). They can reproduce vegetatively, through propagation of stolons and rhizomes, or sexually, through seed production. Because the species is self-incompatible, different genotypes must be planted together in order to set seed (Harlan et al., 1970b).

Objective

The overall objective presented in this thesis was to identify warm season turfgrass species and genotypes with different attributes that could be associated with drought resistance. Two experiments were conducted to address this objective. The first study (Chapter 2) provides comparative knowledge of root morphology for different warm season turfgrass species. The second study (Chapter 3) compares the response of warm season turfgrass species undergoing a controlled dry down.

CHAPTER 2 ROOT DEPTH DEVELOPMENT OF WARM-SEASON TURFGRASS SPECIES

Introduction

The use of water and fertilizers on commercial and residential turf is increasingly regulated at the national and regional levels. Water scarcity is one of the biggest long-term problems that the turf industry faces worldwide. This includes the chronic shortages typical of arid and semi-arid zones, as well as the occasional extended droughts occurring in humid regions (Sifers and Beard, 1998). Better knowledge of drought-resistance mechanisms in turfgrass would improve management strategies and speed progress in the development of drought-resistant cultivars. Drought resistance refers to the ability to survive a severe water stress, which may include entering a dormant condition and then recovering subsequently when water is available (Marcum et al., 1995).

Knowledge of root traits is important for further understanding drought resistance mechanisms. Low evapotranspiration (ET) rates and deep extensive root systems are desirable drought avoidance characteristics (Huang and Gao, 2000). Salaiz et al. (1991) considers root distribution to be more important than total root production when selecting for drought. Therefore, the evaluation and selection of turfgrass species and cultivars with deep root systems that tap greater volumes of soil water is especially important (Qian et al., 1997).

Turfgrass research has shown that light, frequent irrigation encourages shallow rooting (Shearman and Beard, 1973; Richie et al., 2002). Less frequent and deeper irrigation may encourage drought avoidance mechanisms, such as deeper rooting. Research has shown a correlation between plant rooting patterns and drought

avoidance mechanisms (Richie et al., 2002). As an example, Carrow (1996a) showed that reduced wilting and leaf firing for tall fescue (*Festuca arundinacea* Schreb.) cultivars was correlated with higher root length density deeper into the root zone (20 to 60 cm depth), and demonstrated that high root length density in the surface 3 to 10 cm of soil, in fact, enhanced wilting, possibly due to rapid depletion of the surface soil water. Another example with warm season turfgrasses was realized by Hays, et al. (1991), who determined differences among 10 bermudagrass genotypes regarding their ability to avoid drought stress associated with the capacity to distribute roots down in the soil profile. The genotypes that uniformly distributed their roots throughout the soil in response to drought, were able to maintain greater visual quality.

With concerns over water and fertilizer use, emphasis has been placed on breeding lower maintenance cultivars of the species more frequently used in lower latitudes [hybrid bermudagrass (*C. dactylon* L. var. *dactylon* × *C. transvaalensis* Burt-Davy), and St. Augustinegrass], and on the identification and breeding of alternative reduced input species that may be suitable for turf purposes. The objective of the present study was to determine the variation for 1) rate of root depth development and 2) root distribution (volume and length) among warm-season turfgrass species and/or genotypes within species.

Materials and Methods

Location and Material

The study was conducted in Gainesville, Florida (29° 39'5" N/ 82°19'30"W), at the Archer Road Plant Physiology and Breeding Laboratory facilities of the University of Florida Agronomy Department. Twenty-six genotypes were evaluated from the following

species: *Zoysia japonica*, *Zoysia matrella*, carpetgrass, centipedegrass, common bermudagrass, African bermudagrass, hybrid bermudagrass and St. Augustinegrass.

The genotypes and cultivars that were evaluated are shown in Table 2-1. The study was conducted during the summers of 2009 and 2010. The two studies were initiated 1 July, 2009 and 1 June, 2010.

Procedure

Procedures were a modification of these described by Acuna (2009). Plants were grown outdoors in clear acrylic tubes with a depth of 122 cm by 6.4 cm diameter; these tubes were set inside of 7.6 cm PVC pipes to block sunlight and simulate underground conditions (Figure 2-1, A and B). Tubes were filled with an 80% USGA-spec sand and 20% peat mix. Soilless 5 cm plugs of each genotype were planted into the tubes, previously, formed roots were cut at 1.5 cm from the plant crowns. The experiment was arranged in a randomized complete block design with four replications. One week after planting, plants were fertilized with a 10-10-10 Scotts (Marysville, OH, USA) granular fertilizer at a rate of 48 kg ha⁻¹, N as urea (7.9%) and ammoniacal nitrogen (2.1%). Plants were subsequently fertilized weekly with a water soluble fertilizer (Miracle-Gro, Marysville, OH, USA), (36-0-6), at 5 kg ha⁻¹, N as urea (33.2%) and ammoniacal nitrogen (2.8%); 1.8 kg N ha⁻¹ per application.

The tubes were grown outdoors, irrigated to sustain growth (when rainfall was inadequate), and placed at an angle of 75° to the floor to facilitate the visibility of the roots in the clear tubes for data measurements (Figure 2-1, C). Root depth measurements were initiated the first week after planting and subsequently recorded three times per week. The plants were trimmed every two weeks to 6.35 cm. Sixty days after planting the breakdown of tubes was initiated; the tubes were fully watered to keep

the column of soil wet and to remove the intact soil/root samples. Roots were separated by cutting the roots from the base of the crown and rhizomes. The roots were then sectioned into 30 cm horizons: horizon A (0-30 cm), horizon B (30 to 60 cm), horizon C (60 to 90 cm), and horizon D (90 to 120 cm). Roots were washed until free of soil and analyzed using WinRHIZO (Québec, Canada) software to estimate root length (cm) and volume (cm³). Root length density (RLD) was calculated with the root length data provided by the scanner by considering the diameter of the tubes and the length of each horizon. The root length data were divided by the volume of soil for each horizon to obtain the root length density (RLD). Subsequently, roots and rhizomes were dried at 60°C for 72 h, and dry weights were determined for both.

Statistical Analysis

Data were analyzed using the SAS statistical package for Windows (SAS Systems for Windows Version 9.2, SAS Institute Inc. Cary, NC, USA) using the PROC GLIMMIX procedure. Least square means were estimated and tested for significant differences at an alpha level of 0.05. The sources of variation included for the analysis of variance were year, species, genotype nested within species and the following interactions: year × species and year × genotype nested within species.

Regression analysis was used to estimate the rate of root depth development (RRDD) corresponding to the slope of the linear function between time and depth of the deepest visible root. The RRDD data were analyzed using PROC GLM as a randomized complete block design. An analysis of variance using Proc GLIMMIX (SAS Systems for Windows Version 9.2, SAS Institute Inc. Cary, NC, USA) was performed to test for treatment differences and if interactions were significant (Table 2.2). The ANOVA table

includes only the tested treatment effects and not the associated error terms. For root length development (RLD) and root volume a significant interaction occurred for species × years. Therefore, data for 2009 and 2010 are presented separately.

Results and Discussion

Rate of Root Depth Development (RRDD) Between Species

The RRDD provided the rate of daily root growth for each species. In 2009, the highest daily rate of root depth development was in common bermudagrass at 5.5 cm day⁻¹ (Table 2-3). The daily growth rates in 2009 ranged from 2.1 to 5.5 cm day⁻¹. In 2010, common bermudagrass, St. Augustinegrass, carpetgrass and *Zoysia japonica* had the greatest daily root growth. Root growth in 2010 ranged from 1.7 to 2.5 cm day⁻¹. It is not known why the daily root extension rates were so different between years. A possible reason is that in 2010 the experiment was conducted during the months of June and July, one month earlier than in 2009 (July- August).

RRDD Between Genotypes

The genotypic ranges for RRDD in 2009 and 2010 were 1.88 to 6.94 cm day⁻¹ and 1.43 to 2.80 cm day⁻¹, respectively (Table 2-4). In both years, common bermudagrass genotypes were grouped among those having the fastest RRDD. The centipedegrass entries tended to group together, with low RRDD in 2009 and moderate RRDD among all genotypes in 2010. Genotypes of *Z. japonica* had a higher RRDD in both years than *Z. matrella*. The only RRDD information that the authors are aware of in the literature for grass species are those reported by Acuna (2009). The author reported RRDD values averaging approximate 2.0 cm day⁻¹ for 13 bahiagrass lines, which is similar to the results shown for 2010.

RRDD Within Species

There were no differences for RRDD between genotypes within centipedegrass or *Z. matrella* in either year (Table 2-5). Differences occurred within African bermudagrass for both years. Genotype 'UFCT42' was the most consistent entry between years. Carpetgrass and common bermudagrass had differences in RRDD between respective genotypes in 2009 only. Common bermudagrass genotypes 'UFCD347' and 'UFCD12' exhibited the fastest RRDD in 2009. Carpetgrass accession 'UFA120' had greater RRDD than 'UFA101'. Genotypes within *Z. japonica* exhibited RRDD differences in both years, with greatest RRDD in '182' and 'DALZ 5269-24' than other *Z. japonica* entries.

Root Morphology between Species

Root length and root volume was recorded for each 30 cm. horizon for each treatment. Table 2-6 indicates that the volume of horizon A was near or more than 50% of the total root volume for all species. For both 2009 and 2010, the horizon A percent root volume of total volumes for each species were: *Zoysia spp.*, 63 to 73%; bermudagrass spp., 55 to 76%; carpetgrass, 61 to 64%; centipedegrass, 44 to 57%; and St. Augustinegrass, 42 to 45%. These results are in agreement with Doss et al. (1960), who found that root concentrations of warm season forages (including common bermudagrass) were highest nearer the surface (76% of roots in the upper 15 cm of soil) and thus decreased with increasing depth in the root zone. The results obtained for root volume illustrate the magnitude of the upper 30 cm rooting depth (Horizon A) compared with the other horizons.

The root volume analyses (Table 2-7, Figures 2-3 and 2-4), indicated that centipedegrass (2009, 2010), carpetgrass (2010), common bermudagrass (2009), and St. Augustinegrass (2010) had the largest total root volumes. Within individual horizons,

one or two of the above species had significantly greater root volume. Root length density (RLD) is displayed by horizon and species in Table 2-8 and Figures 2-5 and 2-6. In 2009, common bermudagrass had greatest total RLD (11 cm root/cm³ soil). In 2010 common bermudagrass, centipedegrass and St. Augustinegrass had the highest total RLD (6.7 to 7.8 cm root/cm³ soil).

In horizon A, *Zoysia spp.* had the greatest RLD for both years (2.91 to 3.84 cm root/cm³soil) followed by African bermudagrass (2.75 to 3.27 cm root/cm³soil). This is opposite to the root volume results for horizon A. In horizon A, the *Zoysia spp.* (2009 and 2010), African bermudagrass (2010) and St. Augustinegrass (2010) have more roots of a smaller diameter. However, the remaining species have fewer roots of greater diameter and volume (Figure 2-3 and 2-4). The scanned images of horizon A (Figures 2-2 A, B, C, D, E and F) illustrate the differences among root diameters for the species studied. Loresto et al. (1983) evaluated drought resistance in rice and determined that cultivars with a lower number of deeper and thicker roots were highly drought resistant at the reproductive stage. For the remaining horizons (B, C and D), common bermudagrass, (2009, 2010) centipedegrass (2009, 2010) and St. Augustinegrass (2010) had the greatest RLDs.

Dry Weight

Root dry weights (Table 2-9) are similar to root volume results. Total root dry weight (DW) was higher for centipedegrass (2009, 2010), carpetgrass (2010), and St. Augustinegrass (2010). In contrast, Lehman and Engelke (1985), in a root comparison study with St. Augustinegrass, zoysiagrass and buffalograss, determined that St. Augustinegrass produced a significantly heavier root mass than zoysiagrass in the top

30 cm. Our results differ, because for both years the root dry weight in the horizon A for zoysiagrass and St. Augustinegrass were not different.

By Genotypes

Root volume

Root volume analysis between genotypes is reported in Tables 2-10 and 2-11. In 2009, horizon A volumes ranged from 3.5 to 9.7 cm³, and in 2010 the volumes ranged from 4.8 to 16.4 c m³. This may be of importance if we compare this data with the RRDD. As indicated, the RRDD for 2010 was significantly lower compared to 2009. The reduced RRDD in 2010 may be explained by greater root production compared with 2009. This pattern was similar in all horizons.

Root length density

Tables 2-12 and 2-13 provide the RLD comparisons between genotypes. In 2009, the ranges for each horizon A-D were 2.11 to 4.28 cm, 1.74 to 3.51 cm, 0.71 to 3.11 cm, and 0.33 to 3.53 cm, respectively. These RLDs illustrate that increasing root depth is associated with decreased in RLD. Both *Zoysia* spp. had greater RLDs in the A horizon, which then dropped significantly for deeper horizons. The remaining genotypes were somewhat mixed for their RLDs between species for horizon A, but did not decrease as greatly in RLD as root depth increased. These results agree with those from Qian et al. (1997) who reported that the highest RLD for all species (bermudagrass, buffalograss, zoysiagrass and tall fescue) was in the upper 30 cm of roots. Similar to this experiment, they found that at 30 to 60 cm the RLD of zoysiagrass was less than that of all other grasses and at 60 to 90 cm the RLD of bermudagrass was 100% greater than that of zoysiagrass.

Root dry weight

Root dry weights followed a similar pattern as obtained for root volume. These data are shown in Tables 2-14 and 2-15. For total root DW, experimental centipedegrass genotypes UFE21 and UFE24 in 2009 and 2010 had the highest DW respectively.

Within Species

The analysis within species is presented in Figures 2-7 to 2-30 and Tables 2-16 to 2-29. These provide comparisons of genotypes within species. The analysis by species follows.

Common bermudagrass

In common bermudagrass, 'UFCD347' was in the top statistical category for total root volume for both years while 'UFCD295' and UFCD12 were comparable to UFCD347 in 2009 (Figures 2-7 to 2-10, Tables 2-17 and 2-18). The commercial cultivar 'Celebration' was in the lowest statistical category in both years. Horizon comparisons yield no to little differences for these genotypes in the upper 30 cm of soil (horizon A). There were differences between genotypes for their root volumes within the B, C, and D horizons. UFCD347 had consistently greater root volumes in these lower horizons and was always higher than Celebration.

Total RLD showed the highest statistical grouping with UFCD347 and UFCD12 in 2009. In 2010, UFCD347 had greater total RLD than all other entries. (Figures 2-9 and 2-10). Celebration was not different in either year from the worst performing entries. There were minor differences for RLD in the A horizon in 2009 and no differences in 2010. As with root volume, there were more differences for the B, C, and D horizons and UFCD347 had consistently better RLDs for these horizons when compared to all

other common bermudagrass entries except for UFCD12 in 2009. Hays et al. (1991), in a study investigating drought avoidance in bermudagrass genotypes determined that root dry weights for ten bermudagrass genotypes differed by root depths. The authors reported similar results for bermudagrass genotypes (Table 2-16).

Zoysia species

Within *Z. japonica*, the experimental line '182' and commercial cultivar 'JaMur' were in the top statistical grouping for total root volume and RLD during both years (Tables 2-19 and 2-20; Figures 2-11, 2-12, 2-13 and 2-14). Additionally, 'DALZ 5269-24' was equal to 182 and JaMur for root volume in 2009 and the commercial cultivar, 'Empire' was equal in RLD in both years. It may be of interest that while Empire did well for total RLD, its root volume does not compare to the top entries. The experimental genotype 'DALZ 4360' always had the lowest total values for root volume and RLD.

Within horizons, Empire had the lowest root volume in the A horizon than did other entries in 2009, but was only different from 182 in 2010 (Table 2-19). Genotype 182 produced some of the highest root volumes and RLD for the B, C and D horizons. In the B horizon 182's root volume was different from the other entries except for JaMur in 2009. The differences for the C and D horizons can be attributed to DALZ 4360 and its lack of root volume lower in the soil profile.

Root length densities for the horizon A did not yield any significant differences between the *Z. japonica* entries (Table 2-20). Differences in RLD for the subsequent horizons appear to be associated with the reduced values found for DALZ 4360 (horizons B and D, both years; C in 2010) and DALZ 5269-24 (horizon B, both years). Genotypic comparisons of *Z. matrella* entries did not result in many differences for root volume and RLD (Figures 2-15 to 2-18; Tables 2-21 and 2-22). The commercial cultivar

'Zeon' had significantly greater RLD in 2010 versus other entries; however, because Zeon was not consistent between years it is uncertain whether this observed difference is biologically important.

Centipedegrass

Centipedegrass comparisons can be found in Figures 2-19 to 2-22 and Tables 2-23 and 2-24. The experimental entries 'UFE21' and 'UFE25' had the greatest total root volumes in both years, but were not different from the commercial cultivar 'TifBlair' in 2009 (Figure 2-19) or the experimental genotype 'UFE24' in 2010 (Figure 2-20). 'UFE04' had consistently lower total root volume for both years. Consistent horizon responses for centipedegrass genotypes were that UFE21 and UFE25 had higher root volumes for all horizons in both years and that UFE04 had lower root volumes for all horizons in both years. Root length density comparisons between centipedegrass genotypes showed minimal differences (Figures 2-21 and 2-22). UFE04 had consistently lower RLDs across years, but was not different than all other entries for at least one year of the two year study.

African bermudagrass

Comparisons of the two African bermudagrass accessions and the commercial cultivar 'TifSport' yielded few differences for root volume and RLD (Figures 2-23 to 2-26 and Tables 2-25 and 2-26). 'UFCT42' produced significantly greater root volume in 2009 than did 'UFCT33' or TifSport (Figure 2-23). Within horizons, for 2009, UFTC42 had higher volumes compared to UFCT33 for horizons A, B, and C; and compared to TifSport for all horizons. However, in 2010 (Figure 2-24), there were no differences among the three entries.

Total RLDs for the African bermudagrass genotypes and TifSport resulted in a few differences in 2009 and no differences that were biologically important in 2010. In 2009 UFCT42 had greater total RLD than TifSport. For specific horizons, UFCT42 had greater RLD than TifSport in the B and C horizons and in the C horizon compared to UFCT33.

Carpetgrass

Carpetgrass genotype 'UFA120' produced greater total root volume in comparison to 'UFA101' and greater volume in A horizon in 2009 (Table 2-27 and 2-28, Figures 2-27 to 2-30). In 2010, there were not differences in total root volume. There were no differences in RLDs for either year.

Summarizing the data within species there were similarities for RLD in horizon A for most entries within species for both years. Only *Zoysia* spp. showed some differences. Horizons B, C and D exhibited greater differences within species except for carpetgrass genotypes. Root volume showed significant differences for genotypes within species in all horizons with the exception of carpetgrass which was similar within entries for all horizons but, horizon A during one year.

Dry weight

Root dry weight results were similar to root volume for the above discussions. For these reason they were not included for interpretation of the within species results. These data are not shown.

Rhizomes

Rhizomes were scanned and compared for the zoysiagrass, and bermudagrass species (Table 2-29). In 2009 the zoysiagrasses had greater rhizome volume than the bermudagrasses, but in 2010 there were no significant difference among species.

Similar to root volume and root DW, the volume and dry weights of rhizomes were greater in 2010. The two zoysiagrass species and common bermudagrass had greater rhizome dry weight than African bermudagrass in 2009; however, common bermudagrass had greater root dry weight compared to the other species in 2010.

Conclusions

Despite similarities in 2010 between species common bermudagrass had the fastest RRDD in this study. This statement was further supported by the results obtained for genotype comparisons. Within the *Zoysia spp.* *Zoysia japonica* had a significantly higher RRDD compared to *Z. matrella*.

Centipedegrass, common bermudagrass, carpetgrass and St. Augustinegrass had higher volume, total RLD and root dry weight than *Zoysia spp.* and African bermudagrass. However, the horizon A (first 30 cm roots) of species with finer roots exhibited greater RLD than those species with larger diameter roots. This type of difference may be important for understanding drought avoidance or dry down responses between the species and warrants further investigation.

Of unique interest from this study was that when RRDD was slower (2010) the volume of roots produced within a given horizon were greater. It is not known if this was due to differing daylengths (the studies in respective years began one month apart), temperatures, or rainfall patterns (rooting tubes were grown outside). This may be of interest for further study. Our findings suggest as have others (Kim et al., 1988; Beard, 1989; Hays et al., 1991; Marcum et al., 1995, and Carrow, 1996b) that species and genotypes within species do differ for root morphology. Understanding how these differences relate to drought avoidance will enable turfgrass breeders to better select for root characteristics.

Table 2-1. Species with genotypes and commercial cultivars in study

<i>Zoysia japonica</i>	<i>Zoysia matrella</i>	Carpetgrass	Centipedegrass	Common bermudagrass	African bermudagrass	St. Augustinegrass
DALZ 5269-24	374	UFA120	UFE04	UFCD12	UFCT42	Floritam*
182	336	UFA101	UFE21	UFCD295	UFCT33	
DALZ 4360	Pristine*		UFE24	UFCD347	TifSport*†	
Empire*	Zeon*		UFE25	UFCD481		
Jamur*			TifBlair*	289922		
				Celebration*		

* Commercially available cultivars.

†TifSport is a hybrid (*C. dactylon* × *C. transvaalensis*) bermudagrass and was included with African bermudagrass for analysis

Table 2-2. Analysis of Variance Root Experiment

Source of variation	RRDD	Totals			RLD Horizons				Root Volume Horizons			
		RLD	Volume	A	B	C	D	A	B	C	D	
	DF	F values										
Year	1	97.48**	46.97**	5.06 ^{NS}	48.91**	12.98*	70.79**	31.04**	13.86**	1.53 ^{NS}	0.07 ^{NS}	0.42 ^{NS}
Specie	6	99.59**	16.96**	49.74**	25.71**	11.19**	24.59**	27.22**	21.01**	53.53**	47.29**	24.62**
Specie × Year	6	62.94**	10.53**	5.44**	1.48 ^{NS}	7.86**	6.75**	12.12**	5.11**	2.72*	2.35 ^{NS}	9.29**
Genotype (Specie)	19	6.41**	7.96**	7.67**	1.64 ^{NS}	6.13**	6.37**	6.8**	4.12**	8.94**	6.56**	4.81**
Genotype × Year (Specie)	19	4.77**	2.31**	0.96 ^{NS}	1.49 ^{NS}	1.79*	1.91*	2.05*	1.05 ^{NS}	1.33 ^{NS}	1.04 ^{NS}	0.97 ^{NS}
Residual	156											

^{NS}, *, **Nonsignificant or significant at p≤ 0.05 or 0.01, respectively.

Table 2-3. Comparison of species for their Rate of Root Depth Development (RRDD) (cm/day) in 2009 and 2010

Species	2009	2010
Common bermudagrass	5.50 a†	2.37 a
African bermudagrass	3.38 b	1.67 c
<i>Zoysia japonica</i>	3.06 bc	2.14 ab
St. Augustinegrass	2.71 cd	2.51 a
<i>Zoysia matrella</i>	2.38 de	1.77 c
Carpetgrass	2.25 de	2.22 ab
Centipedegrass	2.08 e	1.96 bc

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-4. Rate of Root Depth Development (RRDD) (cm/day) in 2009 and 2010 for genotypes

2009		RRDD	2010		RRDD
Genotype	Species		Genotype	Species	
UFCD347	CD [†]	6.94 a‡	UFCD295	CD	2.80 a
UFCD12	CD	6.52 a	Floritam	SS	2.51 ab
Celebration	CD	5.39 b	Celebration	CD	2.46 a-c
UFCD295	CD	5.25 b	UFCD12	CD	2.45 a-d
UFCD481	CD	4.52 c	289922	CD	2.42 a-e
289922	CD	4.38 c	Empire	ZJ	2.35 a-e
UFCT33	CT	4.15 cd	UFCD347	CD	2.31 a-f
182	ZJ	3.62 de	182	ZJ	2.27 a-g
UFCT42	CT	3.58 d-f	UFA120	AF	2.25 a-g
Jamur	ZJ	3.35 e-g	DALZ 5269-24	ZJ	2.20 b-h
DALZ 5269-24	ZJ	3.35 e-g	UFA101	AF	2.19 b-h
Empire	ZJ	2.94 f-h	Jamur	ZJ	2.11 b-h
Floritam	SS	2.71 g-i	TifBlair	EO	2.04 b-h
Pristine	ZM	2.61 h-j	UFE04	EO	2.02 b-h
336	ZM	2.50 h-k	UFE24	EO	1.95 c-i
UFA120	AF	2.44 h-k	UFE25	EO	1.90 d-i
TifSport	CD×T	2.42 h-k	UFCT42	CT	1.89 e-i
374	ZM	2.26 i-k	Pristine	ZM	1.89 e-i
TifBlair	EO	2.20 i-k	UFE21	EO	1.89 e-i
UFE24	EO	2.17 i-k	DALZ 4360	ZJ	1.78 f-i
Zeon	ZM	2.13 i-k	UFCD481	CD	1.78 f-i
UFE21	EO	2.08 i-k	Zeon	ZM	1.77 f-i
UFE25	EO	2.06 i-k	374	ZM	1.71 g-i
UFA101	AF	2.05 jk	336	ZM	1.71 g-i
DALZ 4360	ZJ	2.04 jk	TifSport	CD×T	1.69 hi
UFE04	EO	1.88 k	UFCT33	CT	1.43 i

[†] CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

[‡] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-5. Rate of Root Depth Development (RRDD) (cm/day) in 2009 and 2010 for genotypes within species

	Genotype	2009	Genotype	2010
African bermudagrass	UFCT33	4.15 a†	UFCT42	1.89 a
	UFCT42	3.58 a	TifSport	1.69 ab
	TifSport	2.42 b	UFCT33	1.43 b
Common bermudagrass	UFCD347	6.94 a†	UFCD481	1.78
	UFCD12	6.52 a	UFCD347	2.31
	Celebration	5.39 b	289922	2.42
	UFCD295	5.25 bc	UFCD12	2.45
	UFCD481	4.52 bc	Celebration	2.46
	289922	4.38 c	UFCD295	2.80
<i>Zoysia japonica</i>	182	3.62 a†	Empire	2.35 a
	Jamur	3.35 ab	182	2.27 a
	DALZ 5269-24	3.35 ab	DALZ 5269-24	2.20 a
	Empire	2.94 b	Jamur	2.11 ab
	DALZ 4360	2.04 c	DALZ 4360	1.78 b
<i>Zoysia matrella</i>	Pristine	2.61	336	1.71
	336	2.50	374	1.71
	374	2.26	Zeon	1.77
	Zeon	2.13	Pristine	1.89
Carpetgrass	UFA120	2.44 a†	UFA120	2.25
	UFA101	2.05 b	UFA101	2.19
Centipedegrass	TifBlair	2.20	TifBlair	2.04
	UFE24	2.17	UFE04	2.02
	UFE21	2.08	UFE24	1.95
	UFE25	2.06	UFE25	1.90
	UFE04	1.88	UFE21	1.89

† Means followed by the same letter within a column and species are not significantly different ($P \leq 0.05$).

