EFFECTS OF WATER STRESS ON PHOTOSYNTHESIS
AND EVAPOTRANSPIRATION IN ST. AUGUSTINEGRASS,
Stenotaphrum secundatum (WALT.) KUNTZE

BY

CHARLES HARRIS PEACOCK

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL
OF THE UNIVERSITY OF FLORIDA IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1981

No family is complete without the support of its individuals. To my wife, Madeline, I extend my love and appreciation for constant support, encouragement, and physical help (even while she was pregnant with Daniel Adam) during long, hot summer days. To my mother and father I add a word of special appreciation. I'm sure at times they all wondered if my collegiate career would ever end. It is to them I dedicate this work.

ACKNOWLEDGEMENTS

I should like to thank Dr. A.E. Dudeck, Associate Professor, Department of Ornamental Horticulture, for his advice and guidance during all stages of planning, organizing, executing, and interpretation of results of the research project. His leadership was invaluable. My committee members, Dr. Bruce Augustin, Assistant Professor, Department of Ornamental Horticulture; Dr. Jerry Bennett, Assistant Professor, Department of Agronomy; Dr. Ken Boote, Associate Professor, Department of Agronomy; Dr. Charles Johnson, Associate Professor, Department of Ornamental Horticulture; and Dr. Allen Smajstrla, Assistant Professor, Agricultural Engineering Department, made the project possible by providing technical expertise, constructive advice, and loans of equipment, and by expressing genuine interests in both the research project and my educational goals. I sincerely appreciate their efforts.

I should like to acknowledge financial support from the Golf Course Superintendents' Association of America, The Toro Company, and Mr. Bill Speelman. Their assistance provided funds needed for conducting the project.

To the personnel at the Horticultural Unit, Gainesville, I am indebted for their patience and assistance. Especially helpful in body and spirit were B.J. Williams, Rob Polk, and Tonya Mikell.

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Charles Harris Peacock

December 1981

Chairman: A.E. Dudeck
Major Department: Horticultural Science

The response of St. Augustinegrass [Stenotaphrum secundatum (Walt.) Kuntze] to irrigation scheduling was studied during the summer of 1980 and 1981. Research plots were constructed to maintain a natural soil profile that vertically isolated adjacent plots and prevented lateral water movement. Water stress treatments were implemented by scheduling irrigation with equal volumes of water per day (0.64 cm in 1980 and 0.38 cm in 1981) at either 2-, 3-, 4-, or 6-day intervals. Turfgrass swards were evaluated on 12-day cycles under stress and after 24 hours of recovery following irrigation. Measured parameters included turfgrass quality, carbon exchange rates (CER), evapotranspiration rates (ET), plant water potential component changes, leaf diffusive resistance and transpiration, and rooting densities.

During 1980, the 6-day treatment plots had the greatest reduction in CER under stress (57%) and increase during recovery (77%)

with little change in ET or leaf water potential for the first stress cycle. Two additional stress periods were studied but no differences in leaf water potentials were found among treatments and only moderate reductions in CER and ET were observed while leaf water potentials remained high. Depth of rooting and perching of the water table into the rooting zone precluded stress based on irrigation scheduling.

Irrigation scheduling did affect many of the parameters studied during 1981. The 6-day treatment caused a reduction in CER and ET associated with stomatal closure and loss of turgor pressure during each stress cycle. During recovery following irrigation, CER and ET increased (by as much as 353% and 209%, respectively), turgor pressure increased, and diffusive resistance decreased during each 12-day stress cycle. Averaged over the entire study period CER, ET, leaf water potentials, and transpiration were lowest and diffusive resistance highest for the 6-day treatment plots. All parameters increased or decreased significantly during recovery following irrigation. Turfgrass quality and percent cover were not affected by treatments. Turfgrass water use rates decreased with increasing days between irrigations. Scheduling irrigation once a week for St. Augustinegrass with 2.7 cm of water will likely have no affect on turfgrass quality if adequate mowing height is maintained.

INTRODUCTION

Turfgrass science involves the interaction of environmental factors with management practices to produce an acceptable quality turfgrass. Irrigation is an integral part of a turfgrass management program where the major objective has been to create an environment which is aesthetically suitable for recreation or relaxation. The intensity of management is directly related to cost and availability of energy input. Falk (1976) noted that on a yearly basis of energy input for maintenance, irrigation was the greatest user of external energy resources accounting for 68.6% of the management input into the lawn system on a Kcal/year basis. However, management objectives must change as potable water supplies decrease (Smerdon, 1974), and subsequent use of limited water will most probably impose stress on turfgrass areas which will result in reduced quality. Surveys in Florida have projected that water stress research on turfgrass is needed to help better manage and conserve water.

Previous research in Florida has focused on water requirements for turfgrasses (McCloud, 1954; Weaver and Stephens, 1963; Stewart and Mills, 1967; Stewart et al., 1969). These findings indicate an imbalance during peak growth months between turf water use and precipitation. Irrigation is commonly practiced to offset this deficit even under common home lawn and golf course situations.

Plant water stress can be manifested by a number of physiological responses. Water stress can be a short term effect during a diurnal cycle whereby root absorption lags behind transpiration during the day, but the water deficit is relieved overnight. More severe cases are noted when soil water becomes limiting and complete recovery overnight is impossible (Kramer, 1969). General effects of water stress on plant growth include reductions in cell growth, stomatal opening, carbon dioxide assimilation, respiration, sugar accumulation and translocation, etc. (Hsiao, 1973). The results of water stress may be subtle or dramatic, varying from small changes in leaf water potential to a complete inactivity of the photosynthetic apparatus. Plant water stress results in a lowered rate of photosynthesis, thus reducing plant growth by limiting production of new leaf area (Boyer, 1976). Turfgrass resistance to water stress is highly variable among grass species. This is dependent not only on genetic characters but also on cultural and management practices (Beard, 1973).

Turfgrass can tolerate severe stress for periods during the growth season and completely recover following maintenance of adequate irrigation during the remainder of the season (Jensen, 1968). Hsiao and Acevedo (1974) note that almost any parameter or plant process can be altered by a water stress that is severe and long enough.

The objective of this study was to assess the responses of St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] to short-term water stress implemented by scheduling irrigation at either 2-, 3-, 4-, or 6-day intervals. The resulting water stress treatments approximate the lack of rainfall or various irrigation scheduling programs which

are presently used. In the assessment of the treatment effects, turfgrass swards were evaluated for a number of parameters including turfgrass quality, carbon exchange rates, evapotranspiration rates, plant water potential component changes, and rooting densities.

LITERATURE REVIEW

Plant Response to Water Stress

Plant responses to water stress can be manifested in a variety of morphological and physiological changes. Morphological modifications to plant water deficits include increased rooting depth and root-shoot ratio, decreased leaf number, size and total leaf area, and reduced shoot elongation. Physiological changes are more subtle but involve lower leaf water potentials, lower turgor and osmotic potentials, decreased carbon exchange rates, increased soluble carbohydrate concentration, decreased protein concentration and increased amounts of bound water (Beard, 1973).

Plant Water Potentials and Stomatal Control

Plant water status as measured by water potentials influences both physical and physiological characteristics of the plant. Water movement from the soil through the roots and xylem to the leaf cells must replace water which is transpired from the stomata in the leaf or deficits occur. Water deficits cause stress and can be measured as reductions in the leaf water potential (Levitt, 1980). The most obvious visual effect of water deficits is leaf wilting.

Many physiological changes occur prior to wilting (Kramer, 1969). The most sensitive process as affected by water stress is cell expansion (Hsiao and Acevedo, 1974) which is inhibited earlier and more severely than photosynthesis (Boyer, 1970). Leaf water potentials varying from -1 to -50 bars can inhibit growth (Levitt, 1980).

Perennial ryegrass (Lolium perenne L.) leaves continue to expand fully under stressed conditions in the field although at a slower rate throughout the duration of the stress (Jones et al., 1980a).

Turgor potential is centrally important as the parameter which links the water balance of a crop to its growth processes including carbon dioxide assimilation and cell elongation (Zur and Jones, 1981). Growth is physically dependent on maintaining turgor pressure not only with newly dividing cells in the leaf but also with the guard cells of the stomata. Stomatal opening is directly controlled by the turgor of the guard cells of the stomata and of other epidermal cells (Levitt, 1980). Leaf water potentials at which the stomata begin to close from loss of turgor is variable with species and growth conditions. Kanemasu and Tanner (1969) reported threshold leaf water potential values for tomato (Lycopersicon esculentum Mill.) of -7 to -9 bars and -10 and -12 bars for beans (Phaseolus vulgaris L.). Jordan and Ritchie (1971) measured values as low as -12 to -16 bars in cotton (Gossypium hirsutum L.) before stomatal opening was affected. Hansen (1971) found that sugar beet (Beta vulgaris L.) has little change in diffusive resistance of the leaf until leaf water potentials reached -18 bars, corresponding to initial stomatal closure. O'Toole and Cruz (1980) saw increased stomatal resistance and leaf rolling at the same leaf water potential range (-8 to -12 bars) in rice (Oryza sativa L.). Once the threshold leaf water potential is reached and the stomata begin to close, there is increased resistance to carbon dioxide movement into the leaf and water vapor movement out. A general assumption would be that once the stomata closed, the diffusion processes

would be severely inhibited and both photosynthesis and evapotranspiration would be quite low. Ackerson et al. (1977) in studying the effects of water stress on field grown cotton noted that as leaf water potentials decreased there were increases in leaf diffusive resistance although complete stomatal closure was not observed even at zero turgor potentials. Sorghum [Sorghum bicolor L. (Moench)] plants exposed to water stress for the first time closed their stomata completely, but stomata remained partially open during subsequent drought periods. One study indicated that the stomata remained slightly open all day during a severe stress (Sullivan and Eastin, 1974).

Water Stress Effects on Photosynthesis

Changes in photosynthesis during water stress have been well documented. Boyer (1976) noted that decreases in photosynthesis resulted from decreased stomatal opening and non-stomatal effects on chloroplast activity. Kramer (1969) explains the reduction in photosynthetic rates as a coordination of resistances at the stomata and the mesophyll, limiting carbon dioxide flux into the plant and fixation into sugars at the cellular level. Most data indicate that the primary effect of water stress on photosynthesis is through the reduction of carbon dioxide diffusion caused by increased stomatal resistance (Hsiao, 1973). Numerous studies link the beginning of stomatal closure at some critical threshold leaf water potential level to the beginning of a decrease in photosynthetic rates (Hsiao and Acevedo, 1974). In some species during brief stress, reduction in carbon dioxide assimilation is totally accounted for by stomatal closure (Troughton and Slatyer, 1969). Beadle et al. (1973) found that photosynthetic rates

of corn (Zea mays L.) and sorghum were different at similar leaf water potentials. Sorghum at a leaf water potential of -11.5 bars had a photosynthetic rate of 25% of maximum while corn was severely wilted and photosynthesis had ceased. Recent evidence suggests a more complicated hypothesis. Photosynthesis or substomatal carbon dioxide concentrations have been shown to affect stomatal conductance. Therefore a water stress that reduces photosynthesis may thus reduce stomatal conductance (Wong et al., 1979).

Fock and Lawlor (1979) found that true and apparent photosynthesis decreased linearly in sunflower (Helianthus annuus L.) as a consequence of stomatal and possibly non-stomatal effects of severe stress. Parsons et al. (1979) found similar results in cotton where apparent photosynthesis was reduced under stress conditions in a drying soil. During development of water stress, the non-stomatal changes are probably directly related to biochemical alterations owing to changes in the hydration of the protein molecules (Hansen, 1971). Hsiao (1973) concluded that non-stomatal effects on net carbon dioxide assimilation do occur under conditions of mild or moderate water stress. He notes that there apparently are differences in the magnitude of these responses among species.

Stomatal and Non-Stomatal Aspects of Photosynthetic Recovery

Researchers (Hansen, 1971; Ackerson et al., 1977) have shown closure of stomata during water stress does not totally control photosynthesis and Jones (1973) concluded that water stressed cotton plants showed greater intracellular resistances (non-stomatal) than controls. Wardlaw (1966) suggested that water stress acted directly on the leaf and that some of the effects were non-stomatal since increasing

ambient carbon dioxide concentrations under stressed conditions did not alter photosynthetic rates.

Recovery of photosynthesis following rewatering of stressed plants is dependent on the duration and severity of the stressed period. Recovery time can range from a few hours to a day or more (Kramer, 1969). These responses are generally linked to renewal of cell turgor potentials necessary for stomatal opening, although non-stomatal mechanisms are also involved. Ceulemans et al. (1979) noted recovery of photosynthesis in water stressed Rhododendron simsii (Planch.) plants 24 hours following rewatering.

