PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSE OF WARM-SEASON TURFGRASSES TO SHADE

By

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Abstract:

Shade affects turfgrass growth and development, lowering the quality and playability of sporting fields and golf courses. The desire for large mature trees in the landscape and modern sports stadiums, are expected to increase the frequency and severity of shade in managed turf, implying that increased selection and use of shade resistant grasses is required to improve the turf industry's sustainability. In both field and controlled environment investigations, species and cultivars within species showed heterogeneity for relative shade resistance, but little is known about the mechanisms that impart resistance. Greenhouse studies were conducted at Stillwater, Oklahoma to compare the physiological and morphological response of two species of warm-season grasses varying in their apparent shade resistance. Four genotypes of each species were evaluated on the basis of their photosynthetic and growth parameters. Amongst bermudagrasses (*Cynodon dactylon* × *C. transvaalensis*), shade resistant TifB16108 had lower dark respiration rate, light saturation estimate at 75th percentile (I_{sat75}), and light compensation point (I_{comp}) while having higher F_v/F_m and root:shoot ratio as compared to shade sensitive genotypes 'Tifway' and TifB16119. Amongst St. Augustinegrasses (*Stenotaphrum secundatum*) shade resistant DALSA 1404 and DALSA 1618 had lower I_{comp}, I_{sat75}, root: shoot ratio, and high percent green cover, while shade sensitive 'TamStar' performed poorly under shade. Grasses evaluated for their morphological parameters showed a higher leaf area index (LAI), leaf weight ratio (LWR), and maintained root: shoot biomass for the genotypes showing resistance to shade. 'ST-5' (TifGrand®) had the highest LAI, Specific leaf area, LWR, leaf area ratio, amongst the other bermudagrasses, which suggests leafiness contributes to its shade resistance. Amongst the St. Augustinegrasses, DALSA 1618 and 1329 maintained the lowest canopy elongation rates and highest LAI, SLA, and LWR. But no single parameter or factor could be defined as the tool for predicting sensitivity to shade as it is the aggregation of various adaptive features that impart resistance to shade. Resistance of a genotype was dependent on both physiological tolerance and morphological adaptation to shade but was better explained by their changes in physiology which affected its overall performance.

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CHAPTER I

LITERATURE REVIEW

INTRODUCTION

Light plays a crucial role in turfgrass physiology, morphology, and performance as a turf. Shade caused by tree canopies, buildings, cloud cover, and other structures can influence the growth and development of grasses, primarily by reducing photosynthetically active radiation (PAR), the light spectrum from 400 to 700 nm, available for photosynthesis (Bell et al, 2000). Trends in the architecture of sports stadiums have evolved over the years to incorporate taller and steeper structures, which has worsened shade-related management issues. Similarly, as trees mature on golf courses, they can increasingly become major sources of shade for turfgrasses. Many parks and landscapes have buildings, structures, or mature trees which increase their aesthetic value but at the same time are causing lower light levels for the grasses grown under them.

A decline in PAR is not the only component of shade that can influence physiological and morphological responses. The quality of available light, relative distribution of certain wavelengths, is also a major consideration. The ratio of red to far (R:FR) light is among the most common indices of light quality used to predict plant growth and development. This altered light spectra causes the plant signaling receptors called phytochromes to transform to the inactive form. The inactivation of phytochrome induces a number of morphological and physiological changes that are intended to improve survivability of grasses when competing with neighboring plants for light. Within a turf canopy, the upper leaves can also influence the amount of light reaching the lower leaves (Burton and Deal, 1962). Over shading is the most common problem faced in home lawns and athletic field which tend to deteriorate the turf quality and stress tolerance.

SHADE RESISTANCE, TOLERANCE, AND AVOIDANCE

Resistance is an absolute term where the plant immunize itself to a particular stress, whether biotic or abiotic. It has been generally associated with abiotic stresses like drought and salinity or biotic stresses such as diseases and insects in various plant species. Drought resistance, for instance, is considered as the ability of plant to survive prolonged drought stress through various mechanisms (Unruh, 2017). These mechanisms are most commonly described for perennial plants as drought tolerance and drought avoidance. Likewise, shade resistance can also be defined as the ability of the plant to survive or bear shade through mechanisms such as shade tolerance and shade avoidance. The concept of 'shade resistance' has not been widely adopted by researchers when studying the behavior of plants under shade. Instead, its mechanisms (i.e. shade tolerance and shade avoidance) are comprehensively used in most studies (Gommers et al., 2013; Gong et al., 2015; Ruberti et al., 2012). Tolerance and avoidance are the two opposing strategies evolved in plants to acclimate themselves in response to competition for light. Shade tolerance refers to a group of characteristics that maximize carbon gain under low light conditions, such as increased chlorophyll content, efficient light harvesting, high quantum yields, etc. These typically are the outcomes of physiological response of a plant against shade. On the contrary, shade avoidance includes a set of characteristics which allows for the maximum interception of photons, such as elongation of stem and petiole, hyponasty, reduced branching and lateral growth, thinning of leaves to avoid internal canopy shading, etc. Thus, avoidance is more often the result of morphological adaptations to counter shade (Gong et al. 2015). Interestingly, shade avoidance responses are undesirable characteristics of nearly all major crops (Gommers et al., 2013). Crops which are generally grown under high light intensities tend to demonstrate shade avoidance syndrome under low light intensities, which leads to reallocation of carbon towards stem elongation at the expense of root and leaf development. This leads to a decrease in yield in many crops (wheat, rice, soybean, etc.) and reduces the quality in others (turfgrass).

Researchers have developed relative rankings for shade resistance of major turfgrass species. Of the warm season grasses, St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) is typically considered the most shade resistant, outperforming zoysiagrass (*Zoysia* spp.), bahiagrass (*Paspalum notatum* Flugge), centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.), buffalograss (*Bouteloua dactyloides* (Nutt.) Engelm.) and bermudagrass (*Cynodon* spp.) (Baldwin, 2008; Wilkinson et al., 1975).

GRASS SPECIES DESCRIPTION

Bermudagrass (*Cynodon dactylon* (L.) Pers.)

Bermudagrasses are a warm-season grasses used widely for school grounds, athletic fields, home lawns, roadsides, parks and other areas where close mown and dense turf is required. It is widely distributed between the latitudes of 45ºN and 45ºS and adapted to tropical and subtropical climates of the United States. The base chromosome number of Cynodon species x=9 and a number of euploids are found including diploid (2x = 18), triploid (3x = 27), tetraploid (4x = 36), pentaploid (5x = 45), and hexaploid (6x = 54). Amongst all these, tetraploid is most widely reported. Bermudagrass is also known by other different names such as couch, doob, wiregrass, devilgrass and quickgrass. It belongs to the sub-family Chloridoideae and tribe Cynodonteae. The most widely grown bermudagrasses for use as a fine turf are the common bermudagrass [*C. dactylon* (L.) Pers. var. dactylon] and interspecific hybrid of common bermudagrass and African bermudagrass (*C. transvaalensis* Burtt Davy), commonly known as hybrid bermudagrass (*C. dactylon* × *C. transvaalensis*). Common bermudagrass can be established from seeds, sprigs, sod, or plugs, while hybrid bermudagrass can only be established from sprigs, sod, or plugs. Bermudagrass is drought resistant, having relatively lower water requirements and the ability to go dormant to survive extended periods of drought (Huang et al., 1997). Its tolerance to wear and compaction makes it suitable for use in golf and athletic fields (Reynolds et al., 2013). Bermudagrass is considered sensitive to shade, although variation in shade response has been reported for the species (Beard, 1973; Baldwin et al., 2008; Zhang et al., 2017). 'Riley's Super Sport' (common) and 'ST-5' (hereafter referred to as TifGrand®) (hybrid) have a fair to moderate performance under shade while Riviera, Princess 77 and Patriot have poor shade tolerance. The hybrids Tifway, TifGreen, 'Tift94' (hereafter referred to as TifSport®), and the commons U-3, Sahara, Midlawn have very poor performance under shade (Chhetri et al., 2019).

St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze)

St. Augustinegrass is a warm-season, coarse textured perennial adapted to the southeastern part of the United States and among the least cold hardy turfgrass species. This grass is considered native to the areas adjacent to the Gulf of Mexico, the West Indies and Western Africa. It is also widely grown in South America, Western Africa, Australia, and South Pacific and Hawaiian Islands (Xingwang et al., 2018). The base chromosome number of St. Augustinegrass is $x = 9$ and most cultivars are diploid ($2n = 2x = 18$) but triploids ($2n = 3x = 27$), and tetraploids ($2n = 4x = 36$) are also reported. Some aneuploidy ($2n = 28$, $2n = 32$) genotypes have also been identified recently. It belongs to the tribe Paniceae in the subfamily Panicoideae which is one of the largest subfamilies in Poaceae (grass family). St. Augustinegrass is well suited for sod production, and most cultivars are poor seed producers or do not produce seed at all. The coarse texture of the grass makes it unsuitable to be used on golf course greens, tees, or fairways but has been used in roughs at some locations. This species is adaptable to many soil conditions and grows best in well-drained sandy soils. It has poor drought resistance as compared to other warm-season turfgrasses and requires regular irrigation in most regions. It is susceptible to winter desiccation in drier part of its range and its relatively poor cold tolerance makes its growth limited to warmer regions. It is considered to be the most shade tolerant warm-season turfgrass species (Winstead & Ward, 1974). Prior research has shown shade causes variation among cultivars in chlorophyll concentration and composition and seed head formation (Peacock and Dudeck, 1981; Trenholm et al., 2005). Shade resistance in St. Augustinegrass is generally categorized amongst ploidy levels, with some commercially available diploid (2n = 2x = 18) cultivars expressing shade resistance but exhibiting low levels of resistance to other biotic and abiotic characteristics such as drought, disease, and insects, whereas, cultivars showing polyploidy have poor shade resistance but exhibit resistance to drought, gray leaf spot (*Pyricularia grisea* (Cke.) Sacc.), St. Augustine decline virus, and southern chinch bugs (Meeks & Chandra, 2020). Such diploid cultivars including Amerishade, DelMar, Palmetto, Raleigh and Seville have relatively better performance as compared to polyploid cultivars Floratam and TamStar.

LIGHT AND ITS FATES

Light can exist as energy (waves) and particles (photons). Light that occurs between 400 and 700 nm is termed photosynthetically active radiation (PAR). It is the portion of global irradiance that may be converted from light energy to chemical energy by plants. This spectrum coincides with the visible light spectrum and represents light readily absorbed by chlorophyll and other plant pigments. The quantity of light particles reaching a plant is more important than the energy value of the wavelength when measuring the amount of light available for photosynthesis. Thus, PAR is typically reported as photosynthetic photon flux (PPF). Not all light reaching chlorophyll is used for photosynthesis. Rather, some of the absorbed energy can be converted to heat while the rest is re-emitted as fluorescence. Other components of solar radiation are either reflected, transmitted, or used in plant signaling processes. To sum up, light energy absorbed by chlorophyll molecules can (i) drive photosynthesis; (ii) be re-emitted as heat; or (iii) be re-emitted as light (fluorescence). But these three processes do not exist in isolation but rather in competition with each other. Therefore, each fate is an important parameter which will be discussed in detail later.

Light quantity and quality

Light quantity is a term used to describe the PPF received by a plant. Of the total light received by the plants, only 1-2% is actually utilized for photosynthesis. The intensity of light reaching a plant varies continuously depending on the location, sun angle, cloud cover, season, part of the plant, and atmospheric conditions (Gardner and Goss, 2013). Apart from this, any restrictions due to nearby building, tree, poles, banners, vehicles, etc. can also affect the amount of light reaching grass. This results in the overall reduction of light that the grass receives. Generally, light quantity is quantified in the form of a daily light integral (DLI), which is the sum of PPF in a day and is reported as mol m^{-2} d^{-1}. This allows measurement of total light requirements of the plants in a day and also accounts for shading during different times and durations of day. Researchers have reported the minimum DLI requirements of various turfgrasses in order to quantitatively describe which species or cultivars are more shade resistant (Glenn et al., 2014; Zhang et al., 2017).

Light quality can be defined as the relative percentage of individual spectra within the PAR reaching a surface. Blue light occurs from wavelengths 400 to 500 nm, green light 500 to 600 nm, red light 600 to 700 nm, and far-red light 700 to 800 nm (Taiz and Zeiger, 2006). These are the major spectral wavelengths that are absorbed by plants during photosynthesis. The red-to-far-red (R:FR) ratio is also significant in plant production because it controls phytochrome activity. In areas where the turfgrasses grow in the vicinity of trees and shrubs, shade is often containing filtered or altered light spectra. In particular, the R:FR ratio can decline under foliar shade (Bell et al., 2000).

Photosynthesis

Visible light is within the range 380 to 750 nm and within this range occurs PAR (400 to 700nm). Absorption of PAR occurs in the chloroplast, wherein thylakoid membranes, the photosynthetic pigment molecules receive the photons (Kalaji et al., 2012). Chlorophyll a is known to have peak absorption at 410, 430, and 660 nm, while peak absorption for chlorophyll b occurs at 430 and 640 nm (Taiz and Zeiger, 2010). Receiving light causes the chlorophyll molecule to enter into an excited state which results in a chain reaction passing electrons to other carrier chlorophyll molecules until finally reaching an acceptor at the reaction center of either photosystem I (PSI) or photosystem II (PSII). The reaction center enters a higher energy state where it passes an electron to various intermediaries as part of an electron transport chain. This generates energy molecules in the form of NADPH thus converting absorbed light energy into stereo chemical energy to be used by the plants to assimilate carbon. During this process, some of the electrons are not captured by the electron acceptor and decay back to ground state. During this decay, the energy lost is given off as fluorescence. The yield of the chlorophyll fluorescence emission gives us valuable information about the quantum efficiency of photochemistry and heat dissipation.

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

Carbon-dioxide Water Carbohydrate Oxygen

Chlorophyll fluorescence

The electron transport chain in the thylakoid membrane of the chloroplast consists of a number of electron acceptors and ubiquinone. The passage of the electron from one acceptor to another through quinones keep the reaction centers open and light and dark reactions persist.

Factors such as light intensity and temperature can affects the metabolic state of the plant and lead to the closure of the reaction center which inevitably cause a decline in quantum efficiency of PSII. Chlorophyll fluorescence is a measure of re-emitted light from PSII. Fluorescence quenching includes two major phenomena: photochemical quenching, or qP (light activation of the process of photosynthesis), and non-photochemical quenching, or qE (heat dissipation of chlorophyll excitation energy). Chlorophyll fluorescence can be readily measured using a "Kautsky" fluorometer which compares the dark-adapted leaf pre photosynthetic fluorescent state to maximum fluorescence. This is a measurement of antennae fluorescence with a modulated light intensity that is insufficient to drive photosynthesis. Following that, a brief burst of intense light, or saturation pulse, is used to expose the sample and close all available reaction centers. Maximum fluorescence is determined after all available reaction centers have been closed or chemically reduced. A typical chlorophyll emission curve defines three important parameters: F_o, which represents fluorescence where all reaction centers are open and qP is maximal; F_m, a point of maximum fluorescence; and Ft, a gradual decay to the steady state. The rise from F_o to F_m is called "variable fluorescence" (F_v). Maximum fluorescence is transient, culminating in F_o. F_v/F_m is a measurement ratio that reflects Photosystem II's full possible quantum efficiency if all capable reaction centers were open. The emissions from PSI are generally not taken under consideration because of its insignificant contribution below 700 nm.

Under severe stress conditions, Fm/Fm ratio declines from its normal range (0.7 to 0.8) and can serve as an important indicator for stress in plants (Genty et al., 1989). The F_v/F_m ratio has been used as a rapid indicator of severe plant stress as compared to visual tests giving a linear relationship with the visible injury and has been used for prediction of foliar damage due to natural frost events (Perks et al., 2004).

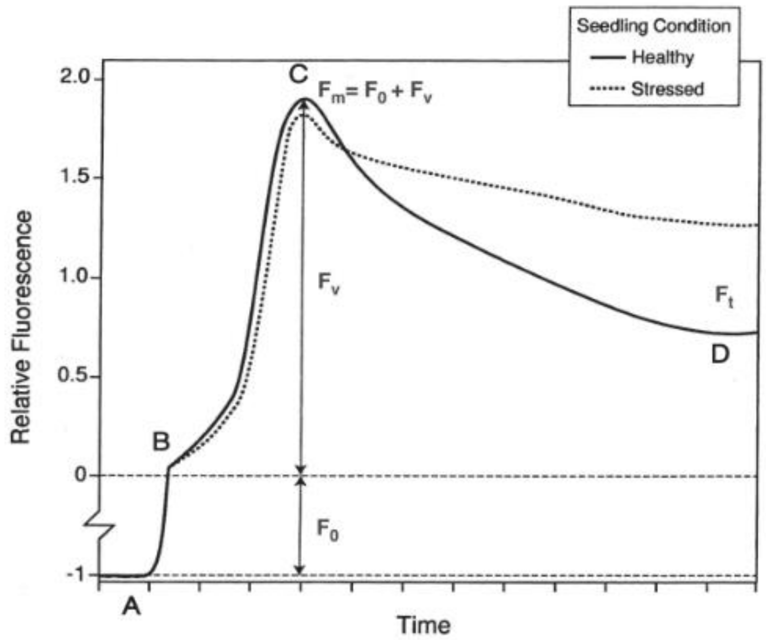

Figure 1. A typical chlorophyll emission curve for a leaf made with a "Kautsky" fluorometer. A is at the point of the actinic light pulse; B is the chlorophyll emission when all reaction centers are open; C is the emission peak; and D is the emission approaching steady state. If the leaf is under significant stress, the emission curve may resemble the upper dotted line (Ritchie G.A., 1998).

Jiang et al (2005) observed consistency in F_v/F_m suggesting that adaptation of photochemical efficiency to low light is not affected by chlorophyll molecule degradation. Under shaded conditions, F_v/F_m is observed to increase which indicates an increase in the PSII photochemical efficiency, or it can be considered as a consequence of reduction in the rate of PSII pigment photo-oxidation (Mauro et al., 2011). Fluorescence studies for the grasses has also been used to establish a relation between plant stress and the light parameters. Any change in the F_v/F_m ratio when turfgrass is exposed to varying light conditions can give a measure of the optimum quantum yield and maximum photosynthetic efficiency.

TRANSMISSION OF LIGHT THROUGH SHADE

Shade, as an environmental stress, has the potential to damage warm season turfgrasses, causing decline in turf quality and its resistance to biotic and abiotic stresses. Shade formed by different sources alter the spectra differently. Some shade structures might only bring change in the quantity of light being transmitted through them by decreasing PPF while others can alter the quality of light through selective transmission of particular wavelengths within light spectra. Thus, light reaching the surface has two components: ‘unfiltered radiation’ which can be either direct or diffused and ‘filtered radiation’ which has been modified as it passed through vegetation or other structure in between. Neutral shade is defined as that producing a decline in the light intensity equally across the majority of wavelengths, while vegetative or foliar shade is defined as that which not only reduces light intensity but also alters the spectral composition (Studzinska et al., 2012). The effect of light quality and quantity on the warm-season turfgrass performance has been previously reported by several authors (Baldwin et al., 2009; Bunnell et al., 2005b; McBee, 1969). For example, the leaf elongation rate of bermudagrasses has been reported to increase under predominantly red light as compared to blue light (McBee, 1969) which occurs as a result of changing light quality through shade.

TURFGRASS RESPONSE TO LOW-LIGHT ENVIRONMENT

Warm-season grasses use the C4-dicarboxylic acid pathway (C4 cycle) as pathway of carbon fixation. In warm season grasses (C4), bundle sheath cells (Kranz anatomy) are specialized anatomical features within the leaf, which have thickened cell walls and large granulated chloroplasts. On the other hand, cool season grasses (C3) do not have Kranz anatomy and instead have bundle sheath cells with thin membranous walls containing no chloroplast. Kranz cells allow C4 plants to function more efficiently under lower ambient CO_2 concentrations and high temperatures than C3 plants (Hopkins & Bell, 2011; Sinha, 2004). The C4 photosynthetic pathway requires two additional ATP molecules as compared to C3 pathway and to fulfil this requirement, higher levels of temperatures (30° to 40° C) and light intensity (390 to 465 W m^{-2}) is needed (Dudeck and Peacock, 1992). On the other hand, cool season grasses require air temperature of about 15 to 20° C and photosynthetic irradiance of 116 to 233 W m^{-2} (Dudeck and Peacock, 1992). In comparison to warm-season turfgrasses, which need full sunlight to reach their light saturation point, cool-season turfgrasses are expected to need 50% of full sunlight to reach their light saturation point (McCarty, 2018).

Reduced photosynthetic irradiances can limit the growth and development of all grasses but due to higher light requirements of the warm-season grasses, they are more affected in shaded environment when the light intensities are not adequate to perform the required amount of photosynthesis. The response of warm-season turfgrass when grown under low light, caused by shade, can be observed as an increased chlorophyll content, lower respiration rate, low compensation point, low carbohydrate reserve, reduced transpiration, etc. Winstead and Ward (1974) studied the physiological response of warm season grass (bermudagrass and St. Augustinegrass) and showed a decreased net photosynthesis and respiration at lower light intensity. A similar study on cool season grasses was done by Wilkinson et al. (1974) on Kentucky bluegrass *(Poa pratensis* L.) and red fescue (*Festuca rubra* L.) which showed no differences in photosynthetic rates but observed a reduced rate of respiration under reduced irradiance. These behaviors of the grasses elucidated the shade adaptive mechanisms of cool season grasses. Reduced respiration contributes to a positive CO_2 balance over time despite of the reducing photosynthetic rates under low light (Wilkinson et al., 1975). Reductions in PAR have also been co-related to light compensation points which tend to decrease under low light. Thus, CO_2 fixation below these levels would likely result in affecting the plant growth (Jiang et al., 2004). In addition, morphological developments are also affected under reduced irradiance that results in taller, thinner stems and lower root and shoot dry weights (Winstead & Ward, 1974; Schnyder & Nelson, 1989).

Physiological response under shade

Shade can lower the amount of irradiance reaching the grasses and a reduced light capture by the leaves can lead to decline in carbon assimilation. This is caused by a reduced photosynthetic efficiency which ultimately affects the quality of turfgrass and its resistance to other biotic and abiotic stresses. Respiration and photosynthesis work in opposite manner. Respiration is an on-going process which uses the stored carbohydrates and oxygen, and converts it into carbon-dioxide, whereas, photosynthesis, which occurs only in the presence of light, uses carbon dioxide and makes oxygen and sugars. These two important physiological functions work in balance for proper growth and development of plants. The light compensation point is the light intensity at which photosynthesis and cellular respiration are equal. The light compensation point of more shade tolerant plants range from 1 to 5 µmol m^{-2} s^{-1} compared to less shade tolerant plants ranging from 10 to 20 µmol m^{-2} s^{-1} (Taiz et al., 2015). Below this light intensity, rate of respiration increases and sugars are used up at greater rates than are being synthesized by photosynthesis. Reduced photosynthesis results in decreased nonstructural carbohydrate concentration under decreased light intensities caused by shade (Jiang et al., 2004). Leaves contribute a greater percentage of the canopy in turfgrass and are therefore responsible for carbon gains but in reduced light environment, the ability of leaves to capture light and convert it with maximum efficiency towards carbon assimilation is reduced. This causes a reduction in quantum efficiency. Further, close frequent mowing, as a management practice in turfgrass, reduces the residual leaf area where photosynthesis must occur. Plants respond by directing more energy to regeneration of leaves removed during mowing. In this process, the carbohydrates stored in roots or stolons are transferred to new shoot production which requires increased respiration rates and results in decline of non-structural carbohydrates (Hull, 1992).

Jiang et al. (2005) observed reduction in photosynthetic parameters under low light as compared to high light in ‘Sea Isle 1’ seashore paspalum (*Paspalum vaginatum* Swartz) and TifSport bermudagrass. Shading resulted in a 49% reduction in bermudagrass as compared to 9% increase for the St. Augustinegrass. (Winstead & Ward, 1974). This reduction in net photosynthesis is suspected to be a cause of decreased turf density when grown in shaded environments. In addition to photosynthesis, there was also a decrease in the dark respiration by 62% in bermudagrasses as compared to 21% in St. Augustinegrass. Van Huylenbroeck and Van Bockstaele (2001) observed reduced photosynthesis rates under reduced irradiance in cool season grasses. Wilkinson et al. (1975) observed reduced light saturated net photosynthesis, lower dark respiration rates, and decreased light compensation points for *P. pratensis and E. rubra* under low light conditions. Chlorophyll levels are usually affected by the light environments. Jiang et al. (2004) observed decline in chlorophyll content in bermudagrasses when subjected to low light conditions for an extended period of time. Similarly, when transferred from low to high light conditions, the increase in chlorophyll content Chl (a+b) was lower in bermudagrasses as compared to seashore paspalum. This indicated poor tolerance of bermudagrass to variable light conditions which affected its recovery and light response. Another observation was the slower recovery of Chl b compared to Chl a and therefore an increased Chl a/b ratio which again suggested a size differential for Photosystem I and II in thylakoid membrane.

Past studies showed that plants with better shade tolerance have low light compensation points, higher quantum efficiency and lower maximum photosynthetic rate due to their ability to use the available low photon flux density, more efficiently for photosynthesis (Jiang et al, 2004; Wilkinson et al, 1975). The studies performed on the cool season grasses for shade tolerance also showed that photosynthetic-respiratory balance is an important factor for shade adaptation. In addition, reduced light compensation point, efficient use of low light intensity were other critical factors observed in red fescue (Wilkinson et al., 1975).

Differences in physiological response to shade have not been as exhaustively explored within a species as across species. Response of turfgrasses to shade vary in individual species or cultivar as well as degree of low light stress and therefore selection of low light tolerant cultivar of turfgrass for use in reduced light conditions is important and beneficial for turf management (Jiang et al., 2004). A study performed by Gaussoin et al. (1988) evaluated the performance of 32 clones of bermudagrass for their shade resistance on the basis of dry matter yield reduction from high to low light treatment. Similarly, Baldwin et al. (2008) classified bermudagrass cultivars on the basis of shade resistance with 'Riley's Super Sport', TifGrand, 'Tift No.1', and 'Transcontinental' as shade resistant and 'SWI-1014', 'Arizona Common', 'Sundevil', 'SR 9554', 'GN-1', and 'Patriot' as shade sensitive. Similarly, Trenholm and Nagata (2005) studied differences between St. Augustinegrass cultivars grown under shade on the basis of turf quality, color, and density. 'Seville', 'Palmetto', 'Bitterblue' and '1997-6' maintained acceptable turf quality even beyond 60% shade while 'Floratam' was the poorest performing. Among these studies, the basic physiological functions and adaptations have not been studied which can be suspected of contributing shade tolerance of these cultivars.

Morphological response under shade

Turfgrasses tend to show shade avoidance responses which involve morphological changes including elongation of stem and petiole, hyponasty, reduced branching and lateral growth, thinning of leaves to avoid internal canopy shading, etc. (Gong et al., 2015). Shade promotes excessive succulent shoot growth, which lowers turfgrass quality for sports use. Changes in light quantity affects the plant growth and biomass production while the changes in light quality alter plant morphogenesis and influence developmental processes mediated through different photoreceptors such as phytochromes which are sensitive to the red-to-far-red (R:FR) ratio (Gautier et al., 1999; Stuefer & Huber, 1998). Stuefer and Huber (1998) studied two stoloniferous herbs, *Potentilla reptans L*. and *P. anserina L* and noted that light quality affected internode length, total stolon and petiole length, rooting patterns, while dry weight, leaf number, specific leaf area and ramet number were affected due to changes in light quantity. In addition, they also observed alterations in growth and biomass production with changes in light quality independent of light quantity. Neutral shade leads to the reduction in the PPF which significantly reduced tillering in perennial ryegrass (*Lolium perenne* L.). Moreover, reduction in R:FR ratio also has a deleterious effect on the tillering unlike the reduction of blue light which had no such significant (Gautier et al., 1999). Another study by Wherley et al. (2005) showed that under low light intensity and high R:FR, tillering, leaf blade width and thickness, and chlorophyll contents were increased in tall fescue (*Festuca arundinacea* Schreb.).

Primary morphological and visual responses of turfgrasses attempting to reach sunlight in reduced light environments is longer internode and elongated stems and leaves. This occurs as a result are of photosynthates and carbohydrate resources being reallocated under reduced light conditions. (Schnyder & Nelson, 1989; Winstead & Ward, 1974). Under such conditions leaf elongation zone becomes a strong sink for assimilates. Schnyder and Nelson (1989) reported reduction in leaf width, thickness, water content per unit leaf area and water content per unit leaf length in the area of leaf elongation in tall fescue at low irradiance. This decrease in leaf thickness was because of the decreasing thickness of mesophyll caused due to shading. Winstead and Ward (1974) observed a notable difference in leaf blade and internode length in warm-season grasses but larger changes were observed in St. Augustinegrass as compared to bermudagrass. Higher shade resistance of St. Augustinegrass was attributed to greater leaf width which possibly increased the photon absorbing surface thus enabling it more adaptability than bermudagrasses under low light conditions. Another experiment conducted by McBee and Holt (1966) for the shade resistance showed increased ground coverage for St. Augustinegrass in comparison to bermudagrass, which showed highest decline in the ground coverage. Greater stem elongation, decreased internode length and stem diameter, and upright type of growth was observed when light levels were reduced from 35 to 25%.

The studies undertaken to evaluate anatomical and physiological characteristics of turf under shaded environments show longer and thinner leaf development as compared to the ones grown in high irradiance. Low irradiance conditions also favor the growth of leaf blade area per unit of dry matter (Allard et al., 1991). When shoots take precedence over roots in energy partitioning relationships, roots might have been a big source of energy (Krans & Beard, 1980). Etiolation is harmful to close-mowed turfgrass, as the increased vertical growth under shade is removed by mowing, and thus ultimately leading to reduction in root biomass (Allard et al., 1991). This results in increase in shoot/root ratio and leaf area ratio for plants grown in low light. Wilkinson and Beard (1975) observed a greater shoot weight in red fescue than Kentucky bluegrass under low light conditions while reverse was true in high light conditions, suggesting higher shoot growth under low photosynthetic irradiance as a characteristic of better performance. Baldwin (2008) observed a significant reduction in root biomass under 64% continuous artificial shade for 60 days. He also found thinner and highly branched root system under shade which could result in reduction in capacity to obtain nutrients thus declining the turfgrass quality.

Meeks & Chandra (2021) reported on various St. Augustinegrass diploid and interploid entries for their shade avoidance and observed decline in daily elongation rate, quality, color and density under shade. Changes in percent ground cover and density was observed by McBee and Holt (1966) in various turfgrasses when exposed to reduced light environments as compared to full sunlight. Similar results were observed by Barrios et al. (1986) for zoysiagrass, St. Augustinegrass, and centipedegrass.

Various parameters such as root biomass, shoot biomass, leaf elongation, turfgrass quality, color, density, and percent green cover have been used to compare different turfgrasses for their shade avoidance behavior. In addition to all these parameters, it is important to understand the growth patterns of grasses when grown under shade. These include changes in the fraction of plant biomass allocated to leaves, or the efficiency with which a plant deploys its photosynthetic resources, etc. which tend to alter with the modifications in carbohydrate partitioning in the above and below ground regions. These growth patterns can help in studying the shade avoidance responses in grasses and can also help in bringing out characteristic differences between various cultivars which are responsible for imparting them shade resistance.

RESEARCH GOALS AND OBJECTIVES:

The long-term goal of this research is to use turfgrasses varying in apparent shade resistance to examine variation in traits suspected of contributing to shade resistance in order to improve selection criteria for plant breeders.

The objectives of this research were as follows:

1. To compare the photosynthetic and growth response to light intensity of four St. Augustinegrasses and four bermudagrasses varying in their apparent shade resistance.

2. To characterize the morphological response of St. Augustinegrass and bermudagrass genotypes grown under varying neutral shade environments.

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CHAPTER II

PHOTOSYNTHETIC RESPONSE OF WARM-SEASON TURFGRASSES TO VARYING LIGHT INTENSITIES

ABSTRACT

Shade alters the growth and development of turfgrasses, ultimately affecting the quality and playability of athletic fields and golf courses. Species and cultivars within species have shown variability for relative shade resistance in both field and controlled environment studies, but little is known about the mechanisms which convey resistance. The objective of this study was to quantify the photosynthetic response of selected warm-season turfgrasses varying in shade resistance. A greenhouse study was conducted on four genotypes each of St. Augustinegrass (*Stenotaphrum secundatum*) and hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*). After establishing the plants in the greenhouse for six weeks, grasses were exposed to shade using a black poly-woven fabric to reduce photosynthetic photon flux by 60 or 90% of ambient conditions for bermudagrass and St. Augustinegrass, respectively. Photosynthesis rate was measured at incremental light intensities using a portable photosynthesis system. A nonrectangular hyperbola model was used to fit the photosynthetic-light response curve and

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estimate the maximum gross CO_2 assimilation (A_{max}), dark respiration rate (R_d), light compensation point (I_{comp}), apparent quantum efficiency (φ), light saturation estimate at 75th percentile (I_{sat75}), and the assimilation rate at 1000 μmol PAR $m^{-2}s^{-1}$ (I_{sat75}) at 4 and 8 weeks after treatment. Clipping yield was measured weekly, and dry mass of roots and aerial shoots was assessed at the end of 8 weeks. Shade resistant TifB16108 achieved I_{sat75} at lower light intensity, had lower R_d and I_{comp}, and higher shoot biomass as compared to other genotypes, while shade sensitive TifB16119 showed contrasting results to TifB16108. The A_{max} and R_d in St. Augustinegrass did not show much variation among genotypes, but lower I_{comp} was observed in DALSA 1404 and DALSA 1405 in comparison to shade sensitive TamStar. Shade resistant DALSA 1618 and DALSA 1404 showed increased PS1000 and higher root: shoot ratio suggesting these traits promote shade tolerance within the species.

INTRODUCTION

Shade stress is among the most common and inevitable challenges in management of modern sport stadiums, golf courses, and home lawns. Use of shade resistant turfgrasses can improve turfgrass quality and potentially reduce inputs needed to maintain acceptable turf in shaded environments. Bermudagrass (*Cynodon dactylon* (L.) Pers.) is described as possessing little or no shade resistance when compared to other warm season turfgrass species (Beard, 1973). While, on the other hand, St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) is thought to be the most shade resistant of the warm-season turfgrasses (Wilkinson et al., 1975). In one study, shade reduced net photosynthesis of bermudagrasses by 49% reduction as compared to a 9% increase for the St. Augustinegrass (Winstead & Ward, 1974). Zhang et al. (2017) quantified minimum light requirements of warm-season turfgrasses and reported bermudagrass as having the highest daily light requirement compared to other warm-season grasses such as St. Augustinegrass, seashore paspalum (*Paspalum vaginatum* Swartz.) and zoysiagrass (*Zoysia japonica* Steud.)

Shade resistance is also known to vary within a species (Baldwin et al., 2008; Gardner & Taylor, 2002; Jiang et al., 2004). Baldwin (2008) characterized bermudagrass cultivars on the basis of turf quality, chlorophyll, root length and biomass, and observed that ‘Riley’s Super Sport’ had better shade tolerance than ‘Tifway’ and ‘DT-1’ (hereafter referred to as TifTuf®). In a separate study, Tifway was considered to be one of the poorest performing bermudagrasses under shade (Gaussoin et al., 1988). Similarly, Trenholm and Nagata (2005) studied differences in shade resistance among St. Augustinegrass genotypes and reported ‘Seville’, ‘Palmetto’, ‘Bitterblue’ and 1997-6 maintained acceptable turf quality even beyond 60% shade, while ‘Floratam’ was the poorest performing.

How variation in shade resistance among and within species occurs is not clearly understood. Tolerance to low irradiance is suspected as being a possible contributor to apparent shade resistance within warm-season turfgrasses. Low irradiance has been reported to reduce net photosynthesis, dark respiration rates, light saturation levels, and light compensation points (Wilkinson et al., 1975; Winstead & Ward, 1974). Jiang et al. (2005) observed reduction in density, canopy photosynthetic rate, and chlorophyll index under low light as compared to high light in seashore paspalum and bermudagrass. Similarly, Van Huylenbroeck and Van Bockstaele (2001) observed reduced photosynthesis rates under reduced irradiance in cool season grasses. Wilkinson et al. (1975) also observed reduced net photosynthesis, lower dark respiration rates, and decreased light compensation points for Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.) under low light conditions. Studies have shown plants with better shade tolerance have low light compensation points, higher quantum efficiency and lower maximum photosynthetic rate due to their ability to use the available low photosynthetic photon flux (PPF) more efficiently for photosynthesis (Jiang et al., 2004; Wilkinson et al., 1975). Shade tolerant turfgrasses have the ability to achieve light saturation levels at lower light intensities, which is often noted as the ability to assimilate carbon more efficiently at lower light intensities (Baldwin, 2008).