Table 2-6. Percentage (%) total root volume for species in each horizon, 2009 and 2010

Horizon	A	B	C	D
	2009 (%)			
<i>Zoysia matrella</i>	69	18	9	3
African bermudagrass	65	17	10	7
Carpetgrass	64	22	9	5
<i>Zoysia japonica</i>	63	17	9	12
Common bermudagrass	55	20	12	13
St. Augustinegrass	45	26	17	12
Centipedegrass	44	31	17	7
	2010 (%)			
African bermudagrass	76	15	6	4
<i>Zoysia matrella</i>	73	18	6	3
<i>Zoysia japonica</i>	67	19	9	5
Common bermudagrass	65	18	9	8
Carpetgrass	61	19	8	12
Centipedegrass	57	26	12	5
St. Augustinegrass	42	29	16	14

Table 2-7. Horizon root volume (cc) comparisons for each species, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Species				
			2009	
Common bermudagrass	7.86 a†	2.78 b	1.77 b	1.82 a
Carpetgrass	7.53 ab	2.59 b	1.05 c	0.59 cd
Centipedegrass	7.05 ab	4.98 a	2.75 a	1.13 b
African bermudagrass	5.49 c	1.47 c	0.87 c	0.58 d
<i>Zoysia matrella</i>	5.42 c	1.45 c	0.73 c	0.27 d
<i>Zoysia japonica</i>	5.34 c	1.44 c	0.76 c	0.98 bc
St. Augustinegrass	5.27 c	3.06 b	1.96 b	1.45 ab
			2010	
Centipedegrass	11.77 a	5.33 a	2.54 a	1.05 b
Carpetgrass	11.67 ab	3.66 b	1.49 b	2.24 a
Common bermudagrass	9.57 bc	2.61 c	1.37 b	1.24 b
St. Augustinegrass	8.03 cd	5.51 a	3.01 a	2.73 a
<i>Zoysia japonica</i>	6.28 d	1.83 d	0.80 c	0.50 c
<i>Zoysia matrella</i>	5.79 d	1.43 d	0.46 c	0.23 c
African bermudagrass	5.58 d	1.11 d	0.41 c	0.27 c

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-8. Horizon root length density (RLD) (cm root/cc soil) comparisons for each species, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Species	2009			
<i>Zoysia matrella</i>	3.84 a†	2.47 b	1.51 b	0.62 d
<i>Zoysia japonica</i>	3.77 a	2.53 b	1.57 b	1.84 b
African bermudagrass	3.27 b	2.43 b	1.71 b	1.20 c
St. Augustinegrass	3.06 bc	2.42 bc	1.71 b	1.37 bc
Centipedegrass	2.85 c	2.57 b	2.40 a	1.35 c
Common bermudagrass	2.84 c	3.10 a	2.41 a	2.63 a
Carpetgrass	2.40 d	1.90 c	0.89 c	0.59 d
	2010			
<i>Zoysia matrella</i>	3.00 a	1.58 c	0.57 d	0.24 c
<i>Zoysia japonica</i>	2.91 a	1.89 b	1.07 c	0.68 b
African bermudagrass	2.75 a	1.33 c	0.64 d	0.27 c
St. Augustinegrass	2.46 ab	2.28 a	1.67 a	1.36 a
Centipedegrass	2.01 b	2.27 a	1.54 a	0.86 b
Common bermudagrass	2.31 b	1.95 b	1.34 ab	1.13 a
Carpetgrass	2.17 b	1.93 b	1.12 bc	1.30 a

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-9. Horizon root dry weight (g) comparisons for each species, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D	Total root DW
Species	2009				
Common bermudagrass	1.30 a†	0.42 b	0.24 b	0.20 a	2.16 ab
Carpetgrass	1.25 a	0.30 bc	0.11 c	0.06 c	1.73 bc
Centipedegrass	1.24 a	0.66 a	0.34 a	0.11 b	2.35 a
<i>Zoysia japonica</i>	1.08 a	0.25 c	0.12 c	0.12 b	1.58 cd
<i>Zoysia matrella</i>	1.07 ab	0.25 c	0.11 c	0.04 c	1.46 cd
St. Augustinegrass	0.97 ab	0.46 b	0.31 ab	0.18 ab	1.91 a-c
African bermudagrass	0.81 b	0.25 c	0.08 c	0.04 c	1.20 d
	2010				
Carpetgrass	1.85 a	0.55 b	0.18 b	0.20 a	2.78 a
Centipedegrass	1.73 a	0.82 a	0.32 a	0.10 b	2.96 a
Common bermudagrass	1.31 b	0.32 c	0.15 b	0.11 b	1.89 b
St. Augustinegrass	1.21 bc	0.71 ab	0.36 a	0.27 a	2.56 a
<i>Zoysia japonica</i>	1.12 c	0.26 cd	0.09 c	0.04 c	1.52 c
<i>Zoysia matrella</i>	1.01 c	0.18 de	0.04 cd	0.01 c	1.25 c
African bermudagrass	0.68 d	0.11 e	0.03 d	0.01 c	0.83 d

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-10. Horizon root volume (cc) for genotype in 2009

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D
UFA120	AF†	9.72 a‡	2.83 c-g	1.33 e-g	0.79 f-k
UFCD295	CD	9.21 ab	3.27 cd	1.97 d-f	1.61 c-e
UFE21	EO	8.98 ab	6.92 a	4.30 a	2.09 bc
UFE25	EO	8.53 a-c	6.84 a	3.81 ab	1.02 d-i
Celebration	CD	8.43 a-c	2.13 d-j	1.10 fg	0.89 e-k
UFCD12	CD	8.41 a-c	3.18 c-e	2.10 c-e	2.74 ab
UFCT42	CT	8.31 a-c	2.39 d-i	1.35 e-g	0.94 e-j
UFCD481	CD	8.26 a-c	2.50 d-h	1.26 e-g	0.90 e-k
TifBlair	EO	7.64 a-d	5.36 b	2.56 cd	1.16 d-g
UFCD347	CD	7.25 a-d	3.78 c	2.95 bc	3.06 a
Pristine	ZM	7.17 b-e	1.61 g-j	0.74 g	0.27 jk
182	ZJ	6.33 c-f	1.94 e-j	0.87 g	1.39 c-f
UFE24	EO	6.20 c-g	4.09 c	1.91 d-f	1.03 d-i
DALZ 5269-24	ZJ	6.04 c-g	1.22 h-j	0.61 g	1.13 d-g
289922	CB	5.62 d-h	1.85 f-j	1.25 e-g	1.71 cd
DALZ 4360	ZJ	5.38 d-h	1.15 ij	0.47 g	0.23 jk
UFA101	AF	5.35 d-h	2.35 d-i	0.78 g	0.39 h-k
Jamur	ZJ	5.28 d-h	1.76 f-j	1.01 fg	1.05 d-i
Floritam	SS	5.27 d-h	3.06 c-f	1.96 d-f	1.45 c-f
374	ZM	5.18 d-h	1.55 g-j	0.94 g	0.36 i-k
336	ZM	5.13 d-h	1.57 g-j	0.73 g	0.25 jk
TifSport	CD×T	4.68 e-h	0.85 j	0.60 g	0.35 i-k
Zeon	ZM	4.21 f-h	1.08 ij	0.52 g	0.20 k
UFE04	EO	3.90 f-h	1.67 g-j	1.20 e-g	0.38 i-k
Empire	ZJ	3.71 gh	1.16 ij	0.84 g	1.11 d-h
UFCT33	CT	3.48 h	1.18 h-j	0.68 g	0.45 g-k

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-11. Horizon root volume (cc) for genotype in 2010

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D
UFE21	EO†	16.35 a‡	7.24 a	3.39 a	1.20 c-f
UFA120	AF	12.57 b	3.87 e-g	1.75 c-f	2.73 a
UFE25	EO	12.45 b	6.25 ab	3.01 ab	0.84 c-g
UFE24	EO	12.22 b	5.97 a-c	2.97 ab	1.32 c-e
UFCD347	CD	11.55 bc	4.10 d-f	2.48 bc	2.49 ab
TifBlair	EO	10.79 b-d	4.62 c-e	2.01 cd	1.07 c-g
UFA101	AF	10.78 b-d	3.46 e-i	1.23 d-g	1.75 bc
UFCD295	CD	10.03 b-e	1.68 j-m	0.88 e-h	0.46 e-g
Celebration	CD	9.62 b-f	2.36 h-l	1.35 d-g	1.04 c-g
UFCD481	CD	9.03 b-g	1.88 j-m	0.86 f-h	0.89 c-g
UFCD12	CD	9.02 b-h	3.66 e-h	1.78 c-e	1.57 b-d
182	ZJ	8.20 c-i	2.96 f-j	1.25 d-g	0.53 e-g
289922	CD	8.15 c-i	1.97 i-m	0.85 f-h	1.01 c-g
Floritam	SS	8.03 c-i	5.51 b-d	3.01 ab	2.73 a
Jamur	ZJ	7.33 d-i	1.92 j-m	0.65 gh	0.44 e-g
UFE04	EO	7.06 e-i	2.58 g-k	1.33 d-g	0.84 c-g
374	ZM	6.40 f-i	1.28 k-m	0.50 gh	0.24 fg
336	ZM	6.21 f-i	1.03 lm	0.28 h	0.12 g
TifSport	CD×T	6.02 f-i	1.30 k-m	0.47 gh	0.29 fg
UFCT42	CT	5.77 g-i	1.20 k-m	0.52 gh	0.36 e-g
Pristine	ZM	5.72 g-i	1.29 k-m	0.56 gh	0.22 g
DALZ 5269-24	ZJ	5.49 g-i	1.39 k-m	0.87 f-h	0.58 e-g
DALZ 4360	ZJ	5.41 hi	1.00 lm	0.32 h	0.19 g
Empire	ZJ	4.97 i	1.86 j-m	0.92 e-h	0.77 d-g
UFCT33	CT	4.95 i	0.84 m	0.23 h	0.16 g
Zeon	ZM	4.82 i	2.14 i-m	0.51 gh	0.34 fg

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-12. Horizon root length density (RLD) (cm root/cc soil) for genotype in 2009

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D
374	ZM†	4.28 a‡	2.80 b-g	1.89 d-g	0.96 g-j
Jamur	ZJ	3.97 ab	2.97 a-f	2.11 c-f	2.21 c-e
Zeon	ZM	3.90 a-c	2.12 i-m	0.92 ij	0.44 j
182	ZJ	3.82 a-c	2.98 a-e	1.70 e-h	2.55 cd
Empire	ZJ	3.81 a-c	2.41 e-k	1.72 e-h	1.97 d-f
DALZ 4360	ZJ	3.75 a-c	2.11 j-m	1.09 h-j	0.48 j
336	ZM	3.72 a-d	2.52 d-j	1.48 f-i	0.55 j
UFCT33	CT	3.51 b-e	2.37 f-l	1.44 f-i	1.01 g-j
DALZ 5269-24	ZJ	3.49 b-f	2.19 h-m	1.25 g-j	2.01 c-f
Pristine	ZM	3.46 b-f	2.44 e-j	1.76 e-h	0.56 j
UFCD347	CD	3.37 c-g	3.46 a	3.11 a	3.53 a
TifSport	CD×T	3.15 d-h	1.80 lm	1.21 g-j	1.02 g-j
UFCT42	CT	3.14 d-h	3.11 a-d	2.47 a-d	1.58 e-h
UFE25	EO	3.08 e-i	2.65 c-j	2.74 a-c	1.03 g-j
Floritam	SS	3.06 e-i	2.42 e-k	1.71 e-h	1.37 f-i
289922	CD	2.99 e-i	2.34 g-m	2.05 d-f	2.67 cd
UFE24	EO	2.97 e-i	2.73 c-i	2.30 b-e	1.41 f-i
Celebration	CD	2.90 f-i	3.15 a-c	1.79 e-g	1.93 d-f
UFE04	EO	2.86 g-i	1.83 k-m	1.87 d-g	0.76 ij
UFCD295	CD	2.81 g-i	3.51 a	2.75 a-c	2.77 bc
UFE21	EO	2.73 hi	2.73 c-h	2.74 a-c	1.92 d-f
UFA101	AF	2.68 h-j	1.74 m	0.71 j	0.33 j
TifBlair	EO	2.63 h-j	2.91 a-g	2.33 b-e	1.64 e-g
UFCD481	CD	2.52 ij	2.77 b-h	1.86 d-g	1.45 e-i
UFCD12	CD	2.48 ij	3.36 ab	2.90 ab	3.46 ab
UFA120	AF	2.11 j	2.06 j-m	1.08 h-j	0.86 h-j

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-13. Horizon root length density (RLD) (cm root/cc soil) for genotype in 2010

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D
Zeon	ZM†	3.81 a‡	2.10 b-g	0.67 h-k	0.40 f-j
Empire	ZJ	3.21 ab	2.27 a-e	1.27 c-f	1.16 b-e
UFCT33	CT	3.01 bc	1.13 j	0.38 k	0.08 j
DALZ 4360	ZJ	2.99 b-d	1.43 h-j	0.55 jk	0.15 ij
374	ZM	2.97 b-d	1.41 h-j	0.58 jk	0.20 h-j
182	ZJ	2.95 b-d	2.29 a-d	1.45 c-e	0.71 d-i
TifSport	CD×T	2.83 b-e	1.24 ij	0.77 g-k	0.28 g-j
Jamur	ZJ	2.81 b-f	2.04 b-g	0.97 f-j	0.63 e-j
Pristine	ZM	2.70 b-g	1.58 g-j	0.64 i-k	0.20 h-j
DALZ 5269-24	ZJ	2.57 b-h	1.44 h-j	1.14 e-g	0.75 c-i
UFCD481	CD	2.55 b-i	1.74 e-i	0.77 g-k	0.60 e-j
336	ZM	2.54 b-i	1.25 ij	0.39 k	0.14 ij
UFCD295	CD	2.52 b-j	1.89 d-h	1.35 c-f	0.77 c-h
Floritam	SS	2.46 c-j	2.28 a-e	1.67 a-d	1.36 bc
UFCT42	CT	2.41 c-j	1.63 g-j	0.78 g-k	0.45 f-j
UFA120	AF	2.36 c-j	2.00 c-g	1.26 c-f	1.61 ab
UFCD12	CB	2.31 d-j	2.01 c-g	1.61 a-d	1.33 bc
UFE04	EO	2.20 e-j	1.72 f-i	1.09 e-i	0.70 d-i
289922	CD	2.20 e-j	1.64 g-j	1.11 e-h	0.77 c-h
UFCD347	CD	2.19 e-j	2.72 a	1.98 a	2.02 a
Celebration	CD	2.13 f-j	1.69 g-i	1.23 d-g	1.28 b-d
TifBlair	EO	2.08 g-j	2.55 ab	1.49 b-e	0.85 c-g
UFE24	EO	2.07 g-j	2.34 a-d	1.92 ab	1.06 b-e
UFA101	AF	1.97 h-j	1.87 d-h	0.98 f-j	0.99 b-f
UFE21	EO	1.86 ij	2.48 a-c	1.71 a-c	0.87 c-g
UFE25	EO	1.84 j	2.25 a-f	1.52 a-e	0.84 c-g

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-14. Horizon dry weight (g) comparisons for each genotype in 2009.

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D	Total root DW
UFA120	AF	1.69 a†	0.34 d-g	0.14 ef	0.076 e-j	2.23 c-e
UFE21	EO	1.62 ab	0.91 a	0.50 a	0.202 bc	3.23 a
UFE25	EO	1.57 a-c	0.85 a	0.45 a	0.109 d-i	2.98 ab
UFCD12	CD	1.55 a-c	0.52 b-d	0.30 bc	0.337 a	2.71 a-c
Celebration	CD	1.41 a-d	0.30 e-g	0.13 ef	0.092 e-j	1.94 d-i
UFCD481	CD	1.36 a-e	0.37 c-g	0.16 d-f	0.077 e-j	1.97 d-h
182	ZJ	1.36 a-e	0.37 c-g	0.17 d-f	0.224 b	2.12 c-f
UFCD295	CD	1.32 a-e	0.48 c-e	0.25 c-e	0.176 b-d	2.22 c-e
UFCD347	CD	1.31 a-e	0.58 bc	0.39 ab	0.359 a	2.64 a-c
TifBlair	EO	1.27 b-e	0.73 ab	0.32 bc	0.113 d-h	2.43 b-d
Pristine	ZM	1.20 c-f	0.25 e-g	0.11 f	0.032 ij	1.59 e-k
DALZ 5269-24	ZJ	1.17 c-f	0.20 g	0.10 f	0.121 d-f	1.59 e-k
UFCT42	CT	1.12 d-g	0.24 fg	0.12 ef	0.076 e-j	1.56 e-k
Jamur	ZJ	1.09 d-h	0.29 e-g	0.15 d-f	0.119 d-g	1.65 e-k
UFE24	EO	1.08 d-h	0.59 bc	0.27 b-d	0.113 d-h	2.05 c-g
Zeon	ZM	1.05 d-i	0.23 fg	0.09 f	0.035 h-j	1.40 g-l
374	ZM	1.05 d-i	0.26 e-g	0.14 d-f	0.044 f-j	1.49 f-l
DALZ 4360	ZJ	1.02 d-j	0.17 g	0.07 f	0.019 j	1.28 i-l
Floratum	SS	0.97 e-j	0.46 c-f	0.31 bc	0.176 b-d	1.91 d-j
336	ZM	0.96 e-j	0.26 e-g	0.11 f	0.034 ij	1.36 h-l
289922	CD	0.87 f-j	0.27 e-g	0.17 d-f	0.151 b-e	1.46 f-l
UFA101	AF	0.82 f-j	0.27 e-g	0.09 f	0.041 g-j	1.22 kl
Empire	ZJ	0.78 g-j	0.22 g	0.13 ef	0.125 c-e	1.25 j-l
TifSport	CDxT	0.70 h-j	0.37 c-g	0.06 f	0.023 j	1.15 kl
UFE04	EO	0.67 ij	0.23 fg	0.14 ef	0.031 j	1.05 kl
UFCT33	CT	0.62 j	0.15 g	0.07 f	0.035 h-j	0.88 l

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CDxT = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-15. Horizon dry weight (g) for genotype in 2010

Genotype	Species	Horizon A	Horizon B	Horizon C	Horizon D	Total root DW
UFE21	EO	2.13 a	0.98 a	0.39 ab	0.10 b-e	3.60 a
UFA120	AF	2.07 ab	0.60 c-e	0.22 d-f	0.25 a	3.15 ab
UFE24	EO	1.95 a-c	1.06 a	0.44 a	0.15 b	3.60 a
TifBlair	EO	1.78 a-d	0.75 bc	0.27 c-e	0.11 b-d	2.91 bc
UFCD347	CD	1.74 b-d	0.56 d-f	0.30 b-d	0.25 a	2.85 bc
UFE25	EO	1.64 c-e	0.89 ab	0.34 a-c	0.07 b-f	2.95 bc
UFA101	AF	1.63 c-e	0.50 ef	0.14 f-j	0.14 bc	2.41 c-e
182	ZJ	1.48 d-f	0.43 e-h	0.15 f-i	0.05 c-f	2.11 d-f
UFCD481	CD	1.31 e-g	0.23 i-k	0.09 g-k	0.07 b-f	1.70 f-i
Celebration	CD	1.30 e-g	0.26 h-k	0.14 f-j	0.10 b-e	1.80 e-h
Jamur	ZJ	1.29 e-g	0.27 h-k	0.07 g-k	0.04 d-f	1.67 f-j
UFCD295	CD	1.29 e-g	0.21 i-k	0.09 g-k	0.04 c-f	1.64 f-j
UFCD12	CD	1.24 f-h	0.46 e-g	0.19 e-g	0.14 bc	2.03 d-g
Floratam	SS	1.21 f-h	0.71 b-d	0.36 a-c	0.27 a	2.56 b-d
UFE04	EO	1.14 f-h	0.39 f-i	0.17 e-h	0.07 b-f	1.77 f-h
374	ZM	1.08 g-i	0.17 jk	0.05 i-k	0.01 ef	1.31 h-l
Zeon	ZM	1.07 g-i	0.29 g-j	0.06 h-k	0.02 d-f	1.44 g-k
289922	CD	1.00 g-j	0.20 jk	0.08 g-k	0.04 d-f	1.32 h-k
Empire	ZJ	1.00 g-j	0.29 f-i	0.11 f-k	0.07 b-f	1.46 g-k
Pristine	ZM	0.99 g-j	0.16 jk	0.05 i-k	0.01 ef	1.20 h-l
DALZ 4360	ZJ	0.96 g-j	0.15 jk	0.03 jk	0.00 f	1.14 i-l
336	ZM	0.92 h-k	0.12 jk	0.02 k	0.01 ef	1.07 j-l
DALZ 5269-24	ZJ	0.89 h-k	0.18 jk	0.11 f-k	0.05 c-f	1.24 h-l
TifSport	CD×T	0.78 i-k	0.14 jk	0.03 jk	0.01 ef	0.97 kl
UFCT42	CT	0.66 jk	0.12 jk	0.04 i-k	0.02 d-f	0.84 kl
UFCT33	CT	0.59 k	0.08 k	0.01 k	0.00 f	0.69 l

† CD = *Cynodon dactylon* (common bermudagrass); CT = *Cynodon transvaalensis* (African bermudagrass); CD×T = *C. dactylon* × *C. transvaalensis* (hybrid bermudagrass); AF = *Axonopus fissifolius* (common carpetgrass); EO = *Eremochloa ophiuroides* (centipedegrass); SS = *Stenotaphrum secundatum* (St. Augustinegrass); ZJ = *Zoysia japonica*; ZM = *Zoysia matrella*

‡ Means within a column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 2-16. Horizon dry weight (g) comparisons for common bermudagrass genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFCD12	1.55 a†	0.52 ab	0.30 ab	0.34 a
Celebration	1.41 a	0.30 c	0.13 d	0.09 c
UFCD481	1.36 a	0.37 bc	0.16 cd	0.08 c
UFCD295	1.32 a	0.48 ab	0.25 bc	0.18 b
UFCD347	1.31 a	0.58 a	0.39 a	0.36 a
289922	0.87 b	0.27 c	0.17 cd	0.15 bc
			2010	
UFCD347	1.74 a	0.56 a	0.30 a	0.25 a
UFCD481	1.31 b	0.23 b	0.09 bc	0.07 b
Celebration	1.30 b	0.26 b	0.14 bc	0.10 b
UFCD295	1.29 b	0.21 b	0.09 bc	0.04 b
UFCD12	1.24 b	0.46 a	0.19 b	0.14 b
289922	1.00 b	0.20 b	0.08 c	0.04 b

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-17. Horizon root volume (cc) comparisons for common bermudagrass genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFCD295	9.21 a†	3.27 ab	1.97 bc	1.61 b
Celebration	8.43 a	2.13 c	1.10 c	0.89 b
UFCD12	8.41 a	3.18 ab	2.10 ab	2.74 a
UFCD481	8.26 a	2.50 bc	1.26 bc	0.90 b
UFCD347	7.25 ab	3.78 a	2.95 a	3.06 a
289922	5.62 b	1.85 c	1.25 bc	1.71 b
			2010	
UFCD347	11.55	4.10 a	2.48 a	2.49 a
UFCD295	10.03	1.68 b	0.88 c	0.46 b
Celebration	9.62	2.36 b	1.35 bc	1.04 b
UFCD481	9.03	1.88 b	0.86 c	0.89 b
UFCD12	9.02	3.66 a	1.78 ab	1.57 ab
289922	8.15	1.97 b	0.85 c	1.01 b

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-18. Horizon root length density (RLD) (cm root/cc soil) comparisons for Common bermudagrass genotypes, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFCD347	3.37 a†	3.46 a	3.11 a	3.53 a
289922	2.99 ab	2.34 c	2.05 b	2.67 c
Celebration	2.90 ab	3.15 ab	1.79 b	1.93 d
UFCD295	2.81 ab	3.51 a	2.75 a	2.77 bc
UFCD481	2.52 b	2.77 bc	1.86 b	1.45 d
UFCD12	2.48 b	3.36 a	2.90 a	3.46 ab
			2010	
UFCD481	2.55	1.74 b	0.77 d	0.60 c
UFCD295	2.52	1.89 b	1.35 bc	0.77 bc
UFCD12	2.31	2.01 b	1.61 ab	1.33 b
289922	2.20	1.64 b	1.11 cd	0.77 bc
UFCD347	2.19	2.72 a	1.98 a	2.02 a
Celebration	2.13	1.69 b	1.23 bc	1.28 b

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-19. Horizon root volume (cc) comparisons for *Zoysia japonica* genotypes, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
182	6.33 a†	1.94 a	0.87 ab	1.39 a
DALZ 5269-24	6.04 a	1.22 b	0.61 ab	1.13 a
DALZ 4360	5.38 a	1.15 b	0.47 b	0.23 b
Jamur	5.28 a	1.76 a	1.01 a	1.05 ab
Empire	3.71 b	1.16 b	0.84 ab	1.11 a
			2010	
182	8.20 a	2.96 a	1.25 a	0.53 ab
Jamur	7.33 ab	1.92 b	0.65 ab	0.44 ab
DALZ 5269-24	5.49 ab	1.39 b	0.87 ab	0.58 ab
DALZ 4360	5.41 ab	1.00 b	0.32 b	0.19 b
Empire	4.97 b	1.86 b	0.92 ab	0.77 a

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-20. Horizon root length density (RLD) (cm root/cc soil) comparisons for *Zoysia japonica* genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
Jamur	3.97 a†	2.97 a	2.11 a	2.21 a
182	3.82 ab	2.98 a	1.70 ab	2.55 a
Empire	3.81 ab	2.41 ab	1.72 ab	1.97 a
DALZ 4360	3.75 ab	2.11 b	1.09 b	0.48 b
DALZ 5269-24	3.49 b	2.19 b	1.25 b	2.01 a
			2010	
Empire	3.21	2.27 a	1.27 a	1.16 a
DALZ 4360	2.99	1.43 b	0.55 b	0.15 b
182	2.95	2.29 a	1.45 a	0.71 a
Jamur	2.81	2.04 a	0.97 ab	0.63 ab
DALZ 5269-24	2.57	1.44 b	1.14 a	0.75 a

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-21. Horizon root volume (cc) comparisons for *Zoysia matrella* genotypes, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
Pristine	7.17 a†	1.61 a	0.74 ab	0.27
374	5.18 ab	1.55 ab	0.94 a	0.36
336	5.13 ab	1.57 ab	0.73 ab	0.25
Zeon	4.20 b	1.08 b	0.52 b	0.20
			2010	
374	6.40	1.28 b	0.50	0.24
336	6.21	1.03 b	0.28	0.12
Pristine	5.72	1.29 b	0.56	0.22
Zeon	4.82	2.14 a	0.51	0.34

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-22. Horizon root length density (RLD) (cm root/cc soil) by *Zoysia matrella* genotypes, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
374	4.28 a†	2.80 a	1.89 a	0.96 a
Zeon	3.90 ab	2.12 c	0.92 b	0.44 b
336	3.72 b	2.52 ab	1.48 ab	0.55 ab
Pristine	3.46 b	2.44 bc	1.76 a	0.56 ab
			2010	
Zeon	3.81 a	2.10 a	0.67	0.40
374	2.97 ab	1.41 b	0.58	0.20
Pristine	2.70 b	1.58 ab	0.64	0.20
336	2.54 b	1.25 b	0.39	0.14

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-23. Horizon root volume (cc) comparisons for centipedegrass genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFE21	8.98 a	6.92 a	4.30 a	2.09 a
UFE25	8.53 a	6.84 a	3.81 a	1.02 b
TifBlair	7.64 ab	5.36 ab	2.56 ab	1.16 ab
UFE24	6.20 ab	4.09 bc	1.91 b	1.03 b
UFE04	3.90 b	1.67 c	1.20 b	0.38 b
			2010	
UFE21	16.35 a	7.24 a	3.39 a	1.20
UFE25	12.45 ab	6.25 ab	3.01 ab	0.84
UFE24	12.22 ab	5.97 ab	2.97 ab	1.32
TifBlair	10.79 ab	4.62 bc	2.01 bc	1.07
UFE04	7.06 b	2.58 c	1.33 c	0.84

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-24. Horizon root length density (RLD) (cm root/cc soil) comparisons for centipedegrass genotypes, 2009 and 2010.