Stomatal Control of Evapotranspiration

Evapotranspiration is the sum of two unique yet similar processes, evaporation from the soil surface and transpiration from the plant. Stomatal transpiration accounts for more than 90% of the loss of water from the plant (Beard, 1981). Stomatal closure is therefore the major cause of decline in transpiration during water stress (Hsiao, 1973). Hansen (1971) showed that stomata of severely dehydrated plants still regulated transpiration. Shimshi (1963) working with corn found that stomatal closure markedly reduced transpiration, but photosynthesis was reduced to a lesser extent. Changes in the ratio of dry matter produced to water use (water use efficiency) under stress do not conform strictly to a stomatal effect. Hsiao and Acevedo (1974) cite evidence that the additional effect of water stress on photosynthesis (non-stomatal) negates any gain in water use efficiency when water deficits develop. Consequently a one to one relation between transpiration and dry matter production is often observed under conditions of varying water supplies.

Soil Moisture Influence on Plant Water Status

Plant moisture stress may develop any time water uptake is less than transpiration. The extent of any imbalance is limited by the water storage capacity of the plant (Turner and Begg, 1981). Plants can extract water from the soil only when their water potential is lower than the soil matrix potential. These differences can result in plant water deficits through inadequate absorption, excessive transpiration or a combination of the two. Plant roots absorb soil water in response to these potential gradients. As the potential differences become greater, the water flow rates become proportional to the potentials. However, as soil moisture decreases, less water is available for root absorption and further increases in potential differences will not increase water flow and eliminate plant water deficits. The effects of depletion of soil moisture on the plant are well documented in the literature. More important is the soil matrix potential at which physiological responses of individual plant species are noted. Beadle et al. (1973) found differences in the rate of stomatal closure between corn (drought intolerant) and sorghum (drought tolerant). Stomatal closure of both species started at a similar soil water tension of -0.3 bars. Corn stomata were completely closed by -0.7 to -0.8 bars while sorghum did not exhibit complete closure until soil water potentials reached -6 to -7 bars in a loam-peat soil. Al-Ani and Bierhuizen (1971) working with beans, cucumber (Cucumis sativas L.) and tomato saw transpiration rates rise and then reduce steadily as soil moisture decreased. Shimshi (1963) suggested that as the soil dries, resistances to water movement at the evaporating surfaces of the mesophyll cells increase. However,

plant water potentials at these surfaces may reach -80 bars without wilting of the leaves. Ritchie (1974) concluded that one of the most important findings concerning plant water relations is that plant growth is controlled directly by water deficits in plants and only indirectly by soil water deficits and atmospheric stresses. Further, soil moisture availability is a function of rooting densities and depth, which effectively controls plant and soil water relationships.

Water Stress Studies on Grasses

Water stress studies on grasses have focused mainly on those species and cultivars grown for forage or pasture with little research conducted on grass under true turfgrass management situations. Beard (1981) has noted that the effects of water stress include increased rooting depth, decreased photosynthesis, and reduced shoot growth rate, all of which are interrelated. He also stated that inherent physiological hardiness to water stress can be affected by cultural practices such as fertilization and irrigation, and noted that mowing will enhance drought resistance.

These inherent properties are evident in studies on range and forage grasses. Dyer and Trlica (1972) in studies on blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] found that photosynthetic rates were not influenced by leaf water potentials as low as -44 bars. Assimilation was reduced by 50% as the leaf water potential reached -60 bars. Hutcheson and Knight (1972) noted that leaf transpiration in blue grama was maximum at -30 bars and leaf area expansion was rapid. Only at -70 bars did leaf expansion stop.

Water Stress Effects on Physiological Parameters in Grasses

Water stress effects on photosynthesis, evapotranspiration and other physiological parameters have been studied in cool-season grasses. Sheehy et al. (1975) observed that canopy photosynthesis of ryegrass declined rapidly only after several days of water stress and that all swards showed a rapid increase in photosynthesis during the first 24 hours after rewatering. Leaf water potential in their study became more negative preceding the decline in photosynthesis. The decline in canopy photosynthesis was associated with decreased single leaf values for photosynthesis, leaf water potential, and conductance. In their more severely stressed plots, loss of leaf tissue limited the recovery of canopy photosynthesis. Jones et al. (1980a) studied water stress effects on perennial ryegrass and found that canopy photosynthesis was reduced by about 50% in stressed field swards and more than 80% in stressed simulated swards (boxes with soil of low water holding capacity). This resulted in a marked reduction in dry matter production. They noted an increased stomatal resistance accounted for these results, although leaf water potentials were not drastically lowered compared to other crops (-16.0 to -20.0 bars). It was found (Jones et al., 1980b) that in the rapidly stressed simulated swards turgor fell to zero for a significant part of the day, and that the critical threshold for stomatal closure was at a relatively high leaf water potential (-13 bars). They concluded that the response of the grass crop to water stress began slowly in the field and was a combination of drought avoidance (reduction of leaf area) and drought tolerance (continued photosynthesis) allowing for the plant to maintain positive

carbon balance. This enabled the crop to resume growth at a vigorous rate once the stress was relieved. The studies on perennial ryegrass were conducted under forage management conditions, not true turfgrass situations, since mowing was not done to maintain uniformity.

Sheffer (1979) in greenhouse studies on turfgrass species under turfgrass management conditions found that Kentucky bluegrass (Poa pratensis L.), perennial ryegrass, and tall fescuegrass (Festuca arundinacea Schreb.) used less water when soil water was limiting. Leaf bud extension and water use were more sensitive to water stress than was leaf water potential. Under moisture stress, less dry matter was produced indicating a limiting of growth processes and photosynthesis. In addition, he noted that species differences were apparent for most parameters studied and that species by treatment interactions were also observed for some factors.

Rooting Effects on Plant Water Status

Rooting can affect plant water status by limiting soil moisture availability. Under non-stress conditions, 49% of the ryegrass assimilate fixed during a normal photoperiod is translocated to plant parts underground (Sheehy and Peacock, 1975). Creation of plant water deficits by reduced rooting can result under turfgrass situations due to low mowing heights (Beard, 1973). Soil moisture stress can also affect root distribution but in a positive manner. Doss et al. (1960) observed that the effective rooting depth of five warm-season forage species decreased as soil moisture increased, while Bennett and Doss (1960) noted similar results on cool-season forage species. This implies that greater rooting depth during soil moisture stress may be a drought avoidance mechanism. Water stress has been shown to alter shoot:root

ratios (Beard, 1973) and this presumably is due to lack of turgor for leaf expansion and redistribution of assimilates to root growth. Sheffer (1979) did not detect changes in root mass due to soil moisture stress, but Ritchie (1974) noted that container-grown plants do not always respond to soil water deficits in the same manner as field plants.

Turfgrass Water Studies

Until recently, water for irrigation of turfgrass was considered plentiful. Even 11 years ago Florida was described as being wealthy in water resources, both in ground water and surface water (Singley, 1970). Smerdon (1974) pointed out that the Water Resources Council concluded that there is enough water for future needs, but there would be regional shortages. Zachariah (1976) warned that while current water needs could be met, problems of water management were going to become more acute as the competition for water increased. Drought problems in 1981 have focused more attention on what now is considered a critical problem in water supplies and consequently turfgrass management for Florida in the coming decade (Warren, 1981). With an estimated one million acres of turfgrass in Florida (A.E. Smajstrla, 1981 personal communication) public awareness has prompted investigations into the area of turfgrass water use. A Florida Turfgrass Association survey noted that 86% of the respondents thought more research was needed in the area of irrigation techniques and 92% felt that research was needed in the area of plant water relations, including work on water use rates, drought resistance, moisture stress, water uptake, and transpiration (Augustin, 1979).

Turfgrass water studies in Florida have spanned some 28 years with work being conducted at Gainesville and Fort Lauderdale field stations. McCloud (1954) measured water use in turfgrasses from soil tanks and developed an empirical formula expressing the following relationship of evapotranspiration rate to mean temperature:

$$\text{Evapotranspiration} = K \cdot W^{T-32}$$

where $K = 0.01$ and $W = 1.07$ are constants and T is the mean temperature in degrees Fahrenheit. McCloud calculated evapotranspiration (ET) rates for three Florida cities based on average temperatures and noted that during the peak growing season of April through August for turfgrasses in Florida, a deficit normally exists between water requirements and rainfall. To prevent water stress this deficit must be corrected by irrigation. McCloud (1970) calculated average daily water use rates of turfgrasses using monthly temperatures for north, central, and south Florida. He concluded that during the peak growing season (April through September) ET would range between 0.30 and 0.87 cm of water per day. While Florida rainfall averages 135 cm per year, there are large seasonal variations and estimates indicate ET will greatly exceed rainfall during the early summer periods.

Turfgrass Water Use Rates

Evapotranspiration from St. Augustinegrass was studied in a series of experiments at Fort Lauderdale, Florida. Weaver and Stephens (1963) found that ET varied from 0.36 to 0.33 cm per day as depth to the water table increased. Evapotranspiration rates for St. Augustinegrass and bermudagrass (Cynodon dactylon (L.) Pers.) were determined in further studies by Stewart and Mills (1967) over a 3-year period in Fort Lauderdale. Although exact data were not given they concluded that the ET

for St. Augustinegrass was slightly higher than for bermudagrass. As an average of five years over the two studies they found turfgrass water use rates, during the peak growing period of April through September, ranged from 0.36 to 0.44 cm of water per day. On a yearly basis turfgrass water use averages 109 cm. Estimated daily evapotranspiration rates for north Florida correlate well with these measurements. Potential ET from long-term weather data at Jacksonville using the Penman method show values during the peak growing season from April to September that range from 0.31 to 0.43 cm per day (L.C. Hammond, personal communication). Values for ET measured by Weaver and Stephens (1963) are lower than those calculated by McCloud at Gainesville. In McCloud's studies ET rates may have been exaggerated by advective heat transfer inflating the ET values (Allen et al., 1978). Kneebone and Pepper (1978) measured water loss under arid conditions from St. Augustinegrass in Arizona and found ET values that ranged from 0.49 to 0.56 cm per day during the summer growing period and a yearly use rate of 118 cm, slightly higher than those values observed in south Florida. Youngner (1979) studied turfgrass water use in bermudagrass and St. Augustinegrass in California and measured daily use rates for the summer months between 0.25 and 0.41 cm. These data correspond well with studies on bermudagrass in the southeastern United States by van Bavel (1961) and in Hawaii by Ekern (1966) where ET values ranged between 0.27 to 0.44 cm per day and between 0.32 to 0.47 cm per day, respectively. Allen et al. (1978) calculated potential ET based on Fort Lauderdale climatological data by the Penman formula and compared these results with the measured ET values for the studies at Fort Lauderdale. They found that in most cases the daily potential ET averaged over

five days exceeded the measured ET values. Further, the yearly water budget was less than annual rainfall, but values during the study period showed maximum monthly deficits ranging from -8.9 cm for 1959 data to -35.6 cm for 1965.

It is apparent from ET data that irrigation is considered a requirement to provide enough water for high quality turfgrass in Florida. Irrigation techniques are based on these three main considerations: (1) water needs of the turfgrass, (2) available moisture capacity of the root zone, and (3) availability and quality of irrigation water (Harrison, 1973). Irrigation interval is a function of soil water holding capacity and rooting depth. Generalized values for Florida indicate a 3-day irrigation interval is necessary to maintain adequate soil moisture for turfgrass growth (Bartholic, 1977). Tovey et al. (1969) found that irrigation frequency could influence turfgrass ET and they measured slight decreases with decreasing frequency of irrigation.

Many studies on water use by grasses have indicated that ET is controlled to a large extent by soil water availability and that as the soil dries, less water is used (Garwood and Williams, 1967; Makkink and van Heemst, 1956; Doss et al., 1964 Doss et al., 1962). Slabbers (1980) reviewing irrigation frequency of field crops, notes that irrigation should be applied when 40 to 60% of available soil moisture is exhausted. Youngner (1979) successfully utilized tensiometers to control irrigation on St. Augustinegrass turf. Three regimes were utilized which provided irrigation when soil moisture tensions reached -15 cb (wet), -40 cb (medium) or -65 cb (dry),

at a depth of either 15 or 30 cm in the soil profile. Acceptable quality turf was maintained with as little as 57.9 cm per year of irrigation (dry) while even the wet treatment required only 77.5 cm of irrigation water per year. Rainfall was 45.2 cm indicating a minimum water application of 103.1 and a maximum of 122.7 cm. These values are consistent with the previously mentioned studies, involving more efficient utilization and lower irrigation amounts by allowing stress to occur, without lowering turf quality. On the basis of Florida data, Bartholic (1977) using computer simulation, found that if effective rooting depth allowed for an increase in available soil water from 1.0 to 1.8 cm, irrigation frequency could be reduced from between 60 and 76 irrigations per year to between 30 and 36. Annual irrigation volumes would approach Youngner's values of between 81.3 and 96.5 cm per year at a non-stress ET rate (Youngner, 1979).