In addition to these photosynthetic responses, growth patterns are also observed to change with altering light intensities. Cai et al. (2011) observed lower shoot dry weights under heavy shade as compared to moderately shaded area suggesting low carbohydrate assimilation under low irradiance. Shade resistant behavior between and within species have also been observed in terms of the changing growth patterns. Wilkinson and Beard (1974) observed a greater shoot weight in red fescue than Kentucky bluegrass under low light conditions while reverse was true in high light conditions, suggesting higher shoot growth under low photosynthetic irradiance as a characteristic of better performance.

OBJECTIVE

The objective of this study was to compare the photosynthetic and growth response to light intensity of four St. Augustinegrasses and four hybrid bermudagrasses (*Cynodon dactylon* × *C. transvaalensis*) varying in their apparent shade resistance.

HYPOTHESIS

- The grasses showing shade tolerant behavior will have higher net photosynthesis, reduced dark respiration rates, lower light compensation points and higher quantum yield under lower light intensities.
- The grasses deemed to be shade resistant will have higher percent green cover and biomass accumulation than shade sensitive grasses under low light intensities.

MATERIAL AND METHODS

This study was conducted at the Oklahoma State University Horticultural Research Greenhouse Complex, Stillwater, Oklahoma. The first experiment was conducted from March 3, 2020 to June 20, 2020 (hereafter referred to as experiment 1) and repeated from October 2, 2020 to January 20, 2021(hereafter referred to as experiment 2). The average minimum and maximum temperature were 17°C and 33°C during the study. Pots received supplemental lighting which resulted in ambient greenhouse conditions having an average daily light integral of 34.13 $\mu mol\ m^{-2}\ d^{-1}$ during experiment 1 while 22.18 $\mu mol\ m^{-2}\ d^{-1}$ during experiment 2. The average daily temperature was 29.06°C during experiment 1 and 20°C during experiment 2.

Growth tubes were created by capping 20 cm long sections of PVC pipe and filling with a peat-based media (Metro-Mix® 36, Sun Gro Horticulture). Tubes were 5 cm and 10 cm in diameter for hybrid bermudagrass and St. Augustinegrass, respectively. Four genotypes of each species were selected on the basis of preliminary field studies to have a gradient of resistance to low irradiance. The four St. Augustinegrasses were DALSA 1404 (shade resistant), DALSA 1618 (shade resistant), DALSA 1405 (moderately resistant), and 'TamStar' (shade sensitive), and the four hybrid bermudagrasses were TifB16108 (shade resistant), TifB16117 (moderately resistant), TifB16119 (shade sensitive) and 'Tifway' (shade sensitive). Genotypes were planted as plugs and allowed to establish within the greenhouse for 6 weeks.

Liquid fertilization was applied using 20N-20P_2O_5-20K_2O soluble fertilizer (Jr Peters Inc., Allentown, PA) at the rate of 146 kg ha^{-1} in split doses (36.6 kg ha^{-1} per week) at weekly intervals. Plants were fertilized with a natural fertilizer (6-2-0, Milorganite Classic, Harrell's, Lakeland, FL) at a rate of 48 kg ha^{-1} N at 0 and 4 weeks after planting. Preventative applications of two different insecticide mixtures were made in rotation at an interval of 15 days to control chinch bugs (*Blissus insularis* Barber), Rhodesgrass mealybugs (*Antonina graminis*), and bermudagrass mites (*Eriophyes cynodoniensis* Sayed). In the first week a mixture of bifenthrin (Talstar P, 7.9% a.i., FMC corp., Philadelphia, PA) at 1.6 L ha^{-1}, abamectin (Avid 0.15 EC, 2% a.i.) (Syngenta, Greensboro, NC) at 0.127 L ha^{-1}, and Prefer 90 Surfactant at 0.127 L ha^{-1} was used and next application was done with imidacloprid (Mallet® 2F T&O, 21.4% a.i.) (Nufarm, Melbourne, Australia) at the rate of 2 L ha^{-1}. Applications of azoxystrobin (Heritage, 22.93% a.i.) (Syngenta, Greensboro, NC) at 32 L ha^{-1} and tebuconazole (Torque, 38.7% a.i., Nufarm, Melbourne, Australia) at 3.18 L ha^{-1} were made every other week to control grey leaf spot (*Pyricularia grisea*) and large patch (*Rhizoctonia solani*). Grasses were clipped once per week at 2 cm and 8 cm for bermudagrasses and St. Augustinegrass, respectively. Plants were hand-watered to prevent drought stress.

After the initial six-week establishment period, half of the experimental units were shaded using a poly-woven fabric nominally rated to reduce photosynthetic photon flux by 60% and 90% of ambient conditions for bermudagrass and St. Augustinegrass, respectively. The shade fabric was mounted over a wooden frame measuring 60 cm × 60cm × 60cm. Supplemental lighting (400-watt high pressure sodium bulbs, Rudd Lighting Inc., Racine, WI) was used in addition to natural light to increase light quantity and standardize day length to 14 hours per day (Bunnell et al. 2005a).

The experimental design for each experiment was a modified split plot design having four replications of each treatment combination (genotype × shade treatment).

Measurements of gas exchange: Light response curves

Photosynthesis rate was measured during photoperiod from 1000 to 1400 h with a LI-6400 portable gas exchange system (LI-COR Inc., Lincoln, NE) and an AutoProgram that took measurements at the following photosynthetic photon flux densities (Q): 2000, 1750, 1500, 1250, 1000, 750, 500, 250, and 0 µmol m^{-2} s^{-1} using an external light source (Kreuser et al, 2014). The instrument was set to a 400 μmol CO_2 mol^{-1} reference CO_2 concentration and 500 μmol s^{-1} flow rate. The data were collected at 4 and 8 weeks after initiating shade treatment (WAT). For St. Augustinegrass, the response was measured as leaf net photosynthesis using a 2 × 3-inch chamber and a 6400-02B LED external light source. Measurements were taken on the second or third fully expanded leaves. Each leaf used for a measurement was subsequently marked using a thin permanent marker to delineate the area within the chamber and then excised using a razor blade. A digital image of each excised leaf was taken on a white background marked with ruler at the back and analyzed for the area using ImageJ 1.52a software (National Institute of heath, USA). A known length in the image was measured to set the scale and then the area over the leaf was adjusted to threshold, and finally the particles in the selected portion were analyzed for their area measurement. Photosynthesis data were adjusted on a leaf area basis and fit to a nonrectangular hyperbola model with assimilation *(A)* as a function of PPF *(I)* using the following equation:

$$A = \frac{\varphi I + A_{max} - \sqrt{(\varphi I + A_{max})^2 - 4\varphi I \theta A_{max}}}{2\theta} - R_d \qquad Eq.[1]$$

where φ is the quantum yield at I =0 μmol m^{-2} s^{-1}, *Amax* is the asymptotic estimate of maximum net CO_2 assimilation, θ is the curvature factor, and R_d is the rate of dark respiration (Baath et al., 2020; Lobo et al., 2013). Light compensation point I_{comp} was calculated as:

$$I_{comp} = \frac{R_d(\varphi R_d - A_{max})}{\varphi(R_d - A_{max})} \qquad Eq.[2]$$

The quantum yield (φ) was calculated as the slope of the curve from I_{comp} to 200 μmol m^{-2} s^{-1}. The parameter I_{sat75} was calculated as the light intensity when the net photosynthesis is equal to 75% of the maximum possible photosynthesis (Lobo et al., 2013) using the following equation:

$$I_{sat75} = \frac{(A_{max}+R_d)(A_{max}-0.75\theta A_{max}-0.25\theta R_d)}{\varphi(A_{max}-R_d)} \qquad Eq.[3]$$

Light response curves measured the photosynthetic parameters for varying light intensities allowing the leaf/leaves to get adapted for certain period of time before taking measurements. But, to measure the photosynthesis in the real time without adapting the leaf to specific conditions, another parameter was measured as photosynthetic gas exchange at 1000 µmol m^{-2} s^{-1} taken at second or third fully expanded leaves of St. Augustinegrass using a portable infra-red gas analyzer (Li-6400, LICOR, Inc., Lincoln, NE) with controlled atmosphere and a 6400-02B LED external light source providing a photo-synthetic photon flux density of 1000 µmol $m^{-2}s^{-1}$.

Due to small leaves, the response for bermudagrass was measured on a canopy-basis as gross photosynthesis using the 6400-17 whole plant Arabidopsis chamber with 6400-18 RGB light source (Bremer et al., 2008). All other instrument settings and parameters were similar to that of St. Augustinegrass measurements. The values for all the photosynthetic parameters of bermudagrasses were corrected on leaf area basis by diving each value to the leaf area index of grass in each tube. Leaf area index of each pot was calculated by dividing the total leaf area of the grass to the area of the pot.

Fluorescence measurement:

Chlorophyll fluorescence was measured at 4 and 8 WAT. Measurements were made on the third or fourth fully expanded young leaves using the OS30p+ Chlorophyll Fluorometer (Opti-Sciences Inc., Hudson, USA). The leaves were adapted in darkness for 25 minutes at room temperature to clear the excited electrons from the electron transport chain and empty the acceptor pool before taking the measurement. Initial fluorescence (Fo) was measured at low light intensity (less than 0.1 µmol m^{-2} s^{-1}), and the maximal fluorescence (Fm) was measured after a saturating pulse of 3,500 μmol m^{-2} s^{-1}. The variable fluorescence (Fv) was calculated using the following equation:

$$Fv\ /\ Fm = [(Fm - Fo)\ /\ Fm]$$

Digital Image Analysis:

Images were taken of each canopy immediately after clipping 4 and 8 WAT using a small light box fitted with two incandescent flood lamps. The images were taken using a digital camera (Powershot G5; Canon, Tokyo, Japan) and were analyzed using ImageJ 1.52a software (National Institute of Health, USA) using a custom macro and the color threshold feature. The software crops pixels outside the turf area and measures the number of green pixels within the remaining image.

Shoot and root biomass:

Clippings were collected each week and dried in an oven at 80° C for 48 hrs and then weighed. At the conclusion of the study, aerial shoots (along with the stolons) were clipped at the soil, roots and rhizomes were washed free of media, and each component was oven dried at 80° C for 48 hr and weighed.

Statistical analysis

The photosynthetic-light curve was fitted to a nonrectangular hyperbola model (Eq. 1) by the non-linear least square procedure using 'onls' package in R (Spiess, 2015). Curves for CO_2 assimilation/ PPDF were generated by plotting light intensity *I* over the desired range and CO_2 assimilated at that point using SigmaPlot (Systat Software Inc., San Jose, CA) and then nonlinear regression analysis was done by supplying it with four parameters i.e. φ (apparent quantum yield), A_{max} (maximum net CO_2 assimilation), θ (the curvature factor), and R_d (rate of dark respiration).

All response variables were analyzed using PROC GLIMMIX in Statistical Analysis System (Version 9.4; SAS Institute Inc., Cary, NC). A one-way analysis of variance (ANOVA) was performed to determine the effects of shade on parameters derived from photosynthetic-light response curves for different genotypes, and the treatment differences were analyzed using the LSMEANS with LINES statement at $\alpha = 0.05$. During the preliminary analysis, a significant treatment × experiment interaction was observed for most of the parameters in both the species. Therefore, the data were analyzed separately for each experiment.

RESULTS

Bermudagrass

Photosynthetic Response

In experiment 1, the genotype main effect was significant for A_{max}, F_v/F_m, and PGC with the genotype × week interaction also significant for A_{max} (Table 1). In experiment 2, the genotype main effect was significant for R_d, I_{comp}, F_v/F_m and PGC, while the genotype × week interaction was also significant for F_v/F_m (Table 2). The treatment × genotype interaction was not significant for any variable in either experiment.

In experiment 1, A_{max} at 8 WAT was greater for TifB16119 compared to TifB16108 (Table 3). TifB16117 had the greatest F_v/F_m, while TifB16119 had the lowest (Table 4). TifB16117 had the lowest PGC, while TifB16108 was the greatest PGC (Table 4).

In experiment 2, TifB16119 and Tifway demonstrated greater R_d compared to TifB16108 (Table 6). TifB16119 also demonstrated the greatest I_{comp} and I_{sat75} compared to other genotypes with values nearly three-fold and two-fold greater than that of TifB16108 for I_{comp} and I_{sat75}, respectively (Table 6). Similar to experiment 1, TifB16117 had the greatest F_v/F_m, while TifB16119 had the lowest at 8 WAT (Table 7).

Root and Shoot biomass

In experiment 1, the genotype main effect was significant only for shoot biomass, while in experiment 2, the genotype main effect was significant for both root density and shoot biomass. Additionally, the treatment × genotype interaction was significant for root density (Table 8).

In experiment 2, TifB16108 maintained high root density both under shade as well as ambient conditions. Tifway on the other hand, had high root density under ambient conditions (similar to TifB16108) but among the lowest under shade conditions. TifB16119 had the lowest root density under ambient conditions but was similar to TifB16117 and Tifway under shaded conditions (Table 10). TifB16108 had the highest shoot biomass during each experiment, while TifB16119 was among the lowest genotypes in each experiment (Table 11).

St. Augustinegrass

In experiment 1, the genotype main effect and higher order interactions involving genotype were not significant for A_{max}, R_d, F_v/F_m, φ, or PS1000 (Table 12). The treatment × genotype interaction was significant for I_{comp}, I_{sat75}, and PGC. Under ambient conditions, DALSA 1404 and DALSA 1618 demonstrated greater I_{comp} than TamStar. Under the shade treatment, DALSA 1618 maintained a large I_{comp} resulting in a greater mean than DALSA 1405 while other comparisons were not significantly different (Table 15). Under ambient conditions, TamStar had similar PGC to other genotypes (Table 15). In contrast, TamStar had the lowest PGC under shaded conditions. Under ambient conditions, TamStar had the lowest I_{sat75} among genotypes. In contrast, I_{sat75} for TamStar increased from 4 WAT to 8 WAT resulting in the greatest I_{sat75} while all other comparisons were not significantly different (Table 16).

In experiment 2, the genotype main effect was significant for I_{comp} and PGC, while the treatment × genotype interaction was significant for PS1000 (Table 13). TamStar had the lowest

I_{comp} compared to other genotypes (Table 17). DALSA 1618 and DALSA 1404 maintained greater PGC than DALSA 1405 regardless of shade treatment (Table 17). DALSA 1618 had the greatest PS1000 at 4 WAT, while both DALSA 1618 and DALSA 1404 had a greater PS1000 than other genotypes at 8 WAT (Table 18).

Root and Shoot biomass

In experiment 1, the genotype main effect was not significant for root density or shoot biomass but did show an effect on the root: shoot ratio (Table 20). DALSA 1405 had the highest root: shoot ratio, but no differences were observed among other genotypes (Table 21).

In experiment 2, the treatment main effect was not significant for root: shoot ratio or the root to shoot interaction. Rather, the treatment × genotype interaction was significant for shoot biomass (Table 20). Root density was highest in DALSA 1405 under ambient conditions, but no differences were detected among genotypes under shaded conditions (Table 23).

DISCUSSION

Experiments studying the relative shade tolerance among turfgrass species have been conducted by many researchers in the past. In an experiment by Dias-Filho (2002) on C4 grasses, shade reduced the photosynthetic capacity and I_{comp}, while φ was unaffected by light regime. The authors reported the R_d for shade resistant plants *Brachiaria humidicola* were more responsive to shade than were the shade sensitive plants *B. brizantha*. Winstead and Ward (1974) reported reductions in R_d and A_{max} in shade sensitive warm-season turfgrass species (bermudagrass), while no differences were noted in relatively resistant species (St. Augustinegrass) when exposed to 70% shade to ambience. Jiang et al. (2004) observed higher shade resistance of seashore paspalum as compared to bermudagrass as the photosynthesis rates decreased to a lower extent for the latter when exposed to similar neutral shades. In contrast, the present study examined the shade tolerance mechanisms among genotypes within a species.

Bermudagrass

The lower PGC for shaded plants indicates the shade severity used in the present study was sufficient to reduce turf aesthetics for all genotypes. Previous research has demonstrated variability among bermudagrasses for maintenance of turf coverage under diminishing light intensities (Hanna et al., 2010). The lower PGC for TifB16117 is indicative of a poor performer in general, but lack of treatment × genotype interaction for PGC was surprising and may suggest longer duration of stress was needed to create variation in this trait.

Baldwin et al. (2008) reported shade reduced root biomass among all bermudagrasses tested, although shade resistant cultivars (Riley's Super Sport and 'TiftNo.2') had greater root biomass than shade sensitive cultivars ('Arizona Common' and 'GN-1') under shade (Baldwin et al., 2008). The same study also found thinner and highly branched root system under shade which they speculated could reduce nutrient uptake efficiency. Similar results were reported in the present study with shade resistant TifB16108 maintaining the highest root density under shade. Wilkinson and Beard (1974) observed a greater shoot weight in red fescue (shade resistant) than Kentucky bluegrass (shade sensitive) under low light conditions, suggesting higher shoot growth under low photosynthetic irradiance as a characteristic of shade resistance. In the present study, the greater shoot biomass for TifB16108 and lower shoot biomass for TifB16119 and Tifway are in agreement with apparent shade resistance reported in field trials.

The declining assimilation rates associated with reduced light intensity are comparable to those reported by Van Huylenbroeck and Van Bockstaele (2001) who also observed reduced photosynthesis rates in cool season grasses under reduced irradiance. TifB16119 being a shade sensitive genotype had the highest I_{sat75} while the shade resistant TifB16108 had the lowest, suggesting that the latter achieved light saturation at a lower light intensity. The potential to achieve light saturation levels at reduced light intensities is a characteristic of shade-tolerant turfgrass species and cultivars which is generally observed as the ability to assimilate carbon more efficiently at reduced light intensities (Baldwin, 2008). Horton et al. (1998) studied a shade tolerant C4 grass grown under 25% ambient sun (75% shade) and could not observe significant differences in light saturation at 90th percentile but lower absolute values for the same as compared to those grown at 50% full sun This indicated that tolerant grasses require lower light intensities to reach 90% of their saturation points.

The greater A_{max} for TifB16119 under ambient conditions was surprising but no such differences were observed under shade. This could be attributed to greater genetic potential for net photosynthesis, but other factors (e.g., leaf morphology) may contribute to the poor shade resistance (see Chapter 3).

In a study by Miller and Edenfield (2002), 'Floradwarf', 'Tifdwarf' and 'Reesegrass' were observed to have lower net photosynthesis than 'TifEagle' and 'Champion' bermudagrass under reduced light conditions. Miller et al. (2005) reported higher rates of net photosynthesis for Floradwarf as compared to Tifdwarf under moderate shade conditions (30% of ambient), which suggested greater ability to assimilate carbon reserves at low light intensities as a possible contributor to shade resistance in this cultivar. In contrast, no differences for net photosynthesis were obtained for grasses grown under moderate to heavy shade (63% of ambient). No differences between genotypes could be observed for A_{max} under shade during the present study as well.

R_d followed a pattern in agreement with known shade resistance of the selected bermudagrasses, such that means were greatest for the two shade sensitive genotypes TifB16119 and Tifway, and lowest for TifB16108. This is in agreement with prior reports showing *Brachiaria humidicola*, a relatively more shade resistant plant as compared to *B. brizantha*, decreased R_d under low light intensities (Dias-Filho, 2002). Wilkinson et al. (1975) similarly noted ‘Pennlawn’ red fescue had lower R_d than ‘Merion’ Kentucky bluegrass at low light intensities, in agreement with known shade resistance of the species. Broadman (1977) and Horton et al. (1998) also described low respiration rates as attributes of shade resistant plants.

The relatively high I_{comp} for shade sensitive genotypes TifB16119 and Tifway suggests this trait may be important for conveying shade tolerance in bermudagrasses. Furthermore, R_d appears to be a major contributor to differences in I_{comp}. Similar results were seen in studies by Taiz et al. (2015) and Miller and Edenfield (2002) who observed that more shade tolerant plants generally have lower I_{comp}.

Higher F_v/F_m ratio under shaded as compared to ambient conditions suggest a photo inhibitory effect occurred (Jiang et al., 2004). TifB16119 had the lowest F_v/F_m ratio, while moderately resistant TifB16117 had the highest. But TifB16108 and Tifway did not show any significant difference in their F_v/F_m ratios. Jiang et al. (2004) similarly reported no differences in F_v/F_m for seashore paspalum (shade resistant) and bermudagrass (shade sensitive) under varying light environments, which suggested that tolerant and sensitive grass species could maintain similar quantum yields and were not affected by shade. Fox (2018) suggested that the F_v/F_m ratio holds promise for differentiating shade tolerance of grasses for both greenhouse and field conditions, but necessitates a specific canopy density, which was influenced by the shade, resulting in etiolation, and thus not providing a strong enough signal for the fluorometer to make the measurement.

St. Augustinegrass

Shade resulted in reduction of PGC which declined even further when exposed to longer durations for 8 weeks. The relatively shade sensitive genotype TamStar had the lowest PGC under shade as compared to other genotypes. Similarly, Wherley et al. (2013) observed that the least shade resistant entry (TAES 5732-6) performed poorly in terms of cover (24.6 %) in shade environments while shade resistant ‘Captiva’ and ‘PI 600734’ maintained more than 50% green cover. Another study by Meeks and Chandra (2021) showed interploid hybrids DALSA 1404, DALSA 1329, and DALSA 1323 to be performing better in terms of visual density compared to other entries and cultivars.

The higher A_{max} for ambient plants is in agreement with Van Huylenbroeck and Van Bockstaele (2001) in cool season grasses, suggesting a similar behavior for all turfgrasses. The lack of variation among genotypes for A_{max} or R_d suggest these traits are not good indicators of shade tolerance in the species, and St. Augustinegrasses generally respond in a similar manner.

The increased I_{comp} and decreased I_{sat75} for TamStar when shaded is in agreement with its previously reported lack of shade resistance. In contrast, the I_{comp} for DALSA 1404 and DALSA 1405 decreased under shade, while the I_{comp} for DALSA 1618 remained unchanged under shade. The increase in I_{comp} occurs when respiration rates surpass photosynthesis rates, resulting in lower total nonstructural carbohydrate content and lower stress recovery capacity. Increased respiration rates and decreased photosynthetic capacity result in the depletion of carbohydrate reserves thus, causing turf quality to decline (Valentino T. E., 2006).

Shade-tolerant turfgrass species and cultivars have the ability to achieve light saturation levels at lower light intensities, which is often noted as the ability to assimilate carbon more efficiently at lower light intensities (Baldwin, 2008).

PS1000 was observed to be higher in shade resistant DALSA 1618 throughout the study with DALSA 1404 also showing a high photosynthesis rate on some dates. These findings suggest PS1000 may be a useful metric for discerning shade tolerance of St. Augustinegrasses for breeding efforts in the future (Hu et al., 2009).

Interestingly, both DALSA 1404 and 1618 also demonstrated a preference for shoot growth over root growth, suggesting their shade tolerance may also be related to maintenance of light harvesting tissues when light becomes limiting. Under light-limited conditions, the growth of roots is reduced more than the growth of the aerial parts, which leads to a decrease in the root/shoot ratio (Hebert et al., 2001). Wilkinson and Beard (1974) also showed better shoot growth of red fescue over Kentucky bluegrass indicating better performance of the former under reduced light conditions. The grass's ability to create abundant shoot growth indicates that it can sustain shoot density and so enhance photosynthesis in low-light conditions.

CONCLUSION

Bermudagrass and St. Augustinegrass had varying shade responses at the intra-specific level. The genotypes deemed resistant to shade performed better than the sensitive ones on the basis of several photosynthetic and growth parameters. Shade resistant TifB16108 had relatively low R_d, $I_{sat75,}$ and I_{comp} and high F_v/F_m and root: shoot ratio as compared to shade sensitive genotypes Tifway and TifB16119. For St. Augustinegrass, PS1000 was among the more reliable parameters for discriminating between shade resistant DALZ 1618 and shade sensitive TamStar. Genetic response was often influenced by shade environment, therefore, it is important to study both the genetic behavior of the species in general as well as the shade response mechanisms adopted by them to fully understand the shade response. This knowledge can further help turfgrass breeders to improve the selection criteria for developing shade resistant grasses.

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Tables and Figures

Table 1. Summary ANOVA table for A_{max} (maximum gross CO_2), R_d (dark respiration), I_{comp} (light compensation point), I_{sat75} (light saturation estimate at 75th percentile), φ (apparent quantum yield), F_v/F_m, PS1000 (gross photosynthesis at 1000 μmol m^{-2} s^{-1}), PGC (percent ground cover) in bermudagrass experiment 1.

Source	A_{max}	R_d	I_{comp}	I_{sat75}	**φ**	F_v/F_m	**PS1000**	**PGC**
Treatment (T)	NS	**	NS	***	NS	NS	*	***
Genotype (G)	*	NS	NS	NS	NS	***	NS	***
Week (W)	*	NS	NS	NS	NS	*	NS	***
G×T	NS	NS	NS	NS	NS	NS	NS	NS
G×W	*	NS	NS	NS	NS	NS	NS	NS
T × W	NS	NS	NS	NS	NS	NS	NS	***
G × T × W	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 2. Summary ANOVA table for A_{max} (maximum gross CO_2), R_d (dark respiration), I_{comp} (light compensation point), I_{sat75} (light saturation estimate at 75th percentile), φ (apparent quantum yield), F_v/F_m, PS1000 (gross photosynthesis at 1000 µmol $m^{-2}s^{-1}$) , PGC (percent ground cover) in bermudagrass experiment 2.

Source	A_{max}	R_d	I_{comp}	I_{sat75}	**φ**	F_v/F_m	**PS1000**	**PGC**
Treatment (T)	**	***	NS	NS	NS	**	**	***
Genotype (G)	NS	*	***	***	NS	***	NS	***
Week (W)	NS	NS	NS	NS	NS	NS	NS	NS
G*T	NS	NS	NS	NS	NS	NS	NS	NS
G*W	NS	NS	NS	NS	NS	*	NS	NS
T*W	NS	NS	NS	NS	NS	NS	NS	NS
G*T*W	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

Table 3. Interaction of two weeks and genotypes of bermudagrass for A_{max} (maximum gross CO_2) in experiment 1.

Week	**Genotype**	***A_{max}***
		μmol CO_2 m^{-2} s^{-1}
4	TifB16108	4.368 ab
	TifB16117	3.266 bcd
	TifB16119	4.151 abc
	Tifway	4.286 ab
8	TifB16108	2.094 d
	TifB16117	2.886 cd
	TifB16119	4.803 a
	Tifway	3.250 bcd

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 4. Main effect of genotypes of bermudagrass for F_v/F_m ratio and PGC (percent green cover) (average of 4th and 8th week) in experiment 1.

Genotype	**Fv/Fm**	**PGC**
		%
TifB16108	0.707 b	79.30 a
TifB16117	0.742 a	57.74 c
TifB16119	0.686 c	65.60 b
Tifway	0.703 bc	61.4 bc

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 5. Interaction of treatment and two weeks for PGC (percent green cover) of bermudagrass in experiment 1.

Week	Treatment	PGC (%)
4	Ambient	77.2 a
	Shade	65.5 b
8	Ambient	79.9 a
	Shade	41.6 c

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 6. Main effect of genotypes of bermudagrass for R_d (dark respiration rate), I_{comp} (light compensation point, I_{sat75} (light saturation estimate at 75th percentile), and PGC (percent green cover) (average of 4th and 8th week) in experiment 2.

Genotypes	R_d	I_{comp}	I_{sat75}	PGC
	-------------μmol m^{-2} s^{-1}-----------			%
TifB16108	2.638 b	13.298 b	16.960 b	65.0 b
TifB16117	3.598 ab	14.535 b	23.200 b	51.6 c
TifB16119	5.198 a	39.330 a	38.859 a	77.3 a
Tifway	4.565 a	20.179 b	22.872 b	76.2 a

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 7. Interaction of two week and genotypes of bermudagrass for F_v/F_m ratio in experiment 2.

Week	**Genotypes**	**F_v/F_m**
4	TifB16108	0.716 bcd
	TifB16117	0.721 bc
	TifB16119	0.706 cd
	Tifway	0.713 cd
8	TifB16108	0.708 cd
	TifB16117	0.746 a
	TifB16119	0.704 d
	Tifway	0.732 ab

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 8. Summary ANOVA table for root: shoot ratio, root density, shoot biomass in bermudagrass experiment 1 and experiment 2.

Experiment	**Source**	**Root: Shoot**	**Root density**	**Shoot biomass**
1	Treatment (T)	*	*	*
	Genotype (G)	NS	NS	*
	T × G	NS	NS	NS
2	Treatment (T)	NS	*	*
	Genotype (G)	NS	*	*
	T × G	NS	*	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 9. Main effect of treatment for root density and shoot biomass after 8 weeks in experiment 1 and experiment 2 for bermudagrass.

Experiment	**Treatment**	**Root density** ---kg/m^3---	**Shoot biomass** --kg/m^2--
1	Ambient	14.095 a	2.046 a
	Shade	4.051 b	0.837 b
2	Ambient	15.714 a	1.105 a
	Shade	8.456 b	0.679 b

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 10. Interaction of treatment and genotypes of bermudagrass for root density after 8 weeks in experiment 2.

Treatment	Genotypes	Root density --- kg/m^3---
Ambient	TifB16108	18.592 a
	TifB16117	15.748 b
	TifB16119	10.970 c
	Tifway	17.541 ab
Shade	TifB16108	12.263 c
	TifB16117	6.412 d
	TifB16119	7.034 d
	Tifway	8.200 d

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 11. Main effect of genotypes of bermudagrass for shoot biomass after 8 weeks, and for percent green cover for average of 4th and 8th week in experiment 1 and experiment 2 for Bermudagrass.

Experiment	**Genotypes**	**Shoot biomass**
		---kg/m^2---
1	TifB16108	1.725 a
	TifB16117	1.482 b
	TifB16119	1.258 c
	Tifway	1.301 c
2	TifB16108	1.089 a
	TifB16117	0.856 bc
	TifB16119	0.704 c
	Tifway	0.920 b

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 12. Summary ANOVA table for A_{max} (maximum net CO_2), R_d (dark respiration), I_{comp} (light compensation point), I_{sat75} (light saturation estimate at 75th percentile), φ (apparent quantum yield), F_v/F_m, PS1000 (net photosynthesis at 1000 μmol $m^{-2}s^{-1}$), PGC (percent ground cover) in St. Augustinegrass experiment 1.

Source	A_{max}	R_d	I_{comp}	I_{sat75}	**φ**	F_v/F_m	**PS1000**	**PGC**
Treatment (T)	NS	NS	NS	*	NS	***	***	*
Genotype (G)	NS	NS	NS	NS	NS	NS	NS	*
Week (W)	NS	NS	NS	*	NS	*	***	NS
G*T	NS	NS	*	***	NS	NS	NS	*
G*W	NS	NS	NS	NS	NS	NS	NS	NS
T*W	NS	*	NS	NS	NS	NS	*	*
G*T*W	NS	NS	NS	*	NS	NS	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 13. Summary ANOVA table for A_{max} (maximum net CO_2), R_d (dark respiration), I_{comp} (light compensation point), I_{sat75} (light saturation estimate at 75th percentile), φ (apparent quantum yield), F_v/F_m, PS1000 (net photosynthesis at 1000 µmol $m^{-2}s^{-1}$), PGC (percent ground cover) in St. Augustinegrass experiment 2.

Source	A_{max}	R_d	I_{comp}	I_{sat75}	**φ**	F_v/F_m	**PS1000**	**PGC**
Treatment (T)	*	***	***	**	NS	NS	***	*
Genotype (G)	NS	NS	*	NS	NS	NS	***	*
Week (W)	NS	*	*	NS	NS	*	*	NS
G*T	NS	NS	NS	NS	NS	NS	NS	NS
G*W	NS	NS	NS	NS	NS	NS	*	NS
T*W	NS	NS	**	*	NS	*	NS	NS
G*T*W	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 14. Interaction of treatment and two weeks for R_d (dark respiration), PS1000 (net photosynthesis at 1000 µmol $m^{-2}s^{-1}$), PGC (percent ground cover) in St. Augustinegrass in experiment 1.

Week	**Treatment**	**R_d**	**PS1000**	**PGC**
		-----µmol m^{-2} s^{-1}-----		%
4	Ambient	1.792 ab	6.643 c	87.6 a
	Shade	1.109 b	7.391 bc	77.8 b
8	Ambient	1.175 b	8.164 b	91.2 a
	Shade	3.166 a	10.781 a	70.4 c

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 15. Interaction of treatment and genotypes of St. Augustinegrass for I_{comp} (light compensation point) and PGC (percent ground cover) averaged for week 4 and week 8 during experiment 1.

Treatment	**Genotypes**	I_{comp} µmol m^{-2} s^{-1}	**PGC** %
Ambient	DALSA 1404	53.808 a	91.7 a
	DALSA 1405	38.561 abc	89.9 a
	DALSA 1618	49.633 ab	87.9 ab
	TamStar	12.541 c	88.2 ab
Shade	DALSA 1404	26.507 bc	79.9 c
	DALSA 1405	17.316 c	83.5 bc
	DALSA 1618	51.435 ab	77.4 c
	TamStar	35.339 abc	55.7 d

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 16. Three-way interaction of Genotypes × treatment × week for I_{sat75} (light saturation estimate at 75th percentile) (µmol m^{-2} s^{-1}) in St. Augustinegrass in experiment 1.

Week	**Genotypes**	**Shade**	**Ambient**
4	DALSA 1404	62.92 c	97.21 bc
	DALSA 1405	53.12 c	133.68 ab
	DALSA 1618	63.73 c	85.00 bc
	TamStar	54.34 c	49.41 c
8	DALSA 1404	43.18 c	153.61 ab
	DALSA 1405	49.54 c	136.93 ab
	DALSA 1618	83.75 bc	114.30 bc
	TamStar	190.90 a	60.31 c

*Means within columns followed by the same letters are not statistically different at P=0.05

Table 17. Main effect of genotypes of St. Augustinegrass for I_{comp} (light compensation point) averaged for week 4 and week 8 in experiment 2.

Genotypes	I_{comp} μmol m^{-2} s^{-1}	**PGC** %
DALSA 1404	24.186 a	89 ab
DALSA 1405	24.535 a	84.3 c
DALSA 1618	28.853 a	91.1 a
TamStar	15.696 b	87.1 bc

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 18. Interaction of two weeks and genotypes of St. Augustinegrass for net photosynthesis at 1000 µmol m^{-2} s^{-1} during experiment 2.

Week	**Genotypes**	**PS1000** µmol m^{-2} s^{-1}
4	DALSA 1404	14.77 b
	DALSA 1405	15.85 b
	DALSA 1618	23.53 a
	TamStar	16.82 b
8	DALSA 1404	22.11 a
	DALSA 1405	15.8 b
	DALSA 1618	23.96 a
	TamStar	17.52 b

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 19. Interaction of treatment and two weeks for), I_{comp} (light compensation point), I_{sat75} (light saturation estimate at 75th percentile), and F_v/F_m in St. Augustinegrass in experiment 2.

Week	Treatment	I_{comp}	I_{sat75}	F_v/F_m
		-----µmol m^{-2} s^{-1}-----		
4	Ambient	23.273 b	87.804 ab	0.739 b
	Shade	17.528 bc	86.844 ab	0.755 ab
8	Ambient	37.055 a	37.055 a	0.769 a
	Shade	15.413 c	63.935 b	0.754 ab

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 20. Summary ANOVA table for root: shoot ratio, root density, shoot biomass in St. Augustinegrass experiment 1 and experiment 2.

Experiment	**Source**	**Root: shoot ratio**	**Root density**	**Shoot biomass**
1	Treatment	*	*	*
	Genotype (G)	*	NS	NS
	T*G	NS	NS	NS
	Treatment	NS	*	*
2	Genotype (G)	NS	NS	NS
	T*G	NS	*	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 21. Main effect of genotypes of St. Augustinegrass for root: shoot ratio after 8 weeks, and percent green cover (average of 4th and 8th week) in experiment 1.

Genotypes	Root: shoot ratio
DALSA 1404	2.034 b
DALSA 1405	3.136 a
DALSA 1618	1.724 b
TamStar	2.393 ab

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 22. Main effect of treatment for root density and shoot biomass after 8 weeks, and for percent green cover (average of 4th and 8th week) in experiment 1 and experiment 2 for St. Augustinegrass.

Experiment	**Treatment**	**Root density**	**Shoot biomass**
		---kg/m^3---	---kg/m^2---
1	Ambient	58.193 a	3.448 a
	shade	16.987 b	2.522 b
2	Ambient	26.631 a	2.132 a
	shade	7.818 b	1.096 b

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 23. Interaction of treatment with genotypes of St. Augustinegrass for root density after 8 weeks during experiment 2.

Treatment	**Genotypes**	**Root density** kg/m^2
Ambient	DALSA 1404	16.482 dc
	DALSA 1405	38.496 a
	DALSA 1618	21.808 bc
	TamStar	29.754 ab
Shade	DALSA 1404	7.546 d
	DALSA 1405	6.295 d
	DALSA 1618	7.410 d
	TamStar	10.020 dc

*Means within columns followed by the same letters are not statistically different at P=0.05.