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFE25	3.08	2.65 ab†	2.74 a	1.03 bc
UFE24	2.97	2.73 ab	2.30 ab	1.41 a-c
UFE04	2.86	1.83 b	1.87 b	0.76 c
UFE21	2.73	2.73 ab	2.74 a	1.92 a
TifBlair	2.63	2.91 a	2.33 ab	1.64 ab
			2010	
UFE04	2.20	1.72 b	1.09 c	0.70
TifBlair	2.08	2.55 a	1.49 bc	0.85
UFE24	2.07	2.34 a	1.92 a	1.06
UFE21	1.86	2.48 a	1.71 ab	0.87
UFE25	1.84	2.25 a	1.52 ab	0.84

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-25. Horizon root volume (cc) comparisons for African bermudagrass genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFCT42	8.31 a†	2.39 a	1.35 a	0.94 a
TifSport	4.68 b	0.85 b	0.60 b	0.35 b
UFCT33	3.48 b	1.18 b	0.68 b	0.45 ab
			2010	
TifSport	6.02	1.30	0.47	0.29
UFCT42	5.77	1.20	0.52	0.36
UFCT33	4.95	0.84	0.23	0.16

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-26. Horizon root length density (RLD) (cm root/cc soil) comparisons for African bermudagrass genotypes, 2009 and 2010

	Horizon A	Horizon B	Horizon C	Horizon D
Genotype			2009	
UFCT33	3.51	2.37 ab†	1.44 a	1.01
TifSport	3.15	1.80 b	1.21 b	1.02
UFCT42	3.14	3.11 a	2.47 a	1.58
			2010	
UFCT33	3.01	1.13	0.38	0.08 b
TifSport	2.83	1.24	0.77	0.28 ab
UFCT42	2.41	1.63	0.78	0.45 a

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).

Table 2-29. Rhizomes volume (cc) and dry weight (g) comparisons for each species, 2009 and 2010

Species	Volume (cc)	Dry Weight (g)
	2009	
<i>Zoysia matrella</i>	6.27 a†	2.17 a
<i>Zoysia japonica</i>	5.83 ab	2.11 a
African bermudagrass	4.31 bc	1.60 b
Common bermudagrass	4.09 c	1.92 ab
	2010	
<i>Zoysia japonica</i>	8.55	2.97 b
Common bermudagrass	8.51	3.54 a
African bermudagrass	8.27	2.53 bc
<i>Zoysia matrella</i>	7.64	2.44 c

† Means followed by the same letter within a column are not significantly different ($P \leq 0.05$).



A



B



C

Figure 2-1. Tubes Root Experiment. (A and B) Acrylic tubes inside of PVC tubes. C) Tubes arranged in 75 degree angle.

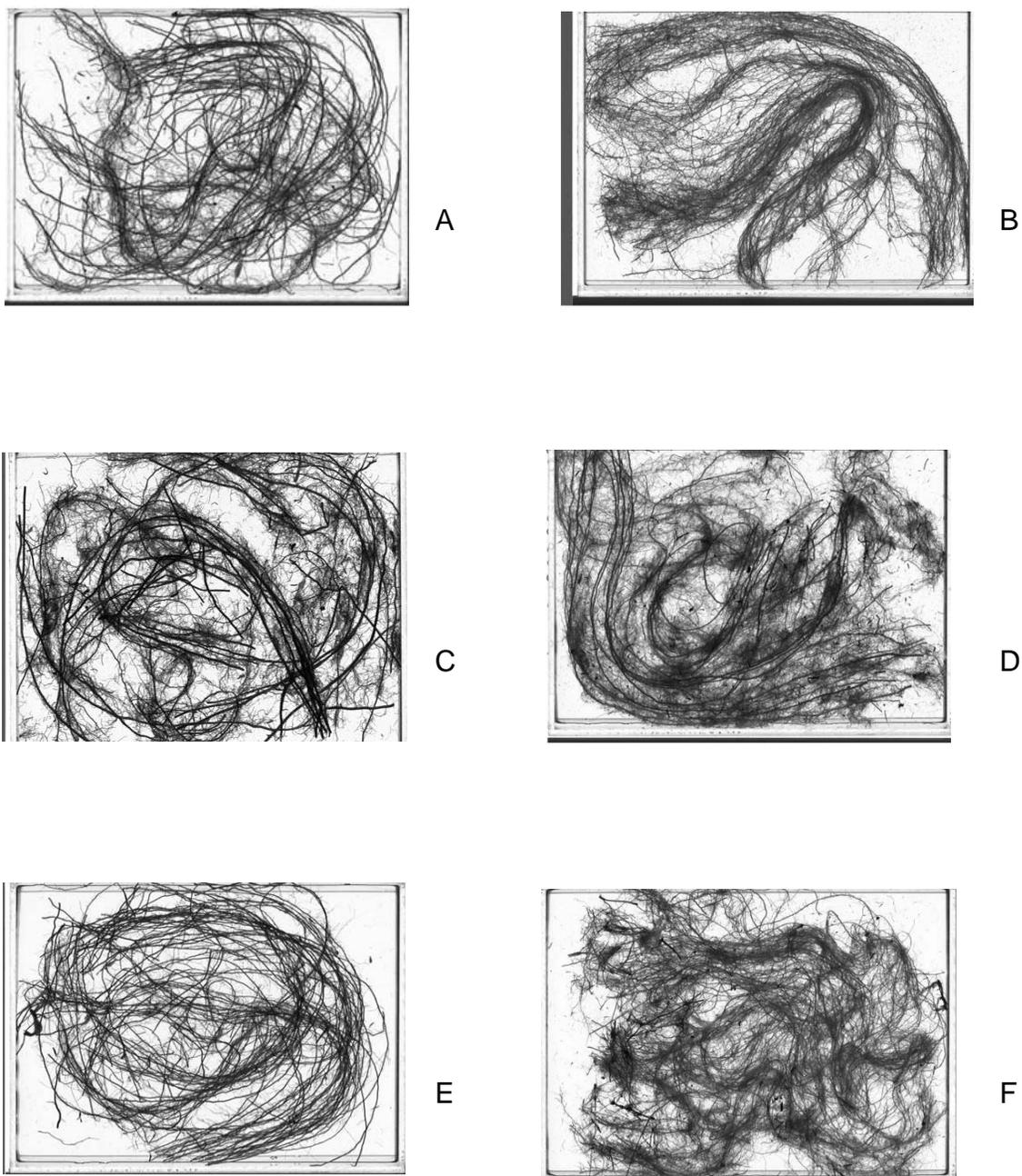
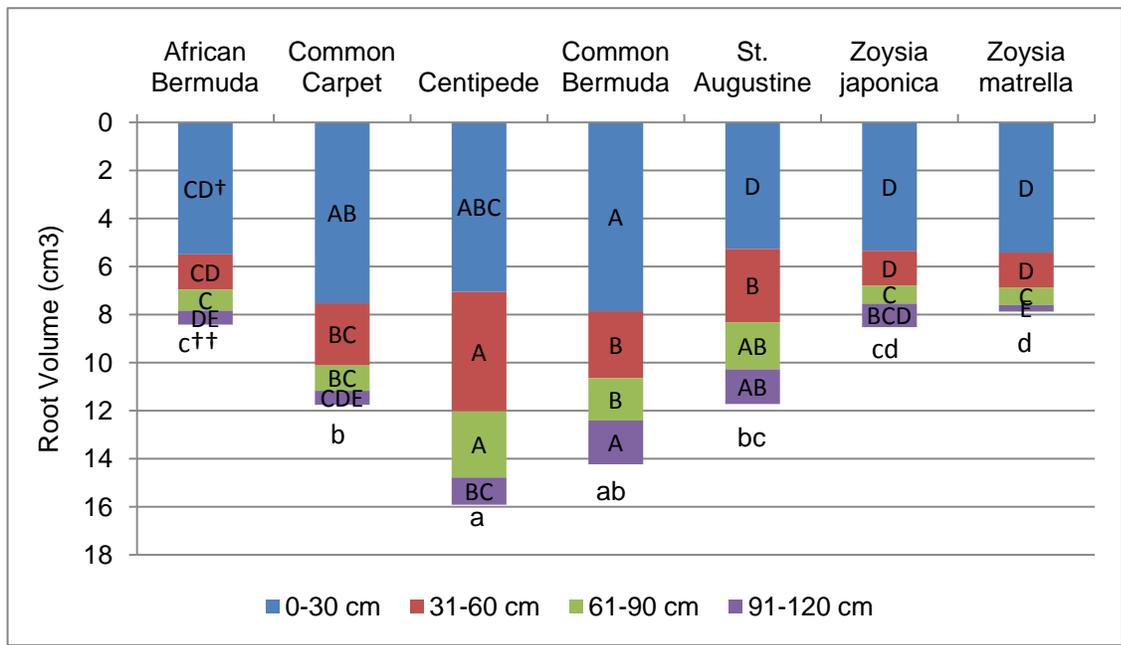
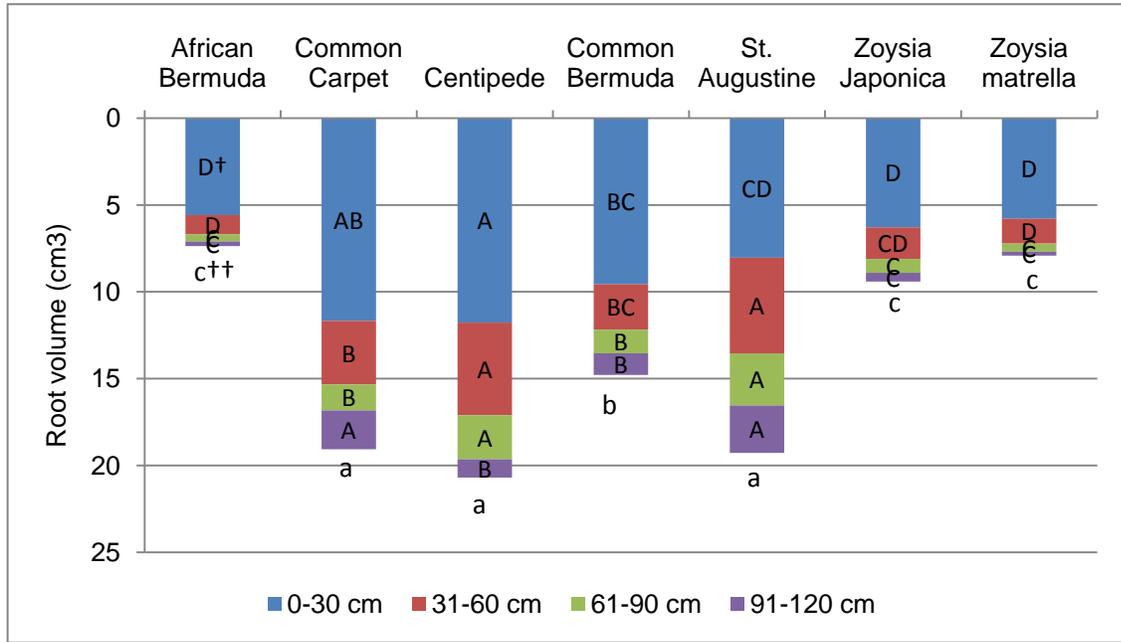


Figure 2-2. Horizon A -root scan samples. A) experimental genotype UFA 101, Carpetgrass, B) commercial cultivar Empire, *Zoysia japonica*, C) commercial cultivar Floratam, St. Augustinegrass, D) experimental genotype UFCD347, common bermudagrass, E) commercial cultivar TifBlair, centipedegrass, F) experimental genotype UFCT42, African bermudagrass.



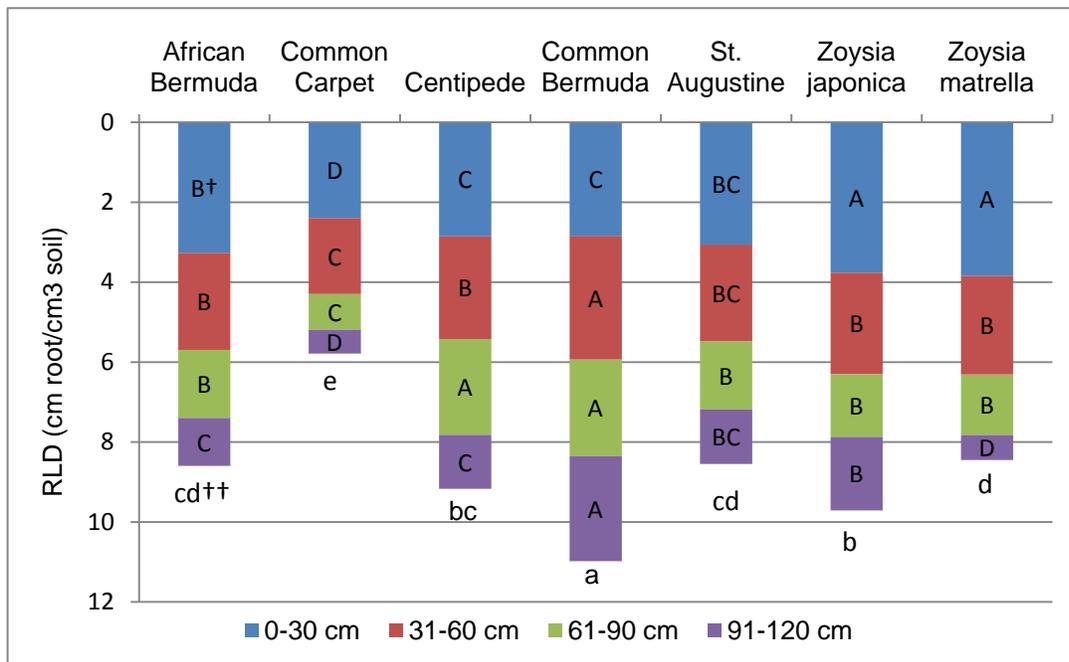
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-3. Differences in root volume by species and horizons, year 2009.



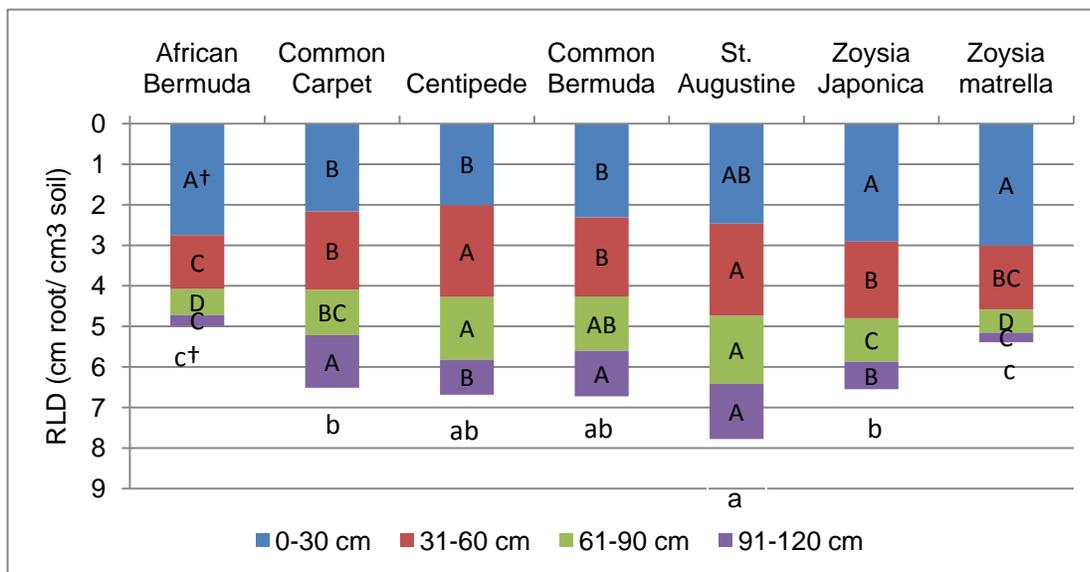
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-4. Differences in root volume by species and horizons, year 2010.



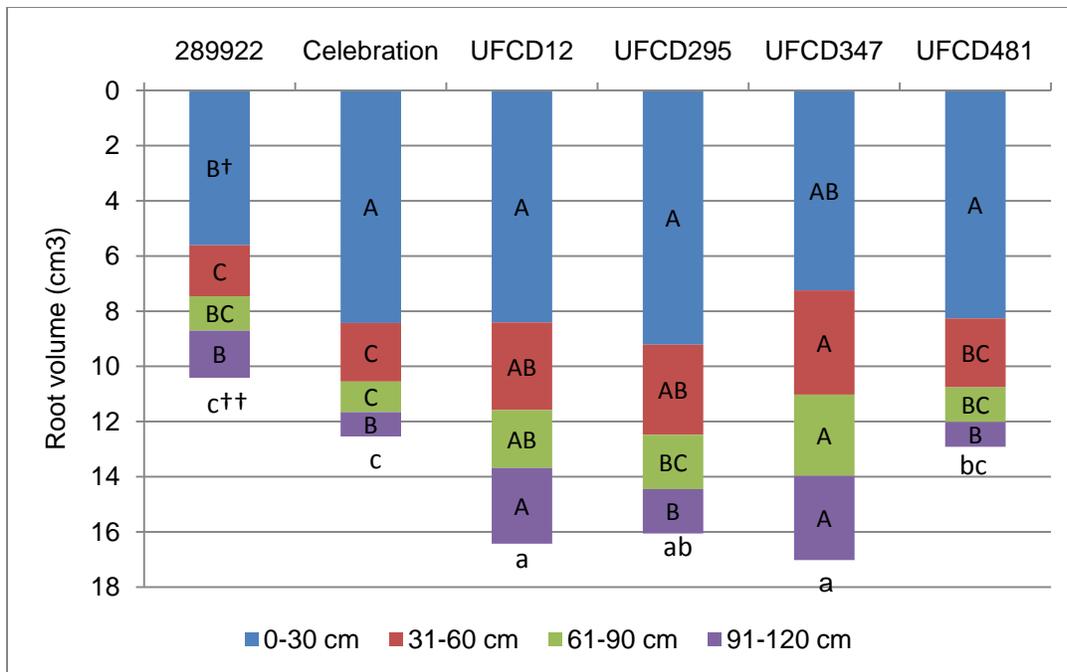
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-5. Differences in root length density (RLD) by species and horizons, year 2009.



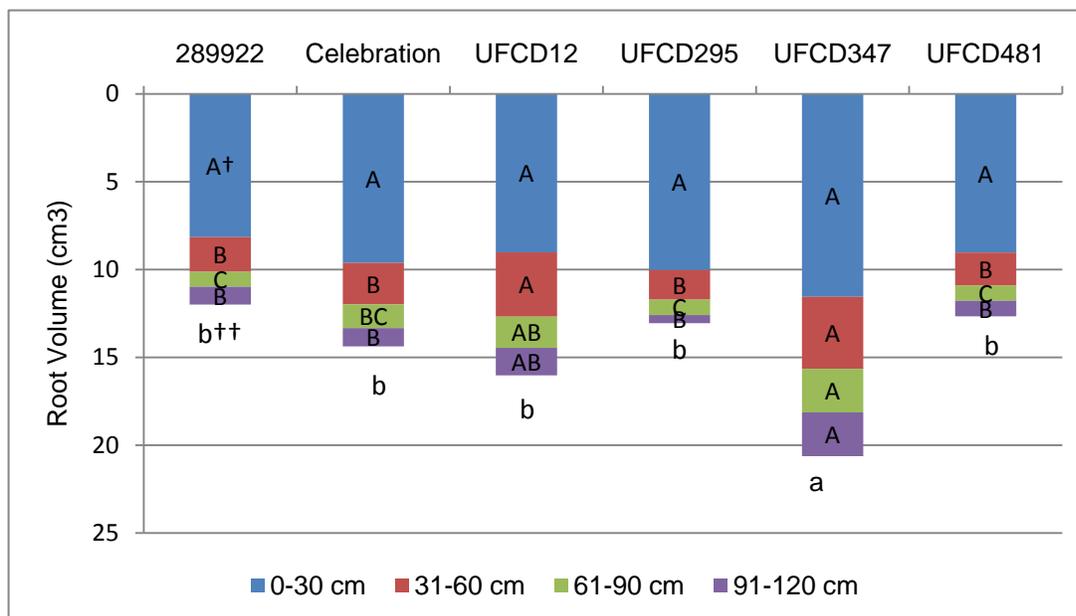
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-6. Differences in root length density (RLD) by species and horizons, year 2010.



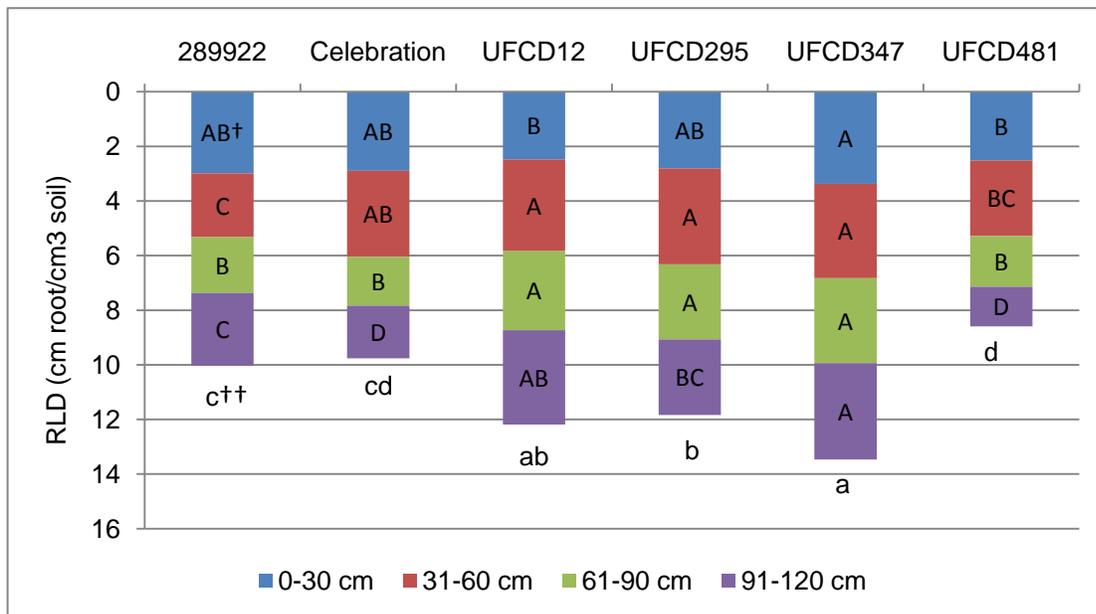
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-7. Differences in root volume by genotypes and horizons in common bermudagrass, year 2009



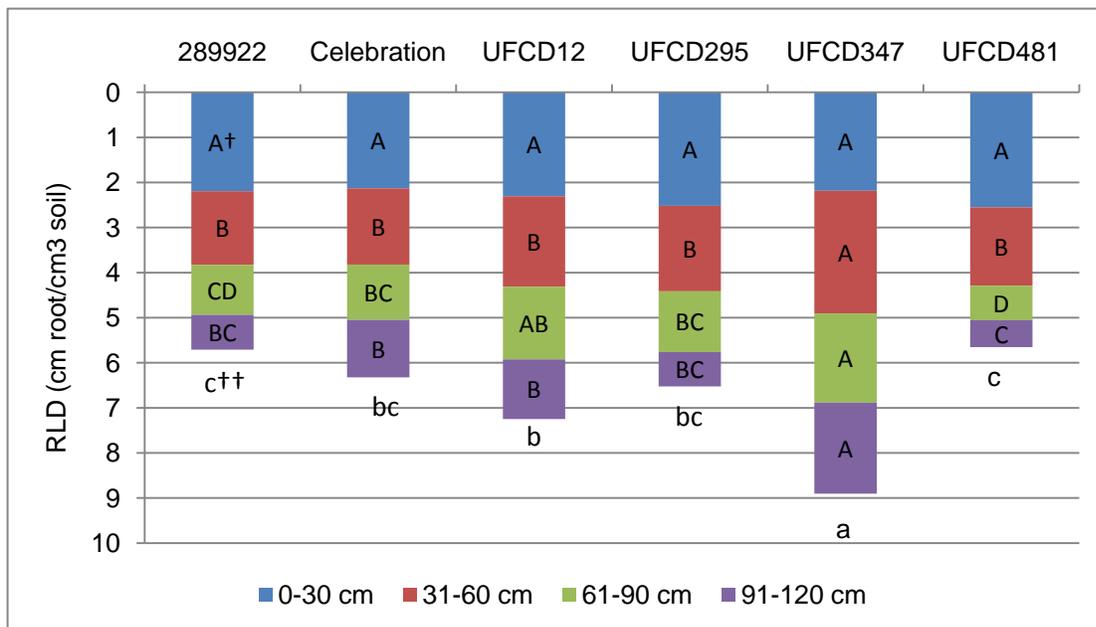
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-8. Differences in root volume by genotypes and horizons in common bermudagrass, year 2010



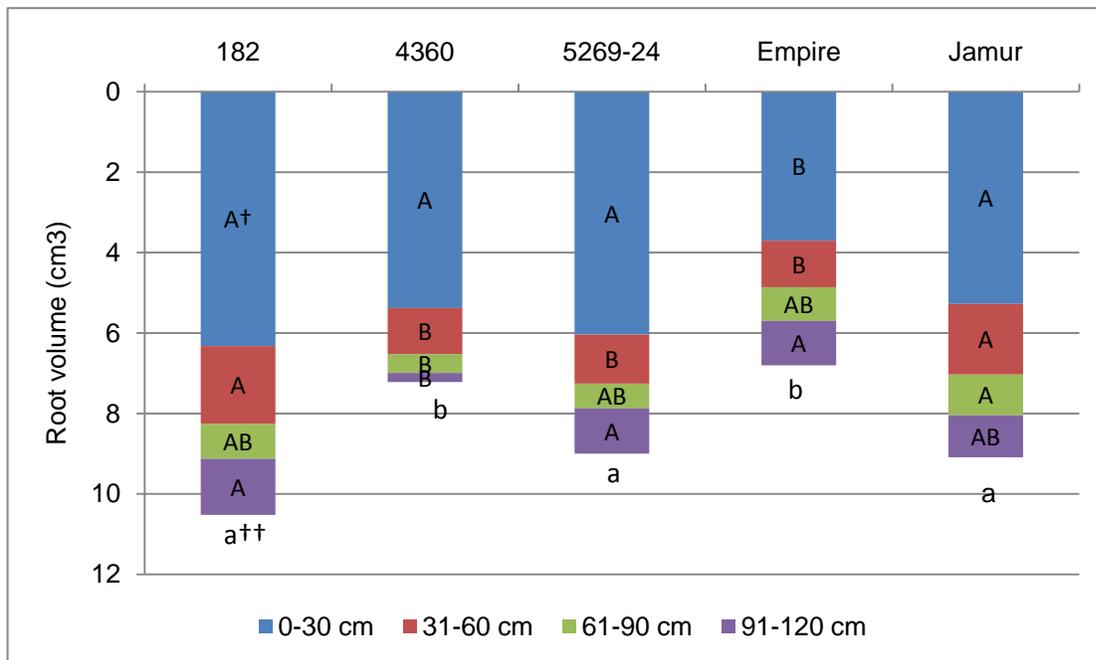
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-9. Differences in root length density (RLD) by genotypes and horizons in common bermudagrass, year 2009



