Physiological Responses of Warm-Season Turfgrasses under Deficit Irrigation

Joon-Hee Lee[1]*, Laurie. E. Trenholm[2] and J. Bryan Unruh[2]

[1]*Hampyung Dynasty Country Club of Daeju Group, Hampyung 525-812, Korea,*

[2]*Dep. of Environmental Horticulture, Univ. of Florida, 1549 Fifield Hall, Gainesville, FL 32611*

소량관수로 인한 난지형 잔디의 생리적 반응

이준희[1]* · Laurie E. Trenholm[2] · J. Bryan Unruh[2]

[1]함평 다이너스티 C.C., [2]플로리다 대학교 환경원예학과

ABSTRACT

Due to increasing concerns over issues with both water quantity and quality for turfgrass use, research was conducted to determine the response of five warm-season turfgrasses to deficit irrigation and to gain a better understanding of relative drought tolerance. St. Augustinegrass(*Stenotaphrum secundatum* [Walt.] Kuntze.) cultivars 'Floratam' and 'Palmetto', 'SeaIsle 1' seashore paspalum(*Paspalum vaginatum*Swartz.), 'Empire' zoysiagrass(*Zoysia japonica* Steud.), and 'Pensacola' bahiagrass(*Paspalum notatum* Flugge) were established in lysimeters in the University of Florida Envirotron greenhouse facility in Gainesville. Irrigation was applied at100%, 80%, 60%, or 40% of evapotranspiration(ET). Evaluations included: a) shoot quality, leaf rolling, leaf firing; b) leaf relative water content(RWC), soil moisture content, chlorophyll content index(CCI), canopy photosynthesis(PS); c) multispectral reflectance(MSR); d) root distribution; and e) water use efficiency. Grasses irrigated at 100% and 80% of ET had no differences in visual quality, leaf rolling, leaf firing, RWC, CCI, and PS. Grasses irrigated at 60% of ET had higher values in physiological aspects than grasses irrigated at 40% of ET.

*Corresponding author. Tel : +82-61-320-7755
E-mail : jle3576@gmail.com

Received : May. 15, 2009, Revised : May. 20, 2009, Accepted : Jun. 1, 2009

'SeaIsle 1' and 'Palmetto' had a deeper root system than 'Empire' and 'Pensacola', while 'Floratam' had the least amount of root mass. Photosynthesis was positively correlated with visual assessments such as turf quality, leaf rolling, leaf firing, and sensor-based measurements such as CCI, soil moisture, and MSR. Reducing the amount of applied water by 20% did not reduce turfgrass quality and maintained acceptable physiological functioning.

Key words: *chlorophyll content, deficit irrigation, drought stress, photosynthesis, warm season turfgrass, water use efficiency*

INTRODUCTION

There are increasing concerns about water use by turfgrass and interest in reducing water use while maintaining acceptable turf quality. Plant water deficit occurs when the rate of transpiration exceeds water uptake from roots. Drought stress can be detrimental to crops because of yield reduction, but mild drought stress may actually enhance drought resistance of ornamental plants(Mayaki et al. 1976). At the cellular level, cellular water deficit can result in a concentration of solutes, changes in cell volume and membrane shape, disruptionof water potential gradients, loss of turgor, disruption of membrane integrity, protein alteration, and denaturation of protein(Bray, 1997).

Plants have drought resistance mechanisms such as the ability to enhance root systems when initial drought stress is sensed from the root. Root characteristics associated with greater drought resistance during soil dry-down included enhanced water uptake from deeper region in the soil profile, root proliferation into deeper soil layers, and persistent root growth or maintenance of root viability in the drying soil surface. Wide variations in root distribution, root viability, and water uptake pattern were found in different species or ecotypes seashore within seashore paspalum(Huang et al., 1997).

Huang and Fry(1998) analyzed genetic variations in morphological, physiological, and anatomical rooting factors that might influence drought resistance in tall fescue cultivars. Tall fescue cultivars 'Kentucky-31', 'Mustang' and 'MIC18'(dwarf, turf type) were examined under well-watered or drought-stress conditions in a greenhouse. Root hairs became less extensive after 28 d of drying. After 14 and 21 d of drying, 'Kentucky 31'(forage type) roots showed significantly lower electrolyte leakage than those of MIC18. Cultivar variations in anatomical, morphological, and physiological features of roots accounted for the variability in shoot performance under drought stress.