CHAPTER III

MORPHOLOGICAL RESPONSE OF TWO WARM-SEASON TURFGRASS SPECIES TO NEUTRAL DENSITY SHADE

ABSTRACT

Low light conditions induce shade avoidance responses in plants causing morphological changes which are undesirable for turfgrass aesthetic quality and plant health. A greenhouse experiment was conducted to examine the effect of varying shade intensities on canopy morphology of St. Augustinegrass (*Stenotaphrum secundatum*) and hybrid bermudagrass (*Cynodon sp.*). Six St. Augustinegrasses and five hybrid bermudagrasses were evaluated for their shade avoidance responses to four levels of shade. Grasses were established as plugs within 20 cm long growth tubes made from capped sections of 10 cm diameter PVC pipe. The grasses were maintained under ambient greenhouse conditions for six weeks before implementing the shade treatments for eight weeks using a black poly-woven fabric to reduce the photosynthetic photon flux by 0, 30, 60 and 90% of the ambient conditions. Leaf elongation rate was measured weekly during the shade period. The leaf area index (LAI), specific leaf area(SLA), leaf area ratio (LAR), leaf weight ratio (LWR), relative water content (RWC), leaf angle and leaf width were measured at the end of eight weeks of shade treatment. Significant differences were observed in morphological parameters which varied with the relative shade resistance of the genotypes

within species. The genotype by treatment interaction was not significant for most of the parameters suggesting that most grasses responded in a similar manner to shade but that genetic behavior in their growth habit had a stronger influence on apparent resistance. ‘ST-5’ (TifGrand®) had the highest LAI, SLA, LWR, LAR amongst the bermudagrasses, which suggests leafiness contributes to its shade resistance. Amongst the St. Augustinegrasses, DALSA 1618 and 1329 maintained the lowest canopy elongation rates and highest LAI, SLA, and LWR. Leaf RWC and leaf angle did not appear to be useful in predicting sensitivity to shade in any of the species. Shade treatment did not seem to have a significant effect on the genotypes which reflects that the apparent resistance of the grasses was mostly influenced by the genetic response as opposed to genetic by environment responses.

INTRODUCTION

Beard (1997) estimated that 20 to 25% of cultivated turfgrass encounters shade. Low light environments caused by shade induce morphological changes in turfgrasses, negatively impacting its growth and aesthetic quality, which results in reduced stand density, enhanced leaf elongation, and reduced rooting (McBee & Holt, 1966; Van Huylenbroeck & Van Bockstaele, 2001; Wilkinson & Beard, 1974). While these responses to shade are intended as a defense mechanism in high plant populations, in a mowed turf these responses result in excessive foliage loss, decreased ability to recover from wear, and poor turfgrass quality (Aldahir, 2015). Managing turf under shade requires suitable cultural practices and most importantly the selection of shade resistant species and cultivars (Gardener & Ross, 2013). The design of modern sports stadiums and desire for large mature trees in the landscape are expected to increase the frequency and severity of shade in managed turf, which suggests increased selection and use of shade resistant grasses is needed to improve sustainability of the turf industry (Tegg & Lane, 2004). Ghimire et al. (2016) reported that consumers’ expressed strong preference for shade resistant varieties suggesting development of this trait would be marketable.

Shade stress occurs when light is blocked by a nearby building, cloud cover, or tree canopy, thereby reducing the quantity of photosynthetic photon flux (PPF) available to the plant and in some instances changing the spectral quality of light. Such change in light quantity and quality results in photo-morphogenic responses in plants, which are mediated through specialized photoreceptors such as phytochromes (Gautier et al., 1999; Stuefer & Huber, 1998). This change in canopy morphology is often termed shade avoidance syndrome (Smith & Whitelam, 1997) and is largely attributed to increased gibberellins resulting in stem elongation and reduction in stem diameter (McBee & Holt, 1966; Tan & Qian, 2003). Shade avoidance syndrome results in carbohydrates being partitioned preferentially to the developing leaf tissue (Pierik & De Wit, 2014), which in the case of turf is quickly removed through mowing. Under shaded conditions, increasing the mowing height is standard practice to increase the leaf area retained, resulting in increased carbon assimilation (Beard, 1973; Dudeck & Peacock, 1992). There is a normal decreasing light gradient from the tip of the leaf to the base, and photosynthetic rates follow this same pattern and frequent mowing eliminates the most photosynthetically active leaf region (Prioul et al., 1980). Turfgrass leaves become more vertically oriented as a result of repeated mowing, requiring more light to reach their light compensation point (Beard, 1973). Increased mowing heights, on the other hand, can have a negative effect on turfgrasses by increasing respiration rates, increasing inter-shading of the turfgrass canopy, reducing leaf evaporation, and reducing resistance to traffic stresses (Beard, 1973; Gardner & Goss, 2013). Differences in shade resistance have been reported by many researchers at the inter-specific level. Barrios et al. (1986) identified ‘Oklawn’ centipede (*Erernochloa ophiuroides* (Munro) Hack.) to be more shade resistant than ‘Floratam’ St. Augustinegrass. McBee and Holt (1966) studied bahiagrass, St. Augustinegrass, zoysiagrass and bermudagrass for their relative shade resistance and identified ‘No-Mow’ bermudagrass as better than St. Augustinegrass followed by additional varieties of bermudagrass, bahiagrass (*Paspalum notatum*), and zoysiagrass. Similarly, Jiang et al. (2004) considered seashore paspalum cultivars to be more shade resistant as compared to bermudagrass cultivars. Intra-specific differences have also been observed by Trenholm and Nagata (2005) in cultivars of St. Augustinegrass showing 'Seville and '1997-6' to be shade resistant entries while 'Floratam' as shade sensitive on the basis of visual quality. Schwartz et al. (2020) studied the performance of 'Tifway' and 'ST-5' (hereafter referred to as TifGrand®) under shade and observed better turf quality of the latter at low light conditions. Similarly, 'Riley's Super Sport' and 'TiftNo.2' were identified as more shade resistant than other bermudagrasses as they had greater root biomass and root length (Baldwin et al., 2007).

Turfgrasses which maintain relatively lower vertical growth rates under shade are often associated with superior shade resistance. Tegg and Lane (2004) observed a small increase in vertical shoot elongation rate for supine Bluegrass (*Poa supina* Schrad.), indicative of shade resistant response, whereas relatively large increases for Kentucky bluegrass were indicative of shade sensitivity. A study by Wherley et al. (2013) showed differences among St. Augustinegrasses wherein 'Amerishade' (1.5 mm d^{-1}) and 'Captiva' (3.6 mm d^{-1}) had significantly lower elongation rates than 'DelMar', 'Palmetto', and 'Raleigh' under heavy shade. The authors suggested reduced leaf extension of St. Augustinegrass as a shade resistance mechanism for the species (Bronsan & Deputy, 2008; Wherley et al., 2013). More recently, Meeks & Chandra (2021) reported that shade resistant St. Augustinegrasses demonstrated greater leaf extension rates than shade sensitive entries suggesting further exploration of this trait is warranted.

Understanding how canopy morphology influences shade response of resistant genotypes within a species may be contribute to more efficient selection and improvement of the shade resistance trait. The major goal of this study was to quantify the avoidance mechanisms and growth patterns of warm-season turfgrasses under shade in order to identify key traits that contribute to shade resistance within these species.

OBJECTIVE

To characterize the morphological response of St. Augustinegrass and bermudagrass genotypes grown under varying neutral shade environments.

HYPOTHESIS

- Grasses deemed to be shade resistant will have lower leaf elongation rates, lower specific leaf area, higher leaf area index and wider leaf angles under shade.
- Shade resistant grasses will show higher root density and greater shoot biomass as compared to sensitive grasses.

MATERIAL AND METHODS

This study was conducted at the Oklahoma State University Horticultural Research Greenhouse Complex, Stillwater, OK. The first experiment was conducted from June 12, 2020 to September 30, 2020 (hereafter referred to as experiment 1) and second experiment from October 5, 2020 to March 14, 2021 (hereafter referred to as experiment 2). The average minimum and maximum temperature were 12°C and 32°C during the study. Four 400-watt HPS ballasts (High Pressure Sodium) (Rudd Lighting Inc., Racine, WI), one over each treatment and control, were used for 14 hours a day to compensate for the decreased available light and to fulfill the minimum light requirements for the grasses, which resulted in an average daily light integral of 26.86 µmol m^{-2} d^{-1} during experiment 1 while 20.34 µmol m^{-2} d^{-1} during experiment 2. The average daily temperature was 30.72℃ during experiment 1 and 14.61℃ during experiment 2.

The experimental design for each experiment was a modified split plot design having four replications of each treatment combination (genotype × shade treatment). Genotypes of each species were selected on the basis of previous field studies to create a gradient of shade resistance (Fontanier, personal communication). The St. Augustinegrasses were DALSA 1329 (shade resistant), DALSA 1404 (shade resistant), DALSA 1618 (shade resistant), DALSA 1405 (moderately resistant), DALSA 1403 (shade sensitive) and 'TamStar' (shade sensitive), and the hybrid bermudagrasses were TifB16108 (shade resistant), TifGrand (shade resistant), TifB16117 (moderately resistant), TifB16119 (shade sensitive) and Tifway (shade sensitive). The experimental units were shaded using a poly-woven fabric nominally rated to reduce PPF by 30%, 60% and 90% of ambient conditions. Grasses were also grown under ambient greenhouse conditions as a control. The shade fabric was mounted over PVC frame measuring 150 cm × 150cm × 120cm. Supplemental lighting was used in addition to natural light to increase light quantity and standardize day length over the duration of the experiments.

Growth tubes were created by capping 20 cm long sections of PVC pipe and filling with a peat-based media (Metro-Mix® 36, Sun Gro Horticulture). Tubes were 10 cm in diameter for both hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) and St. Augustinegrass (*Stenotaphrum secundatum*). Genotypes were planted as plugs and allowed to establish within the greenhouse for 6 weeks. Plants were fertilized with a commercial biosolids product (6N-2P_2O_5-0K_2O, Harrell's, Lakeland, FL) at a rate of 48 kg ha^{-1} N at planting and subsequently 4 weeks later. During the shade treatment period, Liquid fertilization was applied using 20N-20P_2O_5-20K_2O soluble fertilizer (Jr Peters Inc., Allentown, PA) at the rate of 146 kg ha^{-1} in split doses (36.6 kg ha^{-1} per week) at weekly intervals. Plants were fertilized with a natural fertilizer (6-2-0, Milorganite Classic, Harrell's, Lakeland, FL) at a rate of 48 kg of N ha^{-1} at 0 and 4 weeks after planting. Preventative applications of two different insecticide mixtures were made in rotation at an interval of 15 days to control chinch bugs (*Blissus insularis* Barber), Rhodesgrass mealybugs (*Antonina graminis*), and bermudagrass mites (*Eriophyes cynodoniensis* Sayed). In the first week a mixture of bifenthrin (Talstar P, 7.9% a.i., FMC corp., Philadelphia, PA) at 1.6 L ha^{-1}, abamectin (Avid 0.15 EC, 2% a.i.) (Syngenta, Greensboro, NC) at 0.127 L ha^{-1}, and Prefer 90 Surfactant at 0.127 L ha^{-1} was used and next application was done with imidacloprid (Mallet® 2F

T&O, 21.4% a.i.) (Nufarm, Melbourne, Australia) at the rate of 2 L ha^{-1}. Applications of azoxystrobin (Heritage, 22.93% a.i.) (Syngenta, Greensboro, NC) at 32 L of product ha^{-1} and tebuconazole (Torque, 38.7% a.i., Nufarm, Melbourne, Australia) at 3.18 L ha^{-1} were made every other week to control grey leaf spot (*Pyricularia grisea*) and large patch (*Rhizoctonia solani*). Grasses were clipped once per week at 2cm and 8 cm for bermudagrasses and St. Augustinegrass, respectively. Plants were hand-watered daily to prevent drought stress.

Normalized Canopy Elongation Rate (CER)

The grasses were clipped weekly to maintain minimum mowing heights of 0.75 in. for bermudagrass and 3 in. for St. Augustinegrass. Vertical leaf extension was measured from the soil line to the tip of the two longest leaves in each pot, and the daily canopy elongation rate (CER) was calculated by dividing by the number of days between mowing events. The CER data were normalized (NCER) by dividing each shaded experimental unit with the CER under ambient conditions for specific genotype in a replication.

Canopy Morphological Traits

Mowing of grasses was withheld during the final week of each study (8 WAT) for measurement of canopy morphology. Ten shoots were randomly selected from the middle portion of each pot, and leaf (lamina) and pseudostems were separated. Subsequently, all the leaves were placed on a plain white sheet marked with a ruler. The leaves were pressed against the sheet completely using a clear acrylic plate, and an image was taken using a digital camera (Powershot G5; Canon, Tokyo, and Japan) mounted on a stand under ambient light conditions in the lab. The images were then analyzed using a custom macro in ImageJ 1.52a software (National Institute of Health, USA) to measure green area after calibrating with the ruler in the image. The leaf count per shoot and the leaf widths were calculated using 'Analyze particles' option in Image J. The leaves used for measuring leaf area were dried in an oven for 48 hours at 80° C and weighed. The remaining leaves and stems were dried in an oven for 48 hours at 80° C and weighed. The leaf canopy fraction (LCF) in relation to the total canopy weight was calculated as

$$LCF = \frac{leaf\ weight\ (g)}{canopy\ weight\ (g, leaf\ weight\ +\ pseudostem\ weight)}$$

Specific leaf area (SLA) was calculated as the ratio of leaf area to the leaf dry weight using the following formula:

$$SLA = \frac{leaf\ area(m^2)}{leaf\ dry\ weight\ (kg)}$$

After collecting the sub-sample, the remainder of the canopy (leaves and pseudostems) was harvested and dried in an oven for 48 hours at 80°C and weighed. The canopy yield was calculated as the ratio of whole shoot weight (including the sub-sample weight) to the total area (81 cm^2) of the pot (Wolf et al., 1972). Leaf area index (LAI) was calculated using the following formula:

$$LAI = canopy\ yield\ (kg/m^2) \times LCF \times SLA\ (m^2/kg)$$

The roots, rhizomes, and stolons were harvested separately and dried in an oven for 48 hours at 80°C and weighed. This weight plus the canopy dry weight constituted the whole plant dry weight. Leaf weight ratio (LWR) was calculated using the following formula (Kvet et al., 1971):

$$LWR = \frac{leaf\ dry\ weight\ (kg)}{whole\ plant\ dry\ weight\ (kg)}$$

Leaf area ratio (LAR) was calculated using the following formula (Radford, 1967):

$$LAR = \frac{total\ leaf\ area(cm^2)}{whole\ plant\ dry\ weight\ (kg)}$$

Leaf angle was measured between the pseudostem and the leaf blade of the 2nd or 3rd fully expanded leaf on the already selected 10 shoots. The shoots were first excised from the pot and an image collected using the method described for leaf area. The angle was manually measured for each shoot using the measure angle tool within ImageJ 1.52a software.

Relative Water Content (RWC)

Ten leaves were randomly selected from the middle portion of each pot for relative water content analysis. Leaves were weighed individually for determining fresh weight (FW) and then immersed in water for 24 hours until fully hydrated under room temperature. After hydration, the samples were taken out and dried off any surface moisture lightly by using filter paper and weighed again for determining turgid weight (TW). The samples were then oven dried for 48 hours at 80℃ and weighed for the third time after to determine the dry weight (DW). The percentage relative water content (RWC) was calculated by using the formula:

$$RWC\ (\%)\ =\ [(FW - DW)\ /\ (TW - DW)]\ \times\ 100.$$

Statistical Analysis

Data were analyzed separately by species. The study was arranged as a modified split plot design with four replications of each combination of genotype and shade treatment, and the entire experiment was repeated in time. A combined analysis was done for both experimental runs using Statistical Analysis System (Version 9.4; SAS Institute Inc., Cary, NC), and all data were subjected to PROC GLIMMIX with means separated using Fisher's protected least significant difference (α=0.05). For the CER and NCER data, a repeated measures model was used to test the effects over time.

RESULTS

Bermudagrass

Canopy elongation rate of bermudagrass showed a significant genotype × treatment interaction (Table 1). At 0%, 30% and 60% shade treatments, TifB16119 showed the highest CER amongst all the genotypes except for TifB16117 under 60% shade, while no significant differences were observed under 90% shade. TifB16117 showed a significantly higher CER in 60% and 90% shade as compared to the control (Figure 2).

A significant genotype × week interaction was observed for NCER (Table 2). TifB16117, Tifway, and TifGrand had significantly higher NCER as compared to TifB16119 at 1 and 2 WAT (Figure 3). Subsequently, there were no differences among genotypes until 6 WAT, when TifGrand showed the highest NCER amongst all genotypes.

The shade main effect was significant for SLA, leaf width, LWR, shoot biomass, root biomass, and leaf count per shoot. The genotype main effect was significant for LAI, SLA, LAR, LWR, leaf angle, shoot and root biomass, and leaf count per shoot (Table 3).

Shade generally increased SLA from 22.8 to 30.0 $m^2 kg^{-1}$ for 0% and 90% shade treatments, respectively (Table 5). The 60% and 90% shade treatments also reduced leaf width, shoot biomass, and root biomass compared to the control. Only the 90% shade reduced leaf count per shoot compared to the control.

TifB16117 and TifB16119 had lower LAI than each other genotype (Table 4). Similarly, TifB16117 had the lowest SLA compared to other genotypes. TifGrand demonstrated the greatest LAR and LWC among genotypes. Leaf angle was smallest for TifB16119, followed by TifB16108, which was less than other genotypes (Table 4). TifB16119 had the largest leaf width (0.104 cm) while TifB16108 (0.075 cm) had smaller leaf widths than TifGrand but similar widths to other genotypes (Table 4). TifGrand had a greater leaf count per shoot than other genotypes except Tifway.   TifB16119 had less shoot biomass than other genotypes except TifB16117. TifB16108 had the largest root biomass, while TifGrand had the lowest root biomass, resulting in the smallest root: shoot ratio.

St. Augustinegrass

For St. Augustinegrass, CER showed a significant genotype × treatment interaction (Table 6). Grasses under 0%, 30%, and 60% shade showed no difference in their elongation rates while under 90% shade, DALSA 1329 had significantly lower CER as compared to DALSA 1403 (Figure 4). Similarly, DALSA 1329 was the only genotype in which shade did not increase CER compared to the control. For NCER, there were significant treatment × week and genotype × week interactions (Table 7). The treatment × week interaction demonstrated minimal increases in NCER under 30% shade, while NCER under 60% and 90% shade showed sharp increases by 2 WAT before each shade treatment resulting in similar NCER by 4 WAT (Figure 6). DALSA 1403 was greater than TamStar at 2 WAT, while TamStar showed greater NCER than DALSA 1403 and 1404 at 4 WAT.

The treatment main effect showed an increase in the SLA with decreasing light intensity ranging from 25.762 to 33.848 m^2kg^{-1} for the 0% and 90% shade treatments, respectively. Shoot biomass decreased from ambient (9.072 g) to the 90% shade treatment (4.584 g).

There was a significant treatment × genotype interaction for LAR and root biomass, while each parameter except for leaf count per shoot had a significant genotype main effect (Table 8). DALSA 1403 had a smaller LAI than other genotypes except TamStar, the widest leaf angle amongst all other genotypes, and a lower leaf RWC than other genotypes except DALSA 1405 and 1618 (Table 9). DALSA 1618 had the largest leaf width (0.70 cm), while all other genotypes were similar to each other. TamStar had a lower LWR than other genotypes except for DALSA1404. Shoot biomass was lowest for TamStar, although not significantly different from

DALSA 1403. Root: shoot ratio was highest for TamStar and DALSA 1404, while no significant differences were observed in any of the other genotypes.

The two-way interaction for LAR showed differences among genotypes only were present for the 90% shade treatment, wherein TamStar had lower LAR as compared to DALSA 1329 and DALSA 1405 (Figure 7). Similarly, each shade treatment increased LAR for DALSA 1329 compared to the control, and LAR was greater for DALSA 1405 in the 30% and 90% shade treatments. Shade reduced root biomass but the effect was only significant for DALSA 1329, 1404, and 1405 (Figure 8).

Correlation among morphological parameters

Bermudagrass

Linear correlation analysis was performed to assess interdependence of derived morphological parameters. The greatest correlation was observed between LWR and LAR ($r = 0.84$), which was consistent with the analysis of variance (Table 10). Increased LAR of TifGrand could be related to higher LWR, rather than higher SLA, considering a relatively lower correlation of LWR with SLA ($r = 0.501$). LWR was negatively correlated with root: shoot ratio ($r = -0.696$) and positively correlated with shoot biomass ($r = 0.627$), whereas both RWC and leaf count per shoot were not strongly correlated to any of the tested parameters. Despite a strong correlation between LAI and leaf width ($r = 0.624$) and LAI and shoot biomass ($r = 0.792$), the relationship between leaf width and shoot biomass found out to be relatively weaker ($r = 0.454$), although still statistically significant ($p < 0.001$) (Table 10).

St. Augustinegrass

The highest correlation was observed between LWR and LAR ($r = 0.900$), which was again consistent with the univariate statistics. LAR had a higher correlation with LWR than SLA ($r = 0.685$) (Table 12). Both LWR and LAR were negatively correlated with root biomass ($r = -0.623$,

-0.669 respectively) and subsequently to root: shoot ratio (r = -0.774, -0.726). LAI also showed a positive correlation to shoot biomass (r = 0.799), LAR (r = 0.654) and LWR (r = 0.693), but the relationship between LAR and shoot biomass was relatively weaker (r = 0.257), although still statistically significant ($p < 0.001$) (Table 12).

Canonical Discriminant analysis

Bermudagrass

Canonical discriminant analysis resulted in 8 statistically significant functions (variates), out of which two had eigenvalues greater than or approaching 1.0. The first variate explained 39.6% of the variance and the second variate explained 28.4% of the variance, and therefore 68% of the total variance was explained by the first two functions (Table 11). Canonical loadings describe how well the original canopy parameters correlate with the function variate scores. The first variate demonstrated high positive loadings for leaf angle (0.940) and LAR (0.416), while high negative loadings for leaf width (-0.970) compared to other parameters. In contrast, the second variate had high positive loadings for count of leaves per stem (0.845) and leaf width (0.625) and higher negative loadings for LAR (-0.732), RWC (-0.306), and root: shoot ratio (-0.705) (Table 11).

Graphical examination of multivariate space indicated genotypes clustered together closely along the x-axis suggesting Function 1 largely identified traits that differentiated genotypes. TifB16119 demonstrated a large negative score for Function 1, which can be attributed to a low leaf angle and LWR and a large leaf width, while TifGrand showed a large positive score for Function 1, in part due to a high LWR. TiGrand was most closely located to Tifway, which is surprising considering the differences in their shade resistance. This suggests factors other than morphology (e.g., light use efficiency) can drive shade resistance within the species.

Function II largely discriminated the shade response with increasing scores corresponding to increasing light availability. Based on loadings, lower Function 2 scores are indicative of a leafier canopy corresponding to higher LAR and lower root: shoot ratios. Surprisingly, most genotypes did not vary in these shade responses with the exception of the shade sensitive TifB16119 which demonstrated minimal variation in Function 2 regardless of shade severity.

St. Augustinegrass

Two out of eight statistically significant functions had eigenvalues greater than 1.0 which explained 45.4% and 31% of the variance (Table 13). Function I demonstrated high negative loadings for leaf width (-0.941) and positive loadings for SLA (1.468). Function II demonstrated high positive loadings for SLA (2.001), RWC (0.607), LWR (2.846), and root: shoot ratio (0.864) while high negative loadings for LAR (-3.237) (Table 13).

Examination of the multivariate space showed Function I primarily discriminated responses by shade severity with increasing scores associated with decreasing light availability (Figure 10). Most genotypes were located close to the abscissa regardless of shade severity with the exception of shade sensitive DALSA 1403, which demonstrated a low score for Function 2. Otherwise, there were no clear patterns associated with apparent shade resistance.

DISCUSSION

Bermudagrass

Increased shoot elongation is a shade avoidance mechanism, which enhances the competitiveness of plants by increasing leaf area and ability to intercept light. In a turfgrass system, this response has historically been viewed as negative since regular mowing would reduce photosynthate more quickly. Shade resistance has been characterized by low rates of increase in vertical shoot elongation in the shade (Tegg & Lane, 2004). Results from the present study are generally in agreement with Tan and Qian (2003) who observed that reducing light intensity from 52 to 13%

on three different Kentucky bluegrass (*Poa pratensis* L.) cultivars increased shoot elongation by 33% for 'Kenblue Times', 32% for 'Livingston', and 26% for 'NuGlade'. However, not all genotypes performed similarly in displaying a strong shade avoidance response. TifB16117 had an increased NCER during 60% and 90% shade as compared to ambient conditions. On the other hand, TifB16119 (shade sensitive) had a relatively large baseline CER, but did not vary with shade treatment suggesting an inherently faster growing habit and lack of sensitivity to shade under the provided growing conditions. Thus, the theory that shade resistance is related to lack of a shade avoidance response may not be true for all bermudagrasses.

Larger LAI promotes light absorption by the leaves. Plants able to maintain LAI under shade would presumably be better able to maintain a positive carbon balance. Healey et al. (1998) observed a decrease in LAI in *Panicum maximum* cv. Petrie (green panic) and *Bothriochloa insculpta* cv. Bisset (creeping bluegrass) under 25% shade. The lack of a shade treatment effect on LAI suggests increasing SLA and leaf length may be able to compensate for reductions in leaf count per shoot. Larger SLA under low light is regarded as an acclamatory characteristic, as it increases the chance of receiving light per unit of leaf mass (Gong et al., 2015). Plants that are grown in low light tend to increase SLA by expanding their leaf area to capture more light (Reich et al., 1998a).

Leaf weight ratio has been reported to decrease in shade sensitive *Phalseolus vulgaris* L. plants when grown under shaded conditions (Hadi et al., 2006). Shade resistant plants have the ability to maintain a constant LWR over a range of light intensities as an indication of normal plant development patterns (Hadi et al., 2006). In the present study, each genotype responded similarly by reducing LWR with moderate and severe shade conditions. TifB16108 demonstrated a growth habit which favored root production resulting in relatively low LWR, despite a high LAI and SLA. In contrast, TifGrand had the highest LWR and LAR suggesting a leafier canopy. Ericksen and Whitney (1981) found the leafiness index (i.e., LAR) increased under reduced light intensity.

Similar results were observed in soybean (*Glycine max*) by Gong et al. (2015) due to shade in intercropping. Hadi et al. (2006) observed increasing LAR with increasing shade and suggested it to be a result of increasing SLA. Similar results were observed by Loach (1969) in *L. tulipifera*, wherein he observed an increase in LAR under shade but again attributed it to increased SLA rather than LWR.

Leaf angle is an important plant characteristic for distribution of light in canopy. Horizontal leaves intercept more light in upper layers of canopy resulting in heavy shading of lower leaves. Leaf orientation observations revealed that the leaves of most plants are slanted, some to nearly vertical, in full sun and more nearly horizontal in the shade (McMillen & McClendon, 1979). TifB16108 (shade resistant) demonstrated a relatively horizontal leaf angle but less than TifB16119 (shade sensitive). Similarly, the shade sensitive genotype Tifway and shade resistant TifGrand showed similar leaf angles, suggesting this trait alone may not be useful in predicting sensitivity to shade in bermudagrasses. Similarly, leaf count per shoot did not show consistent relationships with known shade resistances of the selected genotypes.

Wilkinson and Beard (1974) observed a greater shoot weight in red fescue (shade resistant) than Kentucky bluegrass (shade sensitive) under low light conditions, suggesting higher shoot growth under low photosynthetic irradiance as a characteristic of shade resistance. In the present study, the lower shoot biomass for TifB16119 followed by TifB16117 is in agreement with their apparent shade resistance. Baldwin et al. (2008) reported shade reduced root biomass among all bermudagrasses tested, although shade resistant cultivars (Riley’s Super Sport and TiftNo.2) had greater root biomass than shade sensitive cultivars (Arizona Common and GN-1) under shade. In the present study, TifB16108 showed highest root biomass indicating shade resistant behavior. Surprisingly, TifGrand, which maintained a high shoot biomass and was generally of good quality had the lowest root biomass amongst all genotypes. This behavior demonstrated a preference for shoot growth over root growth, suggesting their shade resistance may be related to maintenance of light harvesting tissues when light becomes limiting. In contrast, TifB16108 may derive shade resistance from high light use efficiency or tiller density.

St. Augustinegrass

Wherley et al. (2013) reported differences among St. Augustinegrasses wherein 'Amerishade' (1.5 mm d^{-1}) and 'Captiva' (3.6 mm d^{-1}) had significantly lower elongation rates than 'DelMar', 'Palmetto', and 'Raleigh' under heavy shade. The authors suggested reduced leaf extension of St. Augustinegrass as a shade resistance mechanism for the species (Bronsan & Deputy, 2008; Wherley et al., 2013). In the present study, genotype influenced the elongation response with some grasses showing relatively muted increase in CER (e.g., DALSA 1329 and 1404) while others showed stronger responses (e.g., TamStar and DALSA 1618). Similar to our findings in bermudagrasses, the results suggest vertical elongation may not be a consistent mechanism for shade resistance in this species. These findings are in agreement with recent reports showing minimal elongation for some shade resistant genotypes but also stated that low CER does not necessarily implicate shade resistance, and other shade performance traits should also be taken into account for evaluating resistance of a genotype (Meeks & Chandra, 2021). In the present study, the shade avoidance response for CER was influenced by shade severity as well as the duration of exposure to shade. This could be attributed to diminishing carbohydrate reserves in the plant and likely influences why in some cases a muted avoidance response has been preferable, while others show sustained growth (e.g., ability to sustain carbohydrate production) as a better indicator of shade resistance.

Leaf angle, as was the case for bermudagrass, did not consistently follow any pattern corresponding to known shade resistance. For example, although DALSA 1403 (shade sensitive) had relatively wide leaf angles, while TamStar (also shade sensitive) did not.

The relatively low LAI for DALSA 1403 and TamStar are indicative of their sensitivity to shade and in agreement with previous reports from field environments (Meeks & Chandra, 2021). The general increase in SLA in response to shade is similar to what was observed in bermudagrass. Interestingly, two of the more shade resistant genotypes (DALSA 1329 and 1618) had among the smallest SLA, while the shade sensitive genotype TamStar had the largest. Similarly, Chin (2012) observed better shade resistance for St. Augustinegrass compared to *D. longiflora* and suggested that species better adapted to shade show lower SLA than poorly adapted ones. This decrease might be attributed to sustained biomass production accompanied with lower expansion of leaves

Shade generally increased LAR for shade resistant genotypes (DALSA 1329, 1404, and 1618) although this response was not always statistically significant. In contrast, the more shade sensitive genotypes (DALSA 1403 and TamStar) showed nearly no change in LAR in response to increasing shade. These findings suggest maintenance of a leafy canopy is important for conveying shade resistance. Similarly, the lower shoot weights for TamStar and DALSA 1403 and greater root: shoot ratio for TamStar suggest an inherently productive and leafy growth pattern is preferred for shade resistance in St. Augustinegrass.

CONCLUSION

Genetic differences in morphology had a stronger influence on apparent resistance than their response to shade itself. TifB16108 had a higher LAI but lower LWR and LAR which suggested resistance was derived from maintenance of tiller density. Canonical discriminant analysis suggested leaf width, LAR, root: shoot ratio as morphological factors which best differentiated bermudagrass genotypes, while leaf width, LWR, LAR and root: shoot ratio were best for distinguishing among St. Augustinegrass genotypes. Morphological parameters provide insight into how genotypes avoid mowing stress under shaded turf systems. However, resistance of a genotype depends on both physiological tolerance and morphological adaptation to shade and can be better explained by combining their physiological and morphological adaptations in shade.

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Tables and figures

Table 1. Analysis of variance for canopy elongation rate in bermudagrass.

Source	**CER**
Treatment (T)	NS
Genotype (G)	***
Week (W)	***
G*T	***
G*W	***
T*W	*
G*T*W	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

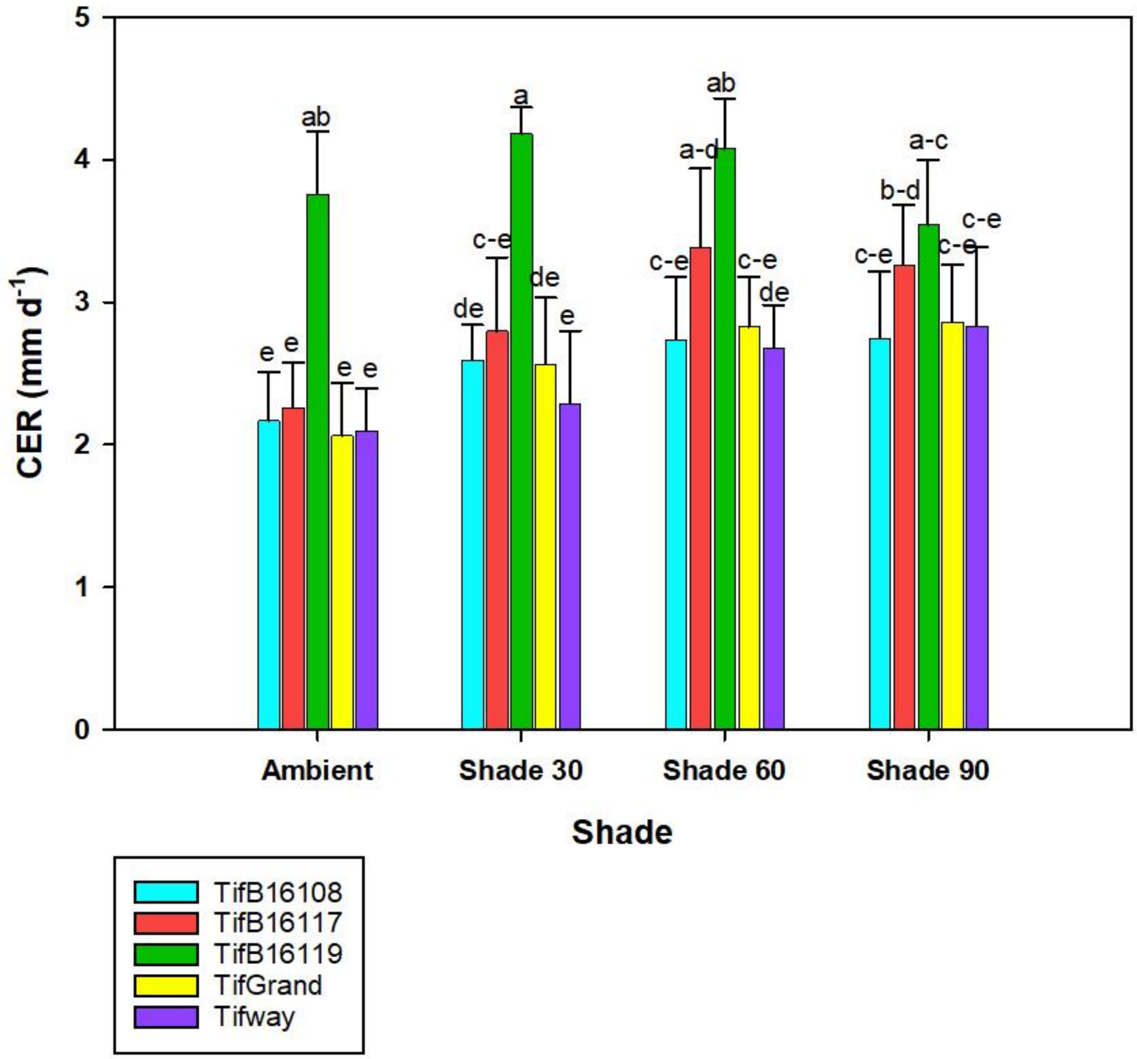

Figure 2. Canopy Elongation Rate (mm d^{-1}) for various genotypes of bermudagrass at ambient conditions and different shade treatments averaged for 6 weeks.

Means with the same letter are not significantly different at P=0.05.

Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

Table 2. Analysis of variance for percent change in canopy elongation rate from control in bermudagrass.