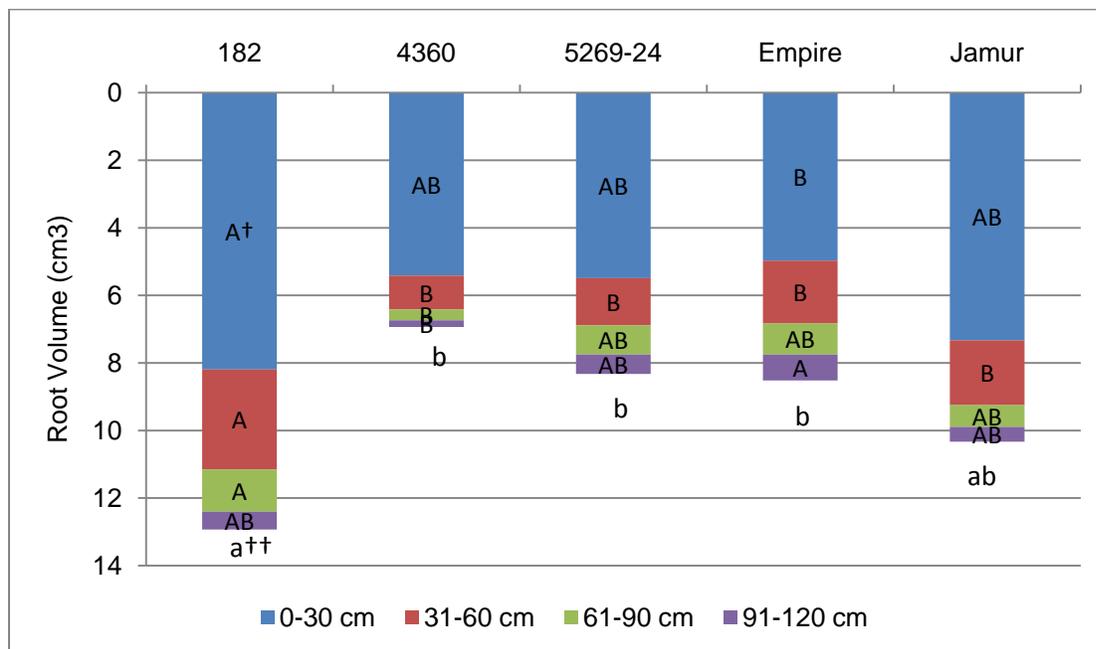
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-10. Differences in root length density (RLD) by genotypes and horizons in common bermudagrass, year 2010



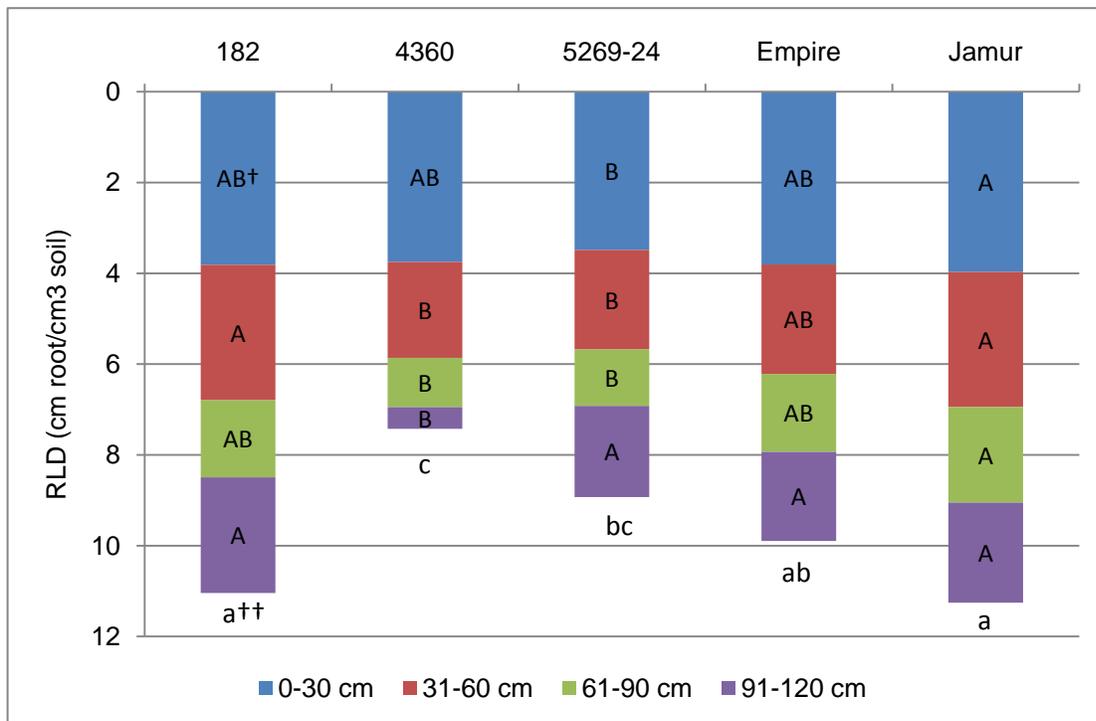
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-11. Differences in root volume by genotypes and horizons in *Zoysia japonica*, year 2009



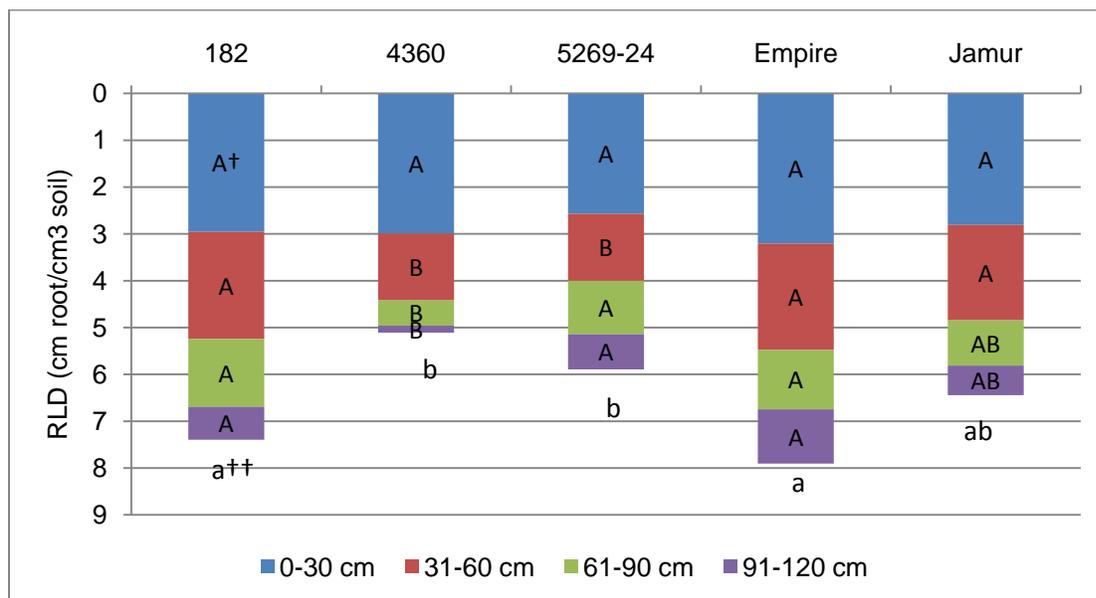
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-12. Differences in root volume by genotypes and horizons in *Zoysia japonica*, year 2010



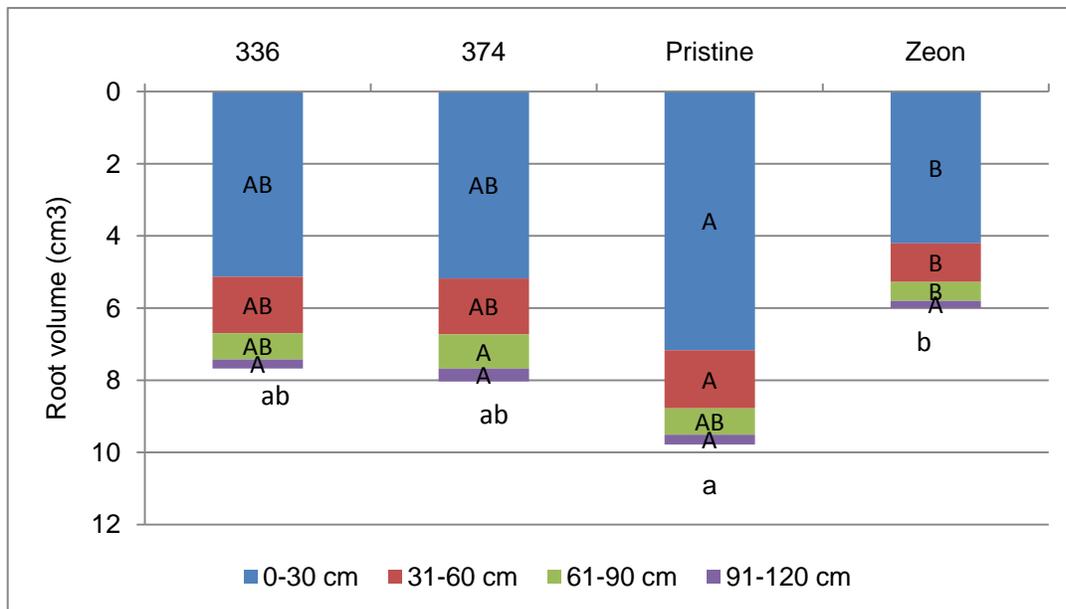
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-13. Differences in root length density (RLD) by genotypes and horizons in *Zoysia japonica*, year 2009



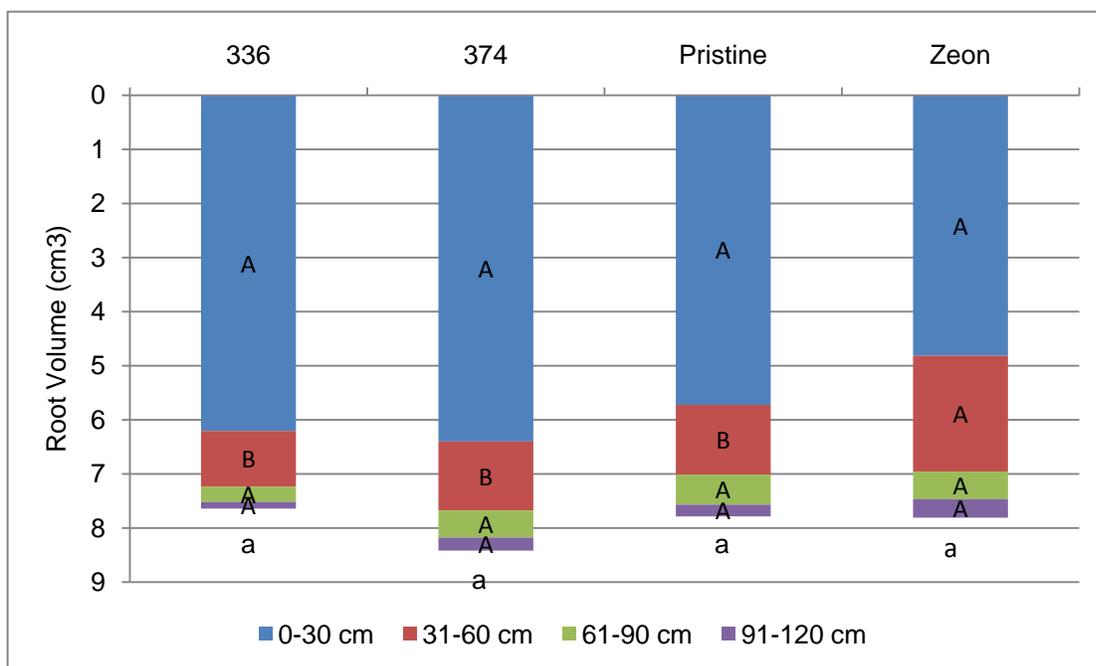
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-14. Differences in root length density (RLD) by genotypes and horizons in *Zoysia japonica*, year 2010



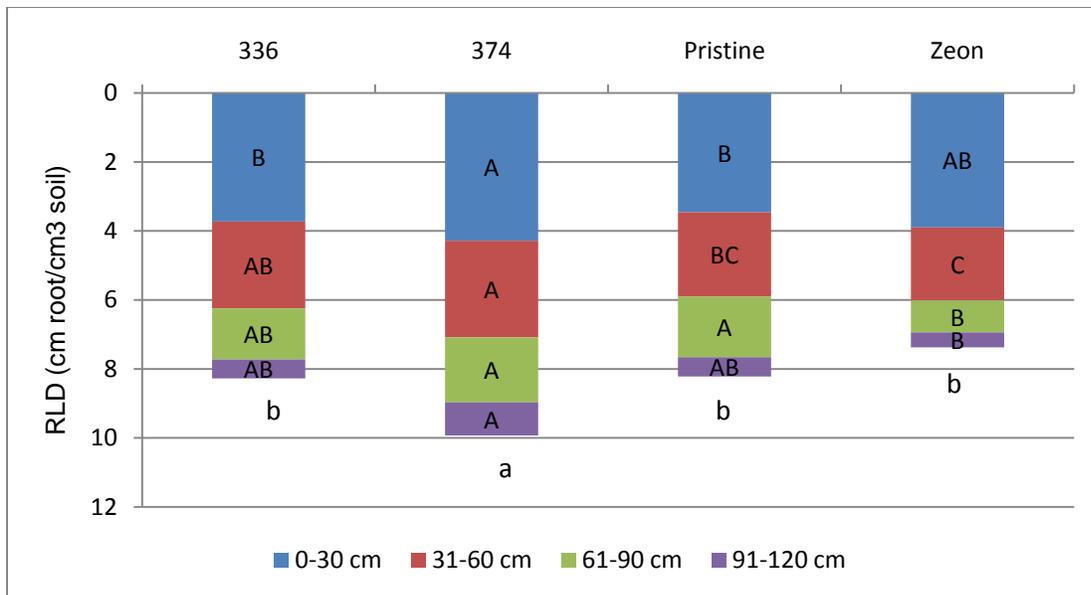
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-15. Differences in root volume by genotypes and horizons in *Zoysia matrella*, year 2009



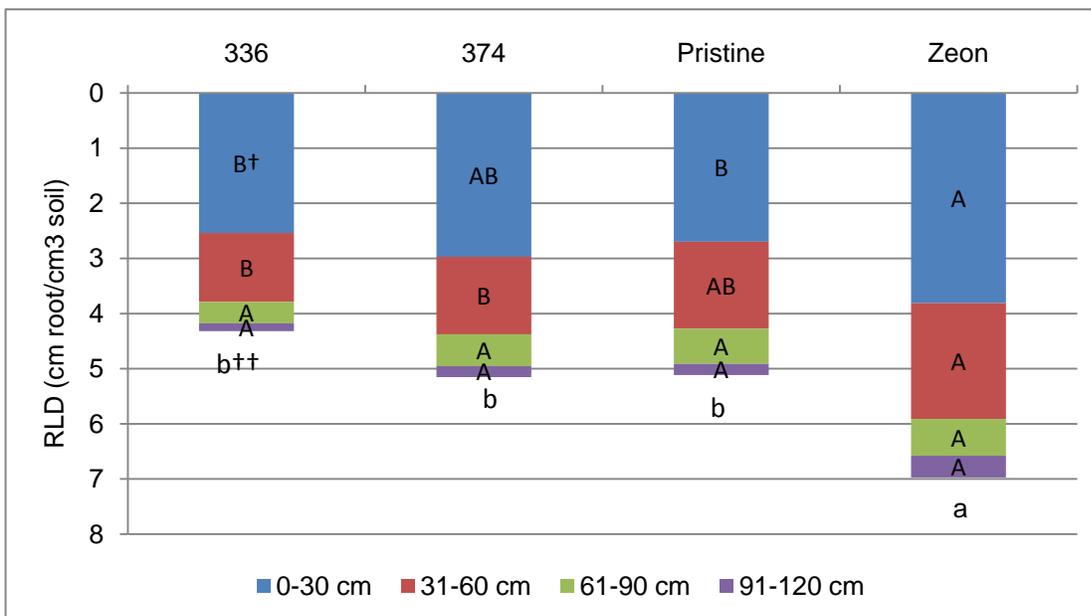
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-16. Differences in root volume by genotypes and horizons in *Zoysia matrella*, year 2010



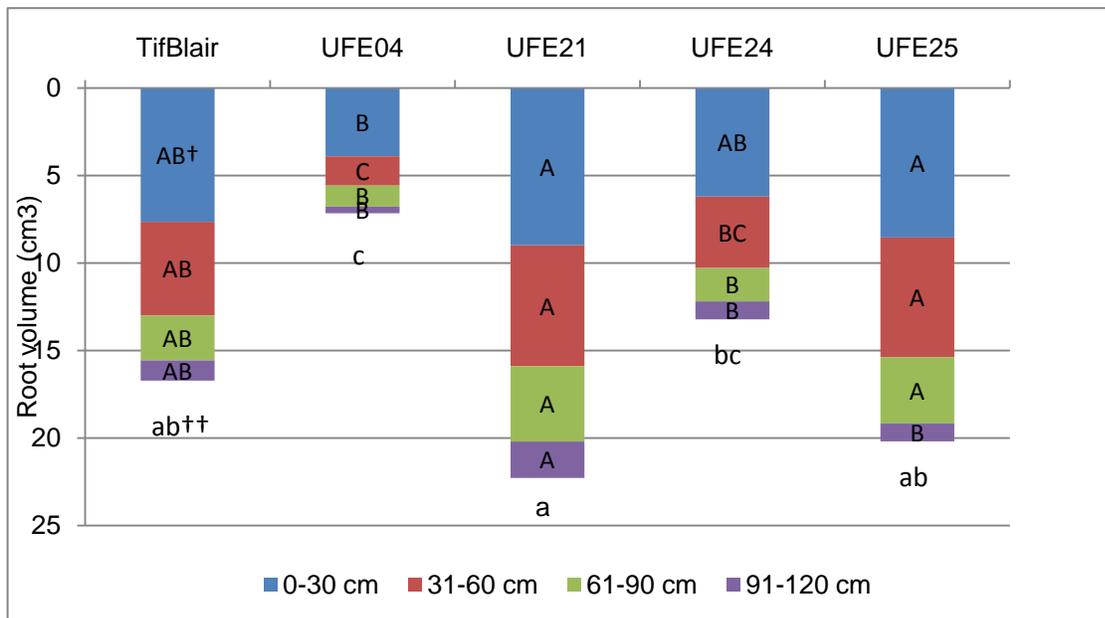
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-17. Differences in root length density (RLD) by genotypes and horizons in *Zoysia matrella*, year 2009



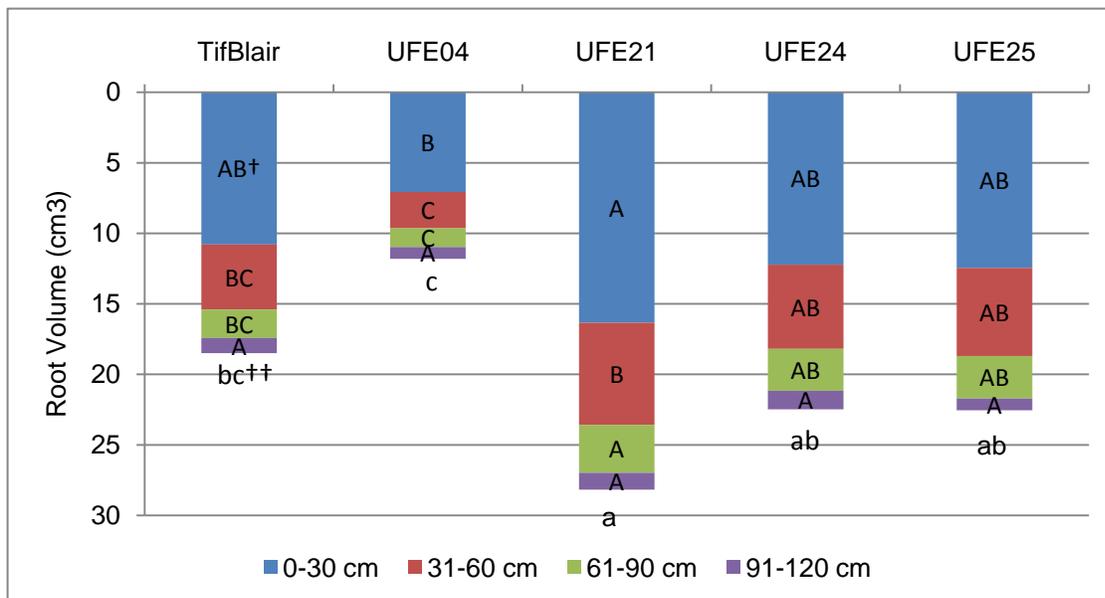
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-18. Differences in root length density (RLD) by genotypes and horizons in *Zoysia matrella*, year 2010



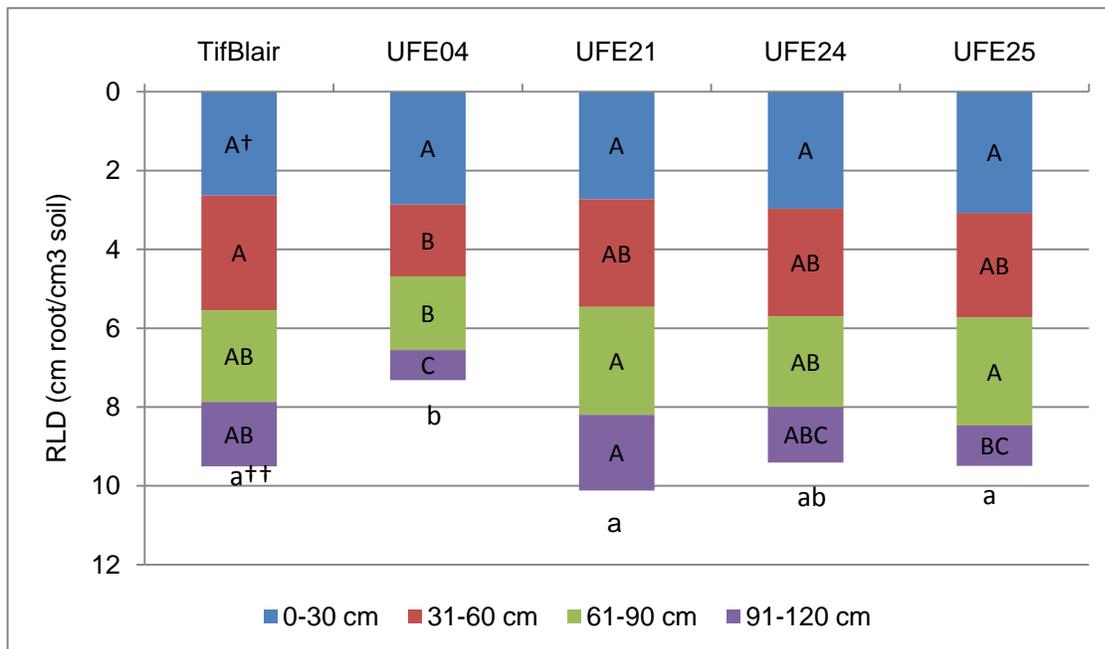
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-19. Differences in root volume by genotypes and horizons in centipedegrass, year 2009



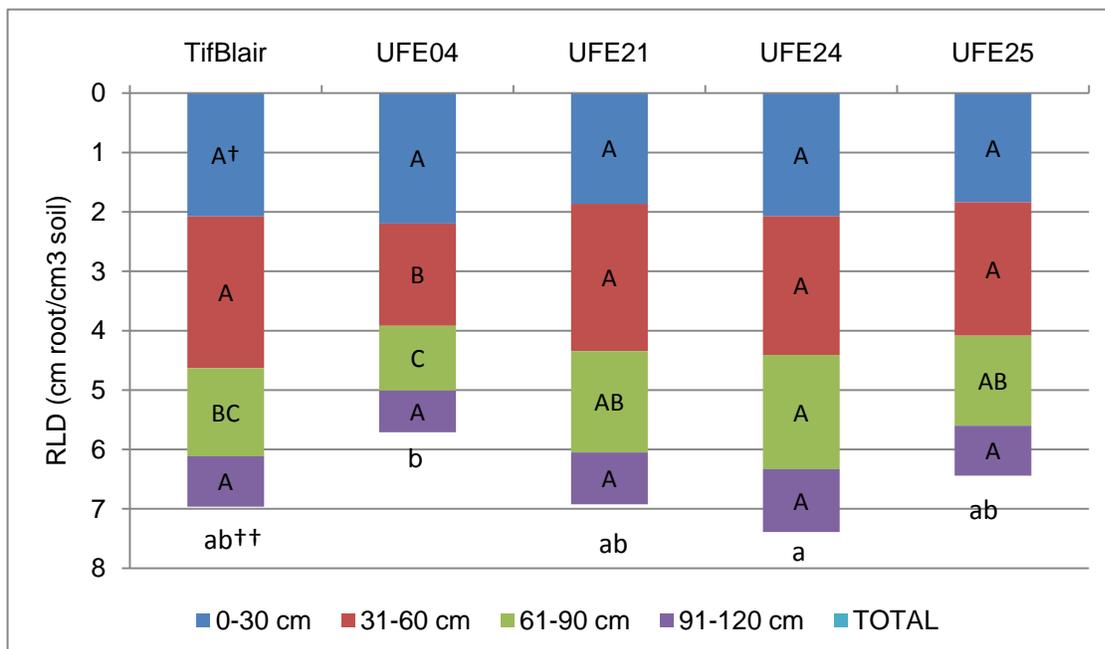
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-20. Differences in root volume by genotypes and horizons in centipedegrass, year 2010