Huang and Gao(1999) examined net photosynthetic rate, stomatal conductance, transpiration rate, relative water content, and photochemical efficiency during drought progression in tall fescue cultivars. The decline in photosynthesis rate resulted mainly from internal water deficit and stomatal closure under mild drought stress conditions.

Stomatal closure among plant defense mechanisms by drought stress is directly related to photosynthesis. Absisic acid(ABA) is formed when drought stress from roots is sensed. Stomata are closed as ABA forms, which reduces internal water loss as well as photosynthesis. Iturbe-Ormaetxe et al. (1998) investigated the correlation between photosynthesis, stomatal conductance, transpiration and soluble protein in pea plant leaves in response to water deficit treatments. Photosynthesis, stomatal conductance, and transpiration were significantly decreased by deficit irrigation. The moderate water deficit(water potential of -1.3 MPa) to pea(*Pisum sativum* L. cv Lincoln) leaves led to a 75% inhibition of photosynthesis. Severe water deficit(-1.9 MPa) almost completely inhibited photosynthesis.

Water use efficiency(WUE) is defined as the total dry matter produced by plants per amount of water used. Increasing dry matter production or reducing water use can improve WUE. Turfgrass research would typically focus on the latter because the goal for turfgrass management is to maintain optimum quality rather than increase yield. There also is little information about how deficit irrigation affects WUE of turfgrass.

The objectives for this research were: 1.) To assess physiological responses among warm-season grasses, and 2.) To evaluate WUE of warm-season grasses under different drought stress conditions.

MATERIALS AND METHODS

Plant Materials

Two repeated Studies were conducted consecutively in a greenhouse at the University of Florida Envirotron Turfgrass Research Laboratory in Gainesville, Florida. Study 1 was conducted from 31 October, 2002 to 16 April, 2003 and Study 2 was conducted from 28 October, 2003 to 30 March, 2004. St. Augustinegrass cultivars 'Floratam' and 'Palmetto', 'SeaIsle 1' seashore paspalum, 'Empire' zoysiagrass, and 'Pensacola' bahiagrass were established in 46-cm-deep and 15-cm diameter PVC lysimeters. Grasseswere established on an Arredondo fine sand soil(loamy, siliceous, hyperthermic, grossarenic paleudult) overlying 5 cm of gravel. Grasses were transplanted from established sod that was washed free of soil before planting. A stock solution fertilizer was applied to supply 2.5g m^{-2} of nitrogen biweekly. Grasses were mowed with hand-held shears once a week at 7cm and irrigation was provided as needed during establishment. Average greenhouse temperatures were 31/27°C day and night, respectively. When grasses were uniformly established, deficit irrigation treatments began and data were obtained over the duration of the dry-down cycles.

Deficit Irrigation Treatments

Irrigation was applied once a week at 100%, 80%, 60%, or 40% of evapotranspiration(ET) as measured gravimetrically. Actual ET rate of grasses was determined by measuring the lysimeters receiving 100% ET. This was calculated by the following formula:

$$ET = W_{max} - W_{min}$$

$$W_{needed} = \text{deficit irrigation level} \times ET_{control}$$

$$W_{max} = W_{min} + W_{needed}$$

W_{min} and W_{max} are lysimeter weights before and after water is applied. W_{needed}represents water amount applied for lysimeters. $ET_{control}$ represents the mean of 100% irrigation levels of ET.

Measurements

Evaluations included turf quality, leaf rolling, leaf firing, soil moisture content, relative water content of leaves(RWC), chlorophyll content index(CCI), canopy photosynthesis(PS), multispectral reflectance(MSR), root distribution, and water use efficiency(WUE). Turf quality was assessed weekly during the dry-down using a 1 to 9 scale based on shoot color, density, uniformity, and drought symptoms, where 1 indicated no live grass and complete wilting, 5 indicated the beginning of drought stress, 6 indicates a minimum acceptable quality without drought stress,and 9 indicated optimum quality. Leaf rolling and leaf firing were assessed daily using a 1 to 9 scale, where 1 equaled no leaf rolling or leaf firing and 9 equaled no live grass.

Volumetric soil moisture content(SMC) (%) was randomly measured from two locations within each pot with a FieldScout 300 TDR(Spectrum Technology, Inc.). Average volumetric water content was measured to a depth of 20 cm.

Relative water content of leaves(RWC) was determined according to the method of Barrs and Weatherley(1962) using the following equation: RWC = (Fresh wt - Dry wt) / (Turgid wt - Dry wt) X 100, where dry weight was determined after drying at

75°C for 24 h, and turgid weight was determined after soaking in deionized water for 4 h at room temperature(20°C).