Source	**NCER**
Treatment (T)	NS
Genotype (G)	***
Week (W)	***
G*T	NS
G*W	***
T*W	NS
G*T*W	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

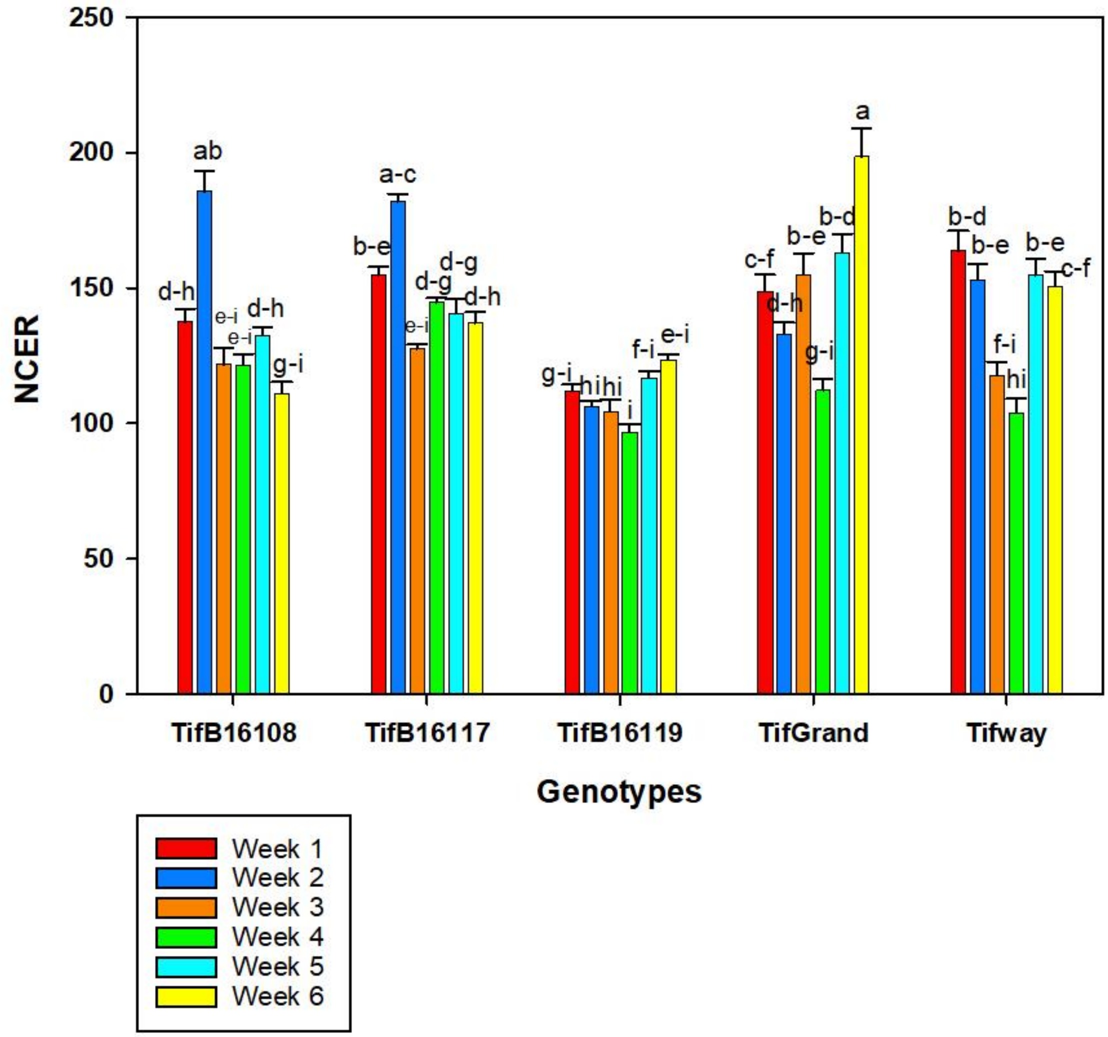

Figure 3. Normalized Canopy Elongation Rate (NCER) (mm d^{-1}) representing percent change in CER from control for various genotypes of bermudagrass for 6 weeks averaged for 30, 60 and 90% shade.

Means with the same letter are not significantly different at P=0.05.

Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

Table 3. Analysis of variance for LAI (Leaf Area Index), SLA (Specific Leaf Area), RWC (Relative Water Content), LAR (Leaf Area Ratio), LWR (Leaf Weight Ratio), leaf angle, shoot biomass, root biomass, root: shoot ratio and count of leaves per stem for bermudagrass.

Source	LAI	SLA (m^2g^{-1})	RWC	LAR (m^2g^{-1})	LWR	Leaf Angle	Leaf width (cm)	Shoot biomass (g)	Root biomass (g)	Root/ shoot biomass	Count of leaves per stem (No.)
Genotype (G)	***	**	NS	*	*	***	***	*	***	***	*
Treatment (T)	NS	**	NS	NS	*	NS	***	*	*	NS	*
G*T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

Table 4. Main effect of Genotypes of bermudagrass on LAI (Leaf Area Index), SLA (Specific Leaf Area), LWR (Leaf Weight Ratio), LAR (Leaf Area Ratio), leaf angle, shoot biomass, root biomass, and count of leaves per stem.

Genotypes	LAI	SLA (m^2kg^{-1})	LWR	LAR (m^2kg^{-1})	Leaf angle	Leaf width (cm)	Shoot biomass (g)	Root biomass (g)	Root/ shoot biomass	Count of leaves per stem (No.)
TifB16108	2.662 a	27.130 a	0.036 c	0.956 b	115.01 b	0.075 c	1.846 a	21.123 a	12.771 a	3.044 c
TifB16117	2.004 b	21.542 b	0.045 bc	0.937 b	126.24 a	0.081 bc	1.644 ab	16.567 b	12.02 a	3.14 bc
TifB16119	2.049 b	25.596 a	0.045 bc	1.124 b	109.44 c	0.104 a	1.397 b	13.277 c	10.56 ab	3.27 bc
TifGrand	2.767 a	28.628 a	0.074 a	2.362 a	129.74 a	0.088 b	1.842 a	9.525 d	7.449 c	3.468 ab
Tifway	2.702 a	27.763 a	0.051 b	1.356 b	128.03 a	0.083 bc	1.755 a	15.5 bc	9.376 bc	3.765 a

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 5. Main effect of treatments on SLA (Specific Leaf Area), LWR (Leaf Weight Ratio), shoot biomass, root biomass, and count of leaves per stem in bermudagrass.

Treatment	SLA (m^2g^{-1})	LWR	Leaf width (cm)	Shoot biomass (g)	Root Biomass (g)	Count of leaves per stem (No.)
Ambient	22.779 c	0.054 ab	0.094 a	2.586 a	22.151 a	3.802 a
30% shade	24.846 bc	0.059 a	0.091 a	2.031 ab	14.670 b	3.550 a
60% shade	28.329 ab	0.042 c	0.080 b	1.194 bc	13.977 b	3.270 ab
90% shade	29.897 a	0.045 bc	0.079 b	0.980 c	9.675 b	2.720 b

*Means within columns followed by the same letters are not statistically different at P=0.05.

Table 6. Analysis of variance for canopy elongation rate in St. Augustinegrass.

Source	CER
Treatment (T)	NS
Genotype (G)	***
Week (W)	***
G*T	*
G*W	NS
T*W	***
G*T*W	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

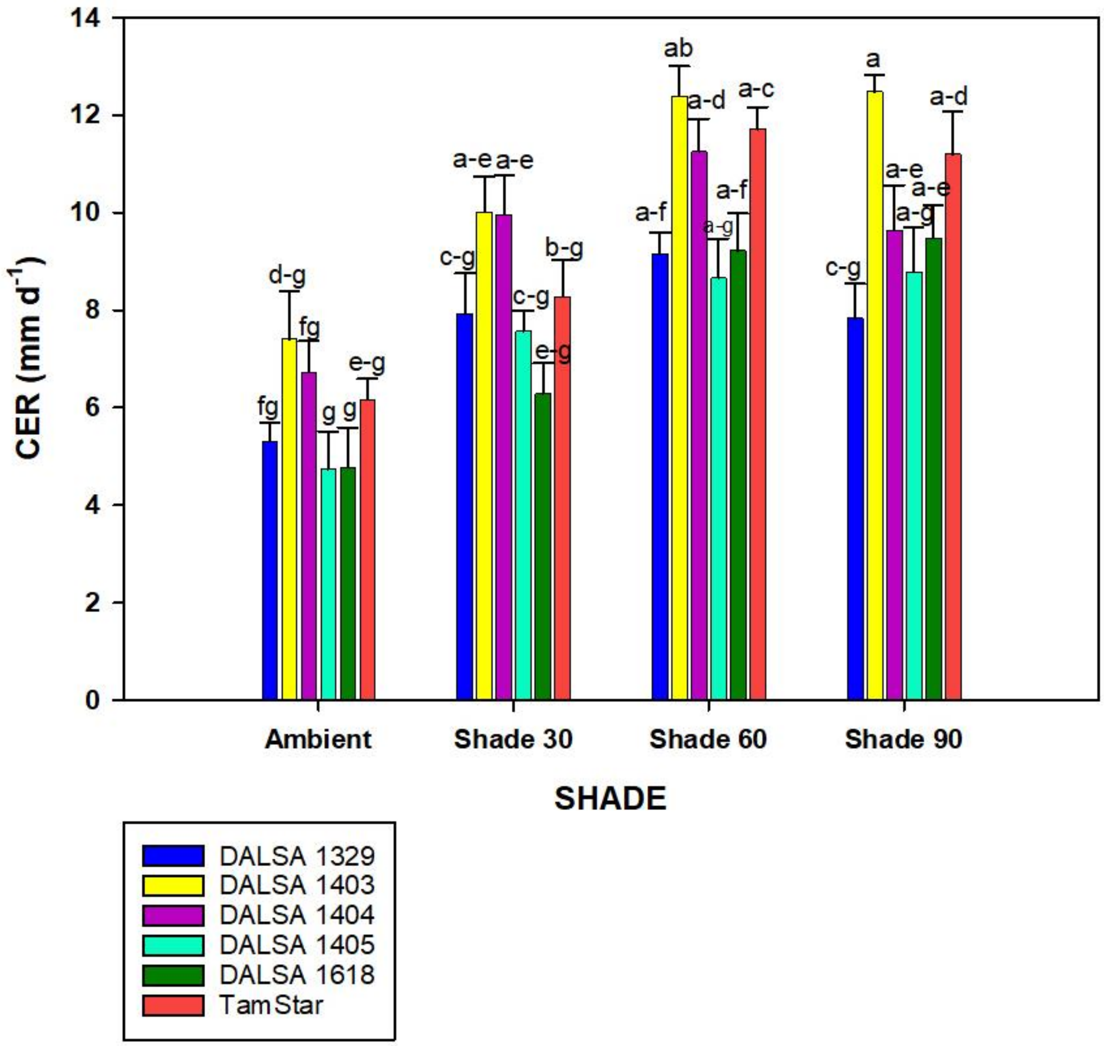

Figure 4. Canopy Elongation Rate (mm d^{-1}) for various genotypes of St. Augustinegrass at ambient conditions and different shade treatments averaged for 6 weeks.

Means with the same letter are not significantly different at P=0.05.

Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

Table 7. Analysis of variance for percent change in canopy elongation rate from control in St. Augustinegrass.

Source	**NCER**
Treatment (T)	NS
Genotype (G)	**
Week (W)	***
G*T	NS
G*W	**
T*W	*
G*T*W	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant.

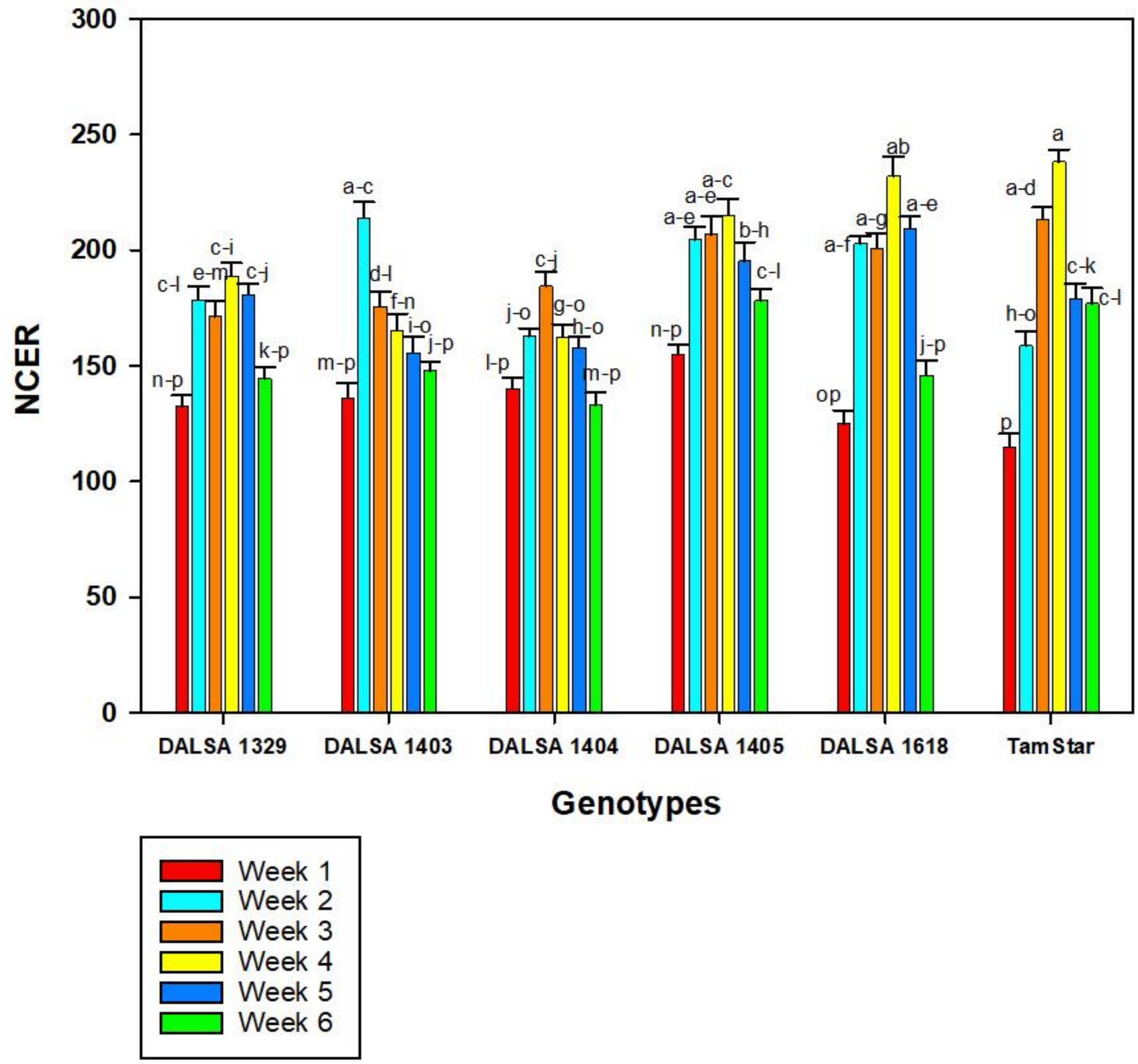

Figure 5. Normalized Canopy Elongation Rate (NCER) (mm d^{-1}) representing percent change in CER from control for various genotypes of St. Augustinegrass for 6 weeks averaged for 30, 60 and 90% shade.

Means with the same letter are not significantly different at P=0.05.

Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

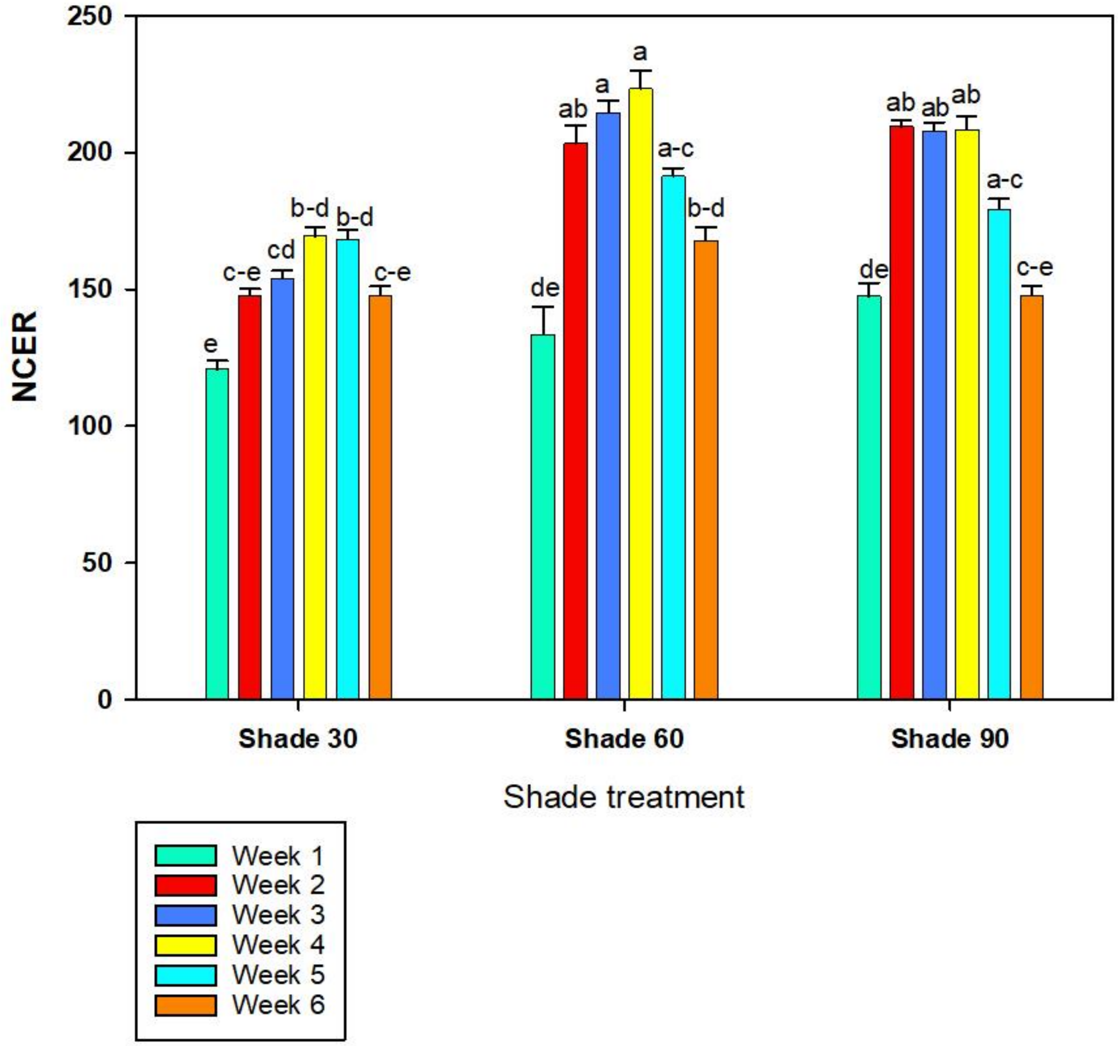

Figure 6. Normalized Canopy Elongation Rate (NCER) (mm d^{-1}) representing percent change in CER from control for different shade treatments for six weeks averaged for St. Augustinegrass genotypes.

Means with the same letter are not significantly different at P=0.05.

Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

Table 8. Analysis of variance for LAI (Leaf Area Index), SLA (Specific Leaf Area), RWC (Relative Water Content), LAR (Leaf Area Ratio), LWR (Leaf Weight Ratio), leaf angle, shoot biomass, root biomass, and count of leaves per stem for St. Augustinegrass.

Source	LAI	SLA (m^2kg^{-1})	RWC	LAR (m^2kg^{-1})	LWR	Leaf width (cm)	Leaf Angle	Shoot biomass (g)	Root biomass (g)	Root/ shoot biomass	Count of leaves per stem
Genotype (G)	***	*	*	**	*	**	***	*	*	*	NS
Treatment (T)	NS	*	NS	NS	NS	*	NS	*	NS	NS	NS
G*T	NS	NS	NS	**	NS	NS	NS	NS	*	NS	NS

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant

Table 9. Main effect of Genotypes of St. Augustinegrass on LAI (Leaf Area Index), SLA (Specific Leaf Area), RWC (Relative Water Content), LWR (Leaf Weight Ratio), leaf angle, and shoot biomass.

Genotypes	LAI	SLA (m^2kg^{-1})	RWC	LAR (m^2kg^{-1})	LWR	Leaf width (cm)	Leaf angle	Shoot biomass (g)	Root/ shoot biomass
DALSA 1329	11.876 ab	28.801 c	94.24 ab	49.016 ab	0.167 ab	0.531 b	130.22 c	6.812 ab	2.775 b
DALSA 1403	9.509 c	29.228 bc	90.43 c	49.523 ab	0.153 bc	0.520 b	144.34 a	6.086 bc	2.151 b
DALSA 1404	12.542 a	29.773 bc	94.51 a	43.184 b	0.135 cd	0.568 b	133.27 b	6.99 ab	3.719 a
DALSA 1405	12.912 a	30.967 ab	91.74 bc	51.280 a	0.166 ab	0.514 b	132.55 bc	6.93 ab	2.607 b
DALSA 1618	13.191 a	28.783 c	92.68 abc	53.665 a	0.178 a	0.702 a	130.26 c	7.399 a	2.494 b
TamStar	10.000 bc	31.929 a	94.34 ab	42.479 b	0.124 d	0.558 b	131.53 bc	5.561 c	4.313 a

*Means within columns followed by the same letters are not statistically different at P=0.05.

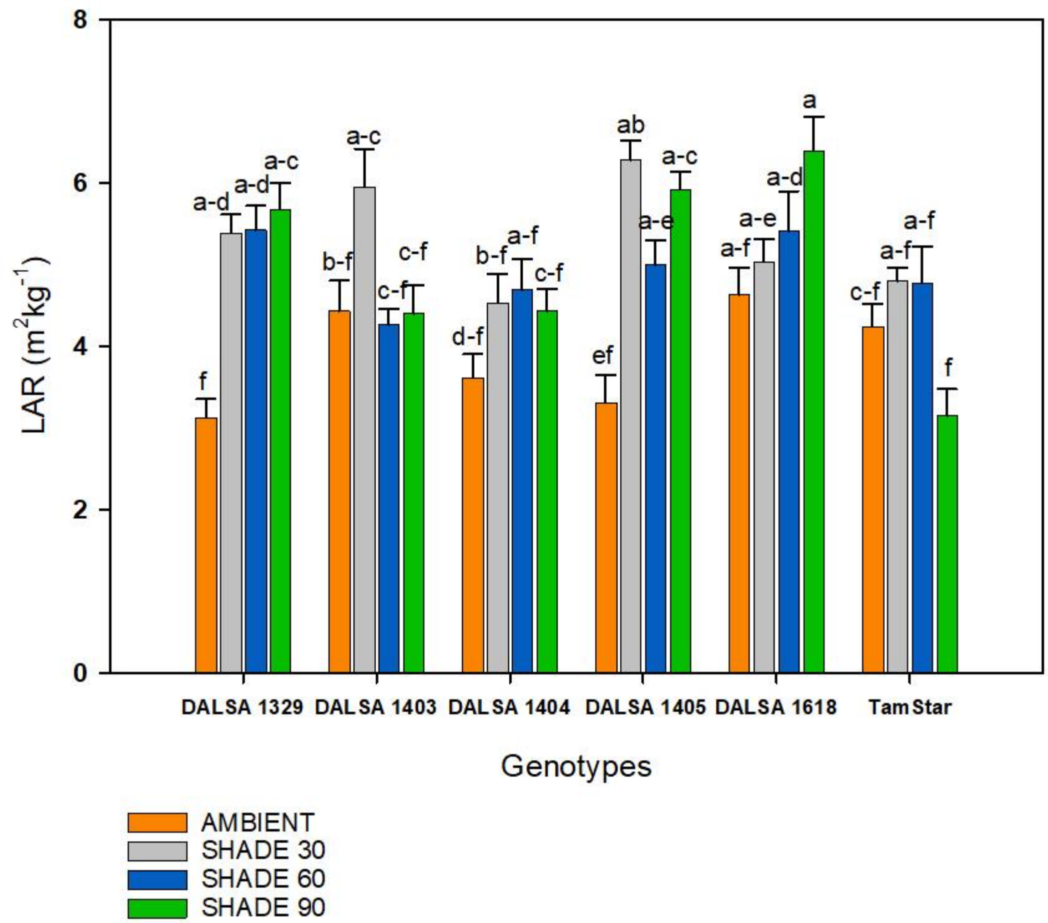

Figure 7. Leaf Area Ratio (m^2kg^{-1}) for various genotypes of St. Augustinegrass at ambient conditions and different shade treatments averaged for 6 weeks.
1329: DALSA 1329; 1403: DALSA 1403; 1404: DALSA 1404; 1405: DALSA 1405; 1618: DALSA 1618.
Means with the same letter are not significantly different at P=0.05.
Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

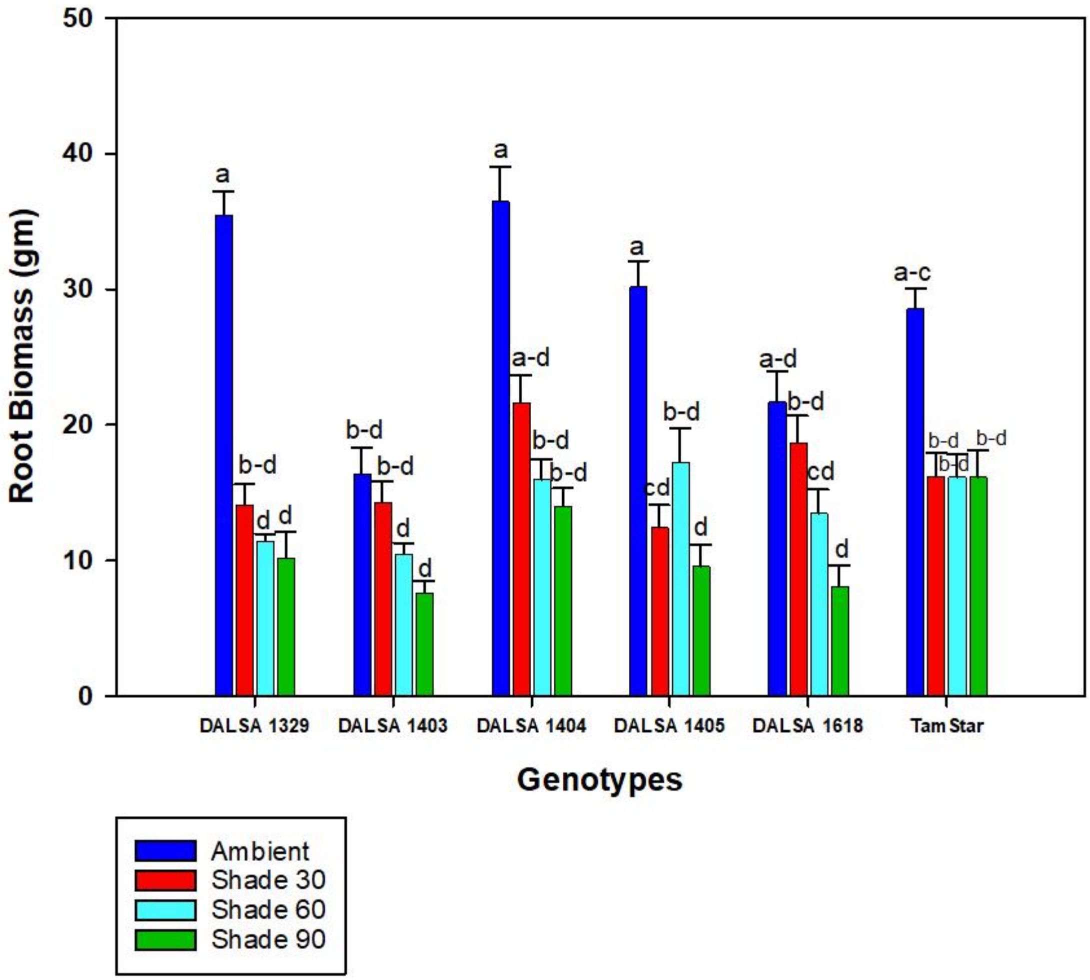

Figure 8. Root biomass (g) for various genotypes of St. Augustinegrass at ambient conditions and different shade treatments averaged for 6 weeks.
1329: DALSA 1329; 1403: DALSA 1403; 1404: DALSA 1404; 1405: DALSA 1405; 1618: DALSA 1618.
Means with the same letter are not significantly different at P=0.05.
Bars above each treatment represent the standard error for the mean of four replications of a genotype under each shade treatment.

Table 10. Linear correlation analysis of derived morphological parameters for five genotypes of Bermudagrass.

	Parameters										
Parameter	**SLA**	**LAR**	**RWC**	**Leaf Angle**	**Leaves/stem**	**Leaf Width**	**Root/ Shoot biomass**	**Shoot Biomass**	**Root Biomass**	**LAI**	**LWR**
SLA		0.501‡	-0.190	0.151	-0.272	0.174	0.050	-0.089	-0.101	0.333	0.051
LAR	***§		-0.001	0.220	0.019	0.473	-0.568	0.427	-0.284	0.616	0.840
RWC	*	NS		0.190	0.197	0.169	-0.078	0.221	0.140	0.147	0.137
Leaf Angle	NS	**	*		0.053	0.212	-0.057	0.131	0.057	0.260	0.213
Leaves/stem	**	NS	*	NS		-0.004	-0.176	0.243	0.116	0.060	0.154
Leaf Width	*	***	*	**	NS		-0.278	0.454	0.165	0.624	0.527
Root/ Shoot biomass	NS	***	NS	NS	*	***		-0.486	0.395	-0.357	-0.696
Shoot Biomass	NS	***	**	*	**	***	***		0.419	0.792	0.627
Root Biomass	NS	***	NS	NS	NS	*	***	***		0.394	-0.234
LAI	***	***	NS	**	NS	***	***	***	***		0.601
LWR	NS	***	NS	**	NS	***	***	***	**	***	

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not sgnificant
SLA: specific leaf area; LAR: leaf area ratio; RWC: relative water content; LWR: leaf weight ratio.
‡ Correlation coefficient (r) is shown in the upper triangle for each year.
§ Significance level of correlation analysis is shown in the lower triangle each year.

Table 11. Canonical loadings generated from canonical discriminant analysis of eight morphological parameters for five genotypes of bermudagrasses.

Canopy parameter	**Function**	
	1	**2**
SLA†	-0.018	0.287
LAR	0.416	-0.732
RWC	0.083	-0.306
Leaf angle	0.940	0.029
Leaves per stem	0.081	0.845
LWR	0.291	0.053
Leaf width	-0.970	0.625
Root: shoot ratio	-0.138	-0.705
Eigenvalue	1.276	0.916
% of variance	39.6	28.4
Canonical correlation	0.749	0.691

† SLA: specific leaf area; LAR: leaf area ratio; RWC: relative water content; LWR: leaf weight ratio.

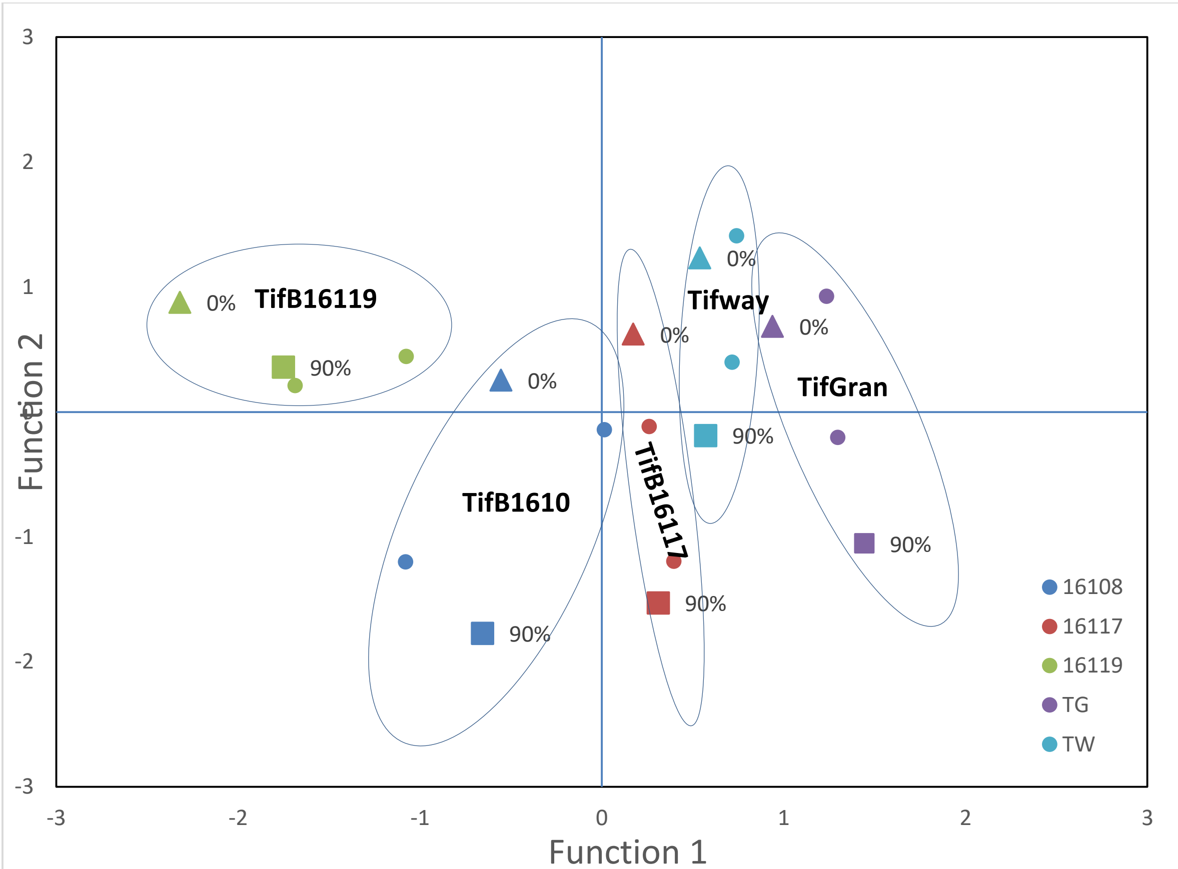

Figure 9. Scatterplot of 20 group centroids from discriminant analysis of eight morphological parameters for five genotypes of Bermudagrass.

Numbers 0% (represented by Δ) and 90% (represented by □) indicate the ambient and heavy shade, respectively to which the grasses were exposed.

16108: TifB16108; 16117: TifB16117; 16119: TifB16119; TG: TifGrand; TW: Tifway

Table 12. Linear correlation analysis of derived morphological parameters for six genotypes of St. Augustinegrasses.

	Parameters										
Parameter	**SLA**	**LAR**	**LWR**	**RWC**	**Leaf width**	**Leaf Angle**	**leaves/ Stem**	**Root/ shoot ratio**	**LAI**	**Shoot biomass**	**Root biomass**
SLA		0.685‡	0.335	-0.141	0.386	-0.217	-0.225	-0.420	0.259	-0.171	-0.568
LAR	***§		0.900	-0.273	0.453	-0.194	-0.187	-0.726	0.654	0.257	-0.669
LWR	***	***		-0.295	0.353	-0.120	-0.106	-0.774	0.693	0.438	-0.623
RWC	NS	***	***		-0.050	0.054	-0.006	0.260	-0.209	-0.202	0.182
Leaf width	***	***	***	NS		-0.267	-0.377	-0.299	0.495	0.327	-0.137
Leaf Angle	**	**	NS	NS	***		0.004	0.042	-0.225	-0.136	-0.056
Leaves/ Stem	**	**	NS	NS	***	NS		0.191	-0.110	-0.052	0.130
Root/ shoot ratio	***	***	***	***	***	NS	**		-0.494	-0.381	0.757
LAI	***	***	***	**	***	**	NS	***		0.799	-0.126
Shoot biomass	*	***	***	**	***	NS	NS	***	***		0.139
Root biomass	***	***	***	*	NS	NS	NS	***	NS	NS	

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; *** significant at the 0.001 probability level; NS not significant
SLA: specific leaf area; LAR: leaf area ratio; RWC: relative water content; LWR: leaf weight ratio.
‡ Correlation coefficient (r) is shown in the upper triangle for each year.
§ Significance level of correlation analysis is shown in the lower triangle each year.

Table 13. Canonical loadings generated from canonical discriminant analysis of eight morphological parameters for six genotypes of St. Augustinegrasses.

Canopy parameter	**Function**	
	1	**2**
SLA	1.468	2.001
LAR	-0.751	-3.273
RWC	0.008	0.607
Leaf angle	0.699	-0.722
Leaves per stem	-0.151	-0.209
LWR	0.439	2.846
Leaf width	-0.941	-0.549
Root: shoot ratio	-0.016	0.864
Eigenvalue	1.634	1.117
% of variance	45.4	31.0
Canonical correlation	0.788	0.726

† SLA: specific leaf area; LAR: leaf area ratio; RWC: relative water content; LWR: leaf weight ratio.