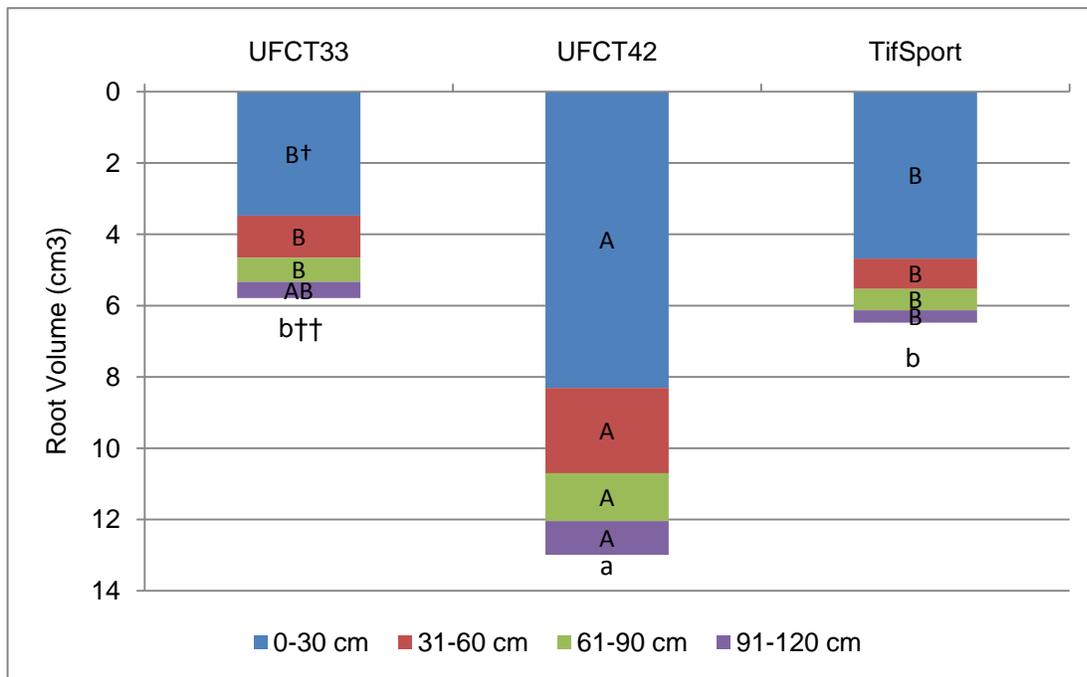
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-21. Differences in RLD by genotypes and horizons in centipedegrass, year 2009



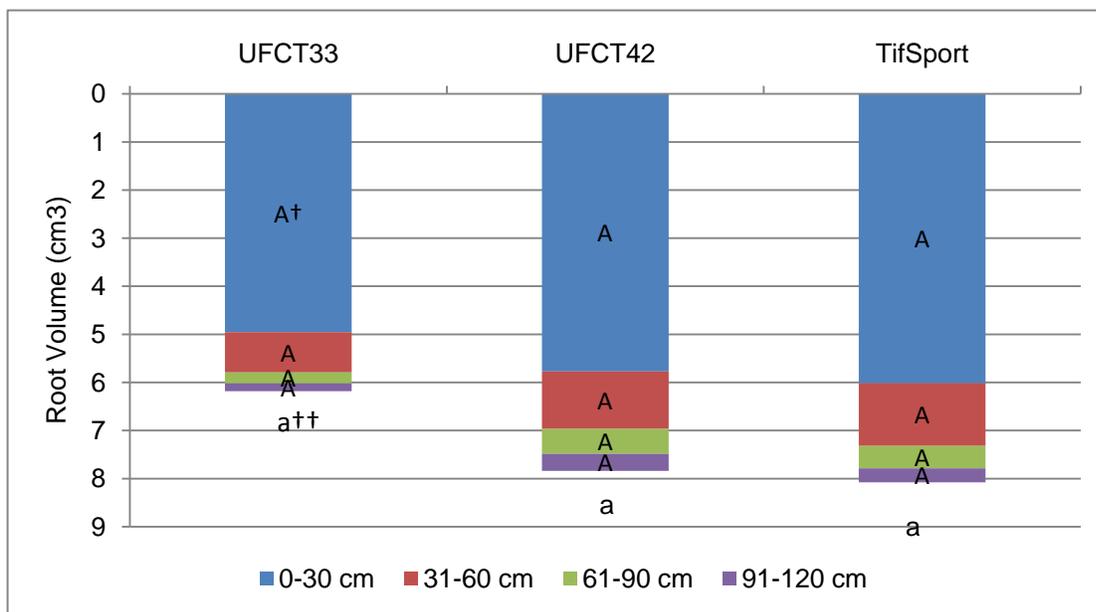
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-22. Differences in RLD by genotypes and horizons in centipedegrass, year 2010



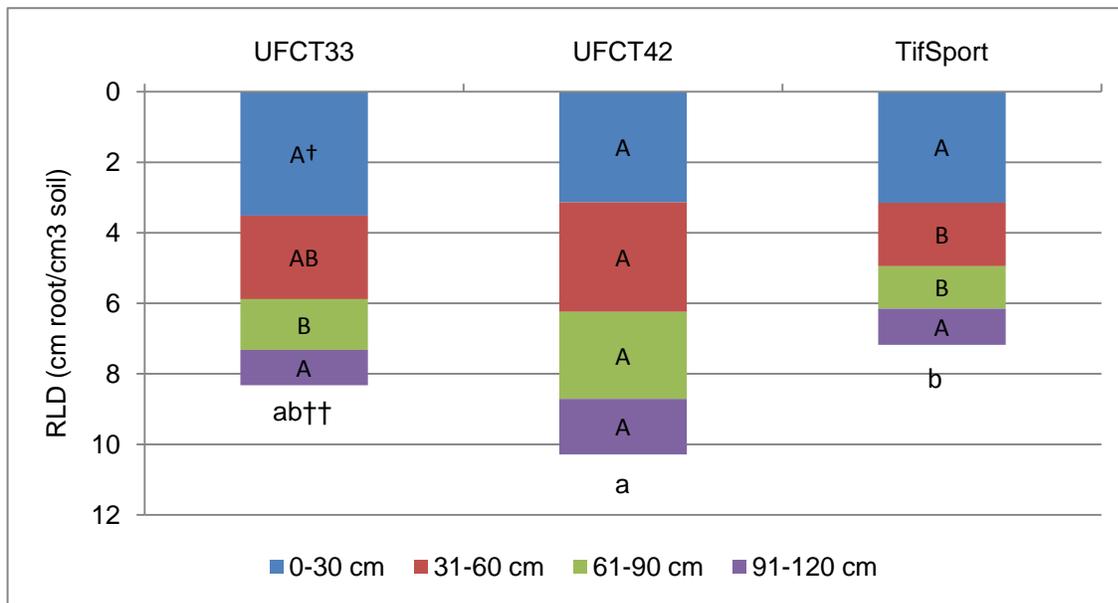
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-23. Differences in root volume by genotypes and horizons in African bermudagrass, year 2009



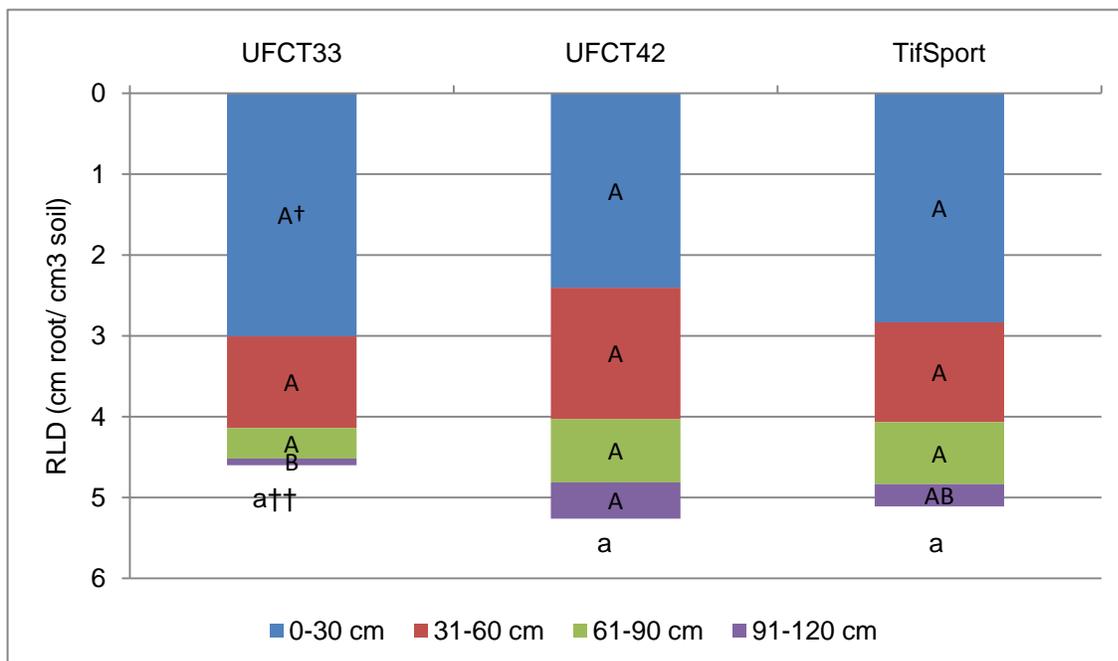
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-24. Differences in root volume by genotypes and horizons in African bermudagrass, year 2010



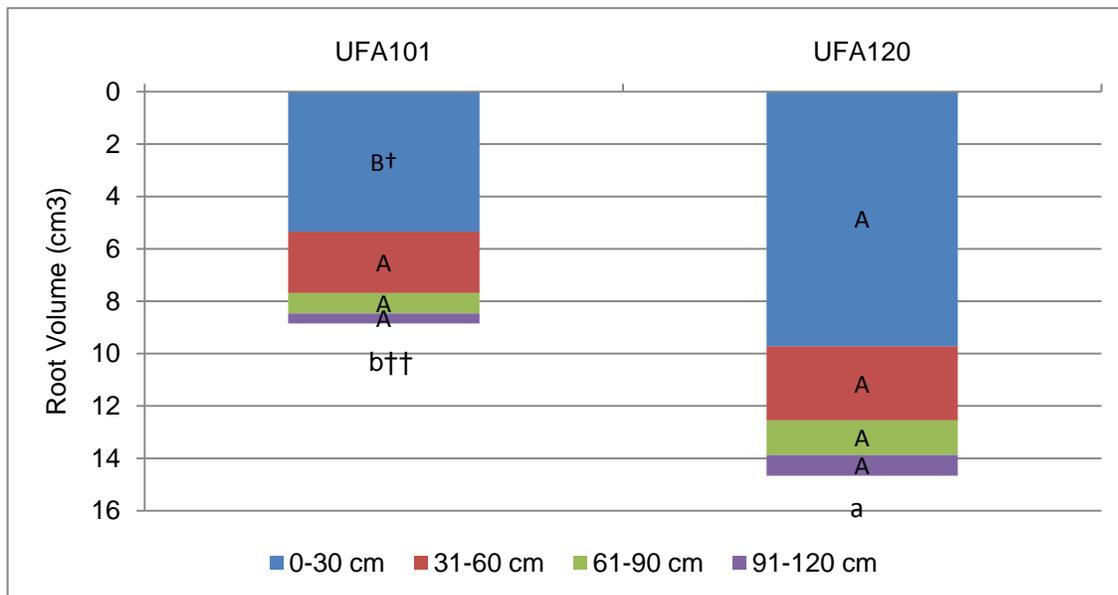
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-25. Differences in RLD by genotypes and horizons in African bermudagrass, year 2009



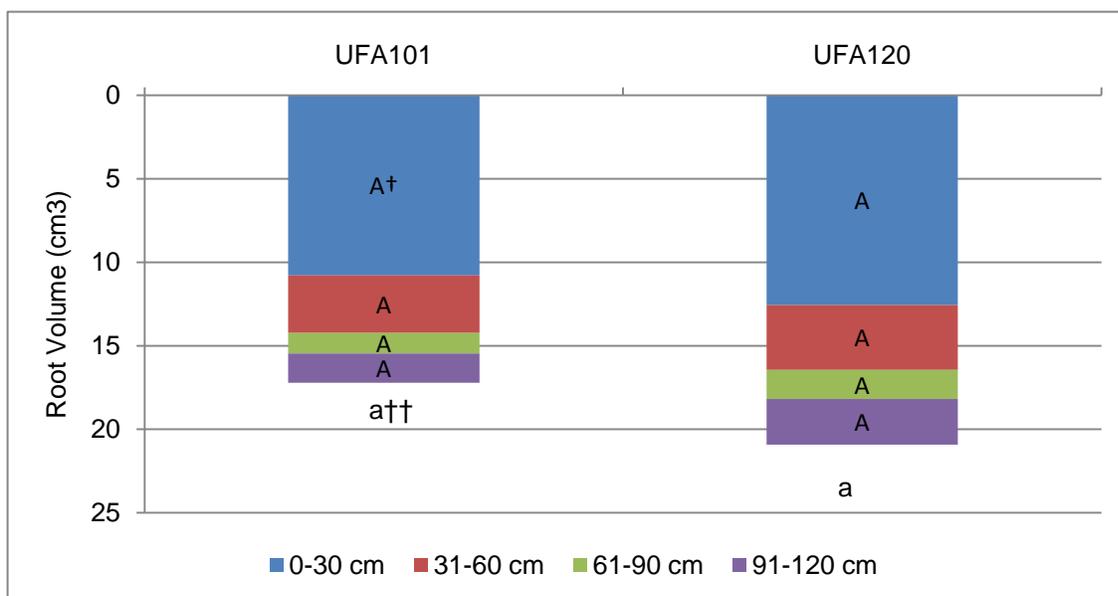
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-26. Differences in RLD by genotypes and horizons in African bermudagrass, year 2010



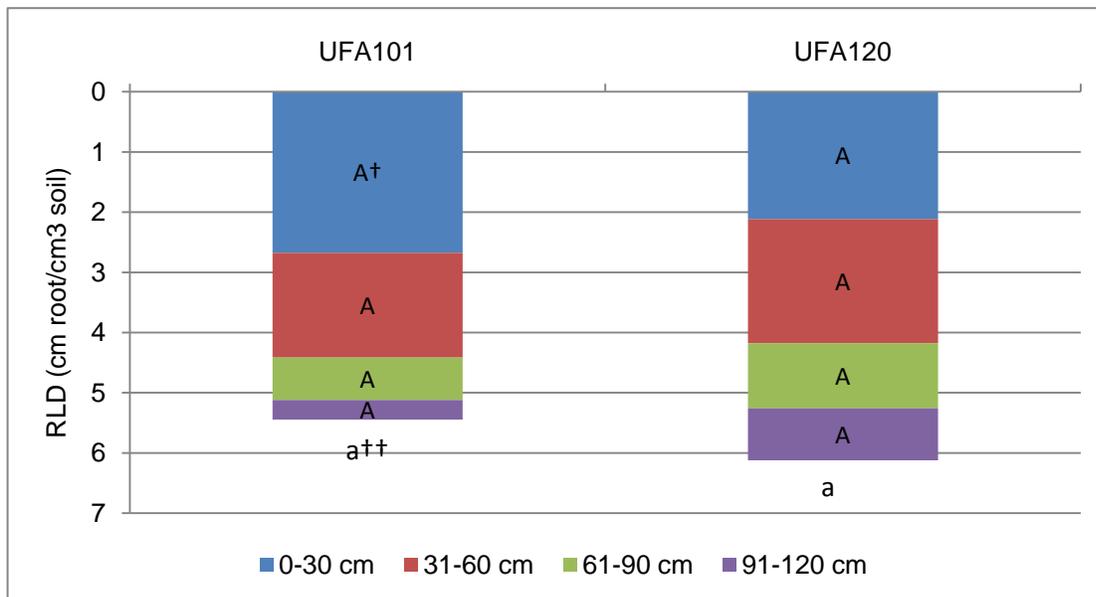
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-27. Differences in root volume by genotypes and horizons in carpetgrass, year 2009



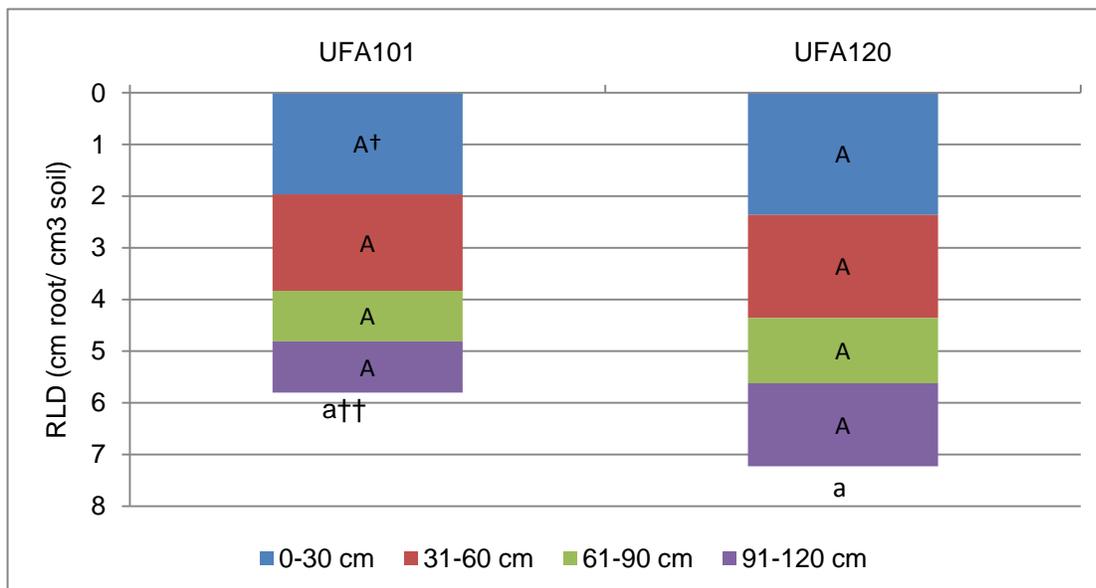
†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root volume

Figure 2-28. Differences in Root volume by genotypes and horizons in carpetgrass, year 2010



†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-29. Differences in RLD by genotypes and horizons in carpetgrass, year 2009



†Upper case letters indicate differences between species within a given horizon
 ††Lower case letters indicate differences between species for total root length density

Figure 2-30. Differences in RLD by genotypes and horizons in carpetgrass, year 2010

CHAPTER 3 TRANSPIRATION RATE CHANGES IN RESPONSE TO SOIL DRYING OF FIVE WARM-SEASON TURFGRASS SPECIES

Introduction

Water for landscape irrigation is a precious commodity. A growing population and industrialization have increased water requirements in many areas, but affordable water supplies have not increased as readily (Richie et al., 2002). Water consumption of most turfgrasses is between 3 and 8 mm per day (Beard, 1973; Beard, 1989). Water availability and cost is of major importance in the production of turfgrass, and is a limiting factor in many areas of the world (Biran et al., 1981).

Water consumption is influenced by a number of factors, including species and cultivar differences. This may result from differences in growth rate, evapotranspiration, or length of growing season. Cultural practices may also affect the rate of water consumption, for example, increasing the mowing height or shortening the irrigation interval may increase water usage (Biran et al., 1981). Potential adverse environmental inputs on the use of water and fertilizers by homeowners and other sections of the turf industry have resulted in national and regional regulation (DEP, 2007). One strategy to reduce irrigation requirements and water stress is to use drought resistant species and cultivars (Huang et al., 1997a).

Turfgrasses may exhibit drought resistance through various strategies, such as developing deep root systems and possessing shoot morphological or physiological mechanisms that reduce evapotranspiration (ET) losses (Huang et al., 1997a). Physiological function may be more important in controlling water uptake and thus drought resistance. Little research has addressed the root physiological characteristics

related to drought resistance, especially in root viability and functionality (Huang et al., 1997b).

In a study that compared the drought responses of four cool-season turfgrasses under moderate evaporative conditions, evapotranspiration rates were measured using lysimeters. Most of the plant characteristics monitored in the study exhibited marked changes when soil water potential decreased to a range of -50 to -80 kPa. It showed that this moisture potential range may represent a threshold level of drought stress for cool season grasses (Aronson et al., 1987). Evapotranspiration research has demonstrated that plant transpiration responds to water deficits on the basis of the fraction of total extractable water in the root zone (Ritchie, 1980; Sinclair and Ludlow, 1986; Miller 2000). The point at which transpiration starts to decline relative to the fraction of transpirable soil water (FTSW) reflects the point at which stomata begin to close and photosynthesis begins to decline (Miller, 2000).

Steinke et al. (2009) measured the turfgrass canopy temperatures of three warm season species (common bermudagrass, St. Augustinegrass and zoysiagrass) during a 60 day drought. Thus, they compare the ability of the species to alleviate heat accumulation during a prolonged dry period. The results indicated considerable heat accumulation from dormant desiccated turf canopies. In their study zoysiagrass maintained higher canopy temperatures compared to bermudagrass and St. Augustinegrass. The authors indicate that the lower canopy temperatures for the latter species may be due to enhanced heat dissipation through greater evapotranspiration.

To make accurate determinations of physiological differences in genotypic responses to soil drying, it is important to ensure that plants are subjected to equivalent

soil water deficits. Physiological measures of plant status (e.g., leaf water potential, turgor, stomatal conductance, or leaf photosynthetic rate) may indicate genotypic differences only because plants are being subjected to differing levels of soil water, not because there were inherent genetic differences in the sensitivity of these physiological parameters (Ray and Sinclair, 1997).

The objective of this study was to assess the water loss rate of 19 genotypes (12 experimental and 7 commercial cultivars) of five warm season turfgrass species to controlled soil drying.

Materials and Methods

Material and Location

An experiment, repeated in time, was conducted at the Archer Road Plant Physiology and Breeding Laboratory facilities of the University of Florida Agronomy department (29° 39'5" N/ 82°19'30"W). Transpirational response to soil drying was tested using clonally propagated plugs grown in 11.4 cm diameter × 9.5 cm tall pots. Nineteen genotypes were evaluated from the following species: *Zoysia spp.* [*Z. japonica* (Steud) and *Z. matrella* L.], common bermudagrass (*Cynodon dactylon* L. Pers. var. *dactylon*), African bermudagrass (*Cynodon transvaalensis* Burtt-Davy), hybrid bermudagrass (*C. dactylon* L. var. *dactylon* × *C. transvaalensis* Burtt-Davy) and St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] (Table 3-1).

For the study, pots were filled with Black Kow Topsoil (Black Gold Compost Co, Oxford, FL). Each genotype was represented by 10 pots. The pots were established and grown in a greenhouse under natural daylength and watered daily for 90 days. Weekly fertilization of all pots was performed by applying 18-18-21 Miracle-Grow water soluble Plant Food (Marysville, OH, USA) at rates of 12.2 kg ha⁻¹.

Procedure

The grasses were trimmed once a week to 6.35 cm. Two weeks prior to initiating the dry-down cycle a light sand topdress was applied to the pots to encourage new growth. The experiment follows the methodology described by Johnson et al. (2009), with minor changes. Four pots of each genotype were maintained as well-watered pots and six pots were subjected to a controlled dry down until each pot was below its NTR (0.12) as described by Sinclair and Ludlow (1986) and Miller (2000), and thus implying that the plant is not capable of further transpiration. The pots were arranged in a completely randomized design in two controlled temperature rooms (30°C days and 22°C nights). The experiment was initiated on 04 April 2010 and repeated beginning 30 April 2010. The day prior to drying all pots were trimmed and fully watered in the late afternoon so that water drained freely from each pot. The following morning each pot was weighed to obtain the weight for the upper limit of extractable water in each pot. To obtain the transpiration rate for a period of ≈ 24 h, the weight of each pot was recorded at ≈ 1300 HR each day. In the four well watered pots of each genotype water was added daily to return its weight to 30 g less than its initial weight. The 30 g deficit prevented the soil from being water-saturated yet maintained the soil water in the well-watered range for the control pots (Sinclair and Ludlow, 1986). Decrease in the soil water content of the six drying pots of each grass was controlled by rewatering the pots so that the drying cycle extended over two weeks. On each day water was added to each of the drying pots if necessary to return a pot weight to ≈ 30 g below the net pot weight from the previous day; this ensures that the drying cycle did not advance too quickly for precise measurements of the point at which transpiration began to decline (Ray and Sinclair, 1998). The daily transpiration rate of each pot was calculated by subtracting

the pot weight measured on the current day from the combined weight on the previous day of the pot and added water. After 18 days, when the dry down cycle finished, daily transpiration rate, average normalized transpiration rate (NTR), fraction of transpirable soil water (FTSW), total transpirable soil water (TSW) and days to reach the endpoint were recorded.

The response of each pot to drying on each day was assessed by calculating the ratio between the transpiration rate of the drying pot and the mean transpiration rate of the four well-watered (control) pots on each day (Johnson et al., 2009; Miller, 2000; Sinclair and Ludlow, 1986). The transpiration ratios on the first few days of the drying cycle while the pots were still in a well watered condition were used to calculate the normalization value for each pot (NTR). The transpiration ratio on each day was divided by the average of the transpiration ratios from the first few days for each pot. Following Miller (2000) and Sinclair and Ludlow (1986) methodology, the FTSW was calculated to represent the water deficit achieved in each drying pot on each day. The response of NTR to FTSW was analyzed using a two segment linear regression model (Prism Graph Pad Software, version 5.03). The break point (FTSW point in which stomata begin to close) was then calculated for each genotype.

Percent leaf wilting was visually rated and recorded three times a week during the drying cycle. The National Turfgrass Evaluation Program (NTEP) was using with 100% being completely wilted and 0% being without wilting (Morris and Shearman, 2006). The first ratings were collected the second day after the experiments started.

Statistical Analysis

Data were analyzed using the SAS statistical package for Windows (SAS Systems for Windows Version 9.2, SAS Institute Inc. Cary, NC, USA) using the PROC GLIMMIX procedure. Least square means were estimated and tested for significant differences at an alpha level of 0.05. The sources of variation included for the analysis of variance were experiment, species, genotype nested within species, and the following interactions: experiment × species and experiment × genotype nested within species. The ANOVA table includes only the tested treatment effects and not the associated error terms (Table 3.2).

An initial analysis was conducted to determine if there was an interaction between the two controlled growth rooms used and between species or genotypes with the two runs of the experiment. There was not a significant interaction (data not shown) for determination of the break point (BP). There was a significant experiment × genotype nested within species interaction for days to BP and both days to endpoint and TSW had significant experiment × species and experiment × genotype nested within species interactions. Because the days to BP, days to endpoint and TSW are dependent on the calculation of BP all data was pooled for analysis.

Results and Discussion

The two segmented linear regression model used to calculate the break points indicated an R^2 greater than 97% for both species and individual genotypes. Data for species are shown in Table 3-3 and the data for individual genotypes are not shown. Consequently, the equation used adequately described the NTR response.

Between Species

There were not significant differences in BP between turfgrass species (Table 3-3), the range was 0.30 for *Z. matrella* to 0.34 for St. Augustinegrass, but the species differed in the number of days to reach BP (the range was 8 days for *Z. matrella* to 7.1 days for St. Augustinegrass). Therefore, overall species did not differ for when transpiration declined in response to soil drying, but they differed in their transpiration rate. These differences were obtained from plants grown in pots with limited root zones and available soil volumes; therefore, it is not known what type of effect this will equate to in a field setting. Ray and Sinclair (1997) and Miller (2000) state that plants that exhibit an early onset of transpiration reduction should have more water available for longer term drought survival and should take a longer period to reach their endpoint in a drying cycle. While stomatal closure and transpiration was not directly measured, an earlier reduction in transpiration could have resulted in the results reported by Steinke et al. (2009) when 24 cultivars of three warm-season turfgrass species (bermudagrass, St. Augustinegrass and zoysiagrass) were compared for leaf firing and canopy temperatures during a 60 drought with no supplemental irrigation. Overall, bermudagrass exhibited a slower progression of leaf firing and increasing canopy temperatures followed by St. Augustinegrass (moderate leaf firing and increasing canopy temperatures) and then zoysiagrass which had a significantly faster rate of leaf firing and increasing canopy temperatures. Carrow (1996b) also concluded through ratings of percent leaf firing and wilting that 'Tifway' bermudagrass, common bermudagrass and 'Raleigh' St. Augustinegrass were more drought tolerant than 'Meyer' zoysiagrass.