METHODS AND MATERIALS

Preparation and Maintenance of Field Plots

An experimental area 15 X 75 m at the Turfgrass Field Laboratory, located at the IFAS Horticultural Unit, Gainesville, Florida was prepared in March 1980 by stripping the existing vegetation with a sod cutter and power raking the sod before removal. This allowed removal of the vegetation with little loss of topsoil. The area was graded and surveyed for installation of three blocks of four field plots 2 X 2 m with 25 cm between plots and 2 m between blocks. Elevations were determined with a transit so that a 5 cm crown could be placed on each block to allow for surface drainage. Installation of individual isolated research plots was accomplished by trenching the circumference of each plot to a depth of 81 cm and wrapping the resultant soil monoliths with two layers of 4 mil polyethylene to act as a moisture barrier. The entire area was regraded, lightly rototilled, and fumigated with methyl bromide at a rate of 68 kg/ha. An application of a complete fertilizer in a 16-1.6-6.4 elemental N-P-K ratio (50% water insoluble nitrogen) with minor elements was made to the entire area at a rate of 50 kg N/ha. The area was sodded with 'Floritam' St. Augustinegrass, watered, and mowed as necessary. The surrounding area was seeded to 'Pensacola' bahiagrass (Paspalum notatum Flugge) to provide adequate fetch. The sod was allowed a 4-week establishment period before experimentation began. Because of problems in 1980 with a fluctuating water table, a 10 cm diameter drainage pipe was installed 1.22 m deep around the perimeter of the area in January 1981.

Plots were mowed at 7.5 cm with a rotary mower and clippings returned. Frequency varied from one to two times in a 6-day period, and not less than every six days. In April of 1981, the area was verticut in two directions with a vertical mower spaced at 7.5 cm. A complete fertilizer in a 16-1.6-6.4 elemental N-P-K ratio (50% water insoluble nitrogen) was applied at a rate of 50 kg N/ha and the area watered and mowed at a height of 7.5 cm as needed. Approximately two weeks prior to initiation of the experimental period an additional application of 25 kg N/ha of ammonium nitrate was made. Experimentation was delayed until May 1981 to allow optimum rooting and full turf cover to occur before initiation of treatments. During the 1981 treatment period, plots were mowed every six days at 7.5 cm with a rotary mower and clippings returned. At no time during the 1980 or 1981 experimental period was a herbicide, insecticide, or fungicide used since this might affect some of the physiological processes studied.

Data was collected on selected environmental parameters. Solar radiation was monitored by a Weather Measure Corporation Model R401 Pyranograph on a 24-hour basis. Soil temperatures at 2.5 cm were recorded daily using Science Associates Model 120 Maximum-Minimum soil thermometers under two treatment plots. Daily air temperatures, relative humidity, wind run, rainfall, and pan evaporation were measured at the Field Crops Department Weather Station located east of the Turfgrass Field Laboratory.

Experimental Design

The experimental design was a randomized complete block of four treatments in three replications. Treatments consisted of irrigation

on a 2-, 3-, 4-, or 6-day interval with equal volumes of water on a per day basis. During the 1980 experimental period the grass was provided with the equivalent of 0.64 cm/day of water (0.25 inches/day). This was in excess of the potential ET rate as calculated from Penman's equation based on Jacksonville, Florida data of 0.40 cm/day (0.16 inches/day) (L.C. Hammond, personal communication) so that stress would be induced by irrigation scheduling not quantity. On the basis of the 1980 results, during the 1981 experimental period the turfgrass was irrigated with the equivalent of 0.38 cm of water per day (0.15 inches/day) so that stress would be more easily induced.

All plots were hand watered using a rosette nozzle on a hose and a gasoline powered portable sprayer. Care was taken at the high volumes on the 4- and 6-day treatments to match application with infiltration rates so that no run-off occurred. Each plot was watered in two directions to provide uniform coverage with a measured amount of water to impose the specified treatments. Watering was done as late in the day as possible to minimize evaporation losses.

To insure that the only water the plots received was that applied during scheduled irrigations, three protective rain shelters were initially constructed using PVC pipe as a framework and Monsanto® 602 polyethylene plastic as a cover. After the shelters were destroyed in a severe storm in 1981, new ones were constructed using 1.8 cm electrical conduit as a framework. Use of this polyethylene material provided greater than 90% light passage as photosynthetically active radiation. Shelters were installed over the plots at night and during periods of rainfall. They were designed with a 46 cm overlap to protect the plots

from a blowing rain and were placed on supports 46 cm above the ground to provide for wind movement to prevent excessive heat build-up.

Turfgrass Measurement

Measurements of physiological parameters were taken at the beginning of the study period (initial) to insure that all swards were equivalent prior to initiation of treatments. Measurements were then taken at 12-day intervals (corresponding to a cycle) on the afternoon prior to irrigation. After 24 hours of recovery following irrigation, measurements were reported so comparisons on pre-irrigation and recovery data could be made.

Physiological measurements of carbon dioxide exchange rate (CER) and evapotranspiration (ET) were made using a portable quick draw-down closed chamber system (Boote et al., 1980). Plots were mowed at 7.5 cm late on the preceding day to allow recovery from mowing shock and provide uniform turf height for measurement. Aluminum frame bases 76 X 109 cm covered with a non-permeable Mylar plastic were sunk into the center of the turfgrass plots approximately 2.0 cm deep to ensure a closed system. A 1.03 m³ aluminum frame chamber covered with Mylar plastic was seated to the previously installed chamber base for determinations of CER and ET. The chamber was secured to the base with clamps for 2-4 minutes and measurements recorded. This short time period precluded problems with heat build-up and carbon dioxide depletion. The chamber was equipped with thermocouples to monitor internal air temperatures and a quantum sensor to measure radiation levels as photosynthetically active radiation (PAR). Air was circulated by a permanently mounted electric fan in the chamber to

insure adequate mixing. Tygon[®] tubing connected to the chamber allowed for air to be circulated by a pump for sampling purposes.

Instrumentation for measurements was housed in a mobile van which allowed portability. Air at 0.6 liters/minute was extracted from the circulating chamber air and analyzed for changes in carbon dioxide content with a Beckman Model 865 Infra Red Gas Analyzer. The gas analyzer was calibrated to a carbon dioxide differential of 100 vpm using carbon dioxide gas in a nitrogen carrier certified as to concentration. The air was first passed through a double column of Drierite[®] (Anhydrous Calcium Sulfate) to remove water vapor. Carbon dioxide exchange rates as apparent photosynthesis were recorded for 60 seconds after a linear response was observed. A light-proof white cover was then placed over the chamber and an additional 60 seconds of data recorded once carbon dioxide evolution was observed to be linear. This allowed calculation of CER as dark respiration plus soil respiration. Gross photosynthesis was determined as the sum of apparent photosynthesis and dark respiration. Changes in water vapor content for the initial 30 seconds of sampling were recorded by simultaneously passing undried air from the 8 liter/minute circulation through a General Eastern System 1100 DP Dewpoint Hygrometer for changes in the dewpoint temperature. Dewpoint values were converted to absolute humidity and recorded as mg water vapor change per unit time. Chamber temperature was monitored with a Wescor TH-65 Thermocouple Thermometer using handmade copper-constantine thermocouples and PAR was measured with a Li-Cor Model 190 S Quantum Radiometer. All instrumentation was connected to Gould Brush 105 Dual Pen

Recorders for recording data. Changes in concentrations of carbon dioxide and water vapor could then be calculated per unit time and per unit land area.

Leaf water potentials were measured in 1980 with a Soil Moisture Equipment Company Model 3005 pressure chamber apparatus (Scholander et al., 1965). Fully expanded leaves subtending the leaf bud were excised with a razor blade and mounted in the chamber head with approximately 5 mm of the cut end exposed. Air within the chamber was kept moistened by lining the chamber with paper towels to minimize evaporative drying. Leaf water potentials in 1981 were measured using thermocouple psychrometers. Approximately 25 mm of fully expanded leaf tissue subtending the leaf bud were excised, rolled, carefully placed in the psychrometer cap and sealed. Psychrometers were maintained at ambient temperatures and quickly transported to the laboratory. They were placed in a 30°C water bath and allowed to equilibrate for four hours. Psychrometric determinations of water vapor content were measured with a Li-Cor Model HR-33 T Microvoltmeter and recorded by a strip chart recorder. Calibration curves for each psychrometer were pre-determined with a series of potassium chloride solutions. For osmotic potentials, the psychrometers were placed in a freezer overnight, thawed at room temperature, equilibrated in the water bath at 30°C, and determinations made as described above. Turgor pressure potential was calculated as the difference in leaf water potential of the fresh leaf minus the osmotic potential determined after freezing. Diffusive resistances of the last fully expanded leaf blade were determined for the 1981

period using a Li-Cor Model LI-1600 Steady State Porometer. Diffusive resistance, leaf temperature, and transpiration rates were determined on the adaxial and abaxial leaf surfaces. Individual leaf values were determined as the sum of conductance (expressed as resistance) and transpiration for adaxial and abaxial leaf surfaces.

Soil samples were taken at the beginning and end of the study period each year to determine the treatment effects on rooting density. Rooting cores 5 cm in diameter by 15 cm in length were collected at 15 cm increments to a depth of 75 cm. Two cores were sampled per treatment plot. Samples were washed, screened free of sand and organic material, and the root counts were made on a 1 X 1 cm grid system. An estimate of the total length of root in a sample was determined by the following formula: $R = \frac{\pi N}{2}$ where N equals the number of intersects on a one cm line grid (Newman, 1966). Roots were then dried in an advection oven at 80°C overnight, weighed, and ashed at 550°C for 8 hours and reweighed. Root mass on a dry weight basis was then calculated as the difference in dry weight and ash weight to the nearest tenth milligram on a Mettler H64 analytical balance.

Clipping weights from a 2 m long by 56 cm wide swath were collected from each plot for dry weight determinations at varying intervals during the study period. Clippings represented a 3- to 6-day period of growth. Clippings were dried in an advection oven at 80°C for 24 hours and then reweighed to the nearest hundredth of a gram on a Mettler PL4000 pan balance. Clipping weight data was normalized on a per day basis.

Visual estimates of turfgrass quality and percent cover were made weekly during the study period. Turfgrass quality was assessed on a 1 to 9 scale with a value of 9 representing the highest quality. Percent cover was estimated on a one to one hundred basis as the amount of soil with vegetative cover.

Water Use Estimates

Soil moisture flux, estimated turfgrass water use, and effective rooting depth during stress conditions was monitored by instrumentation installed in each plot. Soil moisture tensiometers were constructed of one bar ceramic cups (Soil Moisture Equipment Company catalog # 655X1-B1M1) glued with a waterproof epoxy (Armstrong Products Corp. A-34 Adhesive) to 2.22 cm diameter extruded acrylic tubing. These were placed at depths of 15, 30, 45, and 60 cm in each plot. Nylon tubing inserted into rubber stoppers connected the tensiometers to a mercury well. Soil moisture tension recorded in millibars from a scale allowed evaluation of soil moisture flux on a periodic basis. Lengths of aluminum irrigation pipe (5.08 cm outside diameter with a 0.127 cm wall thickness) were placed into the center of each plot to a depth of 1.8 m. A Troxler Model 55A Neutron Depth Moisture Gauge and 2600 Scaler (Troxler Electronics, Research Triangle Park, NC) were used to monitor soil water content on a periodic basis.

Gravimetric determinations of soil moisture content were taken at varying intervals to establish a soil water content calibration curve for the neutron probe and secondarily the samples were analyzed for nutrient status. Soil cores 1.9 cm in diameter X 15 cm in depth) were taken to a depth of 45 cm, placed in metal weighing cans, weighed to the

nearest hundredth of a gram, dried at 105°C for 24 hours, and reweighed to determine water loss. Conversion of gravimetric water content to volumetric water content was made on the basis of soil bulk density as derived from the following procedure.