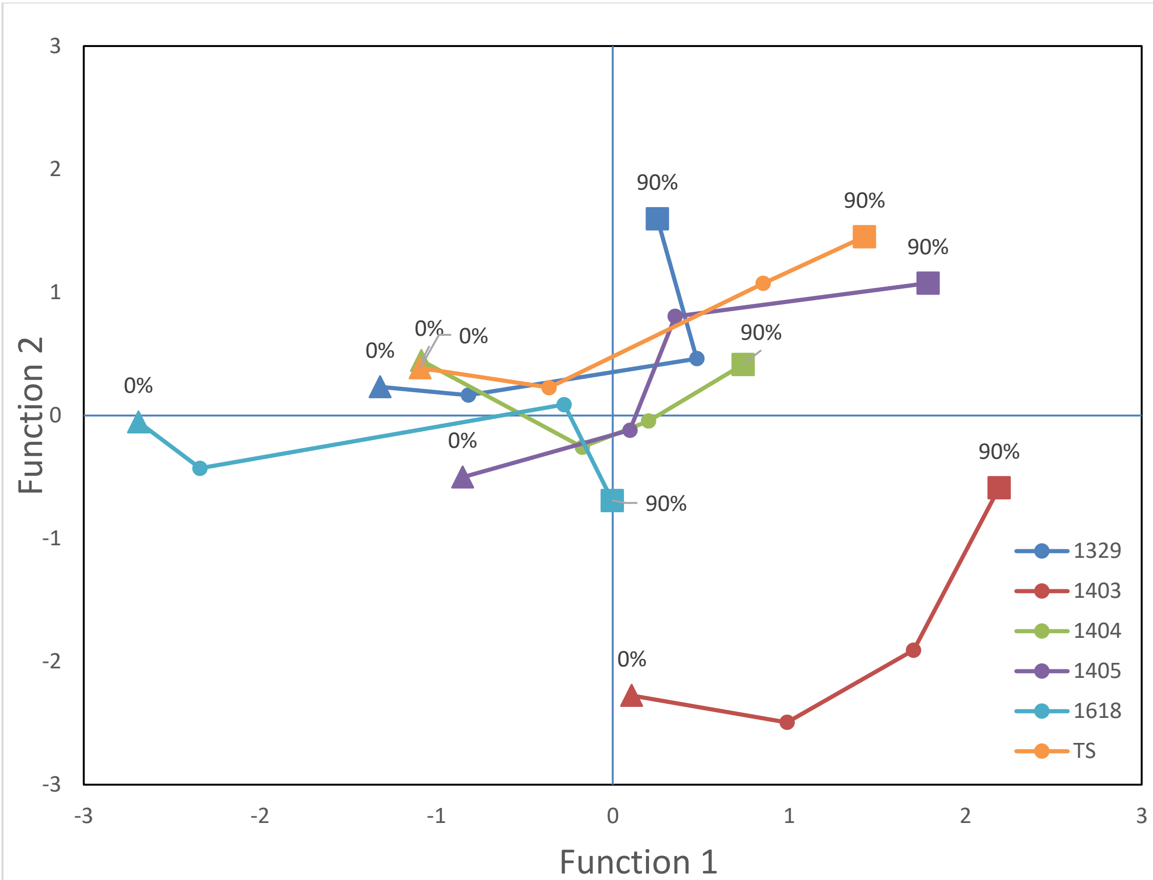

Figure 10. Scatterplot of 24 group centroids from discriminant analysis of eight morphological parameters for six genotypes of St. Augustinegrass.

Numbers 0% (represented by Δ) and 90% (represented by □) indicate the ambient and heavy shade, respectively to which the grasses were exposed.

1329: DALSA 1329; 1403: DALSA 1403; 1404: DALSA 1404; 1405: DALSA 1405; 1618: DALSA 1618; TS: TamStar.

CHAPTER IV

CONCLUSION

Shade resistance is the ability of the plant to survive or bear shade through mechanisms which alters the physiology and/or morphology in order to adapt the low light environment. Variability observed within a species of grasses in terms of their response to shade can be attributed to these mechanisms. A number of studies have been conducted to understand the physiological and morphological changes in warm-season turfgrasses to shade. The research presented herein was designed to examine variation in such traits suspected of contributing to shade resistance with the objective of highlighting the underlying cause for such responses.

The greenhouse experiments demonstrated that both the tolerance and avoidance mechanisms are responsible in imparting shade resistance to the grasses. Although, in most of the genotypes resistance was attributed more to physiological changes than to the morphological adaptations. Reductions in the dark respiration rates, light compensation point and light saturation estimate at 75^{th} percentile of apparently shade resistant grasses suggested that these genotypes were able to maintain a positive CO_2 balance despite of the reducing photosynthetic rates under low light. These reductions were consistent with most of the resistant genotypes within a species and also over the other species, as observed in bermudagrass and St. Augustinegrass.

The morphological response to shade also did contribute towards the resistance of grasses, although varying canopy strategies were demonstrated for avoidance to shade. TifGrand had a preferentially higher shoot growth in terms of leafiness as well as biomass in comparison to root biomass while TifB16108 maintained its leafiness, shoot and root biomass. Both these shade resistant genotypes had different adaptive responses indicating that the resistance of a grass to shade cannot be dependent on a single factor but number of factors determine their performance. This was applicable to the various genotypes of St. Augustinegrass as well.

The genotypes in the study did not show any significant interaction of shade with genotypes, which indicated that this performance exhibited primarily a genetic effect. This might also be due to the controlled environment provided under greenhouse and the results from can likely differ when the same study conducted in the field conditions when the grasses are exposed to interaction of different climatic and edaphic factors. This study can further help the breeders to improve the selection criteria for developing shade resistant grasses by focusing on desirable physiological and morphological characteristics.

APPENDICES

Table1. Photosynthetic rates at different light intensities for each bermudagrass genotype measured for three weeks under shade and non-shade conditions during experiment 1.

S.No.	**Week**	**Treatment**	**Genotype**	**Replication**	**PAR** µmol m^{-2} s^{-1}	**Photosynthesis** µmol CO_2 m^{-2} s^{-1}
1	0	Shade	TifB16108	1	2000	58.969
2	0	Shade	TifB16108	1	1500	57.338
3	0	Shade	TifB16108	1	1000	49.074
4	0	Shade	TifB16108	1	750	41.977
5	0	Shade	TifB16108	1	500	31.495
6	0	Shade	TifB16108	1	250	11.986
7	0	Shade	TifB16108	1	0	-6.060
8	0	Shade	TifB16108	2	2000	64.687
9	0	Shade	TifB16108	2	1500	64.200
10	0	Shade	TifB16108	2	1000	52.917
11	0	Shade	TifB16108	2	750	43.865
12	0	Shade	TifB16108	2	500	31.468
13	0	Shade	TifB16108	2	250	14.074
14	0	Shade	TifB16108	2	0	-13.243
15	0	Shade	TifB16108	3	2000	64.293
16	0	Shade	TifB16108	3	1500	66.149
17	0	Shade	TifB16108	3	1000	55.367
18	0	Shade	TifB16108	3	750	46.134
19	0	Shade	TifB16108	3	500	33.784
20	0	Shade	TifB16108	3	250	16.374
21	0	Shade	TifB16108	3	0	-6.786
22	0	Shade	TifB16108	4	2000	71.579
23	0	Shade	TifB16108	4	1500	71.089
24	0	Shade	TifB16108	4	1000	57.698
25	0	Shade	TifB16108	4	750	45.101
26	0	Shade	TifB16108	4	500	25.969
27	0	Shade	TifB16108	4	250	14.829
28	0	Shade	TifB16108	4	0	-5.827
29	0	Shade	TifB16117	1	2000	47.705
30	0	Shade	TifB16117	1	1500	45.565
31	0	Shade	TifB16117	1	1000	38.074
32	0	Shade	TifB16117	1	750	32.039
33	0	Shade	TifB16117	1	500	23.846
34	0	Shade	TifB16117	1	250	11.264
35	0	Shade	TifB16117	1	0	-5.088
36	0	Shade	TifB16117	2	2000	35.645
37	0	Shade	TifB16117	2	1500	34.072

38	0	Shade	TifB16117	2	1000	29.683
39	0	Shade	TifB16117	2	750	25.305
40	0	Shade	TifB16117	2	500	18.964
41	0	Shade	TifB16117	2	250	8.848
42	0	Shade	TifB16117	2	0	-6.992
43	0	Shade	TifB16117	3	2000	37.819
44	0	Shade	TifB16117	3	1500	37.520
45	0	Shade	TifB16117	3	1000	31.714
46	0	Shade	TifB16117	3	750	25.675
47	0	Shade	TifB16117	3	500	19.178
48	0	Shade	TifB16117	3	250	8.954
49	0	Shade	TifB16117	3	0	-5.446
50	0	Shade	TifB16117	4	2000	51.805
51	0	Shade	TifB16117	4	1500	48.891
52	0	Shade	TifB16117	4	1000	41.224
53	0	Shade	TifB16117	4	750	38.905
54	0	Shade	TifB16117	4	500	35.095
55	0	Shade	TifB16117	4	250	15.559
56	0	Shade	TifB16117	4	0	-3.255
57	0	Shade	TifB16119	1	2000	36.342
58	0	Shade	TifB16119	1	1500	35.858
59	0	Shade	TifB16119	1	1000	31.381
60	0	Shade	TifB16119	1	750	27.223
61	0	Shade	TifB16119	1	500	21.488
62	0	Shade	TifB16119	1	250	11.276
63	0	Shade	TifB16119	1	0	-3.590
64	0	Shade	TifB16119	2	2000	44.057
65	0	Shade	TifB16119	2	1500	44.628
66	0	Shade	TifB16119	2	1000	38.755
67	0	Shade	TifB16119	2	750	33.879
68	0	Shade	TifB16119	2	500	25.785
69	0	Shade	TifB16119	2	250	10.164
70	0	Shade	TifB16119	2	0	-5.795
71	0	Shade	TifB16119	3	2000	37.925
72	0	Shade	TifB16119	3	1500	37.457
73	0	Shade	TifB16119	3	1000	32.356
74	0	Shade	TifB16119	3	750	27.836
75	0	Shade	TifB16119	3	500	20.805
76	0	Shade	TifB16119	3	250	10.028
77	0	Shade	TifB16119	3	0	-6.535
78	0	Shade	TifB16119	4	2000	33.533
79	0	Shade	TifB16119	4	1500	33.247
80	0	Shade	TifB16119	4	1000	28.412

81	0	Shade	TifB16119	4	750	18.231
82	0	Shade	TifB16119	4	500	11.816
83	0	Shade	TifB16119	4	250	6.405
84	0	Shade	TifB16119	4	0	-7.619
85	0	Shade	Tifway	1	2000	60.982
86	0	Shade	Tifway	1	1500	58.528
87	0	Shade	Tifway	1	1000	47.635
88	0	Shade	Tifway	1	750	39.076
89	0	Shade	Tifway	1	500	28.134
90	0	Shade	Tifway	1	250	12.508
91	0	Shade	Tifway	1	0	-4.741
92	0	Shade	Tifway	2	2000	60.619
93	0	Shade	Tifway	2	1500	57.108
94	0	Shade	Tifway	2	1000	45.922
95	0	Shade	Tifway	2	750	36.627
96	0	Shade	Tifway	2	500	26.112
97	0	Shade	Tifway	2	250	11.429
98	0	Shade	Tifway	2	0	-6.377
99	0	Shade	Tifway	3	2000	62.279
100	0	Shade	Tifway	3	1500	58.816
101	0	Shade	Tifway	3	1000	46.641
102	0	Shade	Tifway	3	750	38.727
103	0	Shade	Tifway	3	500	27.222
104	0	Shade	Tifway	3	250	11.395
105	0	Shade	Tifway	3	0	-7.474
106	0	Shade	Tifway	4	2000	45.604
107	0	Shade	Tifway	4	1500	40.980
109	0	Shade	Tifway	4	750	31.301
110	0	Shade	Tifway	4	500	22.814
111	0	Shade	Tifway	4	250	11.229
112	0	Shade	Tifway	4	0	-5.852
113	0	Non Shade	TifB16108	1	2000	63.982
114	0	Non Shade	TifB16108	1	1500	59.315
115	0	Non Shade	TifB16108	1	1000	48.184
116	0	Non Shade	TifB16108	1	750	39.077
117	0	Non Shade	TifB16108	1	500	26.040
118	0	Non Shade	TifB16108	1	250	7.369
119	0	Non Shade	TifB16108	1	0	-9.298
120	0	Non Shade	TifB16108	2	2000	49.229
121	0	Non Shade	TifB16108	2	1500	47.095
122	0	Non Shade	TifB16108	2	1000	43.149
123	0	Non Shade	TifB16108	2	750	39.214
124	0	Non Shade	TifB16108	2	500	28.587

125	0	Non Shade	TifB16108	2	250	16.095
126	0	Non Shade	TifB16108	2	0	-3.050
127	0	Non Shade	TifB16108	3	2000	72.891
128	0	Non Shade	TifB16108	3	1500	68.520
129	0	Non Shade	TifB16108	3	1000	50.587
130	0	Non Shade	TifB16108	3	750	42.750
131	0	Non Shade	TifB16108	3	500	30.179
132	0	Non Shade	TifB16108	3	250	9.098
133	0	Non Shade	TifB16108	3	0	-5.134
134	0	Non Shade	TifB16108	4	2000	59.611
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136	0	Non Shade	TifB16108	4	1000	44.914
137	0	Non Shade	TifB16108	4	750	39.090
138	0	Non Shade	TifB16108	4	500	26.627
139	0	Non Shade	TifB16108	4	250	10.182
140	0	Non Shade	TifB16108	4	0	-6.630
141	0	Non Shade	TifB16117	1	2000	70.248
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143	0	Non Shade	TifB16117	1	1000	51.711
144	0	Non Shade	TifB16117	1	750	41.274
145	0	Non Shade	TifB16117	1	500	30.701
146	0	Non Shade	TifB16117	1	250	12.956
147	0	Non Shade	TifB16117	1	0	-12.299
148	0	Non Shade	TifB16117	2	2000	55.360
149	0	Non Shade	TifB16117	2	1500	54.636
150	0	Non Shade	TifB16117	2	1000	46.772
151	0	Non Shade	TifB16117	2	750	37.774
152	0	Non Shade	TifB16117	2	500	27.302
153	0	Non Shade	TifB16117	2	250	13.692
154	0	Non Shade	TifB16117	2	0	-5.072
155	0	Non Shade	TifB16117	3	2000	24.395
156	0	Non Shade	TifB16117	3	1500	26.918
157	0	Non Shade	TifB16117	3	1000	23.357
158	0	Non Shade	TifB16117	3	750	22.261
159	0	Non Shade	TifB16117	3	500	16.634
160	0	Non Shade	TifB16117	3	250	7.044
161	0	Non Shade	TifB16117	3	0	-3.599
162	0	Non Shade	TifB16117	4	2000	45.280
163	0	Non Shade	TifB16117	4	1500	35.512
164	0	Non Shade	TifB16117	4	1000	28.082
165	0	Non Shade	TifB16117	4	750	24.852
166	0	Non Shade	TifB16117	4	500	18.745
167	0	Non Shade	TifB16117	4	250	9.606

168	0	Non Shade	TifB16117	4	0	-6.062
169	0	Non Shade	TifB16119	1	2000	39.597
170	0	Non Shade	TifB16119	1	1500	39.619
171	0	Non Shade	TifB16119	1	1000	35.368
172	0	Non Shade	TifB16119	1	750	30.279
173	0	Non Shade	TifB16119	1	500	23.581
174	0	Non Shade	TifB16119	1	250	12.360
175	0	Non Shade	TifB16119	1	0	-4.154
176	0	Non Shade	TifB16119	2	2000	55.484
177	0	Non Shade	TifB16119	2	1500	53.706
178	0	Non Shade	TifB16119	2	1000	45.617
179	0	Non Shade	TifB16119	2	750	38.715
180	0	Non Shade	TifB16119	2	500	28.957
181	0	Non Shade	TifB16119	2	250	13.757
182	0	Non Shade	TifB16119	2	0	-5.039
183	0	Non Shade	TifB16119	3	2000	51.805
184	0	Non Shade	TifB16119	3	1500	48.891
185	0	Non Shade	TifB16119	3	1000	41.224
186	0	Non Shade	TifB16119	3	750	38.905
187	0	Non Shade	TifB16119	3	500	35.095
188	0	Non Shade	TifB16119	3	250	15.559
189	0	Non Shade	TifB16119	3	0	-3.255
190	0	Non Shade	TifB16119	4	2000	41.896
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197	0	Non Shade	Tifway	1	2000	94.325
198	0	Non Shade	Tifway	1	1500	86.827
199	0	Non Shade	Tifway	1	1000	68.545
200	0	Non Shade	Tifway	1	750	54.516
201	0	Non Shade	Tifway	1	500	37.489
202	0	Non Shade	Tifway	1	250	16.633
203	0	Non Shade	Tifway	1	0	-5.973
204	0	Non Shade	Tifway	2	2000	41.831
205	0	Non Shade	Tifway	2	1500	43.052
206	0	Non Shade	Tifway	2	1000	36.617
207	0	Non Shade	Tifway	2	750	30.644
208	0	Non Shade	Tifway	2	500	21.239
209	0	Non Shade	Tifway	2	250	8.301
210	0	Non Shade	Tifway	2	0	-6.896

211	0	Non Shade	Tifway	3	2000	36.568
212	0	Non Shade	Tifway	3	1500	39.306
213	0	Non Shade	Tifway	3	1000	32.174
214	0	Non Shade	Tifway	3	750	28.551
215	0	Non Shade	Tifway	3	500	21.474
216	0	Non Shade	Tifway	3	250	10.294
217	0	Non Shade	Tifway	3	0	-7.185
218	0	Non Shade	Tifway	4	2000	42.058
219	0	Non Shade	Tifway	4	1500	40.132
220	0	Non Shade	Tifway	4	1000	32.770
221	0	Non Shade	Tifway	4	750	25.981
222	0	Non Shade	Tifway	4	500	17.766
223	0	Non Shade	Tifway	4	250	7.172
224	0	Non Shade	Tifway	4	0	-8.660
225	4	Shade	TifB16108	1	2000	27.449
226	4	Shade	TifB16108	1	1500	29.646
227	4	Shade	TifB16108	1	1000	28.311
228	4	Shade	TifB16108	1	750	26.488
229	4	Shade	TifB16108	1	500	21.903
230	4	Shade	TifB16108	1	250	11.991
231	4	Shade	TifB16108	1	0	-4.055
232	4	Shade	TifB16108	2	2000	39.147
233	4	Shade	TifB16108	2	1500	38.297
234	4	Shade	TifB16108	2	1000	33.093
235	4	Shade	TifB16108	2	750	28.569
236	4	Shade	TifB16108	2	500	20.941
237	4	Shade	TifB16108	2	250	9.414
238	4	Shade	TifB16108	2	0	-6.238
239	4	Shade	TifB16108	3	2000	27.963
240	4	Shade	TifB16108	3	1500	32.144
241	4	Shade	TifB16108	3	1000	29.934
242	4	Shade	TifB16108	3	750	27.675
243	4	Shade	TifB16108	3	500	22.002
244	4	Shade	TifB16108	3	250	10.785
245	4	Shade	TifB16108	3	0	-6.229
246	4	Shade	TifB16108	4	2000	28.978
247	4	Shade	TifB16108	4	1500	32.121
248	4	Shade	TifB16108	4	1000	30.146
249	4	Shade	TifB16108	4	750	27.345
250	4	Shade	TifB16108	4	500	20.855
251	4	Shade	TifB16108	4	250	10.130
252	4	Shade	TifB16108	4	0	-6.398
253	4	Shade	TifB16117	1	2000	16.952

254	4	Shade	TifB16117	1	1500	19.081
255	4	Shade	TifB16117	1	1000	18.918
256	4	Shade	TifB16117	1	750	18.282
257	4	Shade	TifB16117	1	500	15.567
258	4	Shade	TifB16117	1	250	9.320
259	4	Shade	TifB16117	1	0	-2.866
260	4	Shade	TifB16117	2	2000	15.567
261	4	Shade	TifB16117	2	1500	13.173
262	4	Shade	TifB16117	2	1000	10.510
263	4	Shade	TifB16117	2	750	8.402
264	4	Shade	TifB16117	2	500	4.762
265	4	Shade	TifB16117	2	250	0.739
266	4	Shade	TifB16117	2	0	-16.708
267	4	Shade	TifB16117	3	2000	12.116
268	4	Shade	TifB16117	3	1500	15.654
269	4	Shade	TifB16117	3	1000	15.688
270	4	Shade	TifB16117	3	750	14.582
271	4	Shade	TifB16117	3	500	11.885
272	4	Shade	TifB16117	3	250	6.523
273	4	Shade	TifB16117	3	0	-3.769
274	4	Shade	TifB16119	1	2000	18.818
275	4	Shade	TifB16119	1	1500	20.491
276	4	Shade	TifB16119	1	1000	20.340
277	4	Shade	TifB16119	1	750	19.975
278	4	Shade	TifB16119	1	500	17.268
279	4	Shade	TifB16119	1	250	10.551
280	4	Shade	TifB16119	1	0	-3.889
281	4	Shade	TifB16119	2	2000	15.112
282	4	Shade	TifB16119	2	1500	17.669
283	4	Shade	TifB16119	2	1000	16.755
284	4	Shade	TifB16119	2	750	14.998
285	4	Shade	TifB16119	2	500	10.104
286	4	Shade	TifB16119	2	250	0.955
287	4	Shade	TifB16119	2	0	-13.792
288	4	Shade	TifB16119	3	2000	15.083
289	4	Shade	TifB16119	3	1500	24.838
290	4	Shade	TifB16119	3	1000	23.292
291	4	Shade	TifB16119	3	750	21.388
292	4	Shade	TifB16119	3	500	17.331
293	4	Shade	TifB16119	3	250	10.343
294	4	Shade	TifB16119	3	0	-2.922
295	4	Shade	Tifway	1	2000	23.408
296	4	Shade	Tifway	1	1500	23.997

297	4	Shade	Tifway	1	1000	22.223
298	4	Shade	Tifway	1	750	20.147
299	4	Shade	Tifway	1	500	15.961
300	4	Shade	Tifway	1	250	8.359
301	4	Shade	Tifway	1	0	-4.399
302	4	Shade	Tifway	2	2000	35.801
303	4	Shade	Tifway	2	1500	36.470
304	4	Shade	Tifway	2	1000	32.016
305	4	Shade	Tifway	2	750	27.762
306	4	Shade	Tifway	2	500	20.674
307	4	Shade	Tifway	2	250	9.376
308	4	Shade	Tifway	2	0	-5.313
309	4	Shade	Tifway	3	2000	9.950
310	4	Shade	Tifway	3	1500	9.159
311	4	Shade	Tifway	3	1000	6.922
312	4	Shade	Tifway	3	750	5.116
313	4	Shade	Tifway	3	500	1.818
314	4	Shade	Tifway	3	250	-3.747
315	4	Shade	Tifway	3	0	-14.224
316	4	Shade	Tifway	4	2000	26.350
317	4	Shade	Tifway	4	1500	28.732
318	4	Shade	Tifway	4	1000	25.106
319	4	Shade	Tifway	4	750	21.465
320	4	Shade	Tifway	4	500	14.688
321	4	Shade	Tifway	4	250	4.647
322	4	Shade	Tifway	4	0	-10.042
323	4	Non Shade	TifB16108	1	2000	57.753
324	4	Non Shade	TifB16108	1	1500	58.982
325	4	Non Shade	TifB16108	1	1000	48.260
326	4	Non Shade	TifB16108	1	750	39.372
327	4	Non Shade	TifB16108	1	500	26.001
328	4	Non Shade	TifB16108	1	250	8.465
329	4	Non Shade	TifB16108	1	0	-13.405
330	4	Non Shade	TifB16108	2	2000	58.764
331	4	Non Shade	TifB16108	2	1500	63.466
332	4	Non Shade	TifB16108	2	1000	53.639
333	4	Non Shade	TifB16108	2	750	44.600
334	4	Non Shade	TifB16108	2	500	31.059
335	4	Non Shade	TifB16108	2	250	11.863
336	4	Non Shade	TifB16108	2	0	-10.697
337	4	Non Shade	TifB16108	3	2000	64.489
338	4	Non Shade	TifB16108	3	1500	68.656
339	4	Non Shade	TifB16108	3	1000	57.476

340	4	Non Shade	TifB16108	3	750	49.131
341	4	Non Shade	TifB16108	3	500	34.523
342	4	Non Shade	TifB16108	3	250	14.244
343	4	Non Shade	TifB16108	3	0	-7.045
344	4	Non Shade	TifB16108	4	2000	62.202
345	4	Non Shade	TifB16108	4	1500	60.795
346	4	Non Shade	TifB16108	4	1000	50.582
347	4	Non Shade	TifB16108	4	750	42.133
348	4	Non Shade	TifB16108	4	500	29.071
349	4	Non Shade	TifB16108	4	250	10.990
350	4	Non Shade	TifB16108	4	0	-12.728
351	4	Non Shade	TifB16117	1	2000	58.417
352	4	Non Shade	TifB16117	1	1500	59.849
353	4	Non Shade	TifB16117	1	1000	49.243
354	4	Non Shade	TifB16117	1	750	39.899
355	4	Non Shade	TifB16117	1	500	26.379
356	4	Non Shade	TifB16117	1	250	10.177
357	4	Non Shade	TifB16117	1	0	-15.727
358	4	Non Shade	TifB16117	2	2000	26.399
359	4	Non Shade	TifB16117	2	1500	27.591
360	4	Non Shade	TifB16117	2	1000	23.668
361	4	Non Shade	TifB16117	2	750	19.795
362	4	Non Shade	TifB16117	2	500	12.396
363	4	Non Shade	TifB16117	2	250	0.061
364	4	Non Shade	TifB16117	2	0	-20.726
365	4	Non Shade	TifB16117	3	2000	42.502
366	4	Non Shade	TifB16117	3	1500	50.566
367	4	Non Shade	TifB16117	3	1000	41.607
368	4	Non Shade	TifB16117	3	750	36.454
369	4	Non Shade	TifB16117	3	500	25.469
370	4	Non Shade	TifB16117	3	250	9.630
371	4	Non Shade	TifB16117	3	0	-13.346
372	4	Non Shade	TifB16117	4	2000	42.358
373	4	Non Shade	TifB16117	4	1500	48.030
374	4	Non Shade	TifB16117	4	1000	40.958
375	4	Non Shade	TifB16117	4	750	33.858
376	4	Non Shade	TifB16117	4	500	22.734
377	4	Non Shade	TifB16117	4	250	8.302
378	4	Non Shade	TifB16117	4	0	-13.230
379	4	Non Shade	TifB16119	1	2000	31.226
380	4	Non Shade	TifB16119	1	1500	33.948
381	4	Non Shade	TifB16119	1	1000	31.776
382	4	Non Shade	TifB16119	1	750	28.495

383	4	Non Shade	TifB16119	1	500	21.691
384	4	Non Shade	TifB16119	1	250	9.848
385	4	Non Shade	TifB16119	1	0	-8.025
386	4	Non Shade	TifB16119	2	2000	29.545
387	4	Non Shade	TifB16119	2	1500	31.902
388	4	Non Shade	TifB16119	2	1000	27.083
389	4	Non Shade	TifB16119	2	750	22.497
390	4	Non Shade	TifB16119	2	500	13.436
391	4	Non Shade	TifB16119	2	250	-0.093
392	4	Non Shade	TifB16119	2	0	-24.135
393	4	Non Shade	TifB16119	3	2000	28.785
394	4	Non Shade	TifB16119	3	1500	33.721
395	4	Non Shade	TifB16119	3	1000	29.942
396	4	Non Shade	TifB16119	3	750	26.503
397	4	Non Shade	TifB16119	3	500	18.061
398	4	Non Shade	TifB16119	3	250	3.486
399	4	Non Shade	TifB16119	3	0	-18.954
400	4	Non Shade	TifB16119	4	2000	11.303
401	4	Non Shade	TifB16119	4	1500	11.273
402	4	Non Shade	TifB16119	4	1000	8.202
403	4	Non Shade	TifB16119	4	750	6.607
404	4	Non Shade	TifB16119	4	500	2.388
405	4	Non Shade	TifB16119	4	250	-5.963
406	4	Non Shade	TifB16119	4	0	-20.205
407	4	Non Shade	Tifway	1	2000	35.278
408	4	Non Shade	Tifway	1	1500	41.536
409	4	Non Shade	Tifway	1	1000	36.178
410	4	Non Shade	Tifway	1	750	30.295
411	4	Non Shade	Tifway	1	500	21.565
412	4	Non Shade	Tifway	1	250	8.792
413	4	Non Shade	Tifway	1	0	-7.312
414	4	Non Shade	Tifway	2	2000	61.531
415	4	Non Shade	Tifway	2	1500	66.106
416	4	Non Shade	Tifway	2	1000	52.582
417	4	Non Shade	Tifway	2	750	40.969
418	4	Non Shade	Tifway	2	500	26.377
419	4	Non Shade	Tifway	2	250	7.553
420	4	Non Shade	Tifway	2	0	-15.280
421	4	Non Shade	Tifway	3	2000	53.096
422	4	Non Shade	Tifway	3	1500	56.393
423	4	Non Shade	Tifway	3	1000	45.931
424	4	Non Shade	Tifway	3	750	38.807
425	4	Non Shade	Tifway	3	500	26.435

426	4	Non Shade	Tifway	3	250	10.794
427	4	Non Shade	Tifway	3	0	-10.007
428	4	Non Shade	Tifway	4	2000	74.011
429	4	Non Shade	Tifway	4	1500	73.862
430	4	Non Shade	Tifway	4	1000	56.685
431	4	Non Shade	Tifway	4	750	43.880
432	4	Non Shade	Tifway	4	500	27.696
433	4	Non Shade	Tifway	4	250	10.243
434	4	Non Shade	Tifway	4	0	-11.546
435	8	Shade	TifB16108	1	2000	14.600
436	8	Shade	TifB16108	1	1500	15.984
437	8	Shade	TifB16108	1	1000	15.731
438	8	Shade	TifB16108	1	750	17.166
439	8	Shade	TifB16108	1	500	12.523
440	8	Shade	TifB16108	1	250	7.797
441	8	Shade	TifB16108	1	0	-1.311
442	8	Shade	TifB16108	2	2000	13.980
443	8	Shade	TifB16108	2	1500	14.695
444	8	Shade	TifB16108	2	1000	13.495
445	8	Shade	TifB16108	2	750	13.309
446	8	Shade	TifB16108	2	500	11.594
447	8	Shade	TifB16108	2	250	7.203
448	8	Shade	TifB16108	2	0	-3.225
449	8	Shade	TifB16108	3	2000	11.088
450	8	Shade	TifB16108	3	1500	10.850
451	8	Shade	TifB16108	3	1000	10.144
452	8	Shade	TifB16108	3	750	9.705
453	8	Shade	TifB16108	3	500	5.953
454	8	Shade	TifB16108	3	250	1.298
455	8	Shade	TifB16108	3	0	-11.460
456	8	Shade	TifB16108	4	2000	14.790
457	8	Shade	TifB16108	4	1500	17.388
458	8	Shade	TifB16108	4	1000	18.659
459	8	Shade	TifB16108	4	750	17.651
460	8	Shade	TifB16108	4	500	15.716
461	8	Shade	TifB16108	4	250	9.695
462	8	Shade	TifB16108	4	0	-0.841
463	8	Shade	TifB16117	1	2000	19.174
464	8	Shade	TifB16117	1	1500	18.421
465	8	Shade	TifB16117	1	1000	13.227
466	8	Shade	TifB16117	1	750	11.315
467	8	Shade	TifB16117	1	500	9.867
468	8	Shade	TifB16117	1	250	3.702

469	8	Shade	TifB16117	1	0	-4.201
470	8	Shade	TifB16117	2	2000	17.101
471	8	Shade	TifB16117	2	1500	22.490
472	8	Shade	TifB16117	2	1000	22.549
473	8	Shade	TifB16117	2	750	21.332
474	8	Shade	TifB16117	2	500	16.701
475	8	Shade	TifB16117	2	250	-3.663
476	8	Shade	TifB16117	2	0	-7.122
477	8	Shade	TifB16117	3	2000	22.872
478	8	Shade	TifB16117	3	1500	26.127
479	8	Shade	TifB16117	3	1000	25.082
480	8	Shade	TifB16117	3	750	22.377
481	8	Shade	TifB16117	3	500	17.544
482	8	Shade	TifB16117	3	250	9.458
483	8	Shade	TifB16117	3	0	-2.936
484	8	Shade	TifB16117	4	2000	8.887
485	8	Shade	TifB16117	4	1500	11.725
486	8	Shade	TifB16117	4	1000	13.254
487	8	Shade	TifB16117	4	750	12.706
488	8	Shade	TifB16117	4	500	10.493
489	8	Shade	TifB16117	4	250	6.442
490	8	Shade	TifB16117	4	0	-1.770
491	8	Shade	TifB16119	1	2000	22.833
492	8	Shade	TifB16119	1	1500	24.881
493	8	Shade	TifB16119	1	1000	19.742
494	8	Shade	TifB16119	1	750	15.116
495	8	Shade	TifB16119	1	500	11.377
496	8	Shade	TifB16119	1	250	8.998
497	8	Shade	TifB16119	1	0	-9.695
498	8	Shade	TifB16119	2	2000	29.914
499	8	Shade	TifB16119	2	1500	30.111
500	8	Shade	TifB16119	2	1000	27.757
501	8	Shade	TifB16119	2	750	24.973
502	8	Shade	TifB16119	2	500	19.831
503	8	Shade	TifB16119	2	250	11.025
504	8	Shade	TifB16119	2	0	-2.365
505	8	Shade	TifB16119	3	2000	16.819
506	8	Shade	TifB16119	3	1500	18.532
507	8	Shade	TifB16119	3	1000	17.740
508	8	Shade	TifB16119	3	750	16.302
509	8	Shade	TifB16119	3	500	13.383
510	8	Shade	TifB16119	3	250	8.119
511	8	Shade	TifB16119	3	0	-1.670

512	8	Shade	TifB16119	4	2000	19.792
513	8	Shade	TifB16119	4	1500	21.922
514	8	Shade	TifB16119	4	1000	19.163
515	8	Shade	TifB16119	4	750	19.184
516	8	Shade	TifB16119	4	500	15.705
517	8	Shade	TifB16119	4	250	8.888
518	8	Shade	TifB16119	4	0	-1.610
519	8	Shade	Tifway	1	2000	17.590
520	8	Shade	Tifway	1	1500	19.587
521	8	Shade	Tifway	1	1000	15.330
522	8	Shade	Tifway	1	750	13.268
523	8	Shade	Tifway	1	500	10.157
524	8	Shade	Tifway	1	250	6.330
525	8	Shade	Tifway	1	0	-2.786
526	8	Shade	Tifway	2	2000	15.479
527	8	Shade	Tifway	2	1500	17.450
528	8	Shade	Tifway	2	1000	16.331
529	8	Shade	Tifway	2	750	14.769
530	8	Shade	Tifway	2	500	11.426
531	8	Shade	Tifway	2	250	5.281
532	8	Shade	Tifway	2	0	-3.785
533	8	Shade	Tifway	3	2000	22.559
534	8	Shade	Tifway	3	1500	28.940
535	8	Shade	Tifway	3	1000	28.033
536	8	Shade	Tifway	3	750	25.182
537	8	Shade	Tifway	3	500	20.320
538	8	Shade	Tifway	3	250	12.201
539	8	Shade	Tifway	3	0	-1.171
540	8	Shade	Tifway	4	2000	21.644
541	8	Shade	Tifway	4	1500	22.788
542	8	Shade	Tifway	4	1000	21.048
543	8	Shade	Tifway	4	750	19.141
544	8	Shade	Tifway	4	500	15.225
545	8	Shade	Tifway	4	250	8.058
546	8	Shade	Tifway	4	0	-4.303
547	8	Non Shade	TifB16108	1	2000	32.809
548	8	Non Shade	TifB16108	1	1500	35.095
549	8	Non Shade	TifB16108	1	1000	29.121
550	8	Non Shade	TifB16108	1	750	22.912
551	8	Non Shade	TifB16108	1	500	16.604
552	8	Non Shade	TifB16108	1	250	3.443
553	8	Non Shade	TifB16108	1	0	-17.282
554	8	Non Shade	TifB16108	2	2000	19.505

555	8	Non Shade	TifB16108	2	1500	20.403
556	8	Non Shade	TifB16108	2	1000	21.250
557	8	Non Shade	TifB16108	2	750	20.204
558	8	Non Shade	TifB16108	2	500	16.223
559	8	Non Shade	TifB16108	2	250	7.777
560	8	Non Shade	TifB16108	2	0	-7.612
561	8	Non Shade	TifB16108	3	2000	18.338
562	8	Non Shade	TifB16108	3	1500	21.926
563	8	Non Shade	TifB16108	3	1000	22.760
564	8	Non Shade	TifB16108	3	750	22.211
565	8	Non Shade	TifB16108	3	500	18.733
566	8	Non Shade	TifB16108	3	250	11.087
567	8	Non Shade	TifB16108	3	0	-13.578
568	8	Non Shade	TifB16108	4	2000	23.533
569	8	Non Shade	TifB16108	4	1500	14.942
570	8	Non Shade	TifB16108	4	1000	14.492
571	8	Non Shade	TifB16108	4	750	12.845
572	8	Non Shade	TifB16108	4	500	8.552
573	8	Non Shade	TifB16108	4	250	-1.579
574	8	Non Shade	TifB16108	4	0	-17.799
575	8	Non Shade	TifB16117	1	2000	20.507
576	8	Non Shade	TifB16117	1	1500	22.272
577	8	Non Shade	TifB16117	1	1000	19.750
578	8	Non Shade	TifB16117	1	750	17.441
579	8	Non Shade	TifB16117	1	500	6.247
580	8	Non Shade	TifB16117	1	250	-10.586
581	8	Non Shade	TifB16117	1	0	-18.228
582	8	Non Shade	TifB16117	2	2000	31.989
583	8	Non Shade	TifB16117	2	1500	36.319
584	8	Non Shade	TifB16117	2	1000	32.912
585	8	Non Shade	TifB16117	2	750	29.382
586	8	Non Shade	TifB16117	2	500	21.409
587	8	Non Shade	TifB16117	2	250	8.325
588	8	Non Shade	TifB16117	2	0	-10.271
589	8	Non Shade	TifB16117	3	2000	21.202
590	8	Non Shade	TifB16117	3	1500	24.799
591	8	Non Shade	TifB16117	3	1000	23.399
592	8	Non Shade	TifB16117	3	750	19.646
593	8	Non Shade	TifB16117	3	500	16.637
594	8	Non Shade	TifB16117	3	250	14.294
595	8	Non Shade	TifB16117	3	0	-7.368
596	8	Non Shade	TifB16117	4	2000	13.167
597	8	Non Shade	TifB16117	4	1500	18.973

598	8	Non Shade	TifB16117	4	1000	18.032
599	8	Non Shade	TifB16117	4	750	15.625
600	8	Non Shade	TifB16117	4	500	9.534
601	8	Non Shade	TifB16117	4	250	-1.617
602	8	Non Shade	TifB16117	4	0	-19.220
603	8	Non Shade	TifB16119	1	2000	31.415
604	8	Non Shade	TifB16119	1	1500	27.802
605	8	Non Shade	TifB16119	1	1000	25.187
606	8	Non Shade	TifB16119	1	750	21.318
607	8	Non Shade	TifB16119	1	500	18.661
608	8	Non Shade	TifB16119	1	250	9.907
609	8	Non Shade	TifB16119	1	0	-4.963
610	8	Non Shade	TifB16119	2	2000	26.024
611	8	Non Shade	TifB16119	2	1500	30.067
612	8	Non Shade	TifB16119	2	1000	26.284
613	8	Non Shade	TifB16119	2	750	23.072
614	8	Non Shade	TifB16119	2	500	13.647
615	8	Non Shade	TifB16119	2	250	10.248
616	8	Non Shade	TifB16119	2	0	-25.245
617	8	Non Shade	TifB16119	3	2000	40.656
618	8	Non Shade	TifB16119	3	1500	49.802
619	8	Non Shade	TifB16119	3	1000	42.660
620	8	Non Shade	TifB16119	3	750	36.208
621	8	Non Shade	TifB16119	3	500	25.336
622	8	Non Shade	TifB16119	3	250	8.110
623	8	Non Shade	TifB16119	3	0	-13.554
624	8	Non Shade	TifB16119	4	2000	38.826
625	8	Non Shade	TifB16119	4	1500	41.587
626	8	Non Shade	TifB16119	4	1000	36.865
627	8	Non Shade	TifB16119	4	750	32.696
628	8	Non Shade	TifB16119	4	500	24.693
629	8	Non Shade	TifB16119	4	250	10.317
630	8	Non Shade	TifB16119	4	0	-9.579
631	8	Non Shade	Tifway	1	2000	53.713
632	8	Non Shade	Tifway	1	1500	60.544
633	8	Non Shade	Tifway	1	1000	52.455
634	8	Non Shade	Tifway	1	750	39.946
635	8	Non Shade	Tifway	1	500	22.795
636	8	Non Shade	Tifway	1	250	11.300
637	8	Non Shade	Tifway	1	0	-5.700
638	8	Non Shade	Tifway	2	2000	30.519
639	8	Non Shade	Tifway	2	1500	33.014
640	8	Non Shade	Tifway	2	1000	30.187

641	8	Non Shade	Tifway	2	750	27.070
642	8	Non Shade	Tifway	2	500	19.851
643	8	Non Shade	Tifway	2	250	9.382
644	8	Non Shade	Tifway	2	0	-5.905
645	8	Non Shade	Tifway	3	2000	54.544
646	8	Non Shade	Tifway	3	1500	74.380
647	8	Non Shade	Tifway	3	1000	54.009
648	8	Non Shade	Tifway	3	750	48.477
649	8	Non Shade	Tifway	3	500	33.185
650	8	Non Shade	Tifway	3	250	13.985
651	8	Non Shade	Tifway	3	0	-9.447
652	8	Non Shade	Tifway	4	2000	24.469
653	8	Non Shade	Tifway	4	1500	25.655
654	8	Non Shade	Tifway	4	1000	21.861
655	8	Non Shade	Tifway	4	750	18.434
656	8	Non Shade	Tifway	4	500	12.210
657	8	Non Shade	Tifway	4	250	2.331
658	8	Non Shade	Tifway	4	0	-12.650

Table 2. Photosynthetic rates at different light intensities for each St. Augustinegrass genotype measured for three weeks under shade and non-shade conditions during experiment 1.