Chlorophyll content index of leaves(CCI) was randomly measured from two locations within each pot with a FieldScout CM1000™ chlorophyll meter(Spectrum Technology, Inc.). This chlorophyll meter senses light at wavelengths of 700 nm and 840 nm and develops an index to estimate the quantity of chlorophyll in leaves.

Canopy photosynthesis was measured once a week with the LI-COR 6200 portable photosynthesis system. Each lysimeter was put under high intensity discharge(HID) lamp during photosynthesis measurement to have consistent light intensity. The range of photosynthetic photon flux density(PPFD) was between 1200 and 1800 *u*mol m^{-2} sec^{-1}. All readings were taken from 1200 to 1500 h EST under conditions of minimal cloud cover.

Water use efficiency(WUE) was calculated as shoot dry matter divided by actual ET(g ml^{-1}.day^{-1}). WUE was measured under non-stressed and stressed conditions in Study 2.

At the termination of each Study, root distribution was measured by separating the root system into the top 23 cm and the bottom 23 cm before washing roots. Roots were then washed free of soil and dried in an oven at 24°C for 24 h before being weighed.

The two Studies were compared for differences with analysis of variance at the 0.05 probability level(PROC ANOVA) and data from each Study were analyzed with general linear regression(PROC GLM) or correlation models(PROC CORR)(SAS Institute, 1990). Means were separated using the LSD test($P < 0.05$). Regression analysis was used to test correlations among visual measurements, RWC, soil moisture content, CCI, and multispectral reflectance data. Where data differed between Studies, data are presented separately for both.

RESULTS AND DISCUSSION

Visual Measurements

Turf Quality

'Seashore paspalum' maintained highest visual quality at 100 and 80% ET in Study 1, while at 60% ET, 'Empire' and 'Palmetto', St. Augustinegrass had equal quality scores(Table 1). At 40% ET, visual scores were highest in 'Palmetto'. 'Pensacola' had lowest quality scores at all ET levels. Similar results were seen in Study 2, except that 'Empire' ranked in the highest category at all treatment levels. 'Floratam' and 'Pensacola' did not show acceptable quality scores at any treatment in Study 1, and in Study 2, 'Floratam', St. Augustingrass quality was acceptable only at 100% ET.

Table 1. Average visual for warm-season grasses under deficit irrigation.

By Grass	Study 1				Study 2			
	100 ET[y]	80 ET	60 ET	40 ET	100 ET	80 ET	60 ET	40 ET
Sea Isle 1 Seashore Paspalum	6.37 a[x]	6.39 a	5.66 a	4.28 cd	6.79 a	6.69 a	5.37 a	3.21 b
Empire Zoysiagrass	6.35 a	5.88 bc	5.68 a	4.74 b	6.71 a	6.85 a	5.35 a	3.88 a
Palmetto St. Augustine	6.08 b	6.06 b	5.77 a	5.36 a	6.37 b	6.13 b	5.54 a	3.30 b
Floratam St. Augustine	5.78 c	5.76 c	5.03 b	4.50 bc	6.08 b	5.83 c	4.87 b	3.46 b
Pensacola Bahiagrass	5.16 d	5.51 d	4.74 c	4.20 d	5.29 c	5.62 c	4.13 c	2.77 c
	***	***	***	***	***	***	***	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Column means followed by the same letter are not significantly different ($P < 0.05$).
Turf quality was rated visually on a 1 to 9 scale, where 1 = dead turf, 6 = acceptable quality, and 9 = optimum color and density.
[y]Evapotranspiration.

In Study 1, 'Sea Isle 1', 'Palmetto', and 'Floratam' had no rating differences between 100 and 80% treatments(Table 1). 'Pensacola' had higher ratings at 80 than 100% ET. In Study 2, all grasses had equal ratings at 80 and 100% ET. In both Studies, lowest scores were at 40% ET for all grasses. Regression analysis predicted that 'Sea Isle 1', 'Palmetto', and 'Empire' maintained acceptable quality at 66.9%,