These studies, performed on field plots indicate that these species differ in their dry down characteristics and that early transpiration reduction could equate to the prolonged drydown and better drought resistance reported by Steinke et al. (2009) and Carrow (1996b). In our pot study this was not the case (Table 3-3). Days to endpoint indicate that *Z. japonica* took the longest to reach complete drydown. Common bermudagrass, the fastest to reach the endpoint, was greater than one day earlier than *Z. japonica*. St. Augustinegrass was intermediate and not different than either of the two previous species in days to endpoint. Ray and Sinclair (1997) stated that in addition to a reduction in transpiration (i.e. slower water use rate), plants could take longer to reach their drydown endpoint by having a greater amount of available water. Greater available water could result from increased soil moisture in a field location or deeper and more extensive rooting that has potential to extract more available water to the plant. In the previous field studies a rainout shelter was used (Steinke et al., 2009) or the soil moisture of each plot and irrigation was closely monitored (Carrow, 1996b); therefore, it is likely that rooting characteristics (and not increased soil moisture) of bermudagrass and St. Augustinegrass led to their better drought resistance in these reported studies. Carrow (1996b), in his study, evaluated root length density (RLD) down to 60 cm and in his rankings bermudagrass RLD was greater than St. Augustinegrass which was greater than zoysiagrass. Carrow did point out some edaphic stresses that could have further limited the rooting of zoysiagrass in his study. However, identical rankings for rooting depth for these three species were provided by Beard (1989).

Rooting differences could be a reason for the discrepancies between our pot study and the above mentioned field studies related to drydown performance of warm-season

turfgrass species. In a confined or limited root zone it would be expected that a plant or species with greater root length density or root volume would deplete its available soil moisture sooner than a plant or species with a smaller root length density and/or root volume. For a discussion of rooting comparisons between warm-season species see Chapter 2.

Differences in the transpirable soil water (TSW) were found in our study between St. Augustinegrass and the remaining species (Table 3-3). Sinclair and Ludlow (1986) stated that crops can differ in their ability to extract available water from the soil. It may be that St. Augustinegrass was able to extract a greater amount of water from its pots than other species because it was more effective at exploring the pot soil volume with a more extensive root system. Again, for root comparisons see Chapter 2.

Within Zoysiagrass

Because the two zoysiagrass species, *Z. japonica* and *Z. matrella*, included in this study differ greatly for morphological traits, growth rates and for some management requirements they were independently evaluated. It is typically accepted that *Z. matrella* is less drought resistant than *Z. japonica*. Steinke et al. (2009) reported that *Z. matrella* genotypes accumulated heat during drydown more quickly than did *Z. japonica* genotypes and that leaf firing had a strong relationship with canopy temperatures. When leaf firing increased (reducing transpirational capacity) so did the canopy temperatures and because *Z. matrella*'s canopy temperature increased at a faster rate than *Z. japonica* it was likely less drought resistant. The genotypes entered in the trial for these respective zoysia species are shown in Table 3-4 along with their break point values. Differences among genotypes within both species were found to be significant. The range in BP values for these two species were greater than the ranges for other species

(see bermudagrass, Table 3-5), 0.26-0.41 and 0.25-0.35 for *Z. japonica* and *Z. matrella* respectively.

In theory, as stated above, if a given genotype reduces transpiration earlier than other genotypes it should have available water for a longer period of time and take a greater number of days to reach its drydown endpoint (Ray and Sinclair, 1997; and Miller, 2000). Several of the zoysiagrass genotypes included in this study did not adhere to this theory with respect to the number of days needed to reach the end of the drydown cycle. Differences between *Z. matrella* genotypes were not significant indicating that BP has little to no effect on the length of time required to complete a drydown cycle. Only one *Z. japonica* genotype was different from the other japonicas for days needed to complete the drydown cycle. Genotype 'DALZ 4360' had one of the lowest BPs within *Z. japonica*. This should equate to continued higher transpiration and maintenance of turf quality (to a point) and a shorter number of days to the drydown endpoint, but DALZ 4360 took longer to complete its drying cycle than other japonica types. In comparison, 'DALZ 5269-24' had the highest BP among the japonicas, but took less time to reach its endpoint than DALZ 4360.

The average transpirable soil water between genotypes within both zoysia species was different. For *Z. japonica* the commercial cultivar 'JaMur' and the experimental DALZ 4360 extracted more water than did all other genotypes except '182' which extracted more water than DALZ 5269-24 which extracted the least amount of water. Among the *Z. matrella* genotypes, the commercial cultivar, 'Zeon' extracted less water than the commercial cultivar, 'PristineFlora'.

Within Bermudagrass

Common and African bermudagrass differ morphologically and in their growth habits. African bermudagrass as a species has finer stems and leaves than common bermudagrass and a more upright growth habit (Kenworthy et al., 2007). Information is also lacking for drought resistance in African bermudagrass. For these reasons the two *Cynodon* species were analyzed separately (Table 3-5). 'TifSport' is a hybrid bermudagrass (*C. dactylon* × *transvaalensis*) and was included for analysis with the African bermudagrass genotypes to help balance entry numbers within the species and because the more upright growth habit of TifSport more closely resembles African bermudagrass. Differences in BPs were observed for genotypes within both species (Table 3-5). In common bermudagrass, 'UFCD12' had a much larger BP value than those calculated for other common bermudagrass genotypes. As theorized above, it also took approximately one day longer to complete its drydown in comparison to all of the other genotypes except 'Celebration'.

Celebration extracted the greatest amount of water during the drydown (TSW = 334.17, Table 3-5), but was not statistically different from several other genotypes including, UFCD12 (TSW = 316.42). Among the common bermudagrass entries included in this study UFCD12 may conserve moisture through early reduction of transpiration which thus allows this genotype to persist longer during a prolonged drought. In comparison, Celebration behaved similarly to DALZ 4360 (mentioned above) in that it had the lowest BP value among the bermudagrasses indicating that it maintained a higher transpiration rate for a longer period of time yet its days needed to reach its endpoint were not different from UFCD12. Therefore, these two genotypes exhibit differential transpirational responses to a controlled drydown, but are similar for

water lost through transpiration and the amount time needed to reach the endpoint of the drying cycle.

Genotypes

Genotypes were found to be significantly different, with the lowest BP for genotype '336' (*Z. matrella*, BP = 0.25), and the highest BP for genotype DALZ 5269-24 (*Z. japonica*, BP = 0.41) (Table 3-6). There is much research available for traditional crop species regarding evapotranspiration responses to drought and BP ranges, but only a few studies have involved turfgrasses. The BP range (0.25 to 0.41) (Table 3-6) obtained for all turfgrass genotypes is reflective of reported values found for other plants. Sadras and Milroy (1996) compared cereals [maize (*Zea mays*), wheat (*Triticum spp.*), barley (*Hordeum spp.*), sorghum (*Sorghum spp.*), and pearl millet (*Pennisetum glaucom*)], legumes [soybean (*Glycine max*), and snapbean (*Phaseolus vulgaris*)], sunflower (*Helianthus annuus*) and cotton (*Gossypium spp.*), and found a BP range of 0.25 to 0.40. Sinclair and Ludlow (1986) studying four tropical legumes [soybean (*Glycine max*), cowpea (*Vigna unguiculata*), black gram (*Vigna mungo*), and pigeonpea (*Cajanus cajan*)] obtained a value of 0.3 for the included legume species. The same value was found for maize (*Zea mays*) (Muchow and Sinclair, 1991). In another study with two maize genotypes, again, the resulting BP range was 0.31 to 0.38 (Ray et al., 2002). However, contradictory results are available for maize (*Zea mays*) in an earlier report of a BP range of 0.36 to 0.6 (Ray and Sinclair, 1997). In rhizoma peanuts (*Arachis glabrata* Benth.) a BP range has recently been reported to be 0.17 to 0.32 for three genotypes (Cathey, 2010).

In turf, Miller (2000) examined the drought response of 'Tifdwarf' bermudagrass growing in different soil amendments and found a treatment BP range of 0.12 to 0.39.

While a break point of 0.12 is considered extremely low, the averages across replications for the Tifdwarf study ranged among 0.24 to 0.39. In comparison, these values are similar to the average values in the current study (0.25 to 0.41; Table 3-6). Johnson et al. (2009) studied different genotypes of seashore paspalum (*Paspalum vaginatum* Swartz), for their break points in sand and organic soil. The BP range for organic soil was 0.25 to 0.31 compared to 0.10 to 0.17 for sand. This study determined that the use of an organic soil (Black Kow Topsoil) was more desirable than sand because the organic soil allowed for a longer drydown period and provided a better assessment of transpirational changes.

Table 3-6 provides the BP values, the time (days) needed to complete the drydown cycle and transpirable soil water used during the study for individual genotypes. Differences were significant between genotypes for all parameters. Overall, the BP values among genotypes ranged from 0.25 (genotype 336) to 0.41 (genotype DALZ 5269-24), days to complete the drydown (endpoint) ranged from 12.7 d (genotypes 'UFCD481' and 'UFCD295') to 15.7 d (genotype DALZ 4360), and transpirable soil water (TSW) ranged from 290.2 (genotype DALZ 5269-24) to 349.8 ('Floritam').

Figures 3-1 and 3-2 illustrate the response of plant water loss on drying soil for the experimental genotypes 336 (*Zoysia matrella*) and DALZ 5269-24 (*Zoysia japonica*) that had the lowest and highest BPs respectively. The Figures illustrate the typical two segmented curve in response to dry down. Comparison of the BPs for 336 and DALZ 5269-24 indicate that 336 exhibits delayed stomatal closure and has potential to extract

additional soil water before stomatal closure, and maintain a higher transpiration rate for a longer period of time.

St. Augustinegrass is one of the most used turfgrass species in the southern United States and the cultivar Floratam is planted on more acres than any single turfgrass cultivar used in Florida; therefore it was included in this experiment as a control. While Floratam had one of the higher BP values it was not significantly different than Celebration, a common bermudagrass that is considered to have good drought resistance (Table 3-6). Baldwin et al. (2006) concluded from a comparison of six bermudagrass cultivars (included TifSport) that Celebration and 'Aussie Green' maintained higher quality after two weeks of being watered at five day intervals. In addition, Celebration, 'SWI-1012' and 'Tift.N^o3' had greater root weights than the other included cultivars. In the previously mentioned study conducted by Steinke et al. (2009) there were none to few differences for leaf firing between cultivars within bermudagrass and within zoysiagrass. However, Floratam St. Augustinegrass did have a slower rate of leaf firing in comparison to the other St. Augustinegrass cultivars. In the present study Floratam was different from 'UFCT42', an African bermudagrass, and four zoysiagrass entries (three with lower BP values and one with a higher BP). Break point data indicates that Floratam will slow down its transpiration rate when available soil water begins to decrease. Slowing down transpiration conserves the remaining available soil water and allows the plant to avoid further dehydration and leaf firing. Only one genotype, DALZ 4360, took longer to reach its drydown endpoint compared to Floratam. A higher BP and longer drydown period agree with the theory presented above by Ray and Sinclair (1997) and Miller (2000). Floratam differed greatly from the other included

genotypes for the total water used during the drydown. Floratam either extracted more water through osmotic adjustment or via more extensive root exploration within the pot.

The BP values in Table 3-6 show that when comparing genotypes from multiple species, overall the zoysiagrass entries maintained their rate of transpiration (lower BP values) for a longer period of time compared to other species. Bermudagrass genotypes were overall moderate in their BP values. Again, Floratam was the only St. Augustinegrass entry and had a higher BP value. These comparative species groupings for BP as indicators of transpirational adjustment with the onset of soil drying provide evidence that as a group, the zoysias because they delay their decrease in rate of transpiration for a longer period of time should deplete available soil water sooner than other species and suffer greater leaf firing as indicated by Steinke et al. (2009). It should be noted that both species of zoysiagrass had genotypes that also exhibited an early reduction of transpiration (higher BP values). Similarly, UFCD12 common bermudagrass also had a much higher BP than other common bermudagrass entries. The two included African bermudagrasses resulted in differing BPs. However, because these differences are between only two genotypes it is difficult to determine how African bermudagrass compares to other genotypes across species.

Table 3-7 contains the percent wilting of each genotype during the controlled drydown. This data in combination with BP values and days to endpoint (Table 3-6) identify several genotypes that warrant further discussion. DALZ 4360 maintained its transpiration rate and yet exhibited delayed wilting and required more days than any other genotype to reach its endpoint. This would appear to be in contrast to the theory presented by Ray and Sinclair (1997) and Miller (2000). DALZ 5269-24 had the highest

BP (early reduction of transpiration), had one of the highest percent wilting ratings at each date and was moderate for days to endpoint. UFCD12 also had a high BP, but resisted wilting better than any other genotype and was moderate for days to endpoint.

If we consider the effects of a genotype's base transpiration rate combined with its timing to reduce its transpiration rate (BP value) with the onset of soil drying we can associate the following scenarios with the data presented in Tables 3-6 and 3-7. DALZ 4360 does not wilt early and drydown as would be expected by its BP value. In fact, it avoids wilting and extends its drydown period. The plausible explanation for this is that DALZ 4360 has a lower transpiration rate in comparison to Celebration that had a similar BP value, but higher percent wilting early in the drydown cycle and reached its drydown endpoint ≈ 1.5 d sooner. DALZ 5269-24 had a much higher BP than DALZ 4360 and Celebration and its endpoint was between these two genotypes, but it suffered severe wilt. Like Celebration it is likely that the transpiration rate for 5269-24 is higher resulting in greater wilting and a shorter drydown period. UFCD12 also had a high BP value and a similar endpoint to Celebration and DALZ 5269-24; however, it delayed wilting as good as or better than DALZ 4360. Therefore, UFCD12 may have a lower transpiration rate and early reduction of transpiration in response to soil drying. It is not known what a 1.5 d endpoint difference observed in pots with a limited soil volume will translate to for field performance. Additionally, in the field differential rooting behavior between these two genotypes may lead to different dry down behavior.

Conclusions

In conclusion, BP values, number of days needed to complete a drydown and total water used were determined for several warm season species and individual genotypes within species and across species. Break points indicate that some genotypes respond

to soil drying by decreasing their transpiration rate early in the drydown, while other genotypes maintain their transpiration rate longer into the drying cycle. Most of the zoysiagrass genotypes in this study maintained their transpiration rate longer into the drying cycle than genotypes of other species. However, there were zoysiagrasses that decreased their transpiration rate early with the onset of soil drying. Among these genotypes there were variable wilting responses and days to drydown endpoint for the respective high and low BP values.

Bermudagrass genotypes were overall moderate in their BP values and associated transpirational rate responses to drydown, but reached their drydown endpoints in fewer days than did the genotypes of other species. Perhaps the normal transpiration rate for most bermudagrass genotypes is higher than other species which would lead to their early completion of the drydown.

Floritam St. Augustinegrass was previously shown to delay leaf firing and wilting through the research of Steinke et al. (2009). In this study, Floritam exhibited the properties that should relate to an ability to tolerate a prolonged drydown. Floritam had a high BP value, took longer than many genotypes to complete its drydown and was able to take up more water from the pot's confined root zone than other genotypes.

There were a few genotypes that exhibited interesting responses for days to endpoint and percent wilting when compared to their BPs. DALZ 4360 took longer to reach its endpoint and avoided wilting despite having a lower BP value and DALZ 5269-24 which had a higher BP value did not take as long to reach its endpoint and suffered from severe wilting early in the drying cycle. Additional information is needed that would add valuable information to more accurately describe individual genotypic responses to

drydown and would include base transpiration rates, rooting responses and observation of mature field plots during an extended drydown cycle.

Table 3-1. Experimental genotypes and commercial cultivars evaluated in the dry-down study.

<i>Zoysia japonica</i>	<i>Zoysia matrella</i>	Common bermudagrass	African bermudagrass	St. Augustinegrass
DALZ 5269-24	374	UFCD12	UFCT42	Floritam*
182	336	UFCD295	UFCT33	
DALZ 4360	PristineFlora*	UFCD347	TifSport*†	
Empire*	Zeon*	UFCD481		
JaMur*		289922		
		Celebration*		

* Commercially available cultivars.

†Hybrid bermudagrass (*C. dactylon* x *transvaalensis*) analyzed was included with African bermudagrass

Table 3-2. Analysis of Variance Dry Down Experiment

Source of variation		BP	Days to BP	Days to endpoint	TSW
	DF	F values			
Experiment	1	15.71**	19.25**	65.76**	4.8 ^{NS}
Specie	4	2.09 ^{NS}	8.26**	12.64**	6.69**
Genotype (Specie)	14	5.96**	6.67**	2.98**	4.59**
Experiment x Specie	4	0.93 ^{NS}	1.37 ^{NS}	5.01**	8.57**
Genotype x Experiment (Specie)	14	1.71 ^{NS}	2.45**	4.72**	3.23**
Residuals	189				

^{NS}, *, **Nonsignificant or significant at p≤ 0.05 or 0.01, respectively.

Table 3-3. FTSW (breakpoint) of five warm-season turfgrass species, their number of days required to reach FTSW, number of days to reach the endpoint of the drying cycle and the average transpirable soil water used during the drydown.

Species	FTSW (BP)	R ²	Days to BP	Days to endpoint	TSW
<i>Zoysia matrella</i>	0.30	0.98	8.0 a [†]	13.99 ab	321.2 b
African Bermudagrass	0.30	0.98	7.8 a	13.66 bc	315.4 b
<i>Zoysia japonica</i>	0.32	0.98	7.8 a	14.37 a	319.7 b
Common Bermudagrass	0.32	0.98	7.2 b	13.07 c	320.6 b
St. Augustinegrass	0.34	0.98	7.1 b	13.71 a-c	349.8 a

† Means within a column followed by the same letter are not significantly different (LSD, P ≤ 0.05)

Table 3-4. FTSW (breakpoint) for genotypes within each zoysiagrass species, their number of days required to reach FTSW, number of days to reach the endpoint of the drying cycle and average transpirable soil water used during the drydown.

Genotype	FTSW (BP)	Days to BP	Days to endpoint	TSW
<i>Zoysia japonica</i>				
182	0.26 a [†]	8.4 ab	14.08 b	324.3 ab
DALZ 4360	0.30 ab	9.0 a	15.67 a	334.4 a
JaMur	0.30 ab	8.0 bc	14.17 b	338.1 a
Empire	0.33 b	7.4 c	13.58 b	311.5 b
DALZ 5269-24	0.40 c	6.3 d	14.33 b	290.1 c
<i>Zoysia matrella</i>				
336	0.25 a	8.5 ab	13.71	322.0 ab
PristineFlora	0.29 b	8.6 a	14.38	332.0 a
Zeon	0.32 c	7.8 bc	14.21	311.4 b
374	0.35 c	7.2 c	13.67	319.5 ab

† Means in a column followed with the same letter within a species are not significantly different (LSD, P ≤ 0.05).

Table 3-5. FTSW (breakpoint) for genotypes within each bermudagrass species, their number of days required to reach FTSW, number of days to reach the endpoint of the drying cycle and average transpirable soil water used during the drydown.

Genotype	FTSW (BP)	Days to BP	Days to endpoint	TSW
Common Bermudagrass				
Celebration	0.30 a [†]	7.7 a	13.42 ab	334.1 a
UFCD347	0.31 a	7.3 ab	12.79 b	316.5 ab
289922	0.31 a	7.1 ab	12.92 b	313.7 b
UFCD481	0.32 a	7.2 ab	12.71 b	330.3 ab
UFCD295	0.32 a	6.9 b	12.71 b	312.5 b
UFCD12	0.37 b	6.8 b	13.88 a	316.4 ab
African Bermudagrass				
UFCT42	0.27 a	8.3 a	13.73	314.8
TifSport [‡]	0.31 ab	7.6 ab	13.88	322.0
UFCT33	0.33 b	7.4 b	13.38	309.5

[†] Means in a column followed with the same letter within a species are not significantly different (LSD, $P \leq 0.05$).

[‡]Hybrid bermudagrass (*C. dactylon* × *transvaalensis*) analyzed with African bermudagrass

Table 3-6. FTSW (breakpoint) of 19 warm-season turfgrass genotypes, their number of days required to reach FTSW, number of days to reach the endpoint of the drying cycle and the average transpirable soil water used during the drydown.

Genotype	Species	FTSW (BP)	Days to BP	Days to Endpoint	TSW
336	ZM [†]	0.25 a [‡]	8.5 a-c	13.71 b-d	322.0 b-f
182	ZJ	0.26 ab	8.4 a-d	14.08 bc	324.3 b-f
UFCT42	AB	0.27 a-c	8.3 a-e	13.73 b-d	314.8 ef
PristineFlora	ZM	0.29 a-d	8.6 ab	14.38 b	332.0 b-d
DALZ 4360	ZJ	0.30 b-e	9.0 a	15.67 a	334.4 a-c
JaMur	ZJ	0.30 b-e	8.0 b-f	14.17 bc	338.1 ab
Celebration	CB	0.30 b-e	7.7 d-g	13.42 c-f	334.1 a-c
UFCD347	CB	0.31 b-f	7.33 f-i	12.79 ef	316.5 d-f
TifSport	HB	0.31 b-f	7.6 e-h	13.88 bc	322.0 b-f
289922	CB	0.31 c-f	7.1 g-i	12.92 d-f	313.7 f
UFCD481	CB	0.32 d-f	7.29 g-i	12.71 f	330.3 b-e
UFCD295	CB	0.32 d-f	6.9 h-j	12.71 f	312.5 f
Zeon	ZM	0.32 d-f	7.8 c-g	14.21 bc	311.4 f
Empire	ZJ	0.33 d-g	7.4 f-i	13.58 b-e	311.5 f
UFCT33	AB	0.33 d-g	7.4 f-i	13.38 c-f	309.5 f
Floratom	SA	0.34 e-g	7.1 g-i	13.71 b-d	349.8 a
374	ZM	0.35 fg	7.2 g-i	13.67 b-d	319.5 c-f
UFCD12	CB	0.37 gh	6.8 ij	13.88 bc	316.4 d-f
DALZ 5269-24	ZJ	0.4076 h	6.3 j	14.33 b	290.1 g

[†]AB = African bermudagrass, CB = Common bermudagrass, HB = hybrid bermudagrass, SA = St. Augustinegrass, ZJ = *Zoysia japonica*, ZM = *Zoysia matrella*

[‡] Means within a column followed by the same letter are not significantly different (LSD, P ≤ 0.05).

Table 3-7. Comparative leaf wilting for 19 warm season turfgrass genotypes in response to a controlled drydown.

	Day of Drought				
	7	9	12	14	16
	% Leaf Wilt				
Common Bermudagrass					
Celebration	5.83 a-d†	13.33 d-f	68.33 b-e	92.92 a-e	100.0 a
UFCD481	5.00 a-e	15.83 d-f	71.25 a-e	91.25 b-f	100.0 a
289922	3.33 b-e	25.83 b-e	62.92 de	95.83 a-c	99.6 ab
UFCD295	2.92 b-e	30.42 a-d	74.58 a-e	96.25 a-c	100.0 a
UFCD347	1.67 de	15.83 d-f	70.42 a-e	97.50 ab	100.0 a
UFCD12	0.42 e	7.08 f	43.75 f	86.25 f	97.3 c
African Bermudagrass					
UFCT33	2.92 b-e	20.83 c-f	67.08 b-e	95.42 a-d	99.2 ab
UFCT42	0.83 de	15.42 d-f	61.25 e	90.83 c-f	99.8 ab
TifSport	0.42 e	10.83 ef	61.25 e	87.92 ef	100.0 a
<i>Zoysia matrella</i>					
Zeon	9.58 a	42.92 ab	80.00 a-c	97.92 a	99.0 b
374	7.08 a-c	38.33 a-c	85.42 a	98.33 a	100.0 a
336	4.17 b-e	20.83 c-f	78.75 a-c	97.92 a	100.0 a
PristineFlora	1.67 de	22.08 c-f	75.42 a-e	97.92 a	99.4 ab
<i>Zoysia japonica</i>					
DALZ 5269-24	7.92 ab	45.83 a	82.50 ab	96.67 a-c	100.0 a
Empire	3.33 b-e	29.58 a-d	85.83 a	93.33 a-e	100.0 a
182	0.42 e	25.00 c-e	77.50 a-d	95.42 a-d	100.0 a
DALZ 4360	0.42 e	6.25 f	65.00 c-e	89.17 d-f	99.4 ab
JaMur	0.00 e	15.83 d-f	77.50 a-d	93.75 a-e	100.0 a
St. Augustinegrass					
Floritam	2.50 c-e	27.50 b-e	66.25 c-e	87.92 e	99.8 ab

† Means within a column followed by the same letter are not significantly different (LSD, $P \leq 0.05$).

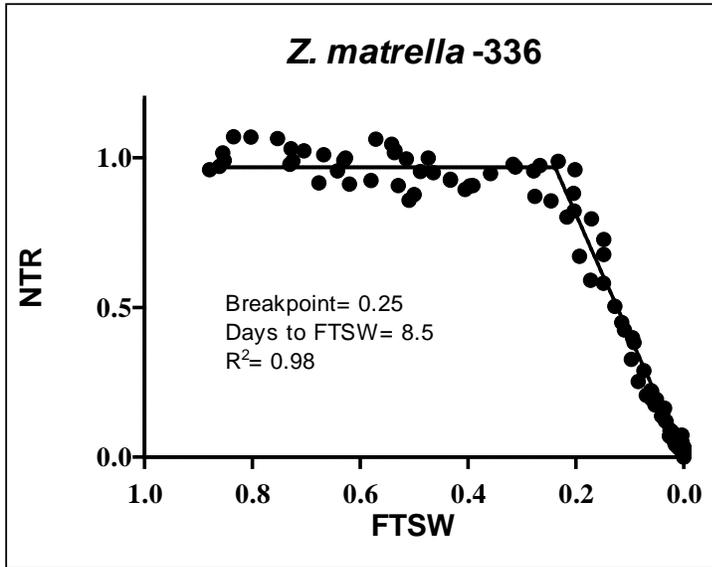


Figure 3-1 Normalization transpiration ratio (NTR) vs. fraction of transpirable soil water (FTSW) on each day of a soil drying cycle for experimental genotype 336-*Zoysia matrella*.

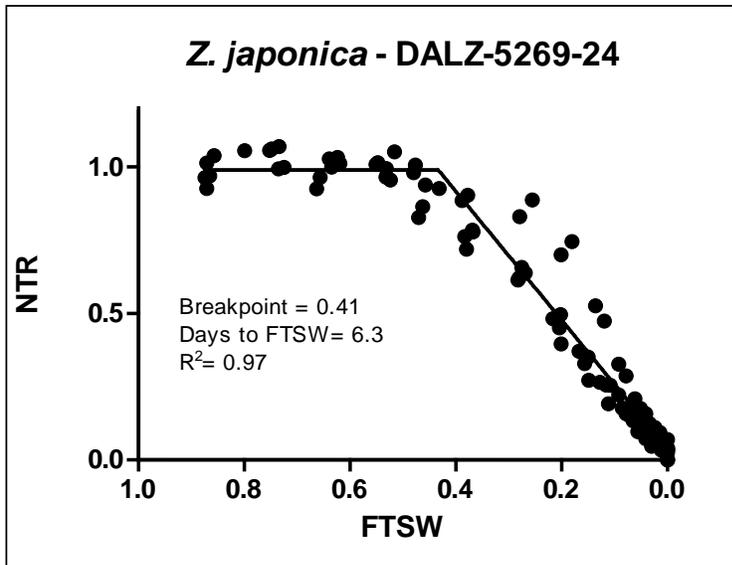


Figure 3-2 Normalization transpiration ratio (NTR) vs. fraction of transpirable soil water (FTSW) on each day of a soil drying cycle for experimental genotype DALZ 5269-24-*Zoysia japonica*.