S.No.	**Week**	**Treatment**	**Genotype**	**Replication**	**PAR** $\mu mol\ m^{-2}\ s^{-1}$	**Photosynthesis** $\mu mol\ CO_2\ m^{-2}\ s^{-1}$
1	0	Shade	DALSA 1404	1	2000	21.770
2	0	Shade	DALSA 1404	1	1500	23.018
3	0	Shade	DALSA 1404	1	1000	20.972
4	0	Shade	DALSA 1404	1	750	17.497
5	0	Shade	DALSA 1404	1	500	14.074
6	0	Shade	DALSA 1404	1	250	6.746
7	0	Shade	DALSA 1404	1	0	-2.596
8	0	Shade	DALSA 1404	2	2000	16.581
9	0	Shade	DALSA 1404	2	1500	17.755
10	0	Shade	DALSA 1404	2	1000	17.104
11	0	Shade	DALSA 1404	2	750	16.999
12	0	Shade	DALSA 1404	2	500	14.210
13	0	Shade	DALSA 1404	2	250	9.739
14	0	Shade	DALSA 1404	2	0	-1.592
15	0	Shade	DALSA 1404	3	2000	19.801
16	0	Shade	DALSA 1404	3	1500	19.091
17	0	Shade	DALSA 1404	3	1000	18.473
18	0	Shade	DALSA 1404	3	750	18.907
19	0	Shade	DALSA 1404	3	500	16.915
20	0	Shade	DALSA 1404	3	250	11.829
21	0	Shade	DALSA 1404	3	0	-3.369
22	0	Shade	DALSA 1404	4	2000	16.575
23	0	Shade	DALSA 1404	4	1500	17.636
24	0	Shade	DALSA 1404	4	1000	16.139
25	0	Shade	DALSA 1404	4	750	16.060
26	0	Shade	DALSA 1404	4	500	16.161
27	0	Shade	DALSA 1404	4	250	7.711
28	0	Shade	DALSA 1404	4	0	-4.376
29	0	Shade	DALSA 1405	1	2000	18.116
30	0	Shade	DALSA 1405	1	1500	19.870
31	0	Shade	DALSA 1405	1	1000	19.242
32	0	Shade	DALSA 1405	1	750	17.764
33	0	Shade	DALSA 1405	1	500	15.251
34	0	Shade	DALSA 1405	1	250	12.965
35	0	Shade	DALSA 1405	1	0	-1.568
36	0	Shade	DALSA 1405	2	2000	22.953
37	0	Shade	DALSA 1405	2	1500	20.819

38	0	Shade	DALSA 1405	2	1000	18.910
39	0	Shade	DALSA 1405	2	750	18.574
40	0	Shade	DALSA 1405	2	500	17.415
41	0	Shade	DALSA 1405	2	250	11.775
42	0	Shade	DALSA 1405	2	0	-0.677
43	0	Shade	DALSA 1405	3	2000	20.957
44	0	Shade	DALSA 1405	3	1500	19.129
45	0	Shade	DALSA 1405	3	1000	19.600
46	0	Shade	DALSA 1405	3	750	18.817
47	0	Shade	DALSA 1405	3	500	17.757
48	0	Shade	DALSA 1405	3	250	13.397
49	0	Shade	DALSA 1405	3	0	-1.939
50	0	Shade	DALSA 1405	4	2000	17.896
51	0	Shade	DALSA 1405	4	1500	17.396
52	0	Shade	DALSA 1405	4	1000	16.794
53	0	Shade	DALSA 1405	4	750	14.536
54	0	Shade	DALSA 1405	4	500	14.190
55	0	Shade	DALSA 1405	4	250	10.001
56	0	Shade	DALSA 1405	4	0	-1.334
57	0	Shade	DALSA 1618	1	2000	25.473
58	0	Shade	DALSA 1618	1	1500	23.882
59	0	Shade	DALSA 1618	1	1000	22.124
60	0	Shade	DALSA 1618	1	750	21.442
61	0	Shade	DALSA 1618	1	500	19.833
62	0	Shade	DALSA 1618	1	250	13.695
63	0	Shade	DALSA 1618	1	0	-0.411
64	0	Shade	DALSA 1618	2	2000	19.484
65	0	Shade	DALSA 1618	2	1500	21.960
66	0	Shade	DALSA 1618	2	1000	21.388
67	0	Shade	DALSA 1618	2	750	20.165
68	0	Shade	DALSA 1618	2	500	17.059
69	0	Shade	DALSA 1618	2	250	10.896
70	0	Shade	DALSA 1618	2	0	-2.844
71	0	Shade	DALSA 1618	3	2000	18.079
72	0	Shade	DALSA 1618	3	1500	18.090
73	0	Shade	DALSA 1618	3	1000	18.378
74	0	Shade	DALSA 1618	3	750	18.529
75	0	Shade	DALSA 1618	3	500	16.016
76	0	Shade	DALSA 1618	3	250	9.999
77	0	Shade	DALSA 1618	3	0	-4.705
78	0	Shade	DALSA 1618	4	2000	18.163
79	0	Shade	DALSA 1618	4	1500	15.973
80	0	Shade	DALSA 1618	4	1000	15.113

81	0	Shade	DALSA 1618	4	750	14.063
82	0	Shade	DALSA 1618	4	500	15.502
83	0	Shade	DALSA 1618	4	250	10.262
84	0	Shade	DALSA 1618	4	0	-2.442
86	0	Shade	TamStar	1	1500	12.220
87	0	Shade	TamStar	1	1000	11.493
88	0	Shade	TamStar	1	750	10.072
89	0	Shade	TamStar	1	500	9.105
90	0	Shade	TamStar	1	250	7.696
91	0	Shade	TamStar	1	0	-5.576
92	0	Shade	TamStar	2	2000	21.284
93	0	Shade	TamStar	2	1500	24.603
94	0	Shade	TamStar	2	1000	22.105
95	0	Shade	TamStar	2	750	21.864
96	0	Shade	TamStar	2	500	18.395
97	0	Shade	TamStar	2	250	14.009
98	0	Shade	TamStar	2	0	-1.060
99	0	Shade	TamStar	3	2000	21.079
100	0	Shade	TamStar	3	1500	19.826
101	0	Shade	TamStar	3	1000	19.061
102	0	Shade	TamStar	3	750	16.962
103	0	Shade	TamStar	3	500	13.263
104	0	Shade	TamStar	3	250	11.457
105	0	Shade	TamStar	3	0	-1.024
106	0	Shade	TamStar	4	2000	18.535
107	0	Shade	TamStar	4	1500	18.540
108	0	Shade	TamStar	4	1000	16.367
109	0	Shade	TamStar	4	750	16.687
110	0	Shade	TamStar	4	500	13.706
111	0	Shade	TamStar	4	250	10.371
112	0	Shade	TamStar	4	0	-1.721
113	0	Non Shade	DALSA 1404	1	2000	18.263
114	0	Non Shade	DALSA 1404	1	1500	17.088
115	0	Non Shade	DALSA 1404	1	1000	16.714
116	0	Non Shade	DALSA 1404	1	750	16.121
117	0	Non Shade	DALSA 1404	1	500	15.412
118	0	Non Shade	DALSA 1404	1	250	11.360
119	0	Non Shade	DALSA 1404	1	0	-6.834
120	0	Non Shade	DALSA 1404	2	2000	16.455
121	0	Non Shade	DALSA 1404	2	1500	15.558
122	0	Non Shade	DALSA 1404	2	1000	14.154
123	0	Non Shade	DALSA 1404	2	750	15.003
124	0	Non Shade	DALSA 1404	2	500	12.909

125	0	Non Shade	DALSA 1404	2	250	9.586
126	0	Non Shade	DALSA 1404	2	0	-3.480
127	0	Non Shade	DALSA 1404	3	2000	20.020
128	0	Non Shade	DALSA 1404	3	1500	18.432
129	0	Non Shade	DALSA 1404	3	1000	19.039
130	0	Non Shade	DALSA 1404	3	750	19.068
131	0	Non Shade	DALSA 1404	3	500	17.270
132	0	Non Shade	DALSA 1404	3	250	11.215
133	0	Non Shade	DALSA 1404	3	0	-2.310
134	0	Non Shade	DALSA 1404	4	2000	15.336
135	0	Non Shade	DALSA 1404	4	1500	15.520
136	0	Non Shade	DALSA 1404	4	1000	14.169
137	0	Non Shade	DALSA 1404	4	750	15.764
138	0	Non Shade	DALSA 1404	4	500	13.561
139	0	Non Shade	DALSA 1404	4	250	10.200
140	0	Non Shade	DALSA 1404	4	0	-1.171
141	0	Non Shade	DALSA 1405	1	2000	11.807
142	0	Non Shade	DALSA 1405	1	1500	14.217
143	0	Non Shade	DALSA 1405	1	1000	9.804
144	0	Non Shade	DALSA 1405	1	750	8.206
145	0	Non Shade	DALSA 1405	1	500	8.350
146	0	Non Shade	DALSA 1405	1	250	8.887
147	0	Non Shade	DALSA 1405	1	0	-5.386
148	0	Non Shade	DALSA 1405	2	2000	17.931
149	0	Non Shade	DALSA 1405	2	1500	19.393
150	0	Non Shade	DALSA 1405	2	1000	18.487
151	0	Non Shade	DALSA 1405	2	750	18.438
152	0	Non Shade	DALSA 1405	2	500	16.564
153	0	Non Shade	DALSA 1405	2	250	12.077
154	0	Non Shade	DALSA 1405	2	0	-4.093
155	0	Non Shade	DALSA 1405	3	2000	20.436
156	0	Non Shade	DALSA 1405	3	1500	18.379
157	0	Non Shade	DALSA 1405	3	1000	18.420
158	0	Non Shade	DALSA 1405	3	750	16.208
159	0	Non Shade	DALSA 1405	3	500	14.938
160	0	Non Shade	DALSA 1405	3	250	10.003
161	0	Non Shade	DALSA 1405	3	0	-1.068
162	0	Non Shade	DALSA 1405	4	2000	15.639
163	0	Non Shade	DALSA 1405	4	1500	15.627
164	0	Non Shade	DALSA 1405	4	1000	14.893
165	0	Non Shade	DALSA 1405	4	750	15.865
166	0	Non Shade	DALSA 1405	4	500	13.745
167	0	Non Shade	DALSA 1405	4	250	10.892

168	0	Non Shade	DALSA 1405	4	0	-0.912
169	0	Non Shade	DALSA 1618	1	2000	18.225
170	0	Non Shade	DALSA 1618	1	1500	19.166
171	0	Non Shade	DALSA 1618	1	1000	19.509
172	0	Non Shade	DALSA 1618	1	750	17.849
173	0	Non Shade	DALSA 1618	1	500	17.563
174	0	Non Shade	DALSA 1618	1	250	13.217
175	0	Non Shade	DALSA 1618	1	0	-4.486
176	0	Non Shade	DALSA 1618	2	2000	18.925
177	0	Non Shade	DALSA 1618	2	1500	18.005
178	0	Non Shade	DALSA 1618	2	1000	17.558
179	0	Non Shade	DALSA 1618	2	750	16.273
180	0	Non Shade	DALSA 1618	2	500	14.618
181	0	Non Shade	DALSA 1618	2	250	10.692
182	0	Non Shade	DALSA 1618	2	0	-2.037
183	0	Non Shade	DALSA 1618	3	2000	19.306
184	0	Non Shade	DALSA 1618	3	1500	19.074
185	0	Non Shade	DALSA 1618	3	1000	19.057
186	0	Non Shade	DALSA 1618	3	750	19.234
187	0	Non Shade	DALSA 1618	3	500	18.033
188	0	Non Shade	DALSA 1618	3	250	12.793
189	0	Non Shade	DALSA 1618	3	0	-2.854
190	0	Non Shade	DALSA 1618	4	2000	15.295
191	0	Non Shade	DALSA 1618	4	1500	15.229
192	0	Non Shade	DALSA 1618	4	1000	14.729
193	0	Non Shade	DALSA 1618	4	750	15.223
194	0	Non Shade	DALSA 1618	4	500	13.680
195	0	Non Shade	DALSA 1618	4	250	11.521
196	0	Non Shade	DALSA 1618	4	0	-1.698
197	0	Non Shade	TamStar	1	2000	13.148
198	0	Non Shade	TamStar	1	1500	13.050
199	0	Non Shade	TamStar	1	1000	12.420
200	0	Non Shade	TamStar	1	750	11.709
201	0	Non Shade	TamStar	1	500	10.975
202	0	Non Shade	TamStar	1	250	9.196
203	0	Non Shade	TamStar	1	0	-0.783
204	0	Non Shade	TamStar	2	2000	13.903
205	0	Non Shade	TamStar	2	1500	14.499
206	0	Non Shade	TamStar	2	1000	13.999
207	0	Non Shade	TamStar	2	750	13.589
208	0	Non Shade	TamStar	2	500	12.759
209	0	Non Shade	TamStar	2	250	11.534
210	0	Non Shade	TamStar	2	0	-3.328

211	0	Non Shade	TamStar	3	2000	13.956
212	0	Non Shade	TamStar	3	1500	13.170
214	0	Non Shade	TamStar	3	750	12.204
215	0	Non Shade	TamStar	3	500	11.700
216	0	Non Shade	TamStar	3	250	9.331
217	0	Non Shade	TamStar	3	0	-2.172
218	0	Non Shade	TamStar	4	2000	14.402
219	0	Non Shade	TamStar	4	1500	12.250
220	0	Non Shade	TamStar	4	1000	11.895
222	0	Non Shade	TamStar	4	500	9.763
223	0	Non Shade	TamStar	4	250	8.574
224	0	Non Shade	TamStar	4	0	-1.120
225	4	Shade	DALSA 1404	1	2000	17.559
226	4	Shade	DALSA 1404	1	1500	15.679
227	4	Shade	DALSA 1404	1	1000	14.583
228	4	Shade	DALSA 1404	1	750	12.572
230	4	Shade	DALSA 1404	1	250	11.357
231	4	Shade	DALSA 1404	1	0	-0.573
232	4	Shade	DALSA 1404	2	2000	13.125
233	4	Shade	DALSA 1404	2	1500	12.951
234	4	Shade	DALSA 1404	2	1000	11.964
235	4	Shade	DALSA 1404	2	750	10.102
236	4	Shade	DALSA 1404	2	500	9.950
237	4	Shade	DALSA 1404	2	250	7.946
238	4	Shade	DALSA 1404	2	0	-0.004
239	4	Shade	DALSA 1404	3	2000	16.272
240	4	Shade	DALSA 1404	3	1500	16.020
241	4	Shade	DALSA 1404	3	1000	14.815
242	4	Shade	DALSA 1404	3	750	14.666
243	4	Shade	DALSA 1404	3	500	12.933
244	4	Shade	DALSA 1404	3	250	9.244
245	4	Shade	DALSA 1404	3	0	-1.553
246	4	Shade	DALSA 1404	4	2000	11.037
247	4	Shade	DALSA 1404	4	1500	9.352
248	4	Shade	DALSA 1404	4	1000	9.151
250	4	Shade	DALSA 1404	4	500	8.542
251	4	Shade	DALSA 1404	4	250	7.904
252	4	Shade	DALSA 1404	4	0	-2.619
253	4	Shade	DALSA 1405	1	2000	18.551
254	4	Shade	DALSA 1405	1	1500	16.663
256	4	Shade	DALSA 1405	1	750	14.615
257	4	Shade	DALSA 1405	1	500	14.471
258	4	Shade	DALSA 1405	1	250	12.816

259	4	Shade	DALSA 1405	1	0	0.046
260	4	Shade	DALSA 1405	2	2000	17.530
261	4	Shade	DALSA 1405	2	1500	16.557
262	4	Shade	DALSA 1405	2	1000	17.000
263	4	Shade	DALSA 1405	2	750	16.030
264	4	Shade	DALSA 1405	2	500	15.565
265	4	Shade	DALSA 1405	2	250	12.234
266	4	Shade	DALSA 1405	2	0	-1.191
267	4	Shade	DALSA 1405	3	2000	15.801
268	4	Shade	DALSA 1405	3	1500	14.841
269	4	Shade	DALSA 1405	3	1000	14.690
270	4	Shade	DALSA 1405	3	750	13.669
271	4	Shade	DALSA 1405	3	500	12.319
272	4	Shade	DALSA 1405	3	250	10.892
273	4	Shade	DALSA 1405	3	0	-0.839
274	4	Shade	DALSA 1405	4	2000	14.677
275	4	Shade	DALSA 1405	4	1500	13.812
276	4	Shade	DALSA 1405	4	1000	10.933
277	4	Shade	DALSA 1405	4	750	11.274
278	4	Shade	DALSA 1405	4	500	11.268
279	4	Shade	DALSA 1405	4	250	6.893
280	4	Shade	DALSA 1405	4	0	-1.855
281	4	Shade	DALSA 1618	1	2000	14.585
282	4	Shade	DALSA 1618	1	1500	14.892
283	4	Shade	DALSA 1618	1	1000	15.028
284	4	Shade	DALSA 1618	1	750	14.091
285	4	Shade	DALSA 1618	1	500	13.091
286	4	Shade	DALSA 1618	1	250	10.003
287	4	Shade	DALSA 1618	1	0	0.000
288	4	Shade	DALSA 1618	2	2000	19.523
289	4	Shade	DALSA 1618	2	1500	18.264
290	4	Shade	DALSA 1618	2	1000	17.319
291	4	Shade	DALSA 1618	2	750	16.658
292	4	Shade	DALSA 1618	2	500	15.800
293	4	Shade	DALSA 1618	2	250	12.293
294	4	Shade	DALSA 1618	2	0	-0.214
295	4	Shade	DALSA 1618	3	2000	21.286
296	4	Shade	DALSA 1618	3	1500	21.334
297	4	Shade	DALSA 1618	3	1000	20.635
298	4	Shade	DALSA 1618	3	750	20.959
299	4	Shade	DALSA 1618	3	500	18.451
300	4	Shade	DALSA 1618	3	250	15.469
301	4	Shade	DALSA 1618	3	0	-7.447

302	4	Shade	DALSA 1618	4	2000	18.735
303	4	Shade	DALSA 1618	4	1500	19.452
304	4	Shade	DALSA 1618	4	1000	18.188
305	4	Shade	DALSA 1618	4	750	19.034
306	4	Shade	DALSA 1618	4	500	17.214
307	4	Shade	DALSA 1618	4	250	12.925
308	4	Shade	DALSA 1618	4	0	-3.318
309	4	Shade	TamStar	1	2000	15.657
310	4	Shade	TamStar	1	1500	15.214
311	4	Shade	TamStar	1	1000	13.063
312	4	Shade	TamStar	1	750	11.590
313	4	Shade	TamStar	1	500	10.578
314	4	Shade	TamStar	1	250	9.623
315	4	Shade	TamStar	1	0	0.161
316	4	Shade	TamStar	2	2000	17.930
317	4	Shade	TamStar	2	1500	16.614
318	4	Shade	TamStar	2	1000	15.416
319	4	Shade	TamStar	2	750	14.321
320	4	Shade	TamStar	2	500	13.020
321	4	Shade	TamStar	2	250	9.264
322	4	Shade	TamStar	2	0	-1.109
323	4	Shade	TamStar	3	2000	14.584
324	4	Shade	TamStar	3	1500	13.917
325	4	Shade	TamStar	3	1000	13.910
326	4	Shade	TamStar	3	750	12.926
327	4	Shade	TamStar	3	500	12.757
328	4	Shade	TamStar	3	250	10.080
329	4	Shade	TamStar	3	0	-0.520
330	4	Shade	TamStar	4	2000	15.721
331	4	Shade	TamStar	4	1500	14.307
333	4	Shade	TamStar	4	750	13.757
334	4	Shade	TamStar	4	500	13.149
335	4	Shade	TamStar	4	250	10.943
336	4	Shade	TamStar	4	0	-2.735
337	4	Non Shade	DALSA 1404	1	2000	19.225
338	4	Non Shade	DALSA 1404	1	1500	20.243
339	4	Non Shade	DALSA 1404	1	1000	20.163
340	4	Non Shade	DALSA 1404	1	750	19.848
341	4	Non Shade	DALSA 1404	1	500	18.787
342	4	Non Shade	DALSA 1404	1	250	15.618
343	4	Non Shade	DALSA 1404	1	0	-8.458
344	4	Non Shade	DALSA 1404	2	2000	19.095
345	4	Non Shade	DALSA 1404	2	1500	20.330

346	4	Non Shade	DALSA 1404	2	1000	15.820
347	4	Non Shade	DALSA 1404	2	750	15.184
348	4	Non Shade	DALSA 1404	2	500	14.775
349	4	Non Shade	DALSA 1404	2	250	11.717
350	4	Non Shade	DALSA 1404	2	0	-1.480
351	4	Non Shade	DALSA 1404	3	2000	12.204
352	4	Non Shade	DALSA 1404	3	1500	12.135
353	4	Non Shade	DALSA 1404	3	1000	9.955
354	4	Non Shade	DALSA 1404	3	750	11.040
355	4	Non Shade	DALSA 1404	3	500	10.925
356	4	Non Shade	DALSA 1404	3	250	6.764
357	4	Non Shade	DALSA 1404	3	0	-2.086
358	4	Non Shade	DALSA 1404	4	2000	15.829
359	4	Non Shade	DALSA 1404	4	1500	14.617
360	4	Non Shade	DALSA 1404	4	1000	11.971
361	4	Non Shade	DALSA 1404	4	750	11.531
362	4	Non Shade	DALSA 1404	4	500	11.942
363	4	Non Shade	DALSA 1404	4	250	5.890
364	4	Non Shade	DALSA 1404	4	0	-1.743
365	4	Non Shade	DALSA 1405	1	2000	21.657
366	4	Non Shade	DALSA 1405	1	1500	20.678
367	4	Non Shade	DALSA 1405	1	1000	20.423
368	4	Non Shade	DALSA 1405	1	750	20.141
369	4	Non Shade	DALSA 1405	1	500	17.254
370	4	Non Shade	DALSA 1405	1	250	10.654
371	4	Non Shade	DALSA 1405	1	0	-1.420
372	4	Non Shade	DALSA 1405	2	2000	22.358
373	4	Non Shade	DALSA 1405	2	1500	21.877
374	4	Non Shade	DALSA 1405	2	1000	19.810
375	4	Non Shade	DALSA 1405	2	750	19.594
376	4	Non Shade	DALSA 1405	2	500	19.158
377	4	Non Shade	DALSA 1405	2	250	15.515
378	4	Non Shade	DALSA 1405	2	0	-1.044
379	4	Non Shade	DALSA 1405	3	2000	19.995
380	4	Non Shade	DALSA 1405	3	1500	20.507
381	4	Non Shade	DALSA 1405	3	1000	19.560
382	4	Non Shade	DALSA 1405	3	750	18.730
383	4	Non Shade	DALSA 1405	3	500	14.974
384	4	Non Shade	DALSA 1405	3	250	5.164
385	4	Non Shade	DALSA 1405	3	0	-5.327
386	4	Non Shade	DALSA 1405	4	2000	15.094
387	4	Non Shade	DALSA 1405	4	1500	13.935
388	4	Non Shade	DALSA 1405	4	1000	13.190

389	4	Non Shade	DALSA 1405	4	750	13.311
390	4	Non Shade	DALSA 1405	4	500	11.841
391	4	Non Shade	DALSA 1405	4	250	7.607
392	4	Non Shade	DALSA 1405	4	0	-0.591
393	4	Non Shade	DALSA 1618	1	2000	14.754
394	4	Non Shade	DALSA 1618	1	1500	14.962
395	4	Non Shade	DALSA 1618	1	1000	16.508
396	4	Non Shade	DALSA 1618	1	750	16.530
397	4	Non Shade	DALSA 1618	1	500	13.487
398	4	Non Shade	DALSA 1618	1	250	10.813
399	4	Non Shade	DALSA 1618	1	0	0.180
400	4	Non Shade	DALSA 1618	2	2000	22.475
401	4	Non Shade	DALSA 1618	2	1500	17.862
402	4	Non Shade	DALSA 1618	2	1000	16.616
403	4	Non Shade	DALSA 1618	2	750	18.538
404	4	Non Shade	DALSA 1618	2	500	18.884
405	4	Non Shade	DALSA 1618	2	250	14.452
406	4	Non Shade	DALSA 1618	2	0	-1.429
407	4	Non Shade	DALSA 1618	3	2000	8.493
408	4	Non Shade	DALSA 1618	3	1500	8.978
409	4	Non Shade	DALSA 1618	3	1000	10.826
410	4	Non Shade	DALSA 1618	3	750	9.843
411	4	Non Shade	DALSA 1618	3	500	9.424
412	4	Non Shade	DALSA 1618	3	250	5.788
413	4	Non Shade	DALSA 1618	3	0	-1.675
414	4	Non Shade	DALSA 1618	4	2000	18.266
415	4	Non Shade	DALSA 1618	4	1500	16.500
416	4	Non Shade	DALSA 1618	4	1000	16.166
417	4	Non Shade	DALSA 1618	4	750	16.485
418	4	Non Shade	DALSA 1618	4	500	14.768
419	4	Non Shade	DALSA 1618	4	250	11.300
420	4	Non Shade	DALSA 1618	4	0	0.181
421	4	Non Shade	TamStar	1	2000	17.331
422	4	Non Shade	TamStar	1	1500	17.728
423	4	Non Shade	TamStar	1	1000	13.079
424	4	Non Shade	TamStar	1	750	12.797
425	4	Non Shade	TamStar	1	500	10.710
426	4	Non Shade	TamStar	1	250	7.662
427	4	Non Shade	TamStar	1	0	-1.597
428	4	Non Shade	TamStar	2	2000	11.844
429	4	Non Shade	TamStar	2	1500	11.060
430	4	Non Shade	TamStar	2	1000	10.032
431	4	Non Shade	TamStar	2	750	10.222

432	4	Non Shade	TamStar	2	500	9.182
433	4	Non Shade	TamStar	2	250	7.306
434	4	Non Shade	TamStar	2	0	-0.398
435	4	Non Shade	TamStar	3	2000	10.429
436	4	Non Shade	TamStar	3	1500	9.962
437	4	Non Shade	TamStar	3	1000	8.804
438	4	Non Shade	TamStar	3	750	9.691
439	4	Non Shade	TamStar	3	500	11.117
440	4	Non Shade	TamStar	3	250	8.464
441	4	Non Shade	TamStar	3	0	-1.896
442	4	Non Shade	TamStar	4	2000	14.732
443	4	Non Shade	TamStar	4	1500	13.528
444	4	Non Shade	TamStar	4	1000	13.530
445	4	Non Shade	TamStar	4	750	12.823
446	4	Non Shade	TamStar	4	500	11.614
447	4	Non Shade	TamStar	4	250	8.781
448	4	Non Shade	TamStar	4	0	-0.805
449	8	Shade	DALSA 1404	1	2000	16.701
450	8	Shade	DALSA 1404	1	1500	13.192
451	8	Shade	DALSA 1404	1	1000	12.603
452	8	Shade	DALSA 1404	1	750	13.726
453	8	Shade	DALSA 1404	1	500	13.020
454	8	Shade	DALSA 1404	1	250	8.912
455	8	Shade	DALSA 1404	1	0	3.623
456	8	Shade	DALSA 1404	2	2000	16.054
457	8	Shade	DALSA 1404	2	1500	12.721
458	8	Shade	DALSA 1404	2	1000	11.442
459	8	Shade	DALSA 1404	2	750	10.902
460	8	Shade	DALSA 1404	2	500	10.710
461	8	Shade	DALSA 1404	2	250	7.006
462	8	Shade	DALSA 1404	2	0	1.662
463	8	Shade	DALSA 1404	3	2000	16.235
464	8	Shade	DALSA 1404	3	1500	15.958
465	8	Shade	DALSA 1404	3	1000	14.905
466	8	Shade	DALSA 1404	3	750	12.092
467	8	Shade	DALSA 1404	3	500	12.059
468	8	Shade	DALSA 1404	3	250	10.309
469	8	Shade	DALSA 1404	3	0	3.054
477	8	Shade	DALSA 1405	1	2000	19.127
478	8	Shade	DALSA 1405	1	1500	17.854
479	8	Shade	DALSA 1405	1	1000	16.685
480	8	Shade	DALSA 1405	1	750	16.173
481	8	Shade	DALSA 1405	1	500	15.742

482	8	Shade	DALSA 1405	1	250	12.933
483	8	Shade	DALSA 1405	1	0	3.874
484	8	Shade	DALSA 1405	2	2000	17.721
485	8	Shade	DALSA 1405	2	1500	14.050
486	8	Shade	DALSA 1405	2	1000	13.937
487	8	Shade	DALSA 1405	2	750	13.616
488	8	Shade	DALSA 1405	2	500	12.218
489	8	Shade	DALSA 1405	2	250	7.925
490	8	Shade	DALSA 1405	2	0	2.538
491	8	Shade	DALSA 1405	3	2000	19.838
492	8	Shade	DALSA 1405	3	1500	18.441
493	8	Shade	DALSA 1405	3	1000	17.333
494	8	Shade	DALSA 1405	3	750	14.166
495	8	Shade	DALSA 1405	3	500	11.289
496	8	Shade	DALSA 1405	3	250	9.484
497	8	Shade	DALSA 1405	3	0	3.682
505	8	Shade	DALSA 1618	1	2000	14.864
506	8	Shade	DALSA 1618	1	1500	14.813
507	8	Shade	DALSA 1618	1	1000	13.887
508	8	Shade	DALSA 1618	1	750	12.112
509	8	Shade	DALSA 1618	1	500	11.519
510	8	Shade	DALSA 1618	1	250	9.241
511	8	Shade	DALSA 1618	1	0	3.668
512	8	Shade	DALSA 1618	2	2000	16.771
513	8	Shade	DALSA 1618	2	1500	15.777
514	8	Shade	DALSA 1618	2	1000	14.788
515	8	Shade	DALSA 1618	2	750	13.928
516	8	Shade	DALSA 1618	2	500	12.794
517	8	Shade	DALSA 1618	2	250	9.468
518	8	Shade	DALSA 1618	2	0	-0.697
519	8	Shade	DALSA 1618	3	2000	13.502
520	8	Shade	DALSA 1618	3	1500	13.371
521	8	Shade	DALSA 1618	3	1000	11.038
522	8	Shade	DALSA 1618	3	750	10.525
523	8	Shade	DALSA 1618	3	500	9.799
524	8	Shade	DALSA 1618	3	250	7.751
525	8	Shade	DALSA 1618	3	0	1.266
	8	Shade	TamStar	1	2000	19.829
533	8	Shade	TamStar	1	1500	17.270
534	8	Shade	TamStar	1	1000	14.703
535	8	Shade	TamStar	1	750	13.326
536	8	Shade	TamStar	1	500	12.297
537	8	Shade	TamStar	1	250	10.157

538	8	Shade	TamStar	1	0	3.807
539	8	Shade	TamStar	2	2000	13.274
540	8	Shade	TamStar	2	1500	10.154
541	8	Shade	TamStar	2	1000	10.456
542	8	Shade	TamStar	2	750	8.678
543	8	Shade	TamStar	2	500	8.096
544	8	Shade	TamStar	2	250	7.382
545	8	Shade	TamStar	2	0	1.936
546	8	Shade	TamStar	3	2000	20.612
547	8	Shade	TamStar	3	1500	19.541
548	8	Shade	TamStar	3	1000	17.141
549	8	Shade	TamStar	3	750	15.085
550	8	Shade	TamStar	3	500	14.278
551	8	Shade	TamStar	3	250	11.792
552	8	Shade	TamStar	3	0	4.766
560	8	Non Shade	DALSA 1404	1	2000	16.602
561	8	Non Shade	DALSA 1404	1	1500	14.010
562	8	Non Shade	DALSA 1404	1	1000	13.494
563	8	Non Shade	DALSA 1404	1	750	11.350
564	8	Non Shade	DALSA 1404	1	500	10.511
565	8	Non Shade	DALSA 1404	1	250	8.789
566	8	Non Shade	DALSA 1404	1	0	1.071
567	8	Non Shade	DALSA 1404	2	2000	17.245
568	8	Non Shade	DALSA 1404	2	1500	16.246
569	8	Non Shade	DALSA 1404	2	1000	16.677
570	8	Non Shade	DALSA 1404	2	750	13.711
571	8	Non Shade	DALSA 1404	2	500	12.092
572	8	Non Shade	DALSA 1404	2	250	5.163
573	8	Non Shade	DALSA 1404	2	0	-0.374
574	8	Non Shade	DALSA 1404	3	2000	16.201
575	8	Non Shade	DALSA 1404	3	1500	11.332
576	8	Non Shade	DALSA 1404	3	1000	9.259
577	8	Non Shade	DALSA 1404	3	750	10.619
578	8	Non Shade	DALSA 1404	3	500	9.021
579	8	Non Shade	DALSA 1404	3	250	5.319
580	8	Non Shade	DALSA 1404	3	0	1.632
588	8	Non Shade	DALSA 1405	1	2000	16.113
589	8	Non Shade	DALSA 1405	1	1500	12.676
590	8	Non Shade	DALSA 1405	1	1000	11.288
591	8	Non Shade	DALSA 1405	1	750	11.824
592	8	Non Shade	DALSA 1405	1	500	9.641
593	8	Non Shade	DALSA 1405	1	250	7.045
594	8	Non Shade	DALSA 1405	1	0	3.061

595	8	Non Shade	DALSA 1405	2	2000	12.703
596	8	Non Shade	DALSA 1405	2	1500	9.764
597	8	Non Shade	DALSA 1405	2	1000	9.981
598	8	Non Shade	DALSA 1405	2	750	8.772
599	8	Non Shade	DALSA 1405	2	500	6.572
600	8	Non Shade	DALSA 1405	2	250	3.959
601	8	Non Shade	DALSA 1405	2	0	0.106
602	8	Non Shade	DALSA 1405	3	2000	16.011
603	8	Non Shade	DALSA 1405	3	1500	14.383
604	8	Non Shade	DALSA 1405	3	1000	12.724
605	8	Non Shade	DALSA 1405	3	750	11.836
606	8	Non Shade	DALSA 1405	3	500	10.888
607	8	Non Shade	DALSA 1405	3	250	5.508
608	8	Non Shade	DALSA 1405	3	0	1.939
616	8	Non Shade	DALSA 1618	1	2000	13.988
617	8	Non Shade	DALSA 1618	1	1500	12.552
618	8	Non Shade	DALSA 1618	1	1000	11.056
619	8	Non Shade	DALSA 1618	1	750	9.930
620	8	Non Shade	DALSA 1618	1	500	8.872
621	8	Non Shade	DALSA 1618	1	250	6.116
622	8	Non Shade	DALSA 1618	1	0	-0.503
623	8	Non Shade	DALSA 1618	2	2000	15.126
624	8	Non Shade	DALSA 1618	2	1500	14.370
625	8	Non Shade	DALSA 1618	2	1000	9.514
626	8	Non Shade	DALSA 1618	2	750	10.671
627	8	Non Shade	DALSA 1618	2	500	7.842
628	8	Non Shade	DALSA 1618	2	250	5.546
629	8	Non Shade	DALSA 1618	2	0	-0.306
630	8	Non Shade	DALSA 1618	3	2000	17.881
631	8	Non Shade	DALSA 1618	3	1500	14.809
632	8	Non Shade	DALSA 1618	3	1000	11.257
633	8	Non Shade	DALSA 1618	3	750	9.656
634	8	Non Shade	DALSA 1618	3	500	8.862
635	8	Non Shade	DALSA 1618	3	250	7.362
636	8	Non Shade	DALSA 1618	3	0	4.206
644	8	Non Shade	TamStar	1	2000	13.988
645	8	Non Shade	TamStar	1	1500	10.552
646	8	Non Shade	TamStar	1	1000	11.056
647	8	Non Shade	TamStar	1	750	9.930
648	8	Non Shade	TamStar	1	500	8.872
649	8	Non Shade	TamStar	1	250	6.116
650	8	Non Shade	TamStar	1	0	-0.503
651	8	Non Shade	TamStar	2	2000	19.126

652	8	Non Shade	TamStar	2	1500	14.370
653	8	Non Shade	TamStar	2	1000	9.514
654	8	Non Shade	TamStar	2	750	10.671
655	8	Non Shade	TamStar	2	500	7.842
656	8	Non Shade	TamStar	2	250	5.546
657	8	Non Shade	TamStar	2	0	-0.306
658	8	Non Shade	TamStar	3	2000	17.881
659	8	Non Shade	TamStar	3	1500	14.809
666	8	Non Shade	TamStar	3	1000	11.257
660	8	Non Shade	TamStar	3	750	9.656
661	8	Non Shade	TamStar	3	500	8.862
662	8	Non Shade	TamStar	3	250	7.362
663	8	Non Shade	TamStar	3	0	4.206

Table 3. Photosynthetic rates at different light intensities for each bermudagrass genotype measured for three weeks under shade and non-shade conditions during experiment 2.