In order to evaluate soil moisture changes from tensiometer data, a soil moisture release curve was constructed. In situ soil samples from topsoil and subsoil were collected in brass rings (9 cm in diameter by 3 cm in height) as four replications by use of a Soil Moisture Equipment Co. Model 200-A Soil Core Sampler. These samples were placed in Tempe Pressure Cells (Soil Moisture Equipment Co. Model 1450), saturated in a water bath, and placed on a pressure regulation system. Air pressure was applied in varying increments from zero to one bar and quantified with a mercury manometer. After each increment of pressure change and after equilibrium had occurred, the cells were weighed to the nearest hundredth of a gram on an analytical balance. Upon termination of the experiment, soil bulk densities for both topsoil and subsoil samples were determined based on oven dry weights of the rings which contained measured volumes of soil. The soil moisture release curve was plotted as soil volumetric moisture content as a function of tension (pressure).

Water use estimates were made using a water balance method. (Tanner, 1968). Soil moisture flux within the soil profile was used to determine volumetric changes as they occurred. The sum of these depletions plus the irrigation applied were taken as estimates of turf-grass water use. Soil moisture contents were evaluated from tensiometer data in the top 60 cm of the plots and to a depth of 1.5 m from the neutron probe data twice weekly.

Data Analysis

Data analysis was performed with Statistical Analysis System programs. Analysis of variance was performed with a randomized complete block design for most parameters. Student's t-Test or the Waller-Duncan k-ratio t-Test was employed for comparison of means (Waller and Duncan, 1969).

RESULTS AND DISCUSSION

1980 Stress Study

Turfgrass stress responses to irrigation scheduling during the 1980 study were limited to two 12-day cycles and one final stress period of 19 days beginning 22 June and ending 6 August. Irrigation treatments consisted of equal volumes of water (0.64 cm/day) applied at intervals of 2, 3, 4, or 6 days. Within a 12-day cycle all plots received 7.6 cm of water. Only the time between irrigations was varied.

Apparent photosynthesis (AP) is the net carbon exchange observed from the turfgrass canopy inclusive of carbon dioxide efflux from soil respiration. Dark respiration (Rd) is the carbon dioxide exchange from the canopy as observed under zero radiation flux. This would include plant respiration from above and below ground parts and microbiological activity from the mat and soil not directly related to the plant respiration. Gross photosynthesis (Pg) is the sum of AP and Rd. Evapotranspiration while calculated on a unit land area basis can be converted to mm/hr by a 1/1000 factor.

Carbon Exchange Rates, Evapotranspiration Rates, and Leaf Water Potentials

Physiological data for the 1980 experimental period indicated that turfgrass carbon exchange rates (CER) of apparent photosynthesis (AP), dark respiration (Rd), and gross photosynthesis and evapotranspiration rates (ET) were very similar in the treatment swards

prior to initiation of treatments (Table 1). Water stress as imposed by irrigation scheduling reduced the CER for 12-day cycle 1 by 4 to 57% with AP being more affected than Rd or Pg. The 6-day treatment showed the greatest reduction in AP and Pg. Leaf water potentials over all treatments were unaffected over the 12-day cycle (Table 2). Overnight recovery following irrigation showed that the greatest increase in CER occurred with the 6-day irrigation treatment with an increase in AP of 77% (Table 3). All treatments showed an increase in Rd (26 to 49%) and Pg (23 to 57%) and only the 2-day treatment exhibited no change in AP. Increases in ET ranged from 9 to 36%. After irrigation, leaf water potentials remained unaffected by the irrigation scheduling treatments (Table 4). Problems with equipment prohibited collection of data under stress during the second 12-day cycle. Comparisons of recovery data for the first and second cycles indicated that week to week changes were evident as AP increased following irrigation, Rd decreased, and Pg was variable among treatments (Table 5). Small changes in ET among treatments were also noted. However, leaf water potentials after rewatering were not different between the study periods (Table 6).

Lack of an induced stress as indicated by high leaf water potentials for the first and second cycles and no indication of wilting of the plants prompted a change in the experimental design. At the end of the second cycle all irrigation was withheld until obvious visual plant water stress was observed by wilting or folding of the leaves. After 19 days without surface irrigation and lack of visual evidence of water stress a decision was made to take final physiological

Table 1. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass at initiation and prior to irrigation on day 12 as affected by irrigation scheduling (12-day cycle 1, 1980).

Treatment	CER									
	Initial					Pre-Irrigation				
	AP	Rd	Pg	AP	Rd	Pg	Initial	ET	Pre-Irrigation	
-days between irrigations-	mg CO ₂ dm ⁻² hr ⁻¹					mg H ₂ O dm ⁻² hr ⁻¹				
2	35 [†]	60	95	25	47	72	4904	5348		
3	28	58	86	31	52	83	§	5027		
4	37	52	89	32	49	81	5923	6286		
6	43	52	95	18	44	62	§	5424		

[†] All values reported as single measurements.

§ No observations recorded.

Table 2. Leaf water potentials of St. Augustinegrass at initiation and prior to irrigation on day 12 as affected by irrigation scheduling (12-day cycle 1, 1980).

Treatment	Leaf Water Potentials	
	Initial	Pre-Irrigation
-days between irrigations-	----- bars -----	
2	-13.9 *	-12.7
3	-12.8	-12.1
4	-12.6	-10.7
6	-12.9	-11.0

* All differences are non-significant at the 5% level using an unpaired t-test.

Table 3. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass prior to irrigation and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle I, 1980).

Treatment	CER									
	Pre-Irrigation					Recovery				
	AP	Rd	Pg	AP	Pg	Rd	AP	Pg	Pre-Irrigation	Recovery
	mg CO ₂ dm ⁻² hr ⁻¹					mg H ₂ O dm ⁻² hr ⁻¹				
-days between irrigations-										
2	25 [†]	47	72	25	25	66	91	5348	6770	
3	31	52	83	32	32	70	102	5027	6827	
4	32	49	81	38	38	62	100	6286	7273	
6	18	44	62	32	32	65	97	5424	5888	

[†] All values reported as single measurements.

Table 4. Leaf water potentials of St. Augustinegrass prior to irrigation and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 1, 1980).

Treatment	Leaf Water Potentials	
	Pre-Irrigation	Recovery
-days between irrigations-	bars	
2	-12.7 *	-10.5
3	-12.1	-10.1
4	-10.7	- 9.0
6	-11.0	-10.1

* All differences are non-significant at the 5% level using an unpaired t-test.

Table 5. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass during recovery from 12-day cycle 1 and recovery from 12-day cycle 2 as affected by irrigation scheduling (1980).

Treatment	CER									
	Recovery									
	Cycle 1					Cycle 2				
	AP	Rd	Pg	AP	Rd	Pg	Cycle 1	Cycle 2	mg H ₂ O dm ⁻² hr ⁻¹	ET

[†] All values reported as single observations.

Table 6. Leaf water potentials of St. Augustinegrass during recovery from 12-day cycle 1 and recovery from 12-day cycle 2 as affected by irrigation scheduling (1980 data).

Treatment	Leaf Water Potentials	
	Recovery	
	Cycle 1	Cycle 2
-days between irrigations-	bars	
2	-10.5 *	-11.5
3	-10.1	- 9.1
4	- 9.0	-10.3
6	-10.1	-12.0

* All differences are non-significant at the 5% level using an unpaired t-test.

measurements and terminate this portion of the experiment at this point. Final stress period CER and ET as compared to the recovery data for the second cycle indicated only a moderate reduction in AP (20 to 45%), Rd (10 to 35%), and Pg (16 to 29%) (Table 7.). Even smaller reductions in ET had occurred (9 to 15%). Leaf water potentials still indicated a lack of water stress since no differences among treatments or between study periods were noted (Table 8).

Physiological data for the first two cycles indicated that CER was affected most by the 6-day irrigation treatment. The 6-day treatment effected reductions prior to irrigation in AP (57%), Rd (16%), and Pg (34%) from initial values and while CER was lowest for this treatment a corresponding decrease in ET was not observed compared with values for other treatments. Following irrigation the 6-day treatment had increased rates of AP (77%), Rd (49%), and Pg (57%) with only a small increase in ET (9%). While this increase in ET was the smallest among all treatments from pre-irrigation to recovery, it was lowest among treatments during recovery. Jones (1980) noted that there is a peak transpiration rate above which no further increase is paralleled by increases in CER. Any increase in CER at this point without an increase in ET would imply non-stomatal inhibitions in photosynthesis.

Leaf water potentials, which ranged among stressed treatments from -10.7 to -12.7 bars, indicated minimum water stress in response to these four different irrigation schedules. Crafts (1968) indicated that until leaf water potentials of many field crops reach -16 bars there is little affect from lowered values.

Table 7. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass during recovery from 12-day cycle 2 and under stress from the 19-day final study period as affected by irrigation scheduling (1980 data).

Treatment	CER						
	Cycle 2 Recovery			Final Stress			ET
	AP	Rd	Pg	AP	Rd	Pg	
	— mg CO ₂ dm ⁻² hr ⁻¹ —			—			mg H ₂ O dm ⁻² hr ⁻¹
-days between irrigations-							
2	40 [†]	56	96	31	37	68	6229
3	35	52	87	28	38	66	5836
4	51	48	99	28	40	68	6446
6	42	44	86	32	40	72	6030

[†] All values are reported as single observations.

Table 8. Leaf water potentials of St. Augustinegrass during recovery from 12-day cycle 2 and under stress from the 19-day final study period as affected by irrigation scheduling (1980 data).

Treatment	Leaf Water Potentials	
	Cycle 2 Recovery	Final Stress
-days between irrigations-	bars	
2	-11.5 *	-12.2
3	- 9.1	-10.0
4	-10.3	-12.8
6	-12.0	-12.1

* All differences are non-significant at the 5% level using an unpaired t-test.

Although leaf water potential values were unaffected by irrigation scheduling, overnight recovery for all treatments for AP, Rd, and Pg showed recovery values being greater in most cases than initial rates. An increase in ET was noted for all treatments which corresponds with more available soil water following irrigation. The highly variable response among CER parameters for cycle 2 recovery, small changes in ET, and lack of an effect of irrigation scheduling on leaf water potentials indicated stress was very low. Lower CER values without a lowering of ET or leaf water potentials might be indicative of some non-stomatal mechanisms involved in control of photosynthesis under water stress. Pre-dawn leaf water potentials prior to irrigation on day 12 of cycle 2 averaged -2.8 bars over all plots with no differences among treatments. At the end of the final stress period CER was slightly affected after 19 days without irrigation. Moderate reductions in Pg (24 to 35%) and ET (5 to 15%) had occurred. Leaf water potentials were unchanged from initial (pre-treatment) values. Soil matric potentials were rarely below -90 millibars during the entire study period. Sub-irrigation was probably occurring due to a fluctuating high water table preventing any induction of water stress based on irrigation scheduling.

Turfgrass Quality and Clipping Weights

Turfgrass quality as judged by visual ratings was unaffected by irrigation treatments averaged over the study period (Table 9). Clipping weights for two harvest (10 July and 1 August)

Table 9. Quality ratings and clipping weights of St. Augustinegrass as affected by irrigation scheduling. Quality ratings are reported as the mean over the study period (1980 data).

Treatment	Quality [†]	Clipping Weights		
		Harvest 1	Harvest 2	Total
-days between irrigations-		kg ha ⁻¹ day ⁻¹		
2	8.4 *§	35	23	58
3	8.6	30	22	52
4	8.6	25	20	45
6	8.7	37	23	60
Mean	8.6	32 *¶	22	

† Quality scores 1 to 9 with 9 representing the highest quality.

*§ Means in columns are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

*¶ Means in row for harvest data are significantly different at the 5% level using an unpaired t-test.

indicated no treatment differences at either harvest. However, the overall means for each harvest are significantly different with the second harvest which was taken during the final stress period indicating a reduction in clipping weights. This reduction in growth correlates with a reduction in leaf area (Sheffer, 1979) and is therefore directly linked to the decreases observed in CER. However, the reduction in leaf area was not visually apparent. Additionally no visual response of the turfgrass to water stress such as color change or wilting was observed. This points out that the turfgrass was really not under severe stress since leaf area was reduced but photosynthetic rates were high.

Turfgrass Water Use Rates

Water use rates for St. Augustinegrass were estimated for six periods during the first year of the study based on irrigation volumes and changes in soil water storage. Estimates were based on two replications for all periods. Volumes of water were carefully controlled by the method of irrigation. Estimates of ET within a given period were based on the sum of irrigation volumes plus changes in soil water content within the soil profile from tensiometer data to a depth of 60 cm. Water use rates for St. Augustinegrass were highly variable among periods (Table 10). Significant time X treatment interactions indicated no pattern to this variability. While differences exist among treatments within study periods, they are probably related to the method of calculation and the high water table indicating a greater change in water storage not entirely attributed to ET. Rates of water use were in general

Table 10. Water use rates of St. Augustinegrass as affected by irrigation scheduling for six treatment periods (1980 data).