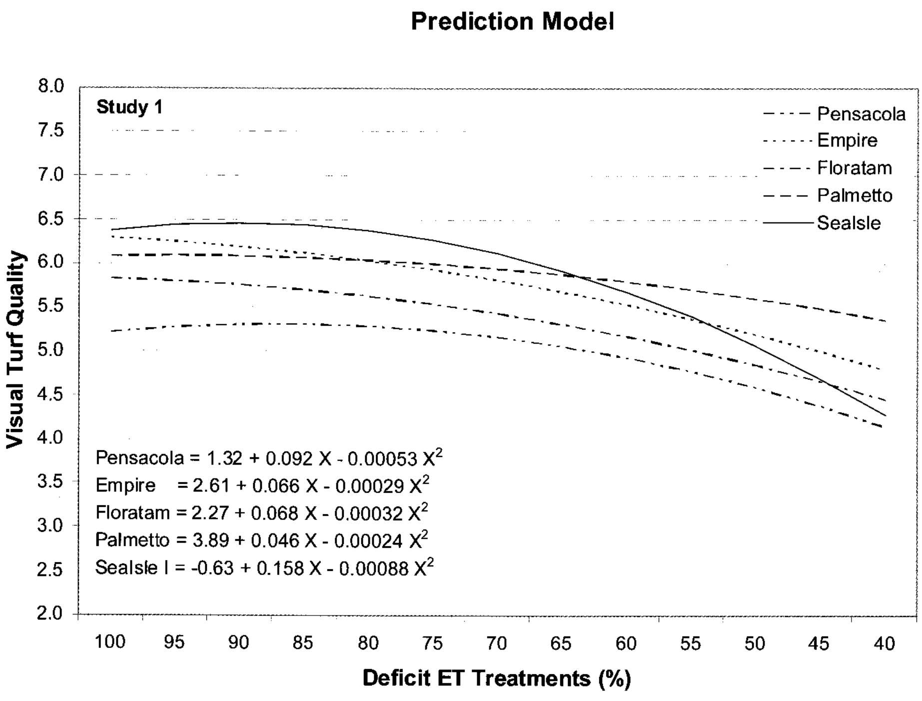

Fig. 1.1

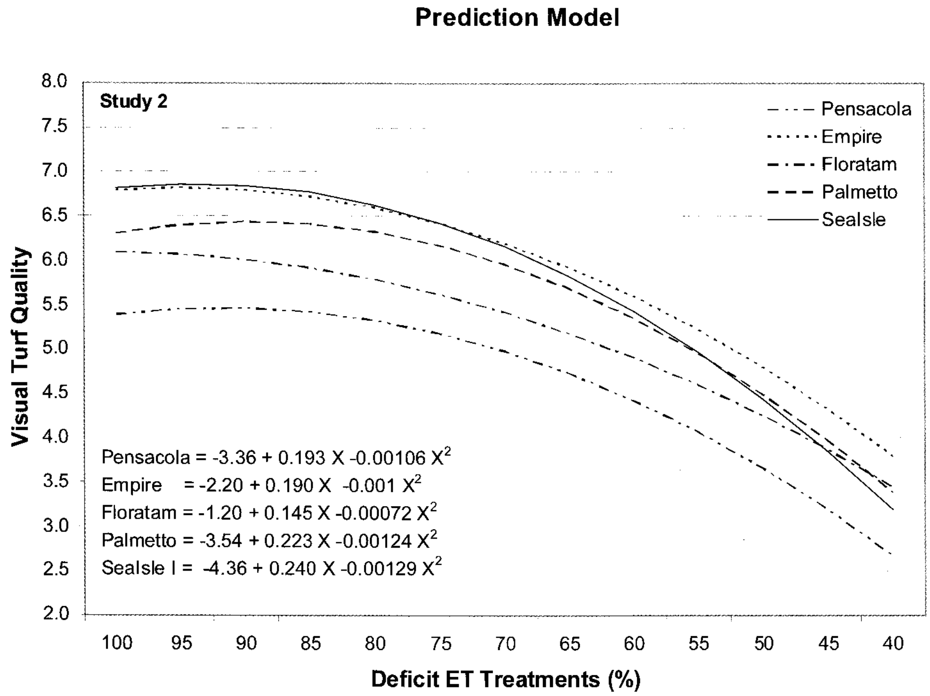

Fig. 1.2

76%, and 78.3% ET, respectively in Study 1(Fig. 1-1). In Study 2, 'SeaIsle 1', 'Palmetto', 'Empire', and 'Floratam' maintained acceptable quality at 68%, 70% 66.3%, and 88.9% ET, respectively(Fig. 1-2). Work done by Meyer et al. (1985) found that reducing water applications to 80% ET decreased quality ratings by 3% for cool-season turf species and by 5% for warm-season turf species. Shackel et al. (2000) found that prune(*Prunus* X *domestica* L.) could be irrigated with approximately 40% less water with no yield reduction. Lee et al. (2004) found that 'Sea Isle 1' seashore paspalum(*Paspalum vaginatum* Swartz) and 'Floratam' St. Augustinegrass (*Stenotaphrum secundatum*(Walt.) Kuntze) maintained acceptable quality in the greenhouse when irrigation was withheld for 27 d and 10 d, respectively. For cool-season turfgrasses, Fry and Butler(1989) found that tall fescue(*Festuca arundinacea*Schreb.) exhibited exceptional resistance to deficit irrigation. Irrigation at 50% evapotranspiration(ETp) resulted in only small reductions in visual quality when they were watered every 2 d.

Leaf Firing

Since there as no difference in leaf firing between 2 Studies, data from both Studies were averaged(Table 2). 'Floratam' and 'Pensacola' had the greatest amount of

Table 2. Average visual leaf firing for warm-season grasses under deficit irrigation treatments in two repeated Studies.

By Grass	Leaf Firing			
	100 ET^y	80 ET	60 ET	40 ET
Sea Isle 1 Seashore Paspalum	8.18 a^x	7.95 a	6.71 a	4.64 c
Empire Zoysiagrass	7.91 b	7.61 b	6.72 a	5.42 b
Palmetto St. Augustine	7.89 b	7.67 b	6.93 a	5.95 a
Floratam St. Augustine	7.19 c	7.12 c	5.87 b	4.89 c
Pensacola Bahiagrass	7.07 c	7.19 c	5.84 b	4.70 c
	***	***	***	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
^{x}Column means followed by the same letter are not significantly different (P < 0.05).
^{y}Evapotranspiration.
Leaf firing was rated visually on a 0 to 9 scale, where 0 = totally fired, and 9 = no fired.