APPENDIX A
 WEATHER CONDITIONS DURING THE EXPERIMENTS PERIODS -FLORIDA AUTOMATED WEATHER NETWORK-
 (FAWN DATA BASE)

Table D-1

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m2)	ET (in)
7/1/2009	80.69	72.68	91.58	0.00	4.54	0.00	17.60	96	229.45	0.18
7/2/2009	82.19	72.91	93.74	0.00	5.85	0.43	21.40	95	252.75	0.19
7/3/2009	80.29	70.09	89.78	0.13	4.86	0.00	22.03	96	188.27	0.15
7/4/2009	84.48	74.01	95.58	0.00	3.24	0.03	12.67	96	279.99	0.21
7/5/2009	81.90	70.75	93.24	0.00	4.62	0.00	15.70	96	234.86	0.18
7/6/2009	80.42	76.57	87.15	0.49	6.33	1.47	23.93	96	119.20	0.11
7/7/2009	78.23	74.07	86.59	1.51	5.47	0.00	24.47	96	107.48	0.10
7/8/2009	76.52	73.80	81.36	0.84	5.83	0.83	27.43	96	80.52	0.08
7/9/2009	77.87	73.02	86.29	0.12	5.00	0.00	26.93	96	161.36	0.13
7/10/2009	77.55	70.38	90.16	0.04	3.28	0.00	18.30	95	223.25	0.17
7/11/2009	77.35	70.59	88.59	0.00	4.10	0.00	17.80	96	193.17	0.15
7/12/2009	79.59	69.60	91.85	0.57	3.07	0.00	14.43	96	269.22	0.19
7/13/2009	80.34	73.49	92.34	0.02	4.19	0.07	26.03	96	241.08	0.18
7/14/2009	81.09	73.80	90.77	0.00	3.45	0.00	16.60	96	223.34	0.17
7/15/2009	80.90	73.58	91.78	0.00	2.67	0.00	23.57	96	170.60	0.14
7/16/2009	81.54	74.61	89.89	0.48	4.02	0.00	22.80	96	218.50	0.17
7/17/2009	82.91	75.63	91.96	0.03	7.20	0.63	22.67	96	257.05	0.20
7/18/2009	79.41	75.49	86.50	0.17	4.43	0.00	25.07	96	152.84	0.12
7/19/2009	80.67	73.65	90.19	0.09	2.88	0.00	13.43	96	247.58	0.18
7/20/2009	79.37	72.73	89.22	0.00	3.03	0.00	15.53	96	231.66	0.17

Table D-1. Continued.

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m2)	ET (in)
7/21/2009	80.47	67.78	92.70	0.00	2.82	0.00	15.63	95	273.43	0.19
7/22/2009	79.37	69.91	92.84	0.14	2.79	0.00	24.47	96	220.43	0.16
7/23/2009	80.35	69.40	91.85	0.00	3.82	0.00	14.97	96	247.62	0.18
7/24/2009	80.22	72.32	90.63	0.17	2.96	0.00	27.27	96	213.01	0.16
7/25/2009	79.34	71.06	92.97	0.16	2.73	0.00	26.73	96	241.39	0.18
7/26/2009	80.76	69.93	90.43	0.00	4.28	0.00	16.87	96	246.73	0.18
7/27/2009	80.97	72.12	91.92	0.00	3.31	0.00	16.10	96	240.60	0.18
7/28/2009	79.89	70.32	92.44	0.00	2.82	0.00	18.87	96	221.51	0.16
7/29/2009	81.96	72.39	92.37	0.10	4.57	0.00	19.17	95	242.83	0.18
7/30/2009	80.62	73.89	92.50	0.02	4.05	0.00	22.20	96	182.57	0.15
7/31/2009	80.19	74.10	91.90	0.70	4.39	0.10	30.77	95	183.15	0.15
8/1/2009	79.94	73.90	92.23	0.16	3.49	0.03	22.27	96	201.29	0.16
8/2/2009	80.87	72.95	92.55	0.00	2.90	0.00	22.20	96	202.54	0.16
8/3/2009	80.54	74.88	90.46	0.09	3.50	0.00	24.33	96	174.90	0.14
8/4/2009	80.84	71.98	92.88	0.01	4.22	0.00	19.23	96	234.83	0.17
8/5/2009	79.61	70.74	92.39	3.74	4.35	0.00	22.80	96	235.07	0.17
8/6/2009	77.84	69.62	91.71	1.84	3.90	0.00	29.10	96	215.28	0.16
8/7/2009	81.53	70.92	93.06	0.00	2.96	0.00	11.03	96	254.68	0.18
8/8/2009	83.57	74.41	94.89	0.00	3.89	0.00	14.70	96	269.95	0.20
8/9/2009	83.05	73.33	94.51	0.00	3.40	0.00	15.73	96	269.22	0.20
8/10/2009	83.25	72.12	94.96	0.00	2.21	0.00	12.73	96	247.33	0.18
8/11/2009	84.09	74.70	96.37	0.00	3.76	0.00	17.77	94	248.29	0.19
8/12/2009	82.75	75.52	94.01	0.00	3.55	0.00	20.20	96	201.74	0.16
8/13/2009	79.49	74.43	89.69	0.17	3.15	0.00	41.57	96	138.04	0.12
8/14/2009	76.74	72.10	84.43	0.03	3.77	0.00	70.10	96	127.50	0.11

Table D-1. Continued.

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m2)	ET (in)
8/15/2009	78.68	73.62	92.08	0.00	4.92	0.33	24.60	96	141.95	0.12
8/16/2009	81.60	74.88	90.12	0.33	5.43	0.00	20.23	96	182.23	0.14
8/17/2009	81.79	76.55	88.38	0.02	4.89	0.10	15.60	96	151.71	0.12
8/18/2009	79.29	74.64	89.74	0.01	3.93	0.00	24.43	96	124.94	0.11
8/19/2009	80.75	73.92	93.56	0.00	4.05	0.00	25.23	95	199.22	0.16
8/20/2009	80.30	73.40	92.01	0.00	3.25	0.00	18.60	96	203.73	0.15
8/21/2009	80.07	73.06	91.58	0.00	2.99	0.00	22.23	96	167.65	0.13
8/22/2009	78.76	74.35	86.68	0.02	4.59	0.17	17.83	96	143.67	0.12
8/23/2009	78.29	66.51	89.10	0.00	3.26	0.00	31.57	96	258.48	0.17
8/24/2009	76.80	62.91	90.48	0.00	2.14	0.00	10.83	95	240.15	0.16
8/25/2009	79.44	69.15	97.66	0.01	2.89	0.00	23.37	96	209.71	0.16
8/26/2009	76.85	71.58	88.86	0.52	3.60	0.00	23.73	96	101.76	0.10
8/27/2009	75.94	72.09	83.26	1.52	3.27	0.00	21.43	96	55.91	0.07
8/28/2009	78.92	73.87	88.05	0.08	2.35	0.00	19.67	96	171.26	0.13
8/29/2009	80.04	70.86	90.32	0.00	3.88	0.00	13.63	96	231.11	0.16
8/30/2009	80.45	71.04	91.98	0.00	3.25	0.00	13.93	96	222.63	0.16
Year 2010										
6/1/2010	77.33	64.65	89.53	0.00	2.96	0.00	23.77	96	294.30	0.19
6/2/2010	78.46	66.97	90.68	0.00	2.94	0.00	13.67	96	276.17	0.19
6/3/2010	77.93	67.75	88.88	0.00	3.02	0.00	14.90	96	227.60	0.16
6/4/2010	78.01	72.00	88.83	0.06	4.61	0.00	24.33	96	156.00	0.13
6/5/2010	81.45	73.17	91.20	0.02	5.19	0.00	21.20	96	215.12	0.17
6/6/2010	80.28	71.29	88.77	0.15	6.50	0.73	27.63	96	149.63	0.13

Table D-1. Continued.

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m2)	ET (in)
6/7/2010	82.66	74.53	92.26	0.00	6.01	0.67	36.27	96	252.22	0.19
6/8/2010	79.03	66.31	90.00	0.00	5.49	0.00	18.27	96	291.48	0.20
6/9/2010	77.73	64.40	89.76	0.00	4.55	0.00	15.70	96	287.88	0.19
6/10/2010	78.87	63.66	92.77	0.00	2.43	0.00	11.73	96	296.08	0.20
6/11/2010	81.64	66.60	96.87	0.00	2.92	0.00	33.30	96	293.63	0.21
6/12/2010	83.33	69.76	95.52	0.00	3.38	0.00	21.40	96	288.52	0.21
6/13/2010	81.65	69.73	96.55	0.00	2.61	0.00	18.40	96	272.54	0.20
6/14/2010	83.13	70.95	97.36	0.00	3.13	0.00	11.80	96	262.49	0.20
6/15/2010	85.06	73.29	97.88	0.00	3.37	0.00	17.97	96	279.33	0.21
6/16/2010	81.36	72.81	97.29	0.77	4.08	0.00	26.73	96	248.18	0.19
6/17/2010	79.74	68.88	94.53	0.35	3.89	0.00	39.63	96	281.84	0.18
6/18/2010	77.29	71.38	93.74	0.05	3.14	0.00	19.90	96	199.48	0.16
6/19/2010	78.68	70.57	91.54	1.03	3.34	0.00	26.57	96	206.31	0.16
6/20/2010	77.97	72.23	91.17	0.01	3.44	0.00	18.70	96	210.42	0.16
6/21/2010	75.55	69.53	89.29	0.71	3.78	0.00	18.93	96	163.02	0.13
6/22/2010	79.25	68.32	93.11	0.04	3.66	0.00	51.00	96	289.81	0.20
6/23/2010	82.43	70.54	94.17	0.00	4.02	0.00	23.53	96	296.85	0.21
6/24/2010	82.12	68.38	94.82	0.00	2.60	0.00	32.90	96	290.92	0.20
6/25/2010	80.70	71.87	95.04	1.06	3.19	0.00	28.53	96	258.81	0.19
6/26/2010	80.70	72.09	94.28	0.38	3.02	0.00	22.00	96	242.87	0.18
6/27/2010	82.49	73.06	92.48	0.00	3.28	0.00	15.13	96	240.02	0.18
6/28/2010	80.68	72.36	91.40	0.00	3.34	0.00	19.53	96	206.09	0.16
6/29/2010	78.62	72.86	89.83	0.26	3.28	0.00	16.90	96	163.19	0.13
6/30/2010	77.75	73.06	88.16	0.27	3.66	0.00	20.27	96	156.64	0.13

Table D-1. Continued.

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m ²)	ET (in)
7/1/2010	76.94	72.36	83.55	0.02	3.68	0.00	11.97	96	149.24	0.12
7/2/2010	77.08	72.84	87.08	0.05	6.46	0.13	46.77	96	200.76	0.15
7/3/2010	77.35	70.48	84.54	0.00	6.85	0.30	22.53	96	184.29	0.14
7/4/2010	76.39	73.02	82.22	0.01	6.47	0.73	19.80	96	171.01	0.13
7/5/2010	76.40	72.21	84.43	0.60	3.45	0.07	40.23	96	131.56	0.11
7/6/2010	78.18	71.08	91.27	0.24	4.36	0.00	77.70	96	216.03	0.16
7/7/2010	78.31	66.60	90.10	0.00	3.27	0.00	35.67	96	280.86	0.19
7/8/2010	79.00	64.04	92.66	0.00	2.03	0.00	27.53	96	287.11	0.19
7/9/2010	82.40	71.31	94.33	0.00	4.41	0.00	45.00	96	274.76	0.20
7/10/2010	81.21	70.65	92.05	0.00	5.47	0.23	17.87	96	278.15	0.20
7/11/2010	80.39	74.43	92.91	0.72	4.62	0.00	29.60	96	185.60	0.15
7/12/2010	80.10	74.37	89.46	0.55	5.04	0.00	22.60	96	173.50	0.14
7/13/2010	82.57	74.28	92.39	0.00	4.90	0.27	14.10	96	267.11	0.20
7/14/2010	81.30	72.55	92.26	0.00	3.86	0.00	17.73	96	266.43	0.19
7/15/2010	77.35	72.16	89.56	0.07	3.37	0.00	17.67	96	111.53	0.11
7/16/2010	80.27	70.02	92.79	0.00	4.05	0.00	14.27	96	242.82	0.18
7/17/2010	83.09	71.60	93.92	0.00	3.81	0.00	13.77	96	269.01	0.20
7/18/2010	82.19	71.31	93.11	0.00	3.96	0.07	31.90	96	270.02	0.19
7/19/2010	82.75	74.55	94.55	0.04	3.70	0.00	20.90	96	255.63	0.19
7/20/2010	83.89	74.64	94.60	0.00	4.84	0.07	15.97	96	254.89	0.19
7/21/2010	83.19	73.08	94.15	0.00	3.71	0.10	11.73	96	273.69	0.20
7/22/2010	82.41	69.98	94.77	0.00	3.54	0.03	15.60	96	279.50	0.20
7/23/2010	82.27	70.00	94.28	0.00	5.51	0.00	22.20	96	273.45	0.20
7/24/2010	83.12	76.46	93.07	0.17	4.56	0.10	20.00	96	213.06	0.17

Table D-1. Continued.

Year 2009	2m T avg (F)	2m T min (F)	2m T max (F)	2m rain tot (in)	10m Wind avg (mph)	10m Wind min (mph)	10m Wind max (mph)	N (# obs)	Sol Rad avg 2m (w/m2)	ET (in)
7/25/2010	83.99	75.04	95.63	0.00	3.75	0.00	46.23	96	243.11	0.19
7/26/2010	83.25	72.57	94.59	0.00	3.38	0.00	16.83	96	236.78	0.18
7/27/2010	85.22	74.01	96.78	0.02	3.90	0.00	15.07	96	264.93	0.20
7/28/2010	80.39	72.68	95.49	1.48	3.85	0.00	24.00	96	179.95	0.15
7/29/2010	83.09	72.43	95.65	0.01	2.77	0.00	40.90	96	222.32	0.17
7/30/2010	83.37	76.41	96.28	0.04	3.74	0.00	16.57	96	200.09	0.16
7/31/2010	80.98	73.98	96.48	1.12	4.50	0.00	30.70	96	170.47	0.15