S.No.	Week	Treatment	Genotype	Replication	PAR µmol $m^{-2} s^{-1}$	Photosynthesis µmol CO_2 $m^{-2} s^{-1}$
1	4	Shade	TifB16108	1	2000	41.922
2	4	Shade	TifB16108	1	1750	35.232
3	4	Shade	TifB16108	1	1500	33.492
4	4	Shade	TifB16108	1	1250	29.120
5	4	Shade	TifB16108	1	1000	28.538
6	4	Shade	TifB16108	1	750	28.381
7	4	Shade	TifB16108	1	500	24.600
8	4	Shade	TifB16108	1	250	12.951
9	4	Shade	TifB16108	1	0	-6.225
10	4	Shade	TifB16108	2	2000	75.913
11	4	Shade	TifB16108	2	1750	75.720
12	4	Shade	TifB16108	2	1500	87.527
13	4	Shade	TifB16108	2	1250	86.574
14	4	Shade	TifB16108	2	1000	86.075
15	4	Shade	TifB16108	2	750	85.291
16	4	Shade	TifB16108	2	500	68.662
17	4	Shade	TifB16108	2	250	35.359
18	4	Shade	TifB16108	2	0	-15.849
19	4	Shade	TifB16108	3	2000	58.834
20	4	Shade	TifB16108	3	1750	59.389
21	4	Shade	TifB16108	3	1500	67.238
22	4	Shade	TifB16108	3	1250	68.039
23	4	Shade	TifB16108	3	1000	71.209
24	4	Shade	TifB16108	3	750	71.123
25	4	Shade	TifB16108	3	500	60.956
26	4	Shade	TifB16108	3	250	40.484
27	4	Shade	TifB16108	3	0	-14.989
28	4	Shade	TifB16108	4	2000	52.743
29	4	Shade	TifB16108	4	1750	54.866
30	4	Shade	TifB16108	4	1500	63.115
31	4	Shade	TifB16108	4	1250	68.396
32	4	Shade	TifB16108	4	1000	69.302
33	4	Shade	TifB16108	4	750	65.206
34	4	Shade	TifB16108	4	500	54.632
35	4	Shade	TifB16108	4	250	31.131
36	4	Shade	TifB16108	4	0	-15.420
37	4	Shade	TifB16117	1	2000	76.412
38	4	Shade	TifB16117	1	1750	76.358
39	4	Shade	TifB16117	1	1500	73.439

40	4	Shade	TifB16117	1	1250	65.533
41	4	Shade	TifB16117	1	1000	61.009
42	4	Shade	TifB16117	1	750	58.631
43	4	Shade	TifB16117	1	500	54.804
44	4	Shade	TifB16117	1	250	33.781
45	4	Shade	TifB16117	1	0	-43.859
46	4	Shade	TifB16117	2	2000	70.097
47	4	Shade	TifB16117	2	1750	86.733
48	4	Shade	TifB16117	2	1500	117.309
49	4	Shade	TifB16117	2	1250	124.865
50	4	Shade	TifB16117	2	1000	118.183
51	4	Shade	TifB16117	2	750	109.162
52	4	Shade	TifB16117	2	500	91.047
53	4	Shade	TifB16117	2	250	44.107
54	4	Shade	TifB16117	2	0	-17.791
55	4	Shade	TifB16117	3	2000	71.034
56	4	Shade	TifB16117	3	1750	81.795
57	4	Shade	TifB16117	3	1500	91.124
58	4	Shade	TifB16117	3	1250	105.759
59	4	Shade	TifB16117	3	1000	109.619
60	4	Shade	TifB16117	3	750	90.341
61	4	Shade	TifB16117	3	500	68.800
62	4	Shade	TifB16117	3	250	31.620
63	4	Shade	TifB16117	3	0	-24.174
64	4	Shade	TifB16117	4	2000	84.845
65	4	Shade	TifB16117	4	1750	87.079
66	4	Shade	TifB16117	4	1500	106.611
67	4	Shade	TifB16117	4	1250	113.179
68	4	Shade	TifB16117	4	1000	113.048
69	4	Shade	TifB16117	4	750	96.625
70	4	Shade	TifB16117	4	500	75.131
71	4	Shade	TifB16117	4	250	38.069
72	4	Shade	TifB16117	4	0	-16.066
73	4	Shade	TifB16119	1	2000	14.052
74	4	Shade	TifB16119	1	1750	24.632
75	4	Shade	TifB16119	1	1500	24.137
76	4	Shade	TifB16119	1	1250	22.883
77	4	Shade	TifB16119	1	1000	18.702
78	4	Shade	TifB16119	1	750	18.488
79	4	Shade	TifB16119	1	500	14.963
80	4	Shade	TifB16119	1	250	7.089
81	4	Shade	TifB16119	1	0	-15.011
82	4	Shade	TifB16119	2	2000	17.769

83	4	Shade	TifB16119	2	1750	22.404
84	4	Shade	TifB16119	2	1500	21.977
85	4	Shade	TifB16119	2	1250	20.743
86	4	Shade	TifB16119	2	1000	18.891
87	4	Shade	TifB16119	2	750	15.909
88	4	Shade	TifB16119	2	500	8.648
89	4	Shade	TifB16119	2	250	2.787
90	4	Shade	TifB16119	2	0	-34.699
91	4	Shade	TifB16119	3	2000	22.415
92	4	Shade	TifB16119	3	1750	19.639
93	4	Shade	TifB16119	3	1500	18.475
94	4	Shade	TifB16119	3	1250	16.353
95	4	Shade	TifB16119	3	1000	13.993
96	4	Shade	TifB16119	3	750	8.585
97	4	Shade	TifB16119	3	500	2.563
98	4	Shade	TifB16119	3	250	5.703
99	4	Shade	TifB16119	3	0	-29.779
100	4	Shade	TifB16119	4	2000	40.892
101	4	Shade	TifB16119	4	1750	36.005
102	4	Shade	TifB16119	4	1500	44.487
103	4	Shade	TifB16119	4	1250	45.960
104	4	Shade	TifB16119	4	1000	45.755
105	4	Shade	TifB16119	4	750	42.125
106	4	Shade	TifB16119	4	500	31.665
107	4	Shade	TifB16119	4	250	11.859
108	4	Shade	TifB16119	4	0	-29.109
109	4	Shade	Tifway	1	2000	69.642
110	4	Shade	Tifway	1	1750	61.396
111	4	Shade	Tifway	1	1500	58.160
112	4	Shade	Tifway	1	1250	41.300
113	4	Shade	Tifway	1	1000	48.657
114	4	Shade	Tifway	1	750	45.878
115	4	Shade	Tifway	1	500	14.737
116	4	Shade	Tifway	1	250	0.946
117	4	Shade	Tifway	1	0	-34.340
118	4	Shade	Tifway	2	2000	81.551
119	4	Shade	Tifway	2	1750	84.250
120	4	Shade	Tifway	2	1500	90.753
121	4	Shade	Tifway	2	1250	84.198
122	4	Shade	Tifway	2	1000	83.070
123	4	Shade	Tifway	2	750	70.861
124	4	Shade	Tifway	2	500	52.028
125	4	Shade	Tifway	2	250	24.550

126	4	Shade	Tifway	2	0	-16.454
127	4	Shade	Tifway	3	2000	94.919
128	4	Shade	Tifway	3	1750	104.270
129	4	Shade	Tifway	3	1500	101.396
130	4	Shade	Tifway	3	1250	109.209
131	4	Shade	Tifway	3	1000	96.124
132	4	Shade	Tifway	3	750	86.962
133	4	Shade	Tifway	3	500	68.504
134	4	Shade	Tifway	3	250	24.991
135	4	Shade	Tifway	3	0	-39.559
136	4	Shade	Tifway	4	2000	114.960
137	4	Shade	Tifway	4	1750	117.388
138	4	Shade	Tifway	4	1500	113.137
139	4	Shade	Tifway	4	1250	153.032
140	4	Shade	Tifway	4	1000	143.426
141	4	Shade	Tifway	4	750	122.140
142	4	Shade	Tifway	4	500	91.436
143	4	Shade	Tifway	4	250	47.205
144	4	Shade	Tifway	4	0	-23.767
145	4	Non-Shade	TifB16108	1	2000	53.178
146	4	Non-Shade	TifB16108	1	1750	61.760
147	4	Non-Shade	TifB16108	1	1500	58.793
148	4	Non-Shade	TifB16108	1	1250	52.126
149	4	Non-Shade	TifB16108	1	1000	50.724
150	4	Non-Shade	TifB16108	1	750	39.692
151	4	Non-Shade	TifB16108	1	500	27.564
152	4	Non-Shade	TifB16108	1	250	6.349
153	4	Non-Shade	TifB16108	1	0	-39.086
154	4	Non-Shade	TifB16108	2	2000	83.407
155	4	Non-Shade	TifB16108	2	1750	108.519
156	4	Non-Shade	TifB16108	2	1500	141.405
157	4	Non-Shade	TifB16108	2	1250	158.163
158	4	Non-Shade	TifB16108	2	1000	140.425
159	4	Non-Shade	TifB16108	2	750	139.000
160	4	Non-Shade	TifB16108	2	500	103.716
161	4	Non-Shade	TifB16108	2	250	55.179
162	4	Non-Shade	TifB16108	2	0	-31.103
163	4	Non-Shade	TifB16108	3	2000	105.361
164	4	Non-Shade	TifB16108	3	1750	115.335
165	4	Non-Shade	TifB16108	3	1500	149.485
166	4	Non-Shade	TifB16108	3	1250	165.370
167	4	Non-Shade	TifB16108	3	1000	158.656
168	4	Non-Shade	TifB16108	3	750	140.916

169	4	Non-Shade	TifB16108	3	500	121.404
170	4	Non-Shade	TifB16108	3	250	46.716
171	4	Non-Shade	TifB16108	3	0	-6.600
172	4	Non-Shade	TifB16108	4	2000	76.070
173	4	Non-Shade	TifB16108	4	1750	105.849
174	4	Non-Shade	TifB16108	4	1500	121.027
175	4	Non-Shade	TifB16108	4	1250	179.513
176	4	Non-Shade	TifB16108	4	1000	166.165
177	4	Non-Shade	TifB16108	4	750	139.499
178	4	Non-Shade	TifB16108	4	500	93.133
179	4	Non-Shade	TifB16108	4	250	38.425
180	4	Non-Shade	TifB16108	4	0	-34.269
181	4	Non-Shade	TifB16117	1	2000	77.293
182	4	Non-Shade	TifB16117	1	1750	73.585
183	4	Non-Shade	TifB16117	1	1500	69.947
184	4	Non-Shade	TifB16117	1	1250	59.588
185	4	Non-Shade	TifB16117	1	1000	54.145
186	4	Non-Shade	TifB16117	1	750	46.097
187	4	Non-Shade	TifB16117	1	500	38.413
188	4	Non-Shade	TifB16117	1	250	11.725
189	4	Non-Shade	TifB16117	1	0	-39.152
190	4	Non-Shade	TifB16117	2	2000	87.279
191	4	Non-Shade	TifB16117	2	1750	96.725
192	4	Non-Shade	TifB16117	2	1500	141.557
193	4	Non-Shade	TifB16117	2	1250	170.053
194	4	Non-Shade	TifB16117	2	1000	159.548
195	4	Non-Shade	TifB16117	2	750	105.021
196	4	Non-Shade	TifB16117	2	500	75.455
197	4	Non-Shade	TifB16117	2	250	35.019
198	4	Non-Shade	TifB16117	2	0	-31.944
199	4	Non-Shade	TifB16117	3	2000	90.078
200	4	Non-Shade	TifB16117	3	1750	105.099
201	4	Non-Shade	TifB16117	3	1500	122.330
202	4	Non-Shade	TifB16117	3	1250	140.016
203	4	Non-Shade	TifB16117	3	1000	148.810
204	4	Non-Shade	TifB16117	3	750	143.222
205	4	Non-Shade	TifB16117	3	500	95.557
206	4	Non-Shade	TifB16117	3	250	35.377
207	4	Non-Shade	TifB16117	3	0	-50.871
208	4	Non-Shade	TifB16117	4	2000	94.421
209	4	Non-Shade	TifB16117	4	1750	112.471
210	4	Non-Shade	TifB16117	4	1500	136.205
211	4	Non-Shade	TifB16117	4	1250	143.980

212	4	Non-Shade	TifB16117	4	1000	108.176
213	4	Non-Shade	TifB16117	4	750	78.834
214	4	Non-Shade	TifB16117	4	500	57.817
215	4	Non-Shade	TifB16117	4	250	48.273
216	4	Non-Shade	TifB16117	4	0	-53.414
217	4	Non-Shade	TifB16119	1	2000	44.750
218	4	Non-Shade	TifB16119	1	1750	49.065
219	4	Non-Shade	TifB16119	1	1500	48.259
220	4	Non-Shade	TifB16119	1	1250	47.630
221	4	Non-Shade	TifB16119	1	1000	47.778
222	4	Non-Shade	TifB16119	1	750	39.763
223	4	Non-Shade	TifB16119	1	500	31.267
224	4	Non-Shade	TifB16119	1	250	14.239
225	4	Non-Shade	TifB16119	1	0	-17.222
226	4	Non-Shade	TifB16119	2	2000	71.379
227	4	Non-Shade	TifB16119	2	1750	83.688
228	4	Non-Shade	TifB16119	2	1500	99.624
229	4	Non-Shade	TifB16119	2	1250	117.449
230	4	Non-Shade	TifB16119	2	1000	117.279
231	4	Non-Shade	TifB16119	2	750	91.604
232	4	Non-Shade	TifB16119	2	500	55.240
233	4	Non-Shade	TifB16119	2	250	12.222
234	4	Non-Shade	TifB16119	2	0	-53.864
235	4	Non-Shade	TifB16119	3	2000	58.270
236	4	Non-Shade	TifB16119	3	1750	66.151
237	4	Non-Shade	TifB16119	3	1500	97.165
238	4	Non-Shade	TifB16119	3	1250	118.277
239	4	Non-Shade	TifB16119	3	1000	127.275
240	4	Non-Shade	TifB16119	3	750	108.018
241	4	Non-Shade	TifB16119	3	500	79.912
242	4	Non-Shade	TifB16119	3	250	19.875
243	4	Non-Shade	TifB16119	3	0	-68.578
244	4	Non-Shade	TifB16119	4	2000	53.277
245	4	Non-Shade	TifB16119	4	1750	67.469
246	4	Non-Shade	TifB16119	4	1500	111.467
247	4	Non-Shade	TifB16119	4	1250	125.123
248	4	Non-Shade	TifB16119	4	1000	114.686
249	4	Non-Shade	TifB16119	4	750	99.769
250	4	Non-Shade	TifB16119	4	500	68.790
251	4	Non-Shade	TifB16119	4	250	27.267
252	4	Non-Shade	TifB16119	4	0	-37.501
253	4	Non-Shade	Tifway	1	2000	56.037
254	4	Non-Shade	Tifway	1	1750	72.096

255	4	Non-Shade	Tifway	1	1500	85.350
256	4	Non-Shade	Tifway	1	1250	71.720
257	4	Non-Shade	Tifway	1	1000	74.315
258	4	Non-Shade	Tifway	1	750	56.991
259	4	Non-Shade	Tifway	1	500	29.700
260	4	Non-Shade	Tifway	1	250	9.527
261	4	Non-Shade	Tifway	1	0	-77.801
262	4	Non-Shade	Tifway	2	2000	123.279
263	4	Non-Shade	Tifway	2	1750	125.255
264	4	Non-Shade	Tifway	2	1500	184.019
265	4	Non-Shade	Tifway	2	1250	200.723
266	4	Non-Shade	Tifway	2	1000	205.515
267	4	Non-Shade	Tifway	2	750	164.232
268	4	Non-Shade	Tifway	2	500	123.108
269	4	Non-Shade	Tifway	2	250	57.108
270	4	Non-Shade	Tifway	2	0	-34.429
271	4	Non-Shade	Tifway	3	2000	139.812
272	4	Non-Shade	Tifway	3	1750	139.410
273	4	Non-Shade	Tifway	3	1500	235.422
274	4	Non-Shade	Tifway	3	1250	252.426
275	4	Non-Shade	Tifway	3	1000	234.172
276	4	Non-Shade	Tifway	3	750	183.594
277	4	Non-Shade	Tifway	3	500	129.265
278	4	Non-Shade	Tifway	3	250	47.418
279	4	Non-Shade	Tifway	3	0	-50.959
280	4	Non-Shade	Tifway	4	2000	83.092
281	4	Non-Shade	Tifway	4	1750	126.357
282	4	Non-Shade	Tifway	4	1500	201.619
283	4	Non-Shade	Tifway	4	1250	271.185
284	4	Non-Shade	Tifway	4	1000	248.741
285	4	Non-Shade	Tifway	4	750	203.141
286	4	Non-Shade	Tifway	4	500	138.810
287	4	Non-Shade	Tifway	4	250	38.982
288	4	Non-Shade	Tifway	4	0	-72.207
289	8	Shade	TifB16108	1	2000	48.148
290	8	Shade	TifB16108	1	1750	49.889
291	8	Shade	TifB16108	1	1500	57.378
292	8	Shade	TifB16108	1	1250	60.988
293	8	Shade	TifB16108	1	1000	62.290
294	8	Shade	TifB16108	1	750	59.286
295	8	Shade	TifB16108	1	500	50.698
296	8	Shade	TifB16108	1	250	27.511
297	8	Shade	TifB16108	1	0	-15.288

298	8	Shade	TifB16108	2	2000	76.787
299	8	Shade	TifB16108	2	1750	87.394
300	8	Shade	TifB16108	2	1500	90.175
301	8	Shade	TifB16108	2	1250	93.006
302	8	Shade	TifB16108	2	1000	95.101
303	8	Shade	TifB16108	2	750	90.699
304	8	Shade	TifB16108	2	500	79.521
305	8	Shade	TifB16108	2	250	46.749
306	8	Shade	TifB16108	2	0	-20.207
307	8	Shade	TifB16108	3	2000	61.471
308	8	Shade	TifB16108	3	1750	61.810
309	8	Shade	TifB16108	3	1500	63.284
310	8	Shade	TifB16108	3	1250	66.895
311	8	Shade	TifB16108	3	1000	70.356
312	8	Shade	TifB16108	3	750	70.267
313	8	Shade	TifB16108	3	500	63.013
314	8	Shade	TifB16108	3	250	39.384
315	8	Shade	TifB16108	3	0	-12.988
316	8	Shade	TifB16108	4	2000	53.094
317	8	Shade	TifB16108	4	1750	56.413
318	8	Shade	TifB16108	4	1500	67.772
319	8	Shade	TifB16108	4	1250	68.817
320	8	Shade	TifB16108	4	1000	73.682
321	8	Shade	TifB16108	4	750	71.824
322	8	Shade	TifB16108	4	500	62.233
323	8	Shade	TifB16108	4	250	36.428
324	8	Shade	TifB16108	4	0	-13.536
325	8	Shade	TifB16117	1	2000	57.410
326	8	Shade	TifB16117	1	1750	68.470
327	8	Shade	TifB16117	1	1500	78.582
328	8	Shade	TifB16117	1	1250	86.189
329	8	Shade	TifB16117	1	1000	86.806
330	8	Shade	TifB16117	1	750	79.246
331	8	Shade	TifB16117	1	500	64.178
332	8	Shade	TifB16117	1	250	37.393
333	8	Shade	TifB16117	1	0	-13.127
334	8	Shade	TifB16117	2	2000	70.707
335	8	Shade	TifB16117	2	1750	86.727
336	8	Shade	TifB16117	2	1500	133.504
337	8	Shade	TifB16117	2	1250	139.406
338	8	Shade	TifB16117	2	1000	131.713
339	8	Shade	TifB16117	2	750	127.461
340	8	Shade	TifB16117	2	500	105.667

341	8	Shade	TifB16117	2	250	59.513
342	8	Shade	TifB16117	2	0	-23.134
343	8	Shade	TifB16117	3	2000	29.117
344	8	Shade	TifB16117	3	1750	42.433
345	8	Shade	TifB16117	3	1500	62.320
346	8	Shade	TifB16117	3	1250	65.866
347	8	Shade	TifB16117	3	1000	63.278
348	8	Shade	TifB16117	3	750	55.695
349	8	Shade	TifB16117	3	500	42.234
350	8	Shade	TifB16117	3	250	20.796
351	8	Shade	TifB16117	3	0	-14.640
352	8	Shade	TifB16117	4	2000	98.213
353	8	Shade	TifB16117	4	1750	103.870
354	8	Shade	TifB16117	4	1500	111.723
355	8	Shade	TifB16117	4	1250	115.428
356	8	Shade	TifB16117	4	1000	111.302
357	8	Shade	TifB16117	4	750	103.345
358	8	Shade	TifB16117	4	500	77.775
359	8	Shade	TifB16117	4	250	47.110
360	8	Shade	TifB16117	4	0	-16.008
361	8	Shade	TifB16119	1	2000	27.565
362	8	Shade	TifB16119	1	1750	28.261
363	8	Shade	TifB16119	1	1500	28.288
364	8	Shade	TifB16119	1	1250	28.880
365	8	Shade	TifB16119	1	1000	28.295
366	8	Shade	TifB16119	1	750	25.408
367	8	Shade	TifB16119	1	500	20.214
368	8	Shade	TifB16119	1	250	11.251
369	8	Shade	TifB16119	1	0	-7.772
370	8	Shade	TifB16119	2	2000	29.335
371	8	Shade	TifB16119	2	1750	32.472
372	8	Shade	TifB16119	2	1500	34.567
373	8	Shade	TifB16119	2	1250	34.542
374	8	Shade	TifB16119	2	1000	32.471
375	8	Shade	TifB16119	2	750	29.933
376	8	Shade	TifB16119	2	500	23.720
377	8	Shade	TifB16119	2	250	9.160
378	8	Shade	TifB16119	2	0	-23.588
379	8	Shade	TifB16119	3	2000	25.981
380	8	Shade	TifB16119	3	1750	27.664
381	8	Shade	TifB16119	3	1500	33.719
382	8	Shade	TifB16119	3	1250	33.231
383	8	Shade	TifB16119	3	1000	33.084

384	8	Shade	TifB16119	3	750	30.783
385	8	Shade	TifB16119	3	500	26.768
386	8	Shade	TifB16119	3	250	16.193
387	8	Shade	TifB16119	3	0	-10.140
388	8	Shade	TifB16119	4	2000	51.976
389	8	Shade	TifB16119	4	1750	52.663
390	8	Shade	TifB16119	4	1500	53.131
391	8	Shade	TifB16119	4	1250	52.966
392	8	Shade	TifB16119	4	1000	49.443
393	8	Shade	TifB16119	4	750	38.166
394	8	Shade	TifB16119	4	500	27.995
395	8	Shade	TifB16119	4	250	8.385
396	8	Shade	TifB16119	4	0	-36.155
397	8	Shade	Tifway	1	2000	93.298
398	8	Shade	Tifway	1	1750	107.140
399	8	Shade	Tifway	1	1500	148.231
400	8	Shade	Tifway	1	1250	160.078
401	8	Shade	Tifway	1	1000	152.199
402	8	Shade	Tifway	1	750	130.523
403	8	Shade	Tifway	1	500	56.127
404	8	Shade	Tifway	1	250	30.246
405	8	Shade	Tifway	1	0	-49.083
406	8	Shade	Tifway	2	2000	123.554
407	8	Shade	Tifway	2	1750	146.413
408	8	Shade	Tifway	2	1500	162.103
409	8	Shade	Tifway	2	1250	160.780
410	8	Shade	Tifway	2	1000	152.872
411	8	Shade	Tifway	2	750	130.766
412	8	Shade	Tifway	2	500	105.889
413	8	Shade	Tifway	2	250	55.299
414	8	Shade	Tifway	2	0	-29.873
415	8	Shade	Tifway	3	2000	54.624
416	8	Shade	Tifway	3	1750	60.261
417	8	Shade	Tifway	3	1500	70.733
418	8	Shade	Tifway	3	1250	73.760
419	8	Shade	Tifway	3	1000	70.692
420	8	Shade	Tifway	3	750	60.686
421	8	Shade	Tifway	3	500	46.295
422	8	Shade	Tifway	3	250	21.804
423	8	Shade	Tifway	3	0	-17.045
424	8	Shade	Tifway	4	2000	107.793
425	8	Shade	Tifway	4	1750	128.152
426	8	Shade	Tifway	4	1500	173.367

427	8	Shade	Tifway	4	1250	180.081
428	8	Shade	Tifway	4	1000	166.212
429	8	Shade	Tifway	4	750	154.245
430	8	Shade	Tifway	4	500	119.824
431	8	Shade	Tifway	4	250	61.388
432	8	Shade	Tifway	4	0	1.081
433	8	Non-Shade	TifB16108	1	2000	71.898
434	8	Non-Shade	TifB16108	1	1750	91.646
435	8	Non-Shade	TifB16108	1	1500	105.521
436	8	Non-Shade	TifB16108	1	1250	114.340
437	8	Non-Shade	TifB16108	1	1000	114.976
438	8	Non-Shade	TifB16108	1	750	102.838
439	8	Non-Shade	TifB16108	1	500	77.342
440	8	Non-Shade	TifB16108	1	250	31.167
441	8	Non-Shade	TifB16108	1	0	-38.055
442	8	Non-Shade	TifB16108	2	2000	86.333
443	8	Non-Shade	TifB16108	2	1750	92.362
444	8	Non-Shade	TifB16108	2	1500	135.088
445	8	Non-Shade	TifB16108	2	1250	147.214
446	8	Non-Shade	TifB16108	2	1000	140.523
447	8	Non-Shade	TifB16108	2	750	117.088
448	8	Non-Shade	TifB16108	2	500	79.835
449	8	Non-Shade	TifB16108	2	250	33.397
450	8	Non-Shade	TifB16108	2	0	-28.685
451	8	Non-Shade	TifB16108	3	2000	112.570
452	8	Non-Shade	TifB16108	3	1750	127.862
453	8	Non-Shade	TifB16108	3	1500	190.834
454	8	Non-Shade	TifB16108	3	1250	204.874
455	8	Non-Shade	TifB16108	3	1000	196.554
456	8	Non-Shade	TifB16108	3	750	168.072
457	8	Non-Shade	TifB16108	3	500	118.525
458	8	Non-Shade	TifB16108	3	250	49.607
459	8	Non-Shade	TifB16108	3	0	-37.933
460	8	Non-Shade	TifB16108	4	2000	114.717
461	8	Non-Shade	TifB16108	4	1750	134.367
462	8	Non-Shade	TifB16108	4	1500	187.437
463	8	Non-Shade	TifB16108	4	1250	193.789
464	8	Non-Shade	TifB16108	4	1000	184.965
465	8	Non-Shade	TifB16108	4	750	161.113
466	8	Non-Shade	TifB16108	4	500	120.701
467	8	Non-Shade	TifB16108	4	250	47.533
468	8	Non-Shade	TifB16108	4	0	-66.252
469	8	Non-Shade	TifB16117	1	2000	99.128

470	8	Non-Shade	TifB16117	1	1750	108.333
471	8	Non-Shade	TifB16117	1	1500	115.464
472	8	Non-Shade	TifB16117	1	1250	127.468
473	8	Non-Shade	TifB16117	1	1000	125.100
474	8	Non-Shade	TifB16117	1	750	109.770
475	8	Non-Shade	TifB16117	1	500	77.450
476	8	Non-Shade	TifB16117	1	250	31.733
477	8	Non-Shade	TifB16117	1	0	-33.179
478	8	Non-Shade	TifB16117	2	2000	106.290
479	8	Non-Shade	TifB16117	2	1750	125.024
480	8	Non-Shade	TifB16117	2	1500	208.427
481	8	Non-Shade	TifB16117	2	1250	225.798
482	8	Non-Shade	TifB16117	2	1000	220.767
483	8	Non-Shade	TifB16117	2	750	197.177
484	8	Non-Shade	TifB16117	2	500	137.219
485	8	Non-Shade	TifB16117	2	250	55.210
486	8	Non-Shade	TifB16117	2	0	3.243
487	8	Non-Shade	TifB16117	3	2000	160.702
488	8	Non-Shade	TifB16117	3	1750	124.631
489	8	Non-Shade	TifB16117	3	1500	210.270
490	8	Non-Shade	TifB16117	3	1250	240.104
491	8	Non-Shade	TifB16117	3	1000	218.888
492	8	Non-Shade	TifB16117	3	750	187.555
493	8	Non-Shade	TifB16117	3	500	137.169
494	8	Non-Shade	TifB16117	3	250	53.200
495	8	Non-Shade	TifB16117	3	0	-66.124
496	8	Non-Shade	TifB16117	4	2000	86.990
497	8	Non-Shade	TifB16117	4	1750	119.428
498	8	Non-Shade	TifB16117	4	1500	150.457
499	8	Non-Shade	TifB16117	4	1250	157.119
500	8	Non-Shade	TifB16117	4	1000	167.139
501	8	Non-Shade	TifB16117	4	750	141.180
502	8	Non-Shade	TifB16117	4	500	100.054
503	8	Non-Shade	TifB16117	4	250	37.750
504	8	Non-Shade	TifB16117	4	0	-47.459
505	8	Non-Shade	TifB16119	1	2000	53.262
506	8	Non-Shade	TifB16119	1	1750	55.538
507	8	Non-Shade	TifB16119	1	1500	66.463
508	8	Non-Shade	TifB16119	1	1250	69.995
509	8	Non-Shade	TifB16119	1	1000	69.276
510	8	Non-Shade	TifB16119	1	750	59.612
511	8	Non-Shade	TifB16119	1	500	46.938
512	8	Non-Shade	TifB16119	1	250	22.110

513	8	Non-Shade	TifB16119	1	0	-22.846
514	8	Non-Shade	TifB16119	2	2000	93.753
515	8	Non-Shade	TifB16119	2	1750	113.976
516	8	Non-Shade	TifB16119	2	1500	160.899
517	8	Non-Shade	TifB16119	2	1250	166.541
518	8	Non-Shade	TifB16119	2	1000	158.151
519	8	Non-Shade	TifB16119	2	750	138.531
520	8	Non-Shade	TifB16119	2	500	99.029
521	8	Non-Shade	TifB16119	2	250	44.173
522	8	Non-Shade	TifB16119	2	0	-43.073
523	8	Non-Shade	TifB16119	3	2000	93.696
524	8	Non-Shade	TifB16119	3	1750	106.401
525	8	Non-Shade	TifB16119	3	1500	159.375
526	8	Non-Shade	TifB16119	3	1250	176.213
527	8	Non-Shade	TifB16119	3	1000	177.870
528	8	Non-Shade	TifB16119	3	750	149.529
529	8	Non-Shade	TifB16119	3	500	111.811
530	8	Non-Shade	TifB16119	3	250	54.654
531	8	Non-Shade	TifB16119	3	0	-44.757
532	8	Non-Shade	TifB16119	4	2000	87.510
533	8	Non-Shade	TifB16119	4	1750	100.216
534	8	Non-Shade	TifB16119	4	1500	115.465
535	8	Non-Shade	TifB16119	4	1250	125.128
536	8	Non-Shade	TifB16119	4	1000	122.121
537	8	Non-Shade	TifB16119	4	750	109.532
538	8	Non-Shade	TifB16119	4	500	81.949
539	8	Non-Shade	TifB16119	4	250	36.558
540	8	Non-Shade	TifB16119	4	0	-39.511
541	8	Non-Shade	Tifway	1	2000	132.456
542	8	Non-Shade	Tifway	1	1750	185.732
543	8	Non-Shade	Tifway	1	1500	201.366
544	8	Non-Shade	Tifway	1	1250	225.171
545	8	Non-Shade	Tifway	1	1000	215.337
546	8	Non-Shade	Tifway	1	750	188.536
547	8	Non-Shade	Tifway	1	500	134.194
548	8	Non-Shade	Tifway	1	250	57.019
549	8	Non-Shade	Tifway	1	0	-57.536
550	8	Non-Shade	Tifway	2	2000	131.135
551	8	Non-Shade	Tifway	2	1750	159.643
552	8	Non-Shade	Tifway	2	1500	176.832
553	8	Non-Shade	Tifway	2	1250	195.933
554	8	Non-Shade	Tifway	2	1000	197.510
555	8	Non-Shade	Tifway	2	750	173.589

556	8	Non-Shade	Tifway	2	500	128.279
557	8	Non-Shade	Tifway	2	250	55.785
558	8	Non-Shade	Tifway	2	0	-47.956
559	8	Non-Shade	Tifway	3	2000	116.232
560	8	Non-Shade	Tifway	3	1750	121.008
561	8	Non-Shade	Tifway	3	1500	189.272
562	8	Non-Shade	Tifway	3	1250	214.022
563	8	Non-Shade	Tifway	3	1000	213.445
564	8	Non-Shade	Tifway	3	750	184.574
565	8	Non-Shade	Tifway	3	500	127.468
566	8	Non-Shade	Tifway	3	250	48.327
567	8	Non-Shade	Tifway	3	0	-44.838
568	8	Non-Shade	Tifway	4	2000	121.289
569	8	Non-Shade	Tifway	4	1750	131.026
570	8	Non-Shade	Tifway	4	1500	199.352
571	8	Non-Shade	Tifway	4	1250	225.597
572	8	Non-Shade	Tifway	4	1000	228.224
573	8	Non-Shade	Tifway	4	750	205.913
574	8	Non-Shade	Tifway	4	500	151.389
575	8	Non-Shade	Tifway	4	250	64.900
576	8	Non-Shade	Tifway	4	0	-69.636

Table 4. Photosynthetic rates at different light intensities for each St. Augustinegrass genotype measured for three weeks under shade and non-shade conditions during experiment 2.