Treatment	Period					
	22 June- 28 June	29 June- 5 July	6 July- 12 July	13 July- 22 July	23 July- 28 July	29 July- 6 Aug
-days between irrigations-	cm day ⁻¹					
						Mean
2	0.69 a [†]	0.58 b	0.65 b	0.65 b	0.31 a	0.21 b
3	0.52 c	0.73 a	0.63 c	0.53 b	0.32 a	0.28 a
4	0.56 b	0.56 b	0.74 d	0.65 a	0.20 b	0.20 b
6	0.58 b	0.56 b	0.57 b	0.67 a	0.27 a	0.15 c
Mean	0.59 c [§]	0.61 b	0.65 a	0.62 b	0.28 d	0.21 e

[†] Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

[§] Irrigation means in row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

agreement with rates found by Weaver and Stephens (1963) at Ft. Lauderdale under non-stress conditions. The mean water use rates for the first four periods was 0.62 cm/day. Estimates from the fifth and sixth periods may be lower than actual rates due to the confounding influence of the high water table. Mean water use indicated a decrease with longer periods between irrigations.

Turfgrass Rooting Characteristics

Rooting characteristics of length and mass were studied at 15 cm increments in the soil profile to a depth of 75 cm. Determinations of initial and final rooting mass and length indicated irrigation treatments had no affect on root distribution at any depth in the soil profile. Root length and mass was different among depths in the profile (Table 11) and total root length and mass was reduced from beginning to end of the study period (Table 12). Lack of an associated water stress with irrigation scheduling was probably related to the extensive rooting which occurred before and during treatments (40% of the roots were below 30 cm in the soil profile). Measurements of the water table under the experimental plots indicated a fluctuation during the final stress period from within 50 to 96 cm from the soil surface. With the extensive rooting that occurred, the saturated conditions allowed more than adequate water uptake. This combination of deep rooting and high soil moisture tensions prevented water stress on the turfgrass.

1980 Summary

It was concluded that during 1980 water stress was not imposed. Photosynthesis and leaf water potentials changed only slightly from

Table 11. Rooting characteristics at 15 cm increments in the soil profile of St. Augustinegrass at initiation and end of study period. Values are reported as means over all treatments (1980 data).

Profile Depth	Root	Mass	Density	Root	Length	Density
	Initial		Final	Initial		Final
cm	_____	mg cm ⁻³	_____	_____	cm cm ⁻³	_____
15	0.32 a *		0.23 a	0.73 a		0.56 a
30	0.22 b		0.14 b	0.40 b		0.22 b
45	0.15 c		0.10 c	0.25 c		0.11 c
60	0.14 c		0.07 cd	0.20 d		0.09 c
75	0.12 c		0.05 d	0.17 d		0.04 d

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 12. Rooting characteristics as a total in the soil profile on a land area basis of St. Augustinegrass as affected by irrigation scheduling at initiation and end of study period. (1980 data).

Treatment	Total Root			
	Mass		Length	
	Initial	Final	Initial	Final
—days between irrigations	— mg cm ⁻² —		— cm cm ⁻² —	
2	24.4 *	15.4	15.4	8.5
3	26.9	16.8	14.9	9.0
4	23.1	14.4	12.7	8.9
6	30.3	14.5	13.6	9.4

* All differences between treatments within columns are non-significant at the 5% level using the Waller-Duncan K-ratio t-test.

initial values and therefore indicated the failure to impose water stress. Rooting characteristics showed a decline in root length and mass presumably linked to the absence of low soil matric potentials or anaerobic conditions from the high water table. Therefore, photosynthates were probably preferentially partitioned into topgrowth as indicated by high turf quality which was unaffected by withholding irrigation. The 1980 study is indicative of a situation where adequate mowing height allowed deep, effective rooting. This coupled with high soil moisture levels from the high water table (depth from the surface did not exceed one meter) allowed the turfgrass to sustain adequate growth with no reduction in turf quality.

1981 Stress Study

Installation of a drainage system under the experimental area prior to the 1981 study period controlled the water table which eliminated the problems encountered in the previous year. Turfgrass response to stress from irrigation scheduling was studied for five 12-day cycles beginning 18 May and ending 17 July. Destruction of the rain-out shelters due to a severe storm during cycle 3 allowed exposure of the plots to natural rainfall. Irrigation treatments consisted of equal volumes of water (0.38 cm/day) applied at intervals of 2, 3, 4, or 6 days. Within a 12-day cycle all plots received 4.57 cm of water. Only the time between irrigations was different.

Physiological Responses During Cycle 1

Physiological data at the initiation of the stress study indicated all swards were equivalent (Table 13 and 14). Stress induced by irrigation scheduling reduced photosynthesis with the 6-day treatment having lowest values among treatments for AP, Pg, and Rd, although Rd was not different from the 2-day or 3-day treatments. Evapotranspiration was increased at the end of cycle 1 from initial values for all but the 6-day treatment. While all plots were equivalent initially, turgor pressure potentials indicate the plots may have been under a slight stress (Table 14). Although total leaf water potentials and osmotic potentials were not statistically different among treatments prior to irrigation on day 12, the 4-day and 6-day treatments had the lowest leaf water potentials. However, turgor pressure potentials were significantly reduced for the 3-day, 4-day, and 6-day treatments. Single leaf diffusive resistance and transpiration data indicate that while initially plants in all swards

Table 13. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass at initiation and prior to irrigation on day 12 as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	CER							
	Initial				Pre-Irrigation			
	AP		Rd		Pg		Pg	
	mg CO ₂ dm ⁻² hr ⁻¹		mg H ₂ O dm ⁻² hr ⁻¹		mg H ₂ O dm ⁻² hr ⁻¹		mg H ₂ O dm ⁻² hr ⁻¹	
-days between irrigations-								
2	43 *	43 a	86 a	41 a	28 ab	69 a	6929 a	7696 a
3	39 a	43 a	82 a	39 a	30 ab	69 a	7246 a	8315 a
4	42 a	39 a	81 a	38 a	31 a	69 a	6743 a	9102 a
6	39 a	43 a	82 a	8 b	19 b	27 b	6743 a	4716 b

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 14. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass at initiation and prior to irrigation on day 12 as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	Leaf Water Potentials					
	Initial			Pre-Irrigation		
	Pt	Po	Ptu	Pt	Po	Ptu
-days between irrigations-						
				bars		
2	-10.6 *	-12.7 a	+2.1 a	-11.6 a	-15.6 a	+4.0 a
3	-13.8 a	-16.6 a	+2.8 a	-13.4 a	-14.9 a	+1.5 b
4	-13.8 a	-16.8 a	+3.0 a	-16.2 a	-15.1 a	-1.0 c
6	-13.8 a	-15.9 a	+2.1 a	-14.9 a	-14.4 a	-0.6 bc

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

were equivalent in diffusive resistance (DR) and transpiration, on day 12 the 6-day treatment DR was highest followed by the 4-day treatment (Table 15). Transpiration rates for all treatments were lowest for the 6-day treatment followed by the 4-day and 3-day treatments. Loss of turgor pressure prompted stomatal closure in the 4-day and 6-day treatments while CER was affected for all the treatments. Reductions in AP and P_g with the 6-day treatment were probably related to stomatal and non-stomatal effects since partial stomatal closure is noted with the 4-day treatment yet AP and P_g rates were not different from the 2-day and 3-day treatments. The 6-day treatment had the lowest ET value among treatments prior to irrigation.

Changes observed in ET from beginning to end of cycle 1 were different for both components since transpiration was reduced yet ET slightly increased from initial values for all but the 6-day treatment. During cycle 1, irrigation at 2-, 3-, or 4-day intervals may have allowed enough water for a slight increase in evaporation. The plants apparently were under stress since CER was reduced. Irrigation scheduling every six days resulted in a loss of turgor, partial stomatal closure, and lowered CER due to stomatal and non-stomatal mechanisms. Hsiao and Acevedo (1974) noted that complete loss of turgor pressure is not necessary to initiate stomatal closure. Apparently most of the reduction in photosynthesis was due to stomatal closure from loss of turgor pressure, while reductions in ET were due to reductions in evaporation and transpiration. Crafts (1968) observed that stress was not entirely dependent on loss of turgor since wilting can occur even when turgor potentials are at +2 to +3 bars.

Table 15. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass at initiation and prior to irrigation on day 12 as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	Diffusive Resistance		Transpiration	
	Initial	Pre-Irrigation	Initial	Pre-Irrigation
-days between irrigations-	sec cm ⁻¹		µg H ₂ O cm ⁻² s ⁻¹	
2	0.77 a *	0.62 c	36.9 a	34.8 a
3	0.67 a	0.67 c	35.9 a	27.4 b
4	0.66 a	1.07 b	38.6 a	22.5 b
6	0.76 a	2.61 a	33.8 a	9.0 c

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Small changes in CER were noted during recovery following irrigation (Table 16) for the 2-day, 3-day, and 4-day treatments. The 6-day treatment exhibited the greatest increase in AP (352%), Rd (62%), Pg (217%), and ET (209%) among treatments following irrigation without a concomitant change in total leaf water potential (Table 17). Values for CER and ET were equivalent among treatments following irrigation. Turgor pressure potentials indicated a re-hydration of the cells and no treatment differences were observed. An associated decrease in DR and increase in transpiration was observed in all treatments (Table 18). While statistically CER and ET data indicate complete recovery for the 6-day treatment following irrigation, higher DR and lower transpiration values for the 6-day treatment would correlate well with the lower AP and Pg values. Lower transpiration values with equivalent ET values would support the concept that some of the increase in ET is related to the evaporation component.

Physiological Responses During Cycles 2 and 3

Carbon exchange rates from cycle 2 were different among treatments with significant reductions in Rd and Pg for the 6-day treatment, although Pg was not different from the 2-day and 4-day treatments (Table 19). Variability in the data precluded noting treatment differences for AP, but the 6-day treatment value was reduced by 228% from the smallest value among the other treatments. The 6-day treatment did not have CER recovery levels following irrigation comparable to the other treatments as it did in cycle 1. Recovery ET was increased most for the 6-day treatment (86%), although the 4-day and 6-day treatments were not statistically different in ET rates.

Table 16. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	CER									
	Pre-Irrigation					Recovery				
	AP	Rd	Pg	Pg	ET	AP	Rd	Pg	Pre-Irrigation	Recovery
	mg CO ₂ dm ⁻² hr ⁻¹					mg H ₂ O dm ⁻² hr ⁻¹				
2	41 *	28 ab	69 a	39 a	31 a	70 a	7696 a	9602 a		
3	38 a	30 ab	70 a	44 a	38 a	82 a	8315 a	10465 a		
4	38 a	31 a	69 a	45 a	37 a	83 a	9102 a	9656 a		
6	8 b	19 b	27 b	26 a	31 a	57 a	4716 b	9834 a		

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 17. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of *St. Augustinegrass* prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	Leaf Water Potentials					
	Pre-Irrigation			Recovery		
	Pt	Po	Ptu	Pt	Po	Ptu
-days between irrigations-	bars					
2	-11.6 a*	-15.6 a	+4.0 a	-12.2 ab	-16.7 b	+4.6 a
3	-13.4 a	-14.9 a	+1.5 b	- 9.8 b	-14.4 c	+4.6 a
4	-16.2 a	-15.5 a	-1.0 c	-15.0 a	-18.2 ab	+3.2 a
6	-14.9 a	-14.4 a	-0.6 bc	-15.5 a	-19.5 a	+3.7 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 18. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 1, 1981).

Treatment	Diffusive Resistance		Transpiration	
	Pre-Irrigation	Recovery	Pre-Irrigation	Recovery
-days between irrigations-	sec cm ⁻¹		µg H ₂ O cm ⁻² s ⁻¹	
2	0.62 c *	0.52 b	34.8 a	45.3 a
3	0.67 c	0.54 b	27.4 b	46.4 a
4	1.07 b	0.52 b	22.5 b	45.1 a
6	2.61 a	0.75 a	9.0 c	34.3 b

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 19. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd) and evapotranspiration rates (ET) of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 2, 1981).