APPENDIX B
FTSW- BREAK POINT GRAPHS BY GENOTYPE EXPERIMENT 1 AND 2

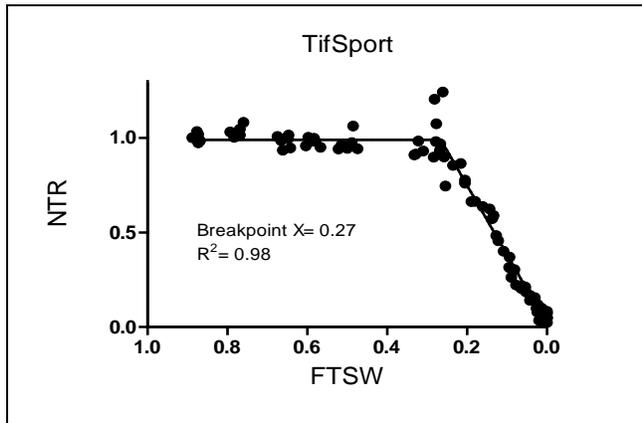


Figure B-1(*) Commercial cultivar TifSport – African Bermuda

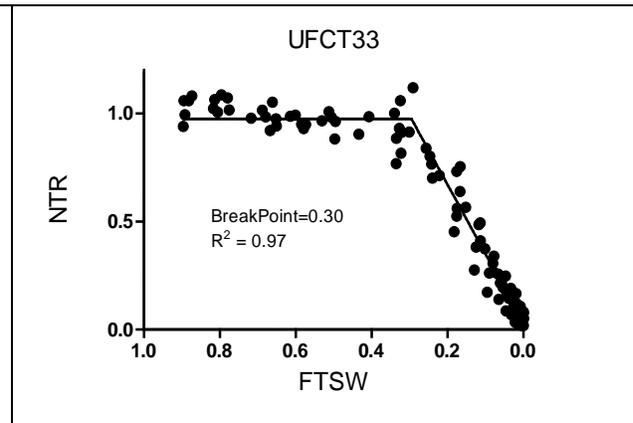


Figure B-2(*) Experimental Genotype UFCT33 – African Bermuda

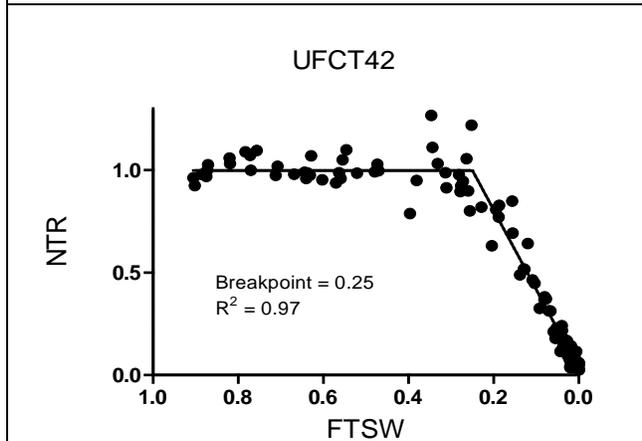


Figure B-3(*) Experimental Genotype UFCT42 – African Bermuda

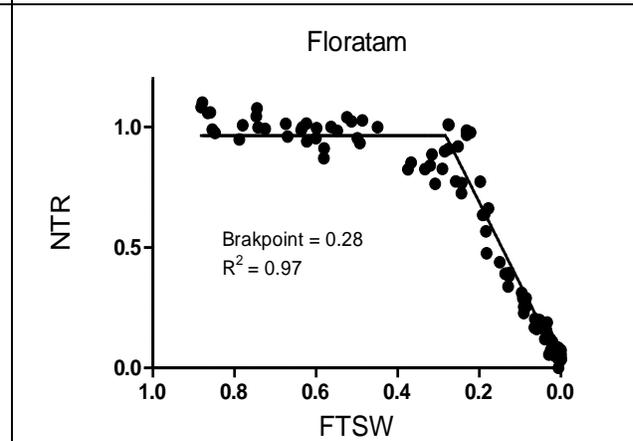


Figure B-4(*) Commercial cultivar Floratam – St. Augustinegrass

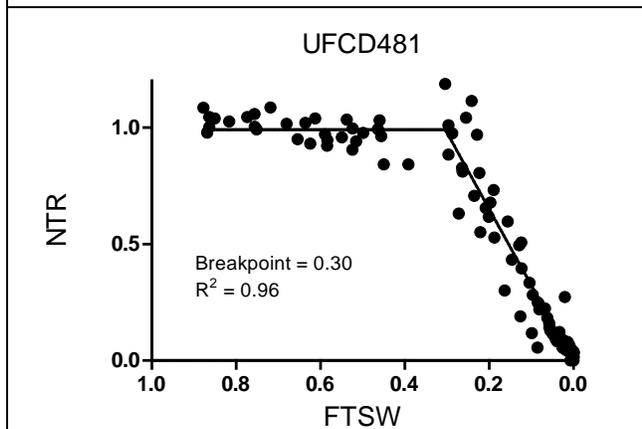


Figure B-5(*) Experimental Genotype UFCD481 – Common Bermuda

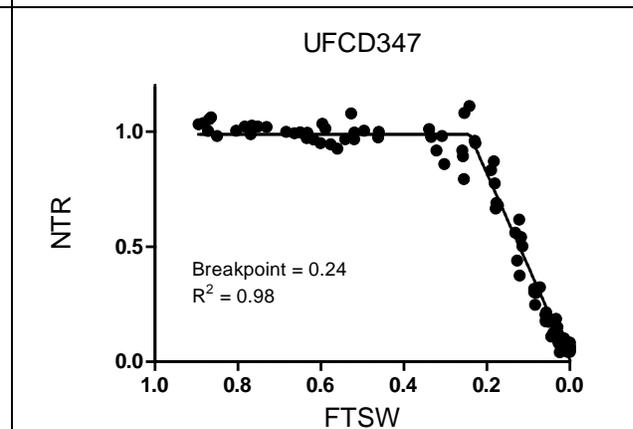


Figure B-6(*) Experimental Genotype UFCD347 – Common Bermuda

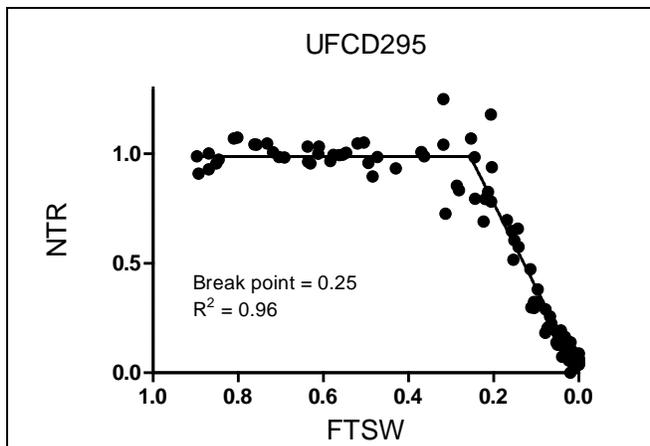


Figure B-7(*) Experimental Genotype UFCD295 – Common Bermuda

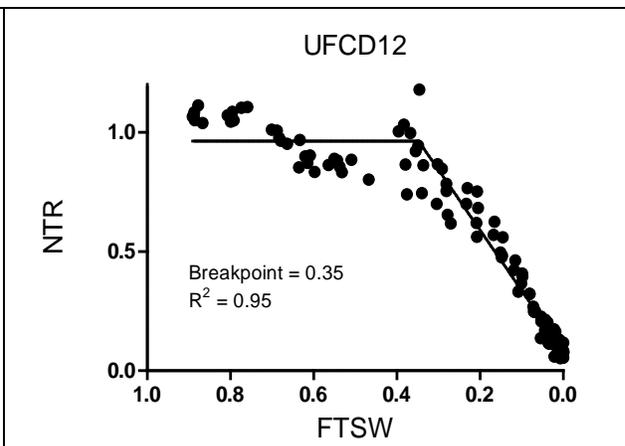


Figure B-8(*) Experimental Genotype UFCD12 – Common Bermuda

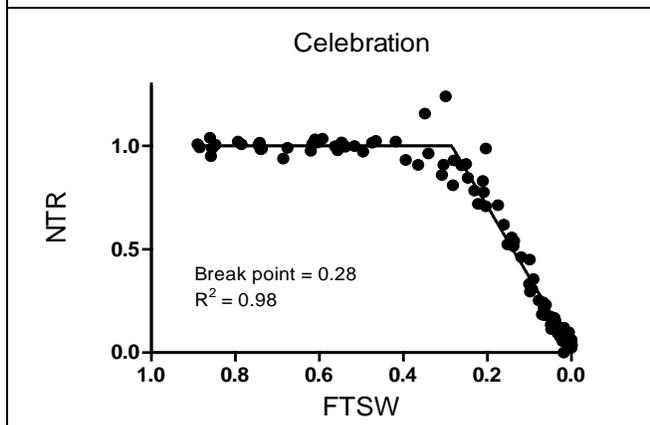


Figure B-9(*) Commercial cultivar Celebration – Common Bermuda

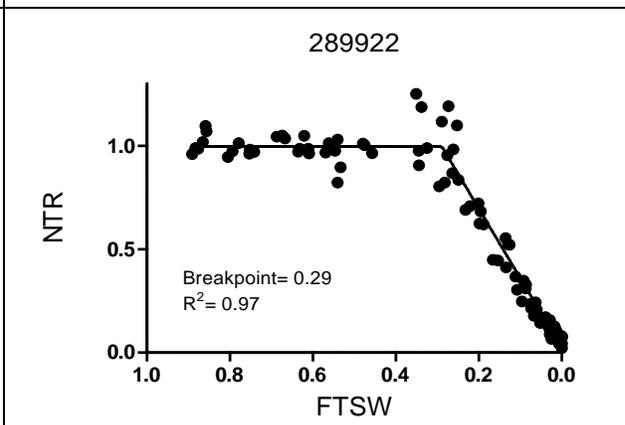


Figure B-10(*) Experimental Genotype 289922 – Common Bermuda

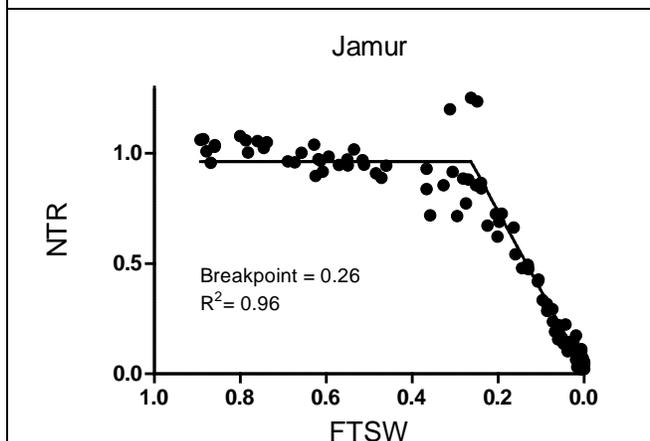


Figure B-11(*) Commercial cultivar Jamur – *Zoysia japonica*

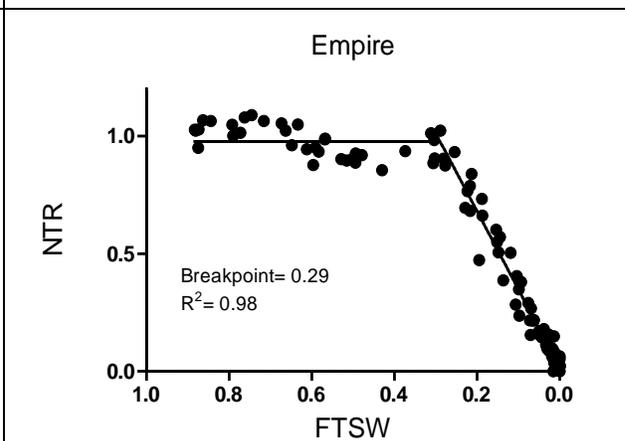


Figure B-12(*) Commercial cultivar Empire – *Zoysia japonica*

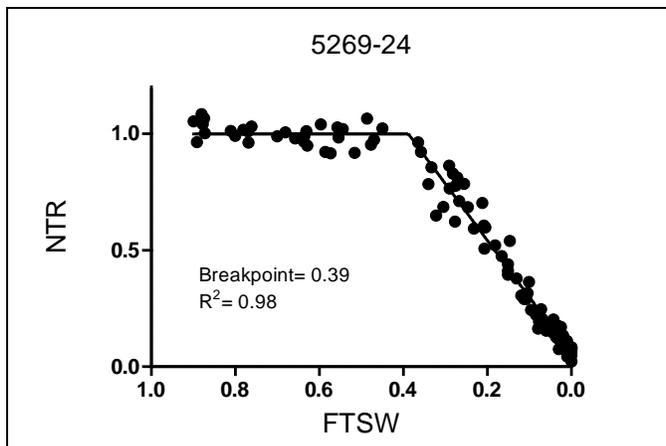


Figure B-13(*) Experimental Genotype 5269-24 – *Zoysia japonica*

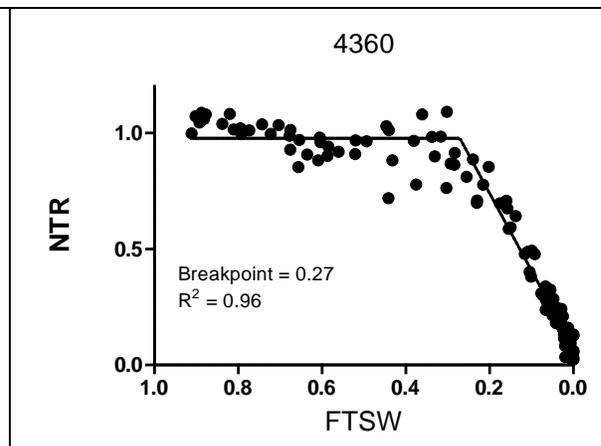


Figure B-14(*) Experimental Genotype 4360 – *Zoysia japonica*

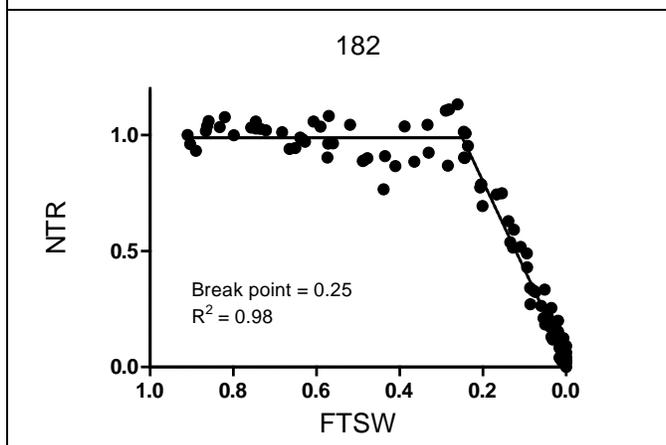


Figure B-15(*) Experimental Genotype 182 – *Zoysia japonica*

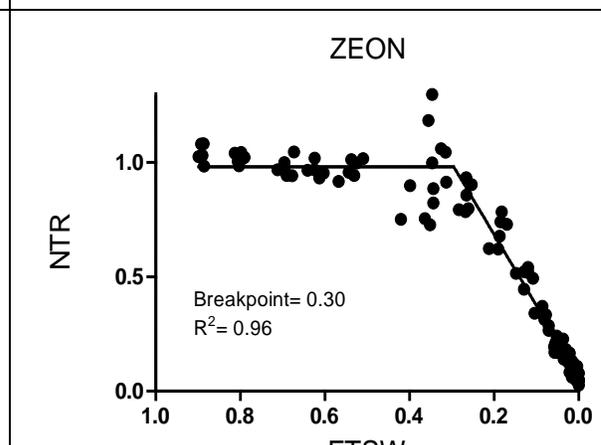


Figure B-16(*) Commercial cultivar Zeon – *Zoysia matrella*

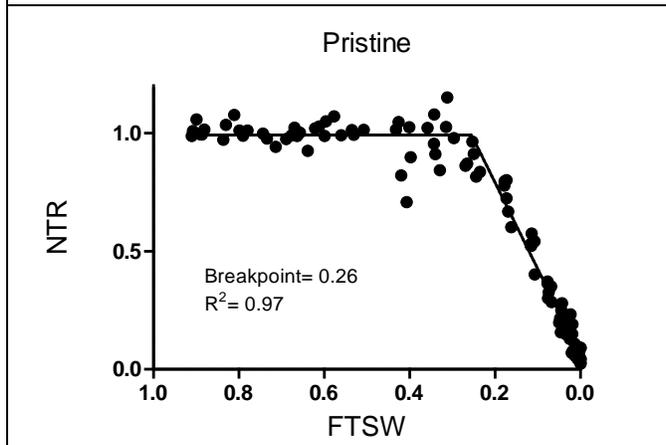


Figure B-17(*) Commercial cultivar Pristine – *Zoysia matrella*

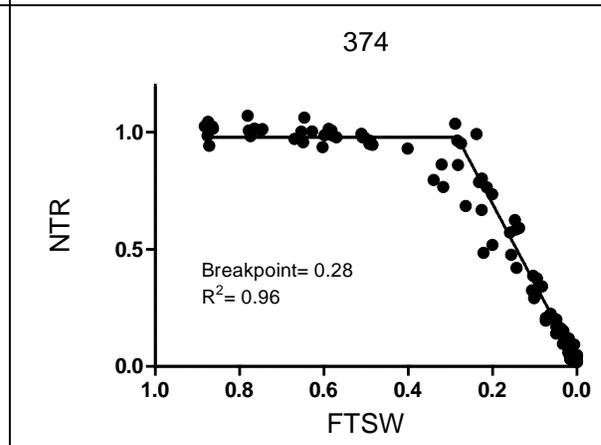
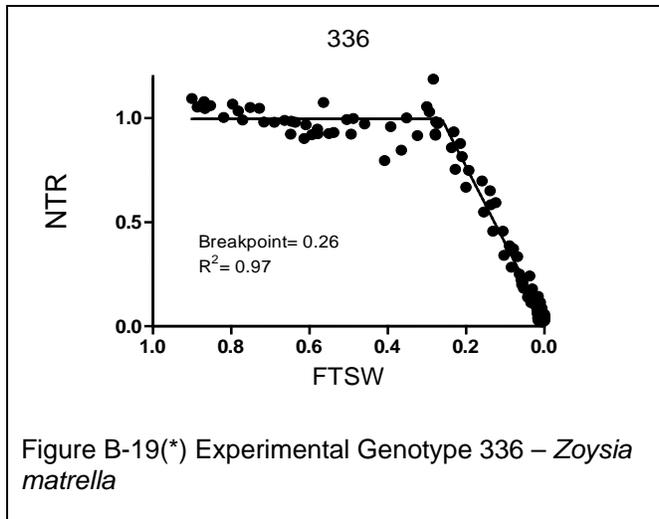
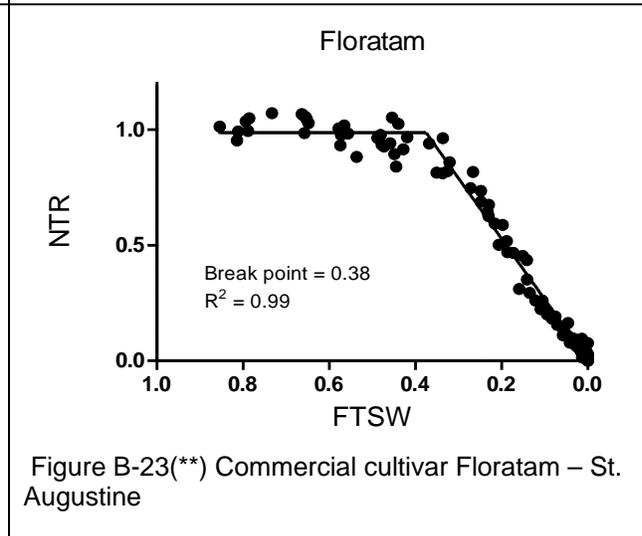
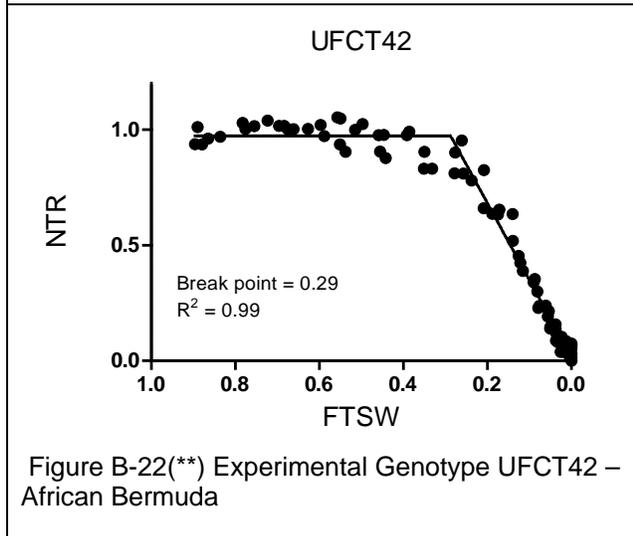
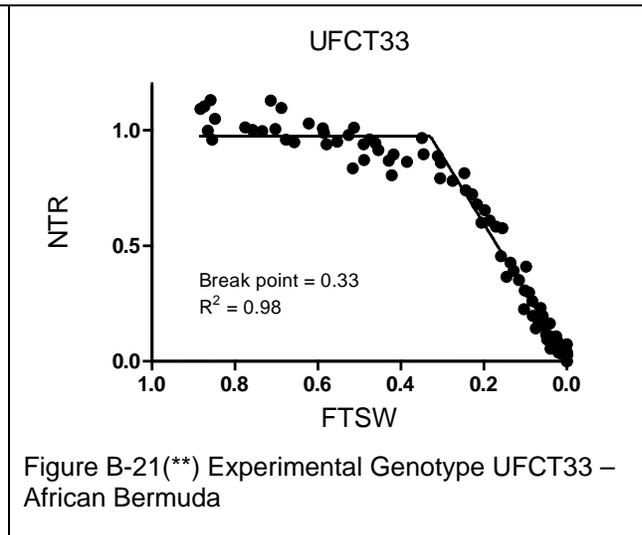
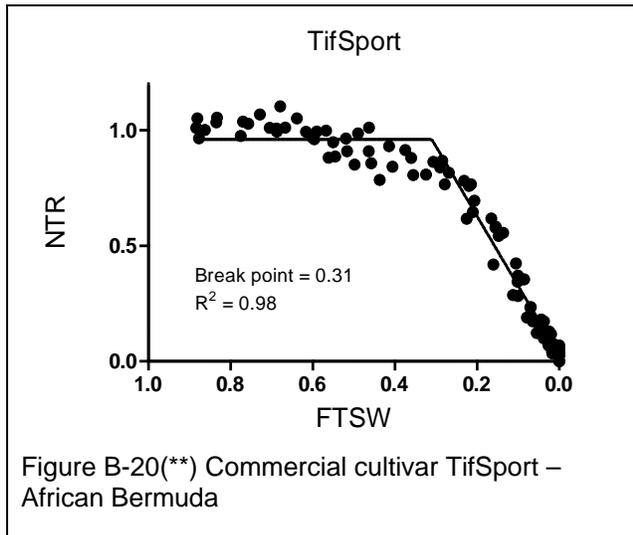


Figure B-18(*) Experimental Genotype 374 – *Zoysia matrella*



(*)Normalization transpiration ratio (NTR) vs. fraction of transpirable soil water (FTSW) on each day of a soil drying cycle for each commercial cultivar or experimental genotype for experiment 1.



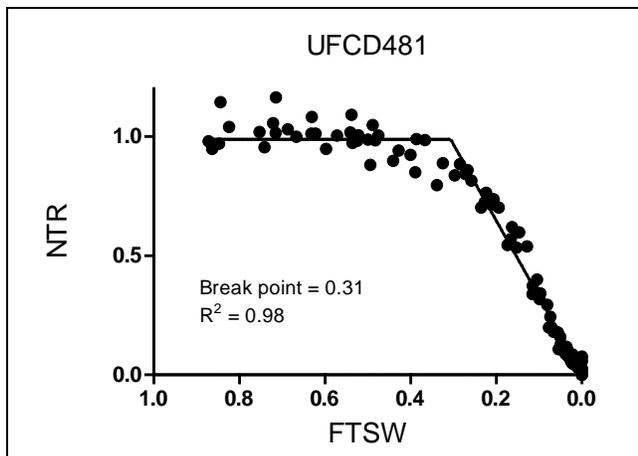


Figure B-24(**) Experimental Genotype UFCD481 – Common Bermuda

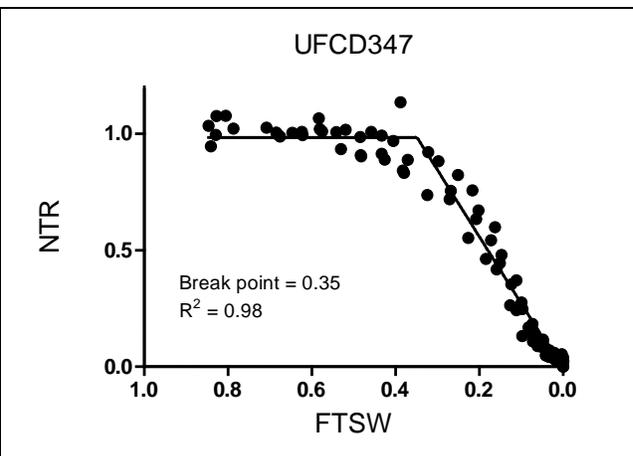


Figure B-25(**) Experimental Genotype UFCD347 – Common Bermuda

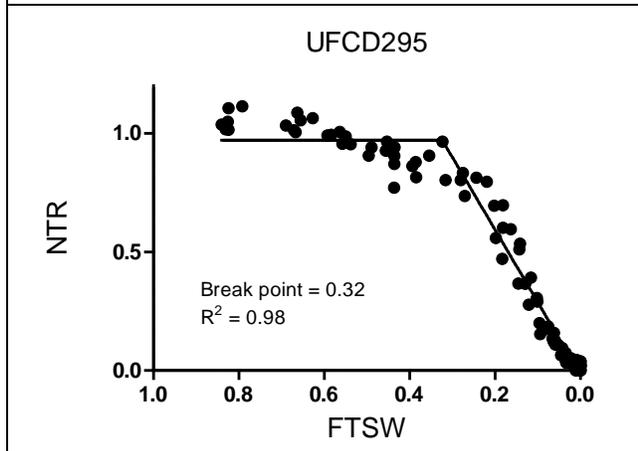


Figure B-26(**) Experimental Genotype UFCD295 – Common Bermuda

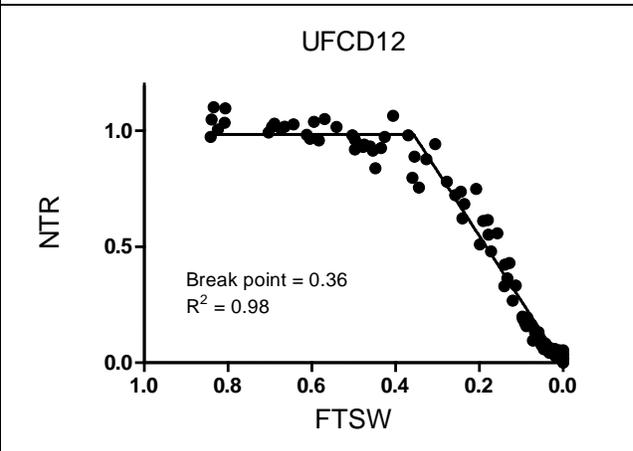


Figure B-27(**) Experimental Genotype UFCD12 – Common Bermuda

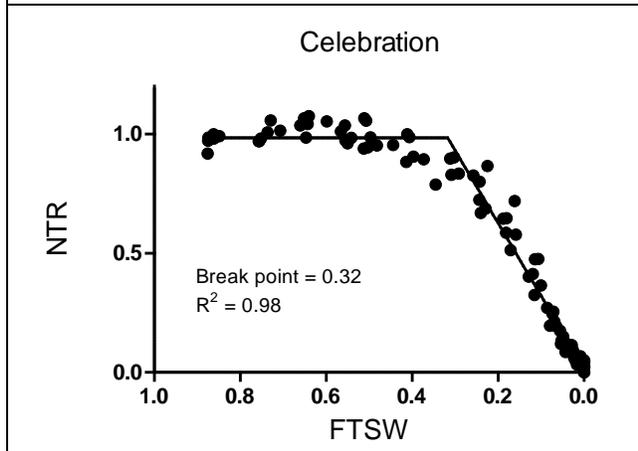


Figure B-28(**) Commercial cultivar Celebration – Common Bermuda

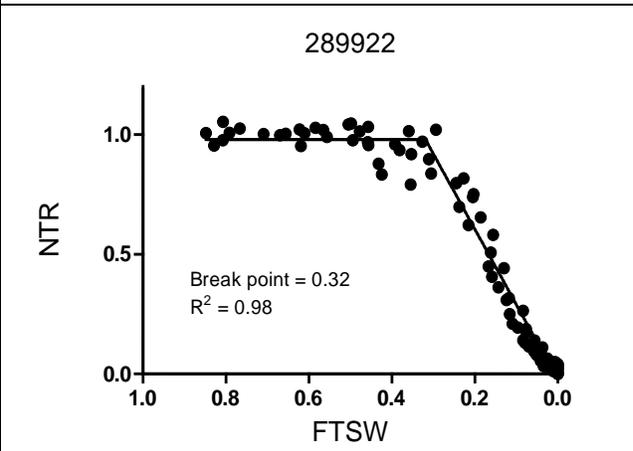


Figure B-29(**) Experimental Genotype 289922 – Common Bermuda

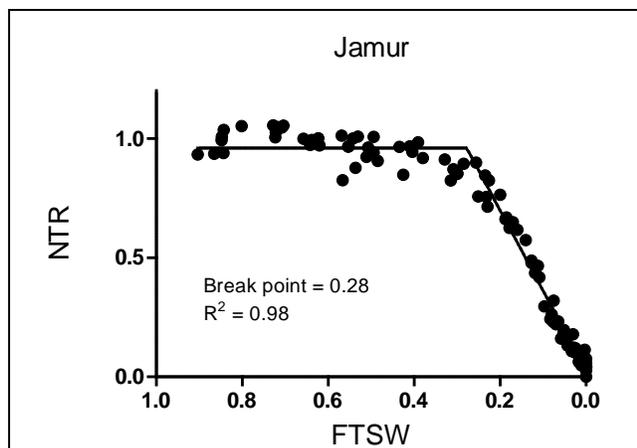


Figure B-30(**) Commercial cultivar Jamur – *Zoysia japonica*

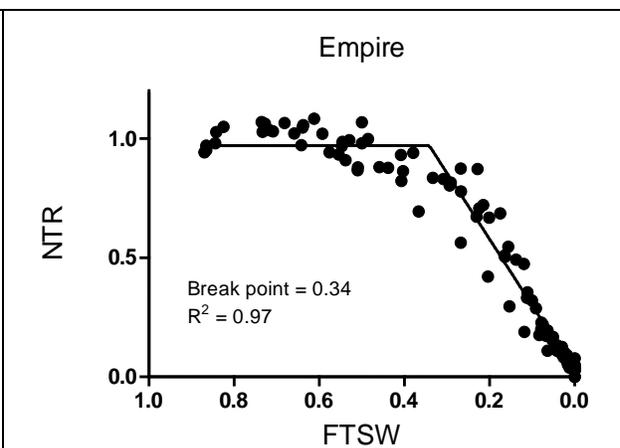


Figure B-31(**) Commercial cultivar Empire – *Zoysia japonica*

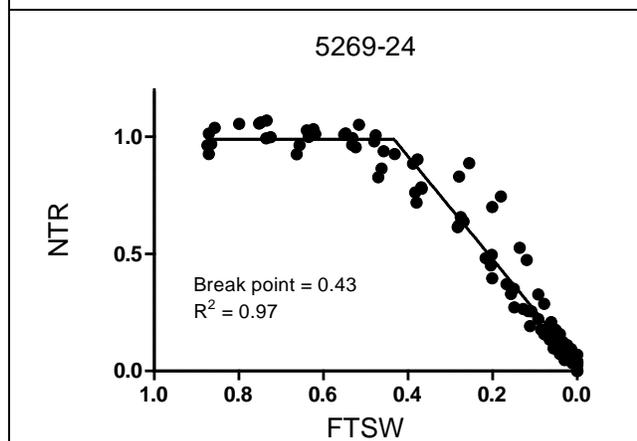


Figure B-32(**) Experimental Genotype 5269-24 – *Zoysia japonica*

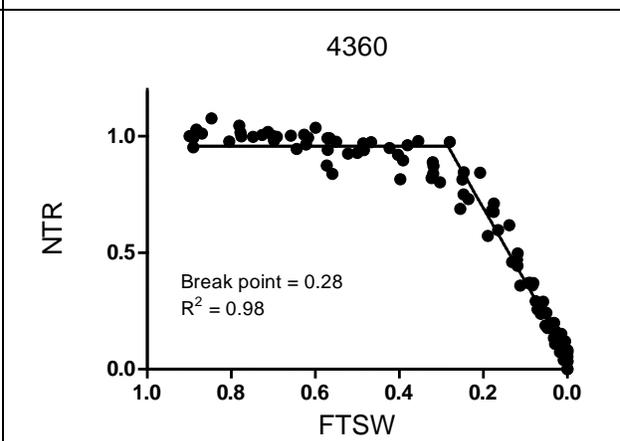


Figure B-33(**) Experimental Genotype 4360 – *Zoysia japonica*

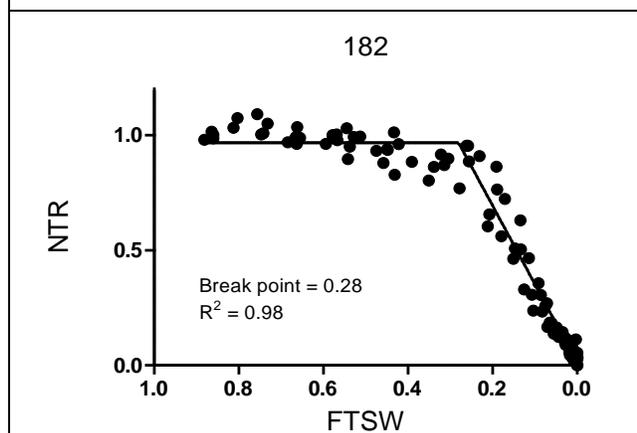


Figure B-34(**) Experimental Genotype 182– *Zoysia japonica*

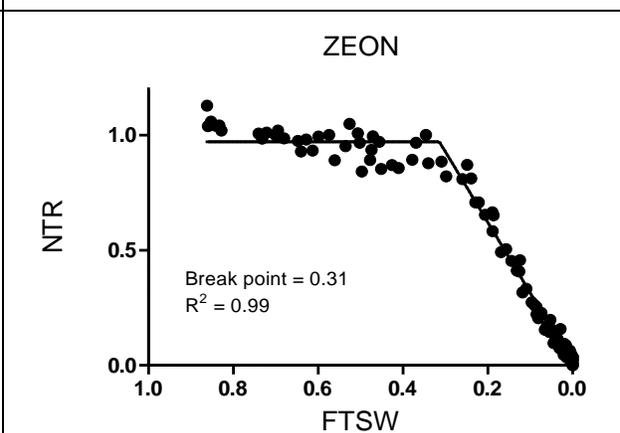
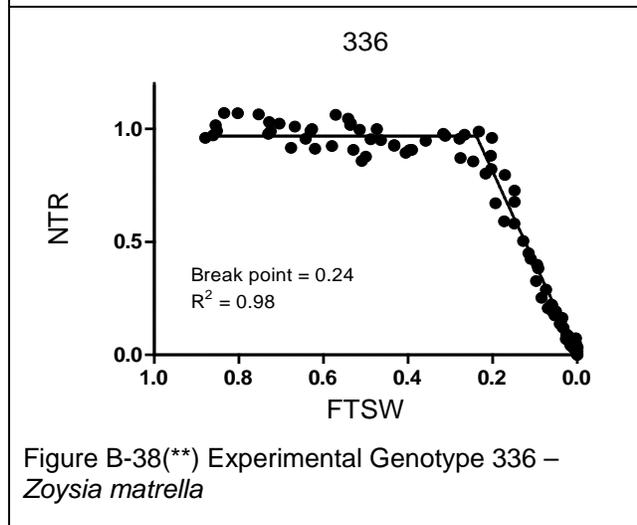
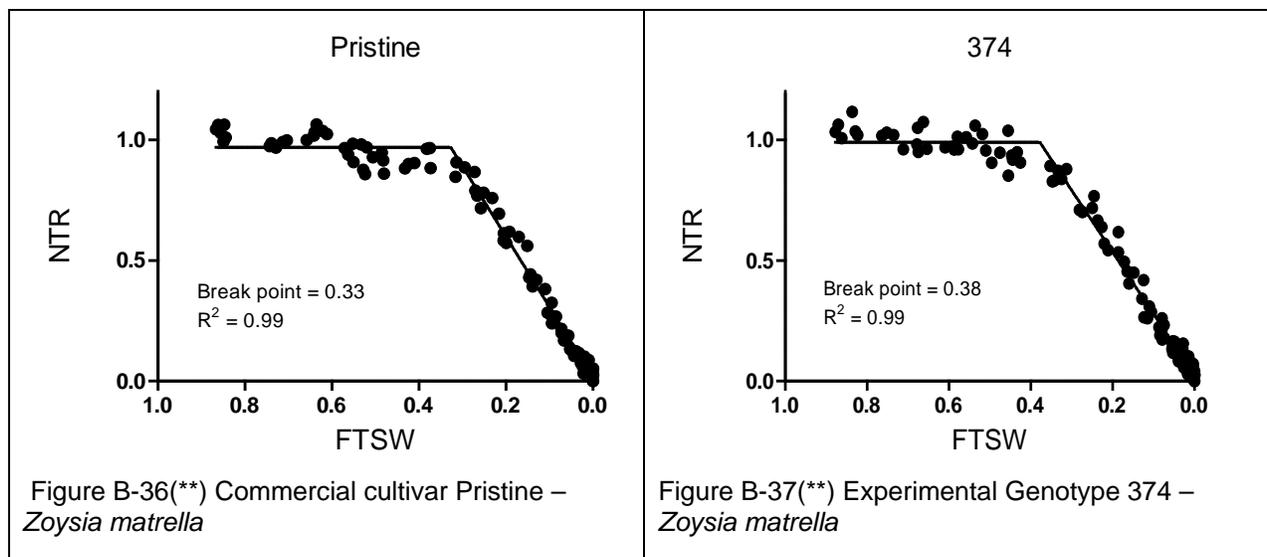


Figure B-35(**) Commercial cultivar Zeon – *Zoysia matrella*



(**)Normalization transpiration ratio (NTR) vs. fraction of transpirable soil water (FTSW) on each day of a soil drying cycle for each commercial cultivar or experimental genotype for experiment 2.

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BIOGRAPHICAL SKETCH

Maria Pilar Fuentealba was born in Valdivia, south of Chile, where she conducted her studies, and in 1987 she enrolled in the College of Agronomy in the Universidad Austral de Chile, in the same city, where she graduated as agronomy engineering. She moved to a central region of Chile, and worked in agricultural extension programs for 10 years. During this time she got married and had her two sons. In 2004 she moved to Gainesville, Florida, to go with her husband who started his PhD studies. In fall, 2008 she enrolled in the master's program, together with a research assistant position in the Agronomy Department, under the supervision of Dr. Kevin Kenworthy, working in drought resistant warm season turfgrass species.