S.No.	Week	Treatment	Genotype	Replication	PAR µmol m^{-2} s^{-1}	Photosynthesis µmol CO_2 m^{-2} s^{-1}
1	4	Shade	DALSA 1404	1	2000	20.218
2	4	Shade	DALSA 1404	1	1750	19.967
3	4	Shade	DALSA 1404	1	1500	19.496
4	4	Shade	DALSA 1404	1	1250	18.422
5	4	Shade	DALSA 1404	1	1000	17.133
6	4	Shade	DALSA 1404	1	750	15.427
7	4	Shade	DALSA 1404	1	500	13.575
8	4	Shade	DALSA 1404	1	0	-1.362
10	4	Shade	DALSA 1404	2	2000	21.491
11	4	Shade	DALSA 1404	2	1750	22.222
12	4	Shade	DALSA 1404	2	1500	22.161
13	4	Shade	DALSA 1404	2	1250	21.088
14	4	Shade	DALSA 1404	2	1000	17.235
15	4	Shade	DALSA 1404	2	750	16.315
16	4	Shade	DALSA 1404	2	500	13.330
18	4	Shade	DALSA 1404	2	0	-1.725
19	4	Shade	DALSA 1404	3	2000	12.497
20	4	Shade	DALSA 1404	3	1750	14.229
21	4	Shade	DALSA 1404	3	1500	16.566
22	4	Shade	DALSA 1404	3	1250	16.803
23	4	Shade	DALSA 1404	3	1000	15.589
24	4	Shade	DALSA 1404	3	750	12.715
25	4	Shade	DALSA 1404	3	500	12.690
26	4	Shade	DALSA 1404	3	250	11.264
27	4	Shade	DALSA 1404	3	0	-0.888
28	4	Shade	DALSA 1404	4	2000	21.675
29	4	Shade	DALSA 1404	4	1750	23.049
30	4	Shade	DALSA 1404	4	1500	21.931
31	4	Shade	DALSA 1404	4	1250	20.643
32	4	Shade	DALSA 1404	4	1000	20.999
33	4	Shade	DALSA 1404	4	750	19.943
34	4	Shade	DALSA 1404	4	500	15.025
35	4	Shade	DALSA 1404	4	250	14.226
36	4	Shade	DALSA 1404	4	0	-1.685
37	4	Shade	DALSA 1405	5	2000	19.459
38	4	Shade	DALSA 1405	5	1750	19.597
39	4	Shade	DALSA 1405	5	1500	19.582

40	4	Shade	DALSA 1405	5	1250	17.817
41	4	Shade	DALSA 1405	5	1000	17.795
42	4	Shade	DALSA 1405	5	750	17.937
43	4	Shade	DALSA 1405	5	500	12.840
44	4	Shade	DALSA 1405	5	250	10.899
45	4	Shade	DALSA 1405	5	0	-2.566
46	4	Shade	DALSA 1405	6	2000	21.064
47	4	Shade	DALSA 1405	6	1750	20.914
48	4	Shade	DALSA 1405	6	1500	24.513
49	4	Shade	DALSA 1405	6	1250	26.971
50	4	Shade	DALSA 1405	6	1000	23.608
51	4	Shade	DALSA 1405	6	750	22.810
52	4	Shade	DALSA 1405	6	500	19.161
53	4	Shade	DALSA 1405	6	250	17.211
54	4	Shade	DALSA 1405	6	0	-0.869
55	4	Shade	DALSA 1405	7	2000	20.409
56	4	Shade	DALSA 1405	7	1750	17.619
57	4	Shade	DALSA 1405	7	1500	17.977
58	4	Shade	DALSA 1405	7	1250	18.240
59	4	Shade	DALSA 1405	7	1000	15.112
60	4	Shade	DALSA 1405	7	750	12.664
61	4	Shade	DALSA 1405	7	500	10.936
62	4	Shade	DALSA 1405	7	250	10.710
63	4	Shade	DALSA 1405	7	0	-0.881
64	4	Shade	DALSA 1405	8	2000	17.319
65	4	Shade	DALSA 1405	8	1750	18.794
66	4	Shade	DALSA 1405	8	1500	18.099
67	4	Shade	DALSA 1405	8	1250	15.376
68	4	Shade	DALSA 1405	8	1000	14.879
69	4	Shade	DALSA 1405	8	750	14.289
70	4	Shade	DALSA 1405	8	500	10.931
71	4	Shade	DALSA 1405	8	0	-1.568
73	4	Shade	DALSA 1618	9	2000	18.582
74	4	Shade	DALSA 1618	9	1750	19.142
75	4	Shade	DALSA 1618	9	1500	21.654
76	4	Shade	DALSA 1618	9	1250	19.808
77	4	Shade	DALSA 1618	9	1000	19.763
78	4	Shade	DALSA 1618	9	750	16.463
79	4	Shade	DALSA 1618	9	500	15.991
80	4	Shade	DALSA 1618	9	250	12.819
81	4	Shade	DALSA 1618	9	0	-1.653
82	4	Shade	DALSA 1618	10	2000	25.187
83	4	Shade	DALSA 1618	10	1750	28.329

84	4	Shade	DALSA 1618	10	1500	26.957
85	4	Shade	DALSA 1618	10	1250	26.750
86	4	Shade	DALSA 1618	10	1000	25.372
87	4	Shade	DALSA 1618	10	750	22.964
88	4	Shade	DALSA 1618	10	500	22.528
89	4	Shade	DALSA 1618	10	250	16.335
90	4	Shade	DALSA 1618	10	0	-2.816
91	4	Shade	DALSA 1618	11	2000	30.363
92	4	Shade	DALSA 1618	11	1750	29.729
93	4	Shade	DALSA 1618	11	1500	28.878
94	4	Shade	DALSA 1618	11	1250	26.951
95	4	Shade	DALSA 1618	11	1000	24.544
96	4	Shade	DALSA 1618	11	750	21.848
97	4	Shade	DALSA 1618	11	500	20.228
98	4	Shade	DALSA 1618	11	250	16.194
99	4	Shade	DALSA 1618	11	0	-1.281
100	4	Shade	DALSA 1618	12	2000	17.115
101	4	Shade	DALSA 1618	12	1750	18.747
102	4	Shade	DALSA 1618	12	1500	17.863
103	4	Shade	DALSA 1618	12	1000	14.901
104	4	Shade	DALSA 1618	12	750	12.539
105	4	Shade	DALSA 1618	12	500	11.320
106	4	Shade	DALSA 1618	12	250	8.168
107	4	Shade	DALSA 1618	12	0	-0.908
109	4	Shade	TamStar	13	2000	18.959
110	4	Shade	TamStar	13	1750	19.162
111	4	Shade	TamStar	13	1500	16.037
112	4	Shade	TamStar	13	1250	16.228
113	4	Shade	TamStar	13	1000	14.037
114	4	Shade	TamStar	13	750	12.802
115	4	Shade	TamStar	13	500	12.069
116	4	Shade	TamStar	13	250	9.318
117	4	Shade	TamStar	13	0	-1.720
118	4	Shade	TamStar	14	2000	32.027
119	4	Shade	TamStar	14	1750	32.791
120	4	Shade	TamStar	14	1500	33.564
121	4	Shade	TamStar	14	1250	31.972
122	4	Shade	TamStar	14	1000	29.144
123	4	Shade	TamStar	14	750	26.863
124	4	Shade	TamStar	14	500	23.924
125	4	Shade	TamStar	14	250	17.481
126	4	Shade	TamStar	14	0	-1.903
127	4	Shade	TamStar	15	2000	30.918

128	4	Shade	TamStar	15	1750	31.698
129	4	Shade	TamStar	15	1500	30.250
130	4	Shade	TamStar	15	1250	25.911
131	4	Shade	TamStar	15	1000	25.787
132	4	Shade	TamStar	15	750	22.702
133	4	Shade	TamStar	15	500	18.741
134	4	Shade	TamStar	15	0	-0.964
136	4	Shade	TamStar	16	2000	11.099
137	4	Shade	TamStar	16	1750	11.207
138	4	Shade	TamStar	16	1500	13.084
139	4	Shade	TamStar	16	1250	13.329
140	4	Shade	TamStar	16	1000	13.535
141	4	Shade	TamStar	16	750	14.537
142	4	Shade	TamStar	16	500	9.253
143	4	Shade	TamStar	16	250	9.067
144	4	Shade	TamStar	16	0	0.029
145	4	Non-Shade	DALSA 1404	17	2000	23.474
146	4	Non-Shade	DALSA 1404	17	1750	25.737
147	4	Non-Shade	DALSA 1404	17	1500	29.099
148	4	Non-Shade	DALSA 1404	17	1250	31.555
149	4	Non-Shade	DALSA 1404	17	1000	31.374
150	4	Non-Shade	DALSA 1404	17	750	29.085
151	4	Non-Shade	DALSA 1404	17	500	25.131
152	4	Non-Shade	DALSA 1404	17	250	17.178
153	4	Non-Shade	DALSA 1404	17	0	-1.932
154	4	Non-Shade	DALSA 1404	18	2000	29.315
155	4	Non-Shade	DALSA 1404	18	1750	33.228
156	4	Non-Shade	DALSA 1404	18	1500	34.923
157	4	Non-Shade	DALSA 1404	18	1250	35.435
158	4	Non-Shade	DALSA 1404	18	1000	31.508
159	4	Non-Shade	DALSA 1404	18	750	30.994
160	4	Non-Shade	DALSA 1404	18	500	25.361
161	4	Non-Shade	DALSA 1404	18	250	20.664
162	4	Non-Shade	DALSA 1404	18	0	-2.704
163	4	Non-Shade	DALSA 1404	19	2000	18.090
164	4	Non-Shade	DALSA 1404	19	1750	18.945
165	4	Non-Shade	DALSA 1404	19	1500	20.908
166	4	Non-Shade	DALSA 1404	19	1250	21.174
167	4	Non-Shade	DALSA 1404	19	1000	19.377
168	4	Non-Shade	DALSA 1404	19	750	17.588
169	4	Non-Shade	DALSA 1404	19	500	16.623
170	4	Non-Shade	DALSA 1404	19	250	14.261
171	4	Non-Shade	DALSA 1404	19	0	-1.500

172	4	Non-Shade	DALSA 1404	20	2000	28.429
173	4	Non-Shade	DALSA 1404	20	1750	32.360
174	4	Non-Shade	DALSA 1404	20	1500	33.967
175	4	Non-Shade	DALSA 1404	20	1250	32.543
176	4	Non-Shade	DALSA 1404	20	1000	32.255
177	4	Non-Shade	DALSA 1404	20	750	32.113
178	4	Non-Shade	DALSA 1404	20	500	24.905
179	4	Non-Shade	DALSA 1404	20	250	20.170
180	4	Non-Shade	DALSA 1404	20	0	-4.111
181	4	Non-Shade	DALSA 1405	21	2000	18.079
182	4	Non-Shade	DALSA 1405	21	1750	20.176
183	4	Non-Shade	DALSA 1405	21	1500	22.160
184	4	Non-Shade	DALSA 1405	21	1250	19.489
185	4	Non-Shade	DALSA 1405	21	1000	17.490
186	4	Non-Shade	DALSA 1405	21	750	16.669
187	4	Non-Shade	DALSA 1405	21	500	16.040
188	4	Non-Shade	DALSA 1405	21	250	12.929
189	4	Non-Shade	DALSA 1405	21	0	-2.484
190	4	Non-Shade	DALSA 1405	22	2000	35.205
191	4	Non-Shade	DALSA 1405	22	1750	40.829
192	4	Non-Shade	DALSA 1405	22	1500	40.210
193	4	Non-Shade	DALSA 1405	22	1250	39.978
194	4	Non-Shade	DALSA 1405	22	1000	37.853
195	4	Non-Shade	DALSA 1405	22	750	31.017
196	4	Non-Shade	DALSA 1405	22	500	30.395
197	4	Non-Shade	DALSA 1405	22	250	18.632
198	4	Non-Shade	DALSA 1405	22	0	-2.990
199	4	Non-Shade	DALSA 1405	23	2000	31.512
200	4	Non-Shade	DALSA 1405	23	1750	36.064
201	4	Non-Shade	DALSA 1405	23	1500	37.751
202	4	Non-Shade	DALSA 1405	23	1250	33.923
203	4	Non-Shade	DALSA 1405	23	1000	32.417
204	4	Non-Shade	DALSA 1405	23	750	29.743
205	4	Non-Shade	DALSA 1405	23	500	26.027
206	4	Non-Shade	DALSA 1405	23	250	19.764
207	4	Non-Shade	DALSA 1405	23	0	-2.488
208	4	Non-Shade	DALSA 1405	24	2000	27.104
209	4	Non-Shade	DALSA 1405	24	1750	32.391
210	4	Non-Shade	DALSA 1405	24	1500	36.776
211	4	Non-Shade	DALSA 1405	24	1250	32.711
212	4	Non-Shade	DALSA 1405	24	1000	32.518
213	4	Non-Shade	DALSA 1405	24	750	31.583
214	4	Non-Shade	DALSA 1405	24	500	24.779

215	4	Non-Shade	DALSA 1405	24	250	20.295
216	4	Non-Shade	DALSA 1405	24	0	-2.338
217	4	Non-Shade	DALSA 1618	25	2000	15.146
218	4	Non-Shade	DALSA 1618	25	1750	21.152
219	4	Non-Shade	DALSA 1618	25	1500	24.361
220	4	Non-Shade	DALSA 1618	25	1250	21.305
221	4	Non-Shade	DALSA 1618	25	1000	19.345
222	4	Non-Shade	DALSA 1618	25	750	18.995
223	4	Non-Shade	DALSA 1618	25	500	18.853
224	4	Non-Shade	DALSA 1618	25	250	12.397
225	4	Non-Shade	DALSA 1618	25	0	-2.511
226	4	Non-Shade	DALSA 1618	26	2000	40.671
227	4	Non-Shade	DALSA 1618	26	1750	43.734
228	4	Non-Shade	DALSA 1618	26	1500	49.105
229	4	Non-Shade	DALSA 1618	26	1250	50.035
230	4	Non-Shade	DALSA 1618	26	1000	49.018
231	4	Non-Shade	DALSA 1618	26	750	42.793
232	4	Non-Shade	DALSA 1618	26	500	35.508
233	4	Non-Shade	DALSA 1618	26	250	25.323
234	4	Non-Shade	DALSA 1618	26	0	-3.741
235	4	Non-Shade	DALSA 1618	27	2000	30.618
236	4	Non-Shade	DALSA 1618	27	1750	33.942
237	4	Non-Shade	DALSA 1618	27	1500	35.371
238	4	Non-Shade	DALSA 1618	27	1250	33.185
239	4	Non-Shade	DALSA 1618	27	1000	29.283
240	4	Non-Shade	DALSA 1618	27	750	23.057
241	4	Non-Shade	DALSA 1618	27	500	19.775
242	4	Non-Shade	DALSA 1618	27	250	13.788
243	4	Non-Shade	DALSA 1618	27	0	-2.925
244	4	Non-Shade	DALSA 1618	28	2000	31.799
245	4	Non-Shade	DALSA 1618	28	1750	33.992
246	4	Non-Shade	DALSA 1618	28	1500	36.386
247	4	Non-Shade	DALSA 1618	28	1250	32.658
248	4	Non-Shade	DALSA 1618	28	1000	29.141
249	4	Non-Shade	DALSA 1618	28	750	28.515
250	4	Non-Shade	DALSA 1618	28	500	24.969
251	4	Non-Shade	DALSA 1618	28	250	17.386
252	4	Non-Shade	DALSA 1618	28	0	-2.577
253	4	Non-Shade	TamStar	29	2000	28.849
254	4	Non-Shade	TamStar	29	1750	30.185
255	4	Non-Shade	TamStar	29	1500	30.341
256	4	Non-Shade	TamStar	29	1250	32.397
257	4	Non-Shade	TamStar	29	1000	28.368

258	4	Non-Shade	TamStar	29	750	28.312
259	4	Non-Shade	TamStar	29	500	22.874
260	4	Non-Shade	TamStar	29	250	20.093
261	4	Non-Shade	TamStar	29	0	-3.201
262	4	Non-Shade	TamStar	30	2000	37.560
263	4	Non-Shade	TamStar	30	1750	40.701
264	4	Non-Shade	TamStar	30	1500	41.475
265	4	Non-Shade	TamStar	30	1250	41.047
266	4	Non-Shade	TamStar	30	1000	38.894
267	4	Non-Shade	TamStar	30	750	35.926
268	4	Non-Shade	TamStar	30	500	30.920
269	4	Non-Shade	TamStar	30	250	21.628
270	4	Non-Shade	TamStar	30	0	-2.813
271	4	Non-Shade	TamStar	31	2000	30.863
272	4	Non-Shade	TamStar	31	1750	32.755
273	4	Non-Shade	TamStar	31	1500	30.006
274	4	Non-Shade	TamStar	31	1250	29.566
275	4	Non-Shade	TamStar	31	1000	29.514
276	4	Non-Shade	TamStar	31	750	25.981
277	4	Non-Shade	TamStar	31	500	22.134
278	4	Non-Shade	TamStar	31	250	16.322
279	4	Non-Shade	TamStar	31	0	-2.049
280	4	Non-Shade	TamStar	32	2000	14.730
281	4	Non-Shade	TamStar	32	1750	18.911
282	4	Non-Shade	TamStar	32	1500	20.468
283	4	Non-Shade	TamStar	32	1250	19.451
284	4	Non-Shade	TamStar	32	1000	17.908
285	4	Non-Shade	TamStar	32	750	17.892
286	4	Non-Shade	TamStar	32	500	16.954
287	4	Non-Shade	TamStar	32	250	11.697
288	4	Non-Shade	TamStar	32	0	-0.690
289	8	Shade	DALSA 1404	33	2000	24.829
290	8	Shade	DALSA 1404	33	1750	28.211
291	8	Shade	DALSA 1404	33	1500	28.715
292	8	Shade	DALSA 1404	33	1250	28.429
293	8	Shade	DALSA 1404	33	1000	28.207
294	8	Shade	DALSA 1404	33	750	26.484
295	8	Shade	DALSA 1404	33	500	22.880
296	8	Shade	DALSA 1404	33	250	16.643
297	8	Shade	DALSA 1404	33	0	-1.973
298	8	Shade	DALSA 1404	34	2000	24.006
299	8	Shade	DALSA 1404	34	1750	26.796
300	8	Shade	DALSA 1404	34	1500	26.079

301	8	Shade	DALSA 1404	34	1250	24.291
302	8	Shade	DALSA 1404	34	1000	23.359
303	8	Shade	DALSA 1404	34	750	23.026
304	8	Shade	DALSA 1404	34	500	20.960
305	8	Shade	DALSA 1404	34	250	16.609
306	8	Shade	DALSA 1404	34	0	-2.299
307	8	Shade	DALSA 1404	35	2000	14.767
308	8	Shade	DALSA 1404	35	1750	13.522
309	8	Shade	DALSA 1404	35	1500	12.168
310	8	Shade	DALSA 1404	35	1250	11.775
311	8	Shade	DALSA 1404	35	1000	11.683
312	8	Shade	DALSA 1404	35	750	10.799
313	8	Shade	DALSA 1404	35	500	11.356
314	8	Shade	DALSA 1404	35	250	7.517
315	8	Shade	DALSA 1404	35	0	-1.571
316	8	Shade	DALSA 1404	36	2000	28.650
317	8	Shade	DALSA 1404	36	1750	30.022
318	8	Shade	DALSA 1404	36	1500	31.229
319	8	Shade	DALSA 1404	36	1250	31.471
320	8	Shade	DALSA 1404	36	1000	30.712
321	8	Shade	DALSA 1404	36	750	28.691
322	8	Shade	DALSA 1404	36	500	25.243
323	8	Shade	DALSA 1404	36	250	18.999
324	8	Shade	DALSA 1404	36	0	-2.693
325	8	Shade	DALSA 1405	37	2000	23.801
326	8	Shade	DALSA 1405	37	1750	26.084
327	8	Shade	DALSA 1405	37	1500	29.698
328	8	Shade	DALSA 1405	37	1250	30.473
329	8	Shade	DALSA 1405	37	1000	28.972
330	8	Shade	DALSA 1405	37	750	27.555
331	8	Shade	DALSA 1405	37	500	25.077
332	8	Shade	DALSA 1405	37	250	18.458
333	8	Shade	DALSA 1405	37	0	-10.270
334	8	Shade	DALSA 1405	38	2000	27.261
335	8	Shade	DALSA 1405	38	1750	31.233
336	8	Shade	DALSA 1405	38	1500	33.528
337	8	Shade	DALSA 1405	38	1250	33.050
338	8	Shade	DALSA 1405	38	1000	31.624
339	8	Shade	DALSA 1405	38	750	29.164
340	8	Shade	DALSA 1405	38	500	24.067
341	8	Shade	DALSA 1405	38	250	17.337
342	8	Shade	DALSA 1405	38	0	-2.428
343	8	Shade	DALSA 1405	39	2000	23.611

344	8	Shade	DALSA 1405	39	1750	28.204
345	8	Shade	DALSA 1405	39	1500	30.669
346	8	Shade	DALSA 1405	39	1250	29.676
347	8	Shade	DALSA 1405	39	1000	27.995
348	8	Shade	DALSA 1405	39	750	26.417
349	8	Shade	DALSA 1405	39	500	23.044
350	8	Shade	DALSA 1405	39	250	17.020
351	8	Shade	DALSA 1405	39	0	-1.771
352	8	Shade	DALSA 1405	40	2000	22.783
353	8	Shade	DALSA 1405	40	1750	23.184
354	8	Shade	DALSA 1405	40	1500	22.340
355	8	Shade	DALSA 1405	40	1250	21.295
356	8	Shade	DALSA 1405	40	1000	18.862
357	8	Shade	DALSA 1405	40	750	17.148
358	8	Shade	DALSA 1405	40	500	15.321
359	8	Shade	DALSA 1405	40	0	-1.735
361	8	Shade	DALSA 1618	41	2000	28.034
362	8	Shade	DALSA 1618	41	1750	28.265
363	8	Shade	DALSA 1618	41	1500	28.484
364	8	Shade	DALSA 1618	41	1250	26.530
365	8	Shade	DALSA 1618	41	1000	24.599
366	8	Shade	DALSA 1618	41	750	22.240
367	8	Shade	DALSA 1618	41	500	19.573
368	8	Shade	DALSA 1618	41	0	-2.180
370	8	Shade	DALSA 1618	42	2000	30.087
371	8	Shade	DALSA 1618	42	1750	28.776
372	8	Shade	DALSA 1618	42	1500	29.255
373	8	Shade	DALSA 1618	42	1250	28.488
374	8	Shade	DALSA 1618	42	1000	26.822
375	8	Shade	DALSA 1618	42	750	25.909
376	8	Shade	DALSA 1618	42	500	24.003
377	8	Shade	DALSA 1618	42	250	18.085
378	8	Shade	DALSA 1618	42	0	-2.401
379	8	Shade	DALSA 1618	43	2000	28.911
380	8	Shade	DALSA 1618	43	1750	31.712
381	8	Shade	DALSA 1618	43	1500	32.014
382	8	Shade	DALSA 1618	43	1250	31.483
383	8	Shade	DALSA 1618	43	1000	29.428
384	8	Shade	DALSA 1618	43	750	28.339
385	8	Shade	DALSA 1618	43	500	26.060
386	8	Shade	DALSA 1618	43	250	19.936
387	8	Shade	DALSA 1618	43	0	-2.595
388	8	Shade	DALSA 1618	44	2000	26.576

389	8	Shade	DALSA 1618	44	1750	27.094
390	8	Shade	DALSA 1618	44	1500	27.287
391	8	Shade	DALSA 1618	44	1250	26.410
392	8	Shade	DALSA 1618	44	1000	25.324
393	8	Shade	DALSA 1618	44	750	23.560
394	8	Shade	DALSA 1618	44	500	21.714
395	8	Shade	DALSA 1618	44	250	16.516
396	8	Shade	DALSA 1618	44	0	-2.352
397	8	Shade	TamStar	45	2000	21.240
398	8	Shade	TamStar	45	1750	23.924
399	8	Shade	TamStar	45	1500	22.767
400	8	Shade	TamStar	45	1250	21.336
401	8	Shade	TamStar	45	1000	20.088
402	8	Shade	TamStar	45	750	18.280
403	8	Shade	TamStar	45	500	16.217
404	8	Shade	TamStar	45	250	12.097
405	8	Shade	TamStar	45	0	-1.941
406	8	Shade	TamStar	46	2000	22.762
407	8	Shade	TamStar	46	1750	23.552
408	8	Shade	TamStar	46	1500	21.886
409	8	Shade	TamStar	46	1250	20.179
410	8	Shade	TamStar	46	1000	18.391
411	8	Shade	TamStar	46	750	17.150
412	8	Shade	TamStar	46	500	14.503
413	8	Shade	TamStar	46	0	-1.514
415	8	Shade	TamStar	47	2000	12.820
416	8	Shade	TamStar	47	1750	23.230
417	8	Shade	TamStar	47	1500	21.358
418	8	Shade	TamStar	47	1250	17.184
419	8	Shade	TamStar	47	1000	16.742
420	8	Shade	TamStar	47	750	15.853
421	8	Shade	TamStar	47	500	14.823
422	8	Shade	TamStar	47	250	11.933
423	8	Shade	TamStar	47	0	-2.012
424	8	Shade	TamStar	48	2000	30.685
425	8	Shade	TamStar	48	1750	28.179
426	8	Shade	TamStar	48	1500	26.254
427	8	Shade	TamStar	48	1250	23.409
428	8	Shade	TamStar	48	1000	21.905
429	8	Shade	TamStar	48	750	21.834
430	8	Shade	TamStar	48	500	19.128
431	8	Shade	TamStar	48	250	10.118
432	8	Shade	TamStar	48	0	-3.654

433	8	Non-Shade	DALSA 1404	49	2000	32.445
434	8	Non-Shade	DALSA 1404	49	1750	34.634
435	8	Non-Shade	DALSA 1404	49	1500	37.022
436	8	Non-Shade	DALSA 1404	49	1250	38.087
437	8	Non-Shade	DALSA 1404	49	1000	35.026
438	8	Non-Shade	DALSA 1404	49	750	32.421
439	8	Non-Shade	DALSA 1404	49	500	29.017
440	8	Non-Shade	DALSA 1404	49	250	20.662
441	8	Non-Shade	DALSA 1404	49	0	-2.791
442	8	Non-Shade	DALSA 1404	50	2000	28.904
443	8	Non-Shade	DALSA 1404	50	1750	31.482
444	8	Non-Shade	DALSA 1404	50	1500	35.178
445	8	Non-Shade	DALSA 1404	50	1250	33.682
446	8	Non-Shade	DALSA 1404	50	1000	31.138
447	8	Non-Shade	DALSA 1404	50	750	27.900
448	8	Non-Shade	DALSA 1404	50	500	23.883
449	8	Non-Shade	DALSA 1404	50	250	16.803
450	8	Non-Shade	DALSA 1404	50	0	-2.981
451	8	Non-Shade	DALSA 1404	51	2000	25.702
452	8	Non-Shade	DALSA 1404	51	1750	28.407
453	8	Non-Shade	DALSA 1404	51	1500	28.732
454	8	Non-Shade	DALSA 1404	51	1250	29.538
455	8	Non-Shade	DALSA 1404	51	1000	29.611
456	8	Non-Shade	DALSA 1404	51	750	28.396
457	8	Non-Shade	DALSA 1404	51	500	25.650
458	8	Non-Shade	DALSA 1404	51	250	18.813
459	8	Non-Shade	DALSA 1404	51	0	-2.992
460	8	Non-Shade	DALSA 1404	52	2000	37.776
461	8	Non-Shade	DALSA 1404	52	1750	41.802
462	8	Non-Shade	DALSA 1404	52	1500	42.817
463	8	Non-Shade	DALSA 1404	52	1250	40.521
464	8	Non-Shade	DALSA 1404	52	1000	37.917
465	8	Non-Shade	DALSA 1404	52	750	34.978
466	8	Non-Shade	DALSA 1404	52	500	29.393
467	8	Non-Shade	DALSA 1404	52	250	19.160
468	8	Non-Shade	DALSA 1404	52	0	-3.083
469	8	Non-Shade	DALSA 1405	53	2000	28.673
470	8	Non-Shade	DALSA 1405	53	1750	35.002
471	8	Non-Shade	DALSA 1405	53	1500	39.793
472	8	Non-Shade	DALSA 1405	53	1250	41.418
473	8	Non-Shade	DALSA 1405	53	1000	39.653
474	8	Non-Shade	DALSA 1405	53	750	34.514
475	8	Non-Shade	DALSA 1405	53	500	27.933

476	8	Non-Shade	DALSA 1405	53	250	18.788
477	8	Non-Shade	DALSA 1405	53	0	-4.446
478	8	Non-Shade	DALSA 1405	54	2000	20.700
479	8	Non-Shade	DALSA 1405	54	1750	27.207
480	8	Non-Shade	DALSA 1405	54	1500	30.045
481	8	Non-Shade	DALSA 1405	54	1250	29.199
482	8	Non-Shade	DALSA 1405	54	1000	24.262
483	8	Non-Shade	DALSA 1405	54	750	18.463
484	8	Non-Shade	DALSA 1405	54	500	16.189
485	8	Non-Shade	DALSA 1405	54	250	14.002
486	8	Non-Shade	DALSA 1405	54	0	-3.834
487	8	Non-Shade	DALSA 1405	55	2000	34.845
488	8	Non-Shade	DALSA 1405	55	1750	41.703
489	8	Non-Shade	DALSA 1405	55	1500	45.865
490	8	Non-Shade	DALSA 1405	55	1250	45.745
491	8	Non-Shade	DALSA 1405	55	1000	41.770
492	8	Non-Shade	DALSA 1405	55	750	36.673
493	8	Non-Shade	DALSA 1405	55	500	30.018
494	8	Non-Shade	DALSA 1405	55	250	19.284
495	8	Non-Shade	DALSA 1405	55	0	-3.059
496	8	Non-Shade	DALSA 1405	56	2000	24.113
497	8	Non-Shade	DALSA 1405	56	1750	30.915
498	8	Non-Shade	DALSA 1405	56	1500	35.330
499	8	Non-Shade	DALSA 1405	56	1250	35.758
500	8	Non-Shade	DALSA 1405	56	1000	33.482
501	8	Non-Shade	DALSA 1405	56	750	29.444
502	8	Non-Shade	DALSA 1405	56	500	24.565
503	8	Non-Shade	DALSA 1405	56	250	17.323
504	8	Non-Shade	DALSA 1405	56	0	-3.196
505	8	Non-Shade	DALSA 1618	57	2000	14.413
506	8	Non-Shade	DALSA 1618	57	1750	19.384
507	8	Non-Shade	DALSA 1618	57	1500	24.838
508	8	Non-Shade	DALSA 1618	57	1250	25.190
509	8	Non-Shade	DALSA 1618	57	1000	26.163
510	8	Non-Shade	DALSA 1618	57	750	24.205
511	8	Non-Shade	DALSA 1618	57	500	20.014
512	8	Non-Shade	DALSA 1618	57	250	13.010
513	8	Non-Shade	DALSA 1618	57	0	-5.346
514	8	Non-Shade	DALSA 1618	58	2000	13.634
515	8	Non-Shade	DALSA 1618	58	1750	15.282
516	8	Non-Shade	DALSA 1618	58	1500	15.449
517	8	Non-Shade	DALSA 1618	58	1250	16.488
518	8	Non-Shade	DALSA 1618	58	1000	16.906

519	8	Non-Shade	DALSA 1618	58	750	15.496
520	8	Non-Shade	DALSA 1618	58	500	13.797
521	8	Non-Shade	DALSA 1618	58	250	10.087
522	8	Non-Shade	DALSA 1618	58	0	-2.540
523	8	Non-Shade	DALSA 1618	59	2000	51.678
524	8	Non-Shade	DALSA 1618	59	1750	58.817
525	8	Non-Shade	DALSA 1618	59	1500	64.808
526	8	Non-Shade	DALSA 1618	59	1250	65.279
527	8	Non-Shade	DALSA 1618	59	1000	61.627
528	8	Non-Shade	DALSA 1618	59	750	53.236
529	8	Non-Shade	DALSA 1618	59	500	41.790
530	8	Non-Shade	DALSA 1618	59	250	27.525
531	8	Non-Shade	DALSA 1618	59	0	-6.437
532	8	Non-Shade	DALSA 1618	60	2000	33.433
533	8	Non-Shade	DALSA 1618	60	1750	39.321
534	8	Non-Shade	DALSA 1618	60	1500	45.029
535	8	Non-Shade	DALSA 1618	60	1250	46.231
536	8	Non-Shade	DALSA 1618	60	1000	41.914
537	8	Non-Shade	DALSA 1618	60	750	36.696
538	8	Non-Shade	DALSA 1618	60	500	29.054
539	8	Non-Shade	DALSA 1618	60	250	18.525
540	8	Non-Shade	DALSA 1618	60	0	-4.235
541	8	Non-Shade	TamStar	61	2000	32.096
542	8	Non-Shade	TamStar	61	1750	36.225
543	8	Non-Shade	TamStar	61	1500	39.883
544	8	Non-Shade	TamStar	61	1250	37.687
545	8	Non-Shade	TamStar	61	1000	31.848
546	8	Non-Shade	TamStar	61	750	29.265
547	8	Non-Shade	TamStar	61	500	26.173
548	8	Non-Shade	TamStar	61	250	19.132
549	8	Non-Shade	TamStar	61	0	-0.142
550	8	Non-Shade	TamStar	62	2000	28.605
551	8	Non-Shade	TamStar	62	1750	28.916
552	8	Non-Shade	TamStar	62	1500	27.555
553	8	Non-Shade	TamStar	62	1250	24.637
554	8	Non-Shade	TamStar	62	1000	22.555
555	8	Non-Shade	TamStar	62	750	22.246
556	8	Non-Shade	TamStar	62	500	21.595
557	8	Non-Shade	TamStar	62	250	16.782
558	8	Non-Shade	TamStar	62	0	-1.680
559	8	Non-Shade	TamStar	63	2000	29.109
560	8	Non-Shade	TamStar	63	1750	30.826
561	8	Non-Shade	TamStar	63	1500	30.028

562	8	Non-Shade	TamStar	63	1250	28.369
563	8	Non-Shade	TamStar	63	1000	26.212
564	8	Non-Shade	TamStar	63	750	24.273
565	8	Non-Shade	TamStar	63	500	21.382
566	8	Non-Shade	TamStar	63	250	16.667
567	8	Non-Shade	TamStar	63	0	-2.183
568	8	Non-Shade	TamStar	64	2000	32.133
569	8	Non-Shade	TamStar	64	1750	35.165
570	8	Non-Shade	TamStar	64	1500	35.648
571	8	Non-Shade	TamStar	64	1250	33.790
572	8	Non-Shade	TamStar	64	1000	32.719
573	8	Non-Shade	TamStar	64	750	30.984
574	8	Non-Shade	TamStar	64	500	27.511
575	8	Non-Shade	TamStar	64	250	17.683
576	8	Non-Shade	TamStar	64	0	-2.772

VITA

ANMOL KAJLA

Candidate for the Degree of

Master of Science

Thesis: PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSE OF WARM-SEASON TURFGRASSES TO SHADE

Major Field: Horticulture

Biographical:

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Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in July, 2021.

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American Society of Agronomy
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