Treatment	CER							
	Pre-Irrigation				Recovery			
	AP	Rd	Pg		AP	Rd	Pg	ET
-days between irrigations-	mg CO ₂ dm ⁻² hr ⁻¹				mg H ₂ O dm ⁻² hr ⁻¹			
2	32 a*	34 a	66 ab		46 a	36 a	82 a	5513 b
3	43 a	36 a	79 a	†	50 a	41 a	91 a	7069 a
4	36 a	30 a	66 ab		47 a	35 ab	82 a	5875 b
6	14 a	18 b	32 b		25 b	24 b	49 b	3514 c

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Leaf water potentials were not significantly different among treatments (Table 20). However, the 6-day treatment again resulted in a loss of turgor pressure and it had the lowest total leaf water potential prior to irrigation. Recovery of turgor was evident following irrigation, and recovery values were comparable among treatments. Diffusive resistance data suggests that stomatal changes occurred regardless of the level of stress indicated by leaf water potentials (Table 21). Turgor pressure probably played a central role in reducing CER and ET since the 6-day treatment had lost turgor and showed increased diffusive resistance and decreased transpiration prior to irrigation. Both parameters recovered to values similar to the other treatments following irrigation.

Destruction of the rain-out shelters during a severe storm allowed exposure of the plots to natural rainfall during cycle 3. Recovery data from cycle 3 showed that after a rainfall event, the plots exposed to stress (notably the 6-day treatment) had recovered to show increases in R_d from values measured during recovery in cycle 2 (Table 22). All CER values were equivalent to initial values. No statistical differences among treatments in AP or P_g were noted during recovery for cycle 3. Excess soil moisture increased ET from initial and cycle 2 values. Treatment differences were noted for ET and the 6-day treatment exhibited the lowest value. This corresponds to the lower AP and P_g rates for the 6-day treatment despite statistically these being similar to the other treatments. Leaf water potentials during recovery from cycle 3 were high and turgor pressure, while variable among treatments, was high and

Table 20. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 2, 1981).

Treatment	Leaf Water Potentials					
	Pre-Irrigation			Recovery		
	Pt	Po	Ptu	Pt	Po	Ptu
-days between irrigations-						
2	- 8.8 a*	-13.3 a	+4.4 a	-6.0 a	-13.3 a	+7.3 a
3	-11.2 a	-15.5 a	+4.3 a	-6.4 a	-11.7 a	+5.3 a
4	-10.4 a	-14.9 a	+4.5 a	-5.6 a	- 9.8 a	+4.2 a
6	-14.6 a	-14.7 a	+0.1 b	-6.0 a	-12.1 a	+6.1 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 21. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 2, 1981).

Treatment	Diffusive Resistance		Transpiration	
	Pre-Irrigation	Recovery	Pre-Irrigation	Recovery
-days between irrigations-	sec cm ⁻¹		µg H ₂ O cm ⁻² s ⁻¹	
2	0.67 b*	0.57 a	28.4 b	44.9 a
3	0.57 b	0.46 a	34.3 a	48.6 a
4	0.58 b	0.64 a	36.3 a	40.5 a
6	1.79 a	0.49 a	13.6 c	48.6 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 22. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass during recovery from 12-day cycle 2 and during recovery from 12-day cycle 3 as affected by irrigation scheduling (1981 data).

Treatment	CER									
	Recovery					ET				
	Cycle 2					Recovery				
	AP	Rd	Pg	AP	Pg	Cycle 2	Cycle 3	Cycle 2	Cycle 3	Recovery
-days between irrigations-	mg CO ₂ dm ⁻² hr ⁻¹					mg H ₂ O dm ⁻² hr ⁻¹				
	2	46 *	36 a	82 a	39 a	84 a	45 ab	8137 a	10476 ab	
	3	50 a	41 a	91 a	42 a	90 a	48 a	8351 a	10823 a	
	4	47 a	35 ab	82 a	41 a	81 a	40 ab	7226 ab	9342 b	
6	25 b	24 b	49 b	26 a	63 a	37 b	6523 b	6943 c		

*. Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

indicated cells probably were fully hydrated (Table 23). Unfortunately, due to rapidly changing climatic conditions on the data collection day, no values for diffusive resistance and transpiration were recorded for cycle 3.

Physiological Responses During Cycle 4

Photosynthetic rates of turf prior to irrigation on day 12 at the end of cycle 4 were reduced in most treatments from initial rates and were lower than those from cycles 1 and 2 (Table 24). The 6-day treatment caused the lowest AP value, although it was not different from the 3-day treatment. Similarly while Rd and Pg were considerably lower for the 6-day treatment they too were not shown to be significantly different. Values of ET prior to irrigation were the lowest for the 6-day treatment although they were not different from the 3-day and 4-day treatments.

All treatments showed increases in CER following irrigation. Values of AP and Pg were not significantly different among treatments. Recovery Rd was lowest for the 6-day treatment although it was not different from the 2-day or 4-day treatments. It should be noted that the lowest values for all CER parameters were recorded by the 6-day treatment. All treatments showed an increase in ET during recovery and while values were equivalent statistically, the 3-day, 4-day, and 6-day treatments were lower than the 2-day treatment.

Leaf water potentials were high and failed to statistically show treatment differences for total, osmotic, or turgor potentials (Table 25). While turgor pressure was positive prior to irrigation the values were low and all treatments indicated an increase in turgor pressure following irrigation. This supports the concept

Table 23. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass during recovery from 12-day cycle 2 and during recovery from 12-day cycle 3 as affected by irrigation scheduling (1981 data).

Treatment	Leaf Water Potentials					
	Recovery					
	Cycle 2			Cycle 3		
	Pt	Po	Ptu	Pt	Po	Ptu
-days between irrigations-	bars					
2	-6.0 a*	-13.3 a	+7.3 a	-8.4 a	-12.2 a	+3.8 bc
3	-6.4 a	-11.7 a	+5.3 a	-6.2 b	-12.7 a	+6.5 a
4	-5.6 a	-9.8 a	+4.2 a	-7.5 ab	-12.7 a	+5.2 ab
6	-6.0 a	-12.1 a	+6.1 a	-6.4 b	-9.6 a	+3.2 c

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 24. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 4, 1981).

Treatment	CER						
	Pre-Irrigation			Recovery			ET
	AP	Rd	Pg	AP	Rd	Pg	
-days between irrigations-	mg CO ₂ dm ⁻² hr ⁻¹			mg H ₂ O dm ⁻² hr ⁻¹			Pre-Irrigation Recovery
2	24 *	38 a	62 a	34 a	46 ab	80 a	5005 a 9436 a
3	21 ab	37 a	58 a	44 a	49 a	93 a	3946 ab 7208 a
4	24 a	34 a	58 a	38 a	43 ab	81 a	3322 ab 7217 a
6	12 b	20 a	32 a	32 a	33 b	66 a	2286 b 6695 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 25. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 4, 1981).

Treatment	Leaf Water Potentials					
	Pre-Irrigation			Recovery		
	Pt	Po	Ptu	Pt	Po	Ptu
-days between irrigations-	bars					
2	- 7.7 a*	-10.9 a	+3.2 a	-6.8 a	-13.3 a	+6.2 a
3	- 7.0 a	- 8.7 a	+1.7 a	-4.4 a	-11.3 a	+6.9 a
4	- 9.9 a	-10.1 a	+0.2 a	-3.3 a	-10.6 a	+7.3 a
6	-10.9 a	-12.2 a	+1.3 a	-5.1 a	- 9.9 a	+4.8 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

that irrigation every other day is more effective for keeping adequate turgor pressure in the turfgrass. Unfortunately due to rapidly changing climatic conditions, no diffusive resistance data was available to document changes in stomatal activity. However, the dramatic increases in ET would indicate that all plots are using the water made available by irrigation and this probably resulted in stomatal opening from increased turgor pressure.

Physiological Responses During Cycle 5

Photosynthetic rates appeared lowest during the entire study period for all stressed treatments during cycle 5. While no statistical differences among treatments were found for AP or Pg the 6-day treatment had the lowest values (Table 26). While values are not as low as those observed prior to irrigation at the end of cycle 4, ET was reduced. The 6-day treatment following irrigation had increases in AP (353%), Rd (57%), and Pg (204%) among the highest recorded during the entire study period. The 6-day treatment ET value was lowest among treatments prior to irrigation, and recovery values following irrigation were equivalent for all treatments. Variability in measurements from plots within the same treatment was noted. While plots were handled the same within treatments, small sample sizes may have masked distinct treatment differences.

No treatment differences in leaf water potentials were noted on day 12 prior to irrigation, although the 3-day, 4-day, and 6-day treatments had lower values than the 2-day treatment (Table 27). All plots exhibited lower turgor pressures prior to irrigation which accompanied the lower CER noted previously. Turgor pressure was regained following irrigation for all treatments. Diffusive

Table 26. Carbon exchange rates (CER) as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 5, 1981).

Treatment	CER						ET	
	Pre-Irrigation			Recovery			Pre-Irrigation	Recovery
	AP	Rd	Pg	AP	Rd	Pg		
	mg CO ₂ dm ⁻² hr ⁻¹						mg H ₂ O dm ⁻² hr ⁻¹	
2	18 a *	36 a	54 a	26 a	39 a	66 a	5590 ab	7214 a
3	21 a	40 a	61 a	25 a	42 a	66 a	7145 a	7502 a
4	21 a	35 a	56 a	24 a	38 a	63 a	5953 a	6999 a
6	7 a	22 b	28 a	24 a	34 a	58 a	3715 b	6535 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 27. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 5, 1981).

Treatment	Leaf Water Potentials					
	Pre-Irrigation			Recovery		
	Pt	Po	Ptu	Pt	Po	Ptu
	_____ bars					
-days between irrigations-						
2	-12.8 *	-12.6 a	-0.2 a	-7.9 a	-13.6 ab	+5.7 a
3	-14.1 a	-12.6 a	-1.5 a	-5.5 a	-11.5 ab	+6.0 a
4	-14.9 a	-13.0 a	-1.9 a	-7.8 a	-14.1 a	+6.3 a
6	-14.8 a	-14.2 a	-0.6 a	-6.0 a	-11.4 b	+5.4 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

resistance and transpiration measurements indicate significant variability within an experiment (Table 28). The 2-day, 4-day, and 6-day treatments had high diffusive resistance values although no treatment differences existed. Transpiration rates, when compared to cycles 1 and 2, were similar. For the 2-day, 4-day, and 6-day treatments irrigation resulted in lower diffusive resistance and increased transpiration. The 3-day treatment did not respond the same way. The low diffusive resistance and high transpiration values prior to irrigation for this treatment cannot be explained and may have masked other distinct treatment effects present.

Overall Physiological Responses of St. Augustinegrass

Photosynthesis as measured via three parameters AP, Rd, and Pg was significantly lower over the 1981 study period for the 6-day treatment (Table 29). Values were reduced for AP by 35%, Rd by 22%, and Pg by 31%. Evapotranspiration was also significantly reduced by the 6-day irrigation schedule by 20%.

Response of St. Augustinegrass during recovery following irrigation from pre-irrigation values was well documented. Recovery values of CER as AP and Pg increased significantly from pre-irrigation measurements and usually recovered to pre-treatment values (Table 30). Only Rd showed no significant increases. This is not unexpected since changes in soil respiration and plant respiration (including roots) are not dependent on stomatal control and only in extreme cases of very low soil moisture levels would this parameter be greatly reduced. Recovery values for ET were also increased significantly over pre-irrigation values for each 12-day cycle, and were similar or greater than initial pre-treatment values.

Table 28. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass prior to irrigation on day 12 and 24 hours following irrigation during recovery as affected by irrigation scheduling (12-day cycle 5, 1981).

Treatment	Diffusive Resistance		Transpiration	
	Pre-Irrigation	Recovery	Pre-Irrigation	Recovery
-days between irrigations-	sec cm ⁻¹		μg H ₂ O cm ⁻² s ⁻¹	
2	0.87 a *	0.47 a	35.9 b	49.7 a
3	0.49 a	0.45 a	54.5 a	57.8 a
4	0.90 a	0.44 a	33.7 b	56.9 a
6	1.00 a	0.49 a	33.7 b	53.5 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 29. Carbon exchange rates as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass averaged over all cycles as affected by irrigation scheduling (1981 data).

Treatment	CER			ET
	AP	Rd	Pg	
-days between irrigations-	— mg CO ₂ dm ⁻² hr ⁻¹ —			mg H ₂ O dm ⁻² hr ⁻¹
2	34 a *	38 a	72 a	7560 a
3	37 a	40 a	77 a	7807 a
4	36 a	36 a	72 a	7142 a
6	22 b	28 b	50 b	5752 b

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 30. Carbon exchange rates as apparent (AP) and gross (Pg) photosynthesis, dark respiration (Rd), and evapotranspiration rates (ET) of St. Augustinegrass averaged over all irrigation treatments for pre-irrigation (PI) and recovery (R) during all cycles (1981 data).

Stress Cycle	CER			ET
	AP	Rd	Pg	
	— mg CO ₂ dm ⁻² hr ⁻¹ —			mg H ₂ O dm ⁻² hr ⁻¹
Initial	41 a *	42 a	83 a	6915 b
PI1	32 bc	27 d	58 cd	7457 b
R1	39 ab	34 bc	73 ab	9894 a
PI2	31 bc	30 cd	61 cd	5493 c
R2	42 a	34 bc	76 ab	7559 b
R3	37 ab	42 a	79 a	9396 a
PI4	20 cd	32 cd	52 cd	3640 d
R4	37 ab	43 a	80 a	7639 b
PI5	16 e	33 bc	50 d	5596 c
R5	26 cd	39 ab	64 bc	7063 b

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

While total and osmotic leaf water potentials were not different among treatments, the turgor pressure decreased as days between irrigations increased (Table 31). Zur and Jones (1981) observed that turgor pressure is the key point in a model simulating the control of photosynthesis by plant water status. Total leaf water potentials increased significantly from pre-irrigation to recovery for all but the first cycle (Table 32). More importantly, turgor potential increased indicating a relief from stress by increasing turgor pressure. Osmotic adjustment was not evident, possibly due to variability among leaves of different age at the same position on the plant; and/or the method used in determining osmotic potential; or that osmotic adjustment does not occur in St. Augustinegrass.

Most of the impact of reduced turgor pressure is mediated by changes in leaf diffusive resistance to carbon dioxide and water vapor. Diffusive resistance was highest over the study period for the 6-day treatment, while transpiration was lowest (Table 33). Diffusive resistance and transpiration fit a similar pattern to CER, ET, and leaf water potential components. Each pre-irrigation to recovery measurement showed significant decreases in diffusive resistance and increases in transpiration (Table 34).

General Responses of St. Augustinegrass to Water Stress

Turfgrass quality as judged by visual ratings initially was not different among treatments (Table 35). With the 6-day treatment, turfgrass quality was reduced at the end of the first cycle and remained low, but it was not different from the other treatments for the remainder of the study. No treatment differences were noted for any other rating period or for the average over the study period.

Table 31. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass averaged over all cycles as affected by irrigation scheduling (1981 data).

Treatment	Leaf Water Potentials		
	Pt	Po	Ptu
-days between irrigations-	bars		
2	- 9.3 a *	-13.4 a	+4.1 a
3	- 9.2 a	-13.0 a	+3.8 a
4	-10.4 a	-13.5 a	+3.1 ab
6	-10.8 a	-13.4 a	+2.5 b

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 32. Leaf water potentials as total (Pt), osmotic (Po), and turgor (Ptu) potentials of St. Augustinegrass averaged over all irrigation treatments for pre-irrigation (PI) and recovery (R) during all cycles (1981 data).

Stress Cycle	Leaf Water Potentials		
	Pt	Po	Ptu
	bars		
Initial	-13.0 ab*	-15.5 b	+2.5 de
PI1	-14.0 a	-15.0 b	+0.9 e
R1	-13.2 ab	-17.2 a	+4.0 c
PI2	-11.3 b	-14.6 bc	+3.3 cd
R2	- 6.0 de	-11.7 def	+5.7 ab
R3	- 7.1 cd	-11.8 def	+4.7 bc
PI4	- 8.9 c	-10.5 f	+1.6 e
R4	- 4.9 e	-11.2 ef	+6.3 a
PI5	-14.2 a	-13.1 cd	-1.1 f
R5	- 6.8 de	-12.6 de	+5.8 ab

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 33. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass averaged over three cycles as affected by irrigation scheduling (1981 data).

Treatment	Diffusive Resistance	Transpiration
-days between irrigations-	— sec cm ⁻¹ —	µg H ₂ O cm ⁻² s ⁻¹
2	0.63 bc *	39.1 b
3	0.55 c	43.6 a
4	0.69 b	39.1 b
6	1.13 a	32.4 c

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 34. Single leaf diffusive resistance and transpiration rates of St. Augustinegrass averaged over all treatments for pre-irrigation (PI) and recovery (R) from three cycles (1981 data).

Stress Cycle	Diffusive Resistance	Transpiration
	—— sec cm ⁻¹ ——	μg H ₂ O cm ⁻² s ⁻¹
Initial	0.69 cd [*]	36.3 d
PI1	1.24 a	23.4 f
R1	0.58 de	42.8 bc
PI2	0.90 b	28.1 e
R2	0.54 e	45.7 b
PI5	0.81 bc	39.5 cd
R5	0.46 e	54.5 a

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 35. Quality of St. Augustinegrass as affected by irrigation scheduling during the 1981 study period.

Treatment	Turfgrass Quality [†]							
	18 May	30 May	11 June	19 June	24 June	2 July	13 July	24 July
-days between irrigations-								Mean
2	8.3 a*§	7.7 a	7.3 a	8.0 a	7.7 a	7.7 a	7.7 a	7.3 a
3	8.0 a	7.7 a	7.3 a	7.7 a	8.0 a	8.0 a	8.0 a	7.7 a
4	8.3 a	7.7 a	7.0 a	7.3 a	7.3 a	7.7 a	7.3 a	7.7 a
6	8.0 a	6.3 b	6.0 a	6.7 a¶	6.7 a	6.7 a	6.3 a	7.0 a
Mean	8.2 a*¶	7.3 bc	6.9 c	7.4 bc	7.4 bc	7.5 b	7.3 bc	7.4 bc

† Ratings 1-9 with 9 representing the highest quality.

*§ Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

*¶ Irrigation means in row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Quality ratings while reduced from initial values were never considered to be unacceptable.

Cover estimates were lower for the 6-day treatment plots during the fourth cycle but ground cover increased by the end of the study (Table 36). The small visual changes throughout the entire study period were not a major factor in turf quality although these differences were statistically significant. Changes in cover during cycle 4 apparently were a factor with the 6-day treatment in cycle 5. Changes in leaf area as estimated by percent cover may have confounded moisture stress and contributed to lower CER and ET values observed during cycle 5.

Clipping weights indicated that the turfgrass was under severe moisture stress from a growth standpoint and was not producing leaf area as rapidly as it would in a well watered condition. Clipping weights for harvest 1 and 3 and as a total of harvests 1, 2, and 4 showed that the 6-day treatment caused the lowest values, although the 6-day treatment was not different from the 2-day and 4-day treatments (Table 37). Harvests 1, 2, and 4 were taken under water stress during deficit irrigation and were significantly lower than harvest 3, which was taken during recovery after a severe storm destroyed the protective shelters and allowed excessive rainfall on the plots. Harvest data corresponded well with CER and ET in that the 6-day treatment had the greatest affect on all parameters. Decreases in CER can be attributed to not only physiological changes from stomatal and non-stomatal effects, but also from a reduction in leaf area in the canopy. Decreased ET can be due to stomatal closure and/or a reduction in leaf area.

Table 36. Cover estimates of St. Augustinegrass as affected by irrigation scheduling during the 1981 study period.

Treatment	Turfgrass Cover Estimates				
	11 June	24 June	2 July	13 July	24 July
-days between irrigations-					Mean
2	98.7 a ^{*†}	99.5 a	99.9 a	99.9 a	99.9 a
3	96.2 a	97.6 a	99.3 ab	99.9 ab	99.8 a
4	97.0 a	98.3 a	99.3 ab	99.8 ab	99.9 a
6	92.7 a	94.3 a	94.3 b	94.0 b	97.6 a
Mean	96.4 d ^{*§}	97.7 c	98.8 b	99.0 b	99.5 a

*† Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

*§ Irrigation means in row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 37. Clipping weights of St. Augustinegrass as affected by irrigation scheduling for four harvests during the 1981 study period.

Treatment	Clipping Weights					Total 1, 2, & 4
	Harvest 1	Harvest 2	Harvest 3	Harvest 4		
-days between irrigations-	kg ha ⁻¹ day ⁻¹					kg/ha
2	6.7 ab ^{††}	9.0 a	25.0 ab	12.3 a		84 ab
3	12.3 a	9.0 a	30.0 a	17.3 a		117 a
4	10.0 ab	7.3 a	20.3 ab	12.0 a		88 ab
6	2.3 b	4.3 a	14.3 b	7.7 a		44 b
Mean	9.0 c ^{‡‡}	8.3 c	25.0 a	14.0 b		

^{††} Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

^{‡‡} Means in row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Estimates of Turfgrass Stress

Percent estimates of the extent of wilting of the plots were taken at various times during the first three cycles. Extensive wilting was evident one week into the experimental period (Table 38). Decreases in wilting usually occurred during recovery from stress after irrigation for all but the 6-day treatment. Over the entire study period more wilting occurred in the 6-day treatment plots than in the other treatments. Variation in wilting was highly evident among treatments and between days in the stress period.

The ability of the turfgrass to tolerate reduced soil water content was low and St. Augustinegrass was extremely sensitive to environmental conditions early in the study period. When soil matric potentials in the top 15 cm exceeded -200 millibars extensive wilt occurred (40-50%). Only in the 2-day, 3-day, and 4-day treatments did irrigation relieve mid-day wilting. However, days during late May and early June 1981 were extremely hot and dry with daily temperatures reaching 40°C and low relative humidity (40-60%). Once the high evaporative demand decreased in mid to late June and July with increased relative humidity mid-day wilting decreased even though soil matric potentials exceeded -200 millibars in the top 15 cm of the 6-day treatment plots.

Turfgrass Water Use

Turfgrass water use rates were variable among treatments when calculated during the 1981 study. Over the entire study period the 4-day treatment plots had the lowest water use rate followed by the 6-day and 2-day treatment plots and the 3-day treatment plots had the highest rate (Table 39). Higher water use rates for the early periods

Table 38. Estimates of percent of total plot area wilted during afternoon hours from the 1981 study.

Treatment	Date											
	May						June					
	25	26	27	28	30	31	1	2	4	7	8	16
-days between irrigations-												
2	32 a [*]	6 b	19 a	16 b	43 b	31 a	26 ab	51 ab	67 ab	2 b	12 a	38 c
	-irrigations every two days beginning 25 May-											
3	31 a	24 b	13 b	21 b	33 b	23 a	45 ab	42 b	65 ab	23 a	15 a	49 b
	-irrigations every three days beginning 26 May-											
4	59 a	8 b	13 b	21 b	36 b	14 a	21 b	42 b	49 b	7 ab	11 a	12 d
	-irrigations every four days beginning 25 May-											
6	65 a	55 a	65 a	76 a	71 a	37 a	59 a	82 a	91 a	17 ab	20 a	93 a
	-irrigations every six days beginning 29 May-											

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 39. Water use rates of St. Augustinegrass as affected by irrigation scheduling for five treatment periods, 1981 data.

Treatment	Period					Mean
	20 May- 26 May	27 May- 5 June	6 June- 13 June	28 June- 3 July	4 July- 10 July	
-days between irrigations-	cm/day					
2	0.37 b ^{*†}	0.53 a	0.36 a	0.39 a	0.43 ab	0.42 b
3	0.57 a	0.56 a	0.40 a	0.44 a	0.47 a	0.49 a
4	0.44 ab	0.31 c	0.44 a	0.26 b	0.25 c	0.34 c
6	0.35 b	0.46 b	0.33 a	0.38 a	0.38 b	0.38 b
Mean	0.43 a ^{*§}	0.46 a	0.38 b	0.37 b	0.38 b	

*† Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

*§ Irrigation means in row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

correspond well with the increased evaporative demands for these periods. The overall water use rate for the 1981 study period was 0.40 cm/day which is comparable to the irrigation amount of 0.38 cm/day. Once initial soil moisture levels were reduced, water use rates were identical to the irrigation rates during the final three periods. Plant water use in excess of irrigation volumes must have come from water stored within the soil profile. Deep rooting allowed the plant to utilize this stored water. This would substantiate that deficit irrigation occurred. The lack of stress as noted by lack of severe wilt except in the 6-day treatment plots indicates that 0.38 cm of water per day was adequate to maintain St. Augustinegrass. Irrigation on a 6-day basis with 2.3 cm of water was not detrimental to overall turfgrass quality.

Rooting Characteristics of St. Augustinegrass

Root mass and length were not different among treatments at the five depths in the profile at initiation of the study. Differences were noted among depths in the profile with the greatest root mass and length from initial and final samples in the first 15 cm, followed by the depth to 30 cm and no differences in the remaining depths in the profile (Table 40). Irrigation scheduling had no affect on root distribution over the study period in that root length and mass were unaffected (Table 41). Root mass increased from initial to final samples for all but the 75 cm depth while root length increased only at the 45 cm and 60 cm depth. In contrast to the 1980 study, initially only 9% of the root length was found below 30 cm in the soil profile. At the final sampling date a small shift in mass (3%) and length (7%) below 30 cm in the soil profile was found.

Table 40. Rooting characteristics at 15 cm increments in the soil profile of St. Augustinegrass at initiation and end of study period. Values are reported as means over all treatments (1981 data).

Profile Depth	Root	Mass	Density	Root	Length	Density
	Initial		Final	Initial		Final
cm	mg cm ⁻³			cm cm ⁻³		
15	1.34 a *		1.81 a	2.56 a		2.20 a
30	0.28 b		0.53 b	0.64 b		0.77 b
45	0.07 c		0.17 c	0.18 c		0.30 c
60	0.06 c		0.12 c	0.16 c		0.26 c
75	0.03 c		0.05 c	0.10 c		0.14 c

* Means in columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test. Means within mass or length connected by lines are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Table 41. Rooting characteristics as a total in the soil profile on a land area basis of St. Augustinegrass as affected by irrigation scheduling at initiation and end of study period (1981 data).

Treatment	Total Root			
	Mass		Length	
	Initial	Final	Initial	Final
-days between irrigations-	— mg cm ⁻² —		— cm cm ⁻² —	
2	27.3 *	38.2	<u>54.6</u>	<u>50.7</u>
3	23.7	41.4	<u>54.6</u>	<u>56.9</u>
4	31.2	43.5	<u>56.7</u>	<u>60.0</u>
6	24.7	38.2	<u>52.6</u>	<u>54.0</u>

* All differences between treatments within the same sample period are non-significant at the 5% level using the Waller-Duncan K-ratio t-test. Means within mass or length connected by lines are not significantly different at the 5% level using the Waller-Duncan K-ratio t-test.

Rooting characteristics probably enhance the induction of water stress since limited use can be made of water deeper in the soil profile. As with other studies, an increase in rooting did occur under these deficit irrigation schedules. Apparently the roots were acting as a sink for photosynthates produced by the turfgrass while under positive carbon balance during water stress. Lack of an increase in root length results in an inability of the plant to avoid drought. Because rooting did occur deep into the soil profile, there was an inherent ability of the turfgrass to maintain a certain level of photosynthesis and ET even when soil water content in the top 30 cm where the roots were most concentrated was at a minimum.

CONCLUSIONS

Responses of St. Augustinegrass to water stress resulting from irrigation scheduling indicated that while CER was reduced dramatically, recovery overnight following irrigation was essentially complete. Turfgrass response from initiation to end of the study period indicated a reduction in CER under each pre-irrigation measurement from initial values. This agrees well with research on other plants in that only when the stress was prolonged did recovery after re-watering require several days (Sandhu and Horton, 1977). Jones (1973) working with cotton and Ceulemans et al. (1979) with Rhododendron simsii Planch. noted recovery 24 hours after re-watering. Reductions in CER under stress are linked directly to photosynthesis which is extremely sensitive to plant water deficits (Sandhu and Horton, 1977). Photosynthesis is more sensitive to water stress than translocation of photosynthates (Sung and Krieg, 1979). Effects on photosynthesis later into the study period may represent a general reduction in physiological response throughout the growing period. Evapotranspiration rates were variable under stress from initial measurements probably in direct response to daily fluctuations in environmental parameters and to undetectable changes in the turfgrass canopy. Changes in ET occurred from cycle to cycle and with similar values of AP ET varied by 87%. Evapotranspiration was more closely correlated to AP ($r=0.69$) than Pg ($r=0.50$).

Leaf water potentials under stress were essentially unchanged from initial values. Fock and Lawton (1979) observed linear decreases in photosynthesis with decreasing leaf water potentials. Crafts (1968) assumed that decreased leaf water potentials control photosynthesis by stomatal closure, mesophyll permeability changes to carbon dioxide, and by enzymatic changes in the cytoplasm. He indicated that correlation of leaf water potentials with photosynthetic activity is difficult. This study indicated that changes in CER did occur without a corresponding lowering of leaf water potentials. However, the most important changes in leaf water potential values were the increases from pre-irrigation to recovery. This implies that absolute value of leaf water potential is not necessarily a good indicator of plant water stress.

Turgor pressure increased following every irrigation. Thus low turgor potential (not necessary zero turgor) affects the CER and ET more than leaf water potential. Crafts (1968) indicated that positive turgor of 2 to 3 bars is necessary to prevent wilting. Levitt (1980) cites evidence that growth is inhibited even under positive turgor of several bars. He noted that turgor is regained in most plants after irrigation. This was well documented for every cycle with the 6-day treatment. However, cycle 5 indicated a lack of turgor with all treatments and recovery following irrigation. This is extremely perplexing since it would indicate that the most frequently irrigated treatment is undergoing loss of turgor every other day suggesting a decrease in general physiological status of the plant as the growing season progresses. This may mean that irrigation to match potential ET could have long-term effects not well documented

in this study. With the plant in positive carbon balance partitioning of the photosynthate may be very important. This could account for the increase observed in root mass with roots acting as a carbon sink.

During each cycle, diffusive resistance was increased in the turfgrass with the more severely stressed 6-day treatment. A decrease in diffusive resistance always accompanied recovery from stress for all cycles. Stomata responded to decreased turgor potential by closure. However, stomata are not closed even at zero turgor pressure in some plants (Hsiao and Acevedo, 1974). Similar results were noted in this study. At low or zero turgor pressure potentials diffusive resistance values indicated the stomata were still partly open and transpiration continued. Hsiao and Acevedo (1974) cited studies where photosynthesis was reduced by stomatal and non-stomatal effects. Sullivan and Eastin (1974) presented evidence supporting this in sorghum where stomata were closed when plants were exposed to water stress for the first time but failed to completely close stomata when subsequently droughted by soil drying and re-watering. Reductions in CER in this study were accompanied by an increase in diffusive resistance. Diffusive resistance values during subsequent cycles always increased, but never to the level observed during cycle 1, even though CER was reduced during cycles 4 and 5 to levels near those observed for cycle 1. This implies that some form of adaptation occurred that is dependent on previous growth conditions. However, it was not related to osmotic adjustment since osmotic potentials did not indicate such an adaptation. Furthermore, this may indeed be a form of non-stomatal influence on photosynthesis

similar to that observed in sorghum. Regardless of the non-stomatal effects, the rapid recovery of St. Augustinegrass CER in most instances to initial levels would lend support that stomatal closure and opening upon rehydration is the primary mechanism involved. Other scientists have noted that stomatal changes occur primarily in association with low water potentials. Reicosky et al. (1975) reported complete closure of stomata only when leaves were severely wilted in corn. Jordan and Ritchie (1971) measured leaf water potentials down to -27 bars in field grown cotton without stomatal closure. Ackerson et al. (1977) found that in cotton stomatal closure was not dependent on leaf water potentials. There was a significant correlation ($r=0.79$) found in this study between leaf turgor potential and stomatal conductance. There were also significant correlations ($r=0.59$) between turgor potential and diffusive resistance and between turgor potential and P_g ($r=0.70$).

Two parameters that are used to aesthetically judge a turfgrass sward are turfgrass quality and cover. Both were maintained at acceptable levels and were essentially unaffected by stress. Clipping weights indicated a reduction in leaf area (mass). This is a desirable effect since this would increase days between mowing. Johns et al. (1980) indicated this would also influence water use since they found an increase in ET with an increase in leaf area.

Turfgrass water use for 1980 and 1981 paralleled irrigation volumes. Acceptable turfgrass quality under stress as judged by decreased CER was maintained in 1981 by a 0.38 cm/day irrigation rate. Even under the most severe stress conditions in 1981, the turfgrass remained in positive carbon balance with 0.38 cm/day of irrigation every six days. Continued growth through leaf area production was probably limited to

times immediately following irrigation and when stress was relieved diurnally. Leaf expansion is much more sensitive to water deficits than photosynthesis and relief of stress can result in leaf expansion rates similar to those in well-watered plants (Turner and Begg, 1981). Regaining turgor pressure following re-watering supports this concept. Turfgrass water use as affected by irrigation frequency showed a general trend for rates to decline as days between irrigation increased. Water use data for the two years showed that the lowest rates were observed with the 4-day and 6-day treatments. Differences in water use rates among treatments from these estimates are small and while statistically significant may not be physiologically significant. Turfgrass irrigation for St. Augustinegrass can be allowed on a 6-day frequency without significant loss of turfgrass quality. This affords an opportunity for a natural rainfall event to provide water in lieu of irrigation. Transpiration rates tended to decrease as soil matric potentials decreased. Ackerson et al. (1977) noted corn ET dropped as soil matric potentials fell. Beadle et al. (1973) observed the stomata of corn close when soil matric potentials were below -0.3 bars. Therefore soil moisture tension has a pronounced influence upon water use. This was confirmed in this study since the 4-day and 6-day treatments had the lowest soil matric potentials and lowest water use rates.

Turfgrass rooting characteristics indicate that at the proper height of cut, enough roots are maintained deep in the soil profile to provide some drought tolerance to the grass. While no effects of long-term stress were involved in this study, an increase in root mass was evident. Under more severe stress, this mechanism may result in

more rooting deeper in the profile. Although there was greater rooting length during the 1981 study root mass was not increased. This was not the consequence of irrigation treatment since initial and final root lengths were similar. Boote (1977) noted that drought intolerance of carpetgrass (Axonopus affinis Chase) is probably related to a very shallow root system making the grass sensitive to moisture stress. St. Augustinegrass exhibited a very similar root system in the 1981 study in that a great proportion of the roots were in the top 30 cm of the soil profile. St. Augustinegrass responded well to the longest irrigation scheduling and some rooting to greater depths in the profile may be a key factor.

The general response of St. Augustinegrass during this study was one linked to stress induced by irrigation scheduling and the ability to recover upon re-watering. Irrigation rates equivalent to potential evapotranspiration based on climatological data were provided. Water use matched these irrigation rates ideally. Carbon balance changed from day to day under the most frequent irrigation regime. No information should be extrapolated from this study for extreme stress conditions of lower irrigation rates and longer periods between irrigations.

APPENDIX

Dates of Study Cycles

1980 Study Period

- 22 June - 2 July (PI) & 3 July (R) -- Cycle 1
- 3 July - 14 July (PI) & 15 July (R) -- Cycle 2
- 2 July - Pre-dawn leaf water potentials taken with
mean for all plots -2.8 bars.
- 16 July - 6 August -- Final Stress Cycle

1981 Study Period

- 18 May - 29 May (PI) & 30 May (R) -- Cycle 1
- 30 May - 10 June (PI) & 11 June (R) -- Cycle 2
- 11 June - 23 June (R) -- Cycle 3
- 23 June - 4 July (PI) & 5 July (R) -- Cycle 4
- 5 July - 16 July (PI) & 17 July (R) -- Cycle 5

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BIOGRAPHICAL SKETCH

Charles Harris Peacock was born in Salisbury, North Carolina on September 2, 1946. He graduated from A.R. Willingham High School, Macon, Georgia in June 1964. From September 1964 to December 1967 he attended the University of Georgia in Athens. In January 1968 he entered the US Army and served in the Republic of Vietnam from May to December 1970. After discharge from the army, he completed his BS degree in 1972 with a major in Biology at Columbus College, Columbus, Georgia.

Following a year of graduate study at Auburn University and a year as a research associate at the University of Tennessee Center for the Health Sciences, Memphis, he completed his MS degree in Zoology at Clemson University, Clemson, South Carolina in 1976. After working as an agricultural science associate in turfgrass research at Clemson University, he entered the University of Florida in January 1979 and began work toward a PhD in Turfgrass Science in the Horticultural Science curriculum.

He and his wife Madeline, have one son, Daniel Adam, born February 20, 1981. They enjoy outdoor activities, especially gardening, camping, canoeing, and golf.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

A.E. Dudeck, Chairman
Associate Professor of
Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerry M. Bennett
Assistant Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ken J. Boote
Associate Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Charles R. Johnson

Charles R. Johnson
Associate Professor of
Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Allen G. Smajstrla

Allen G. Smajstrla
Assistant Professor of
Agricultural Engineering

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1981

Jack L. Fry

Dean, College of Agriculture

Dean for Graduate Studies and
Research