firing at 100, 80, and 60% ET.At 40% ET, 'Palmetto' had the least leaf firing and 'Sea Isle 1' joined 'Floratam' and 'Palmetto' with the most firing. None of the grasses had differences in firing between 100 and 80% ET, with firings increasing as drought stress increased. Huang et al. (1997) found that chlorophyll content measurements showed both chlorophyll loss and leaf firing. Chlorophyll content was reduced with soil drying for 'Emerald' zoysiagrass, 'Common' bermudagrass, and 'AP14' Seashore paspalum.

Leaf Rolling

As drought stress increased in Study 1, 'Pensacola' maintained the lowest leaf rolling scores(Table 3). However, in Study 2, 'Palmetto', 'Floratam', and 'Empire' had the lowest rolling scores at 40% ET. All grasses increased leaf rolling as drought stress increased. Leaf rolling is one of drought avoidance mechanisms to reduce internal water loss from the canopy(Kim and Beard, 1988). Based on this sensitivity to leaf rolling, 'SeaIsle 1' had higher drought avoidance mechanism compared to the

Table 3. Average visual leaf rolling for warm-season grasses under deficit irrigation treatments.

By ET(%)^y	Study 1					Study 2				
	SeaIsle 1	Empire	Palmetto	Floratam	Pensacola	SeaIsle 1	Empire	Palmetto	Floratam	Pensacola
100 ET	7.08 a^x	7.64 a	8.17 a	8.18 a	8.34 a	7.54 a	8.71 a	8.79 a	8.75 a	8.52 a
80 ET	6.65 b	6.72 b	8.13 a	7.90 a	8.19 a	6.96 b	8.29 a	8.38 a	8.46 a	7.79 b
60 ET	5.69 c	6.61 b	7.52 b	7.47 b	8.05 ab	5.54 c	6.27 b	7.04 b	6.73 b	6.25 c
40 ET	4.25 d	5.54 c	6.81 c	6.30 c	7.81 b	3.62 d	4.44 c	4.90 c	4.58 c	3.40 d
	***	***	***	***	NS	***	***	***	***	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
^{x}Column means followed by the same letter are not significantly different (P < 0.05).
^{y}Evapotranspiration.
Leaf rolling was rated visually on a 0 to 9 scale, where 0 = totally rolled, and 9 = no rolled.

other grasses. Leaf rolling sensitivity by drought stress can be ranked as following: 'SeaIsle 1'(greatest) > 'Empire' > 'Palmetto' = 'Floratam' > 'Pensacola'(least) in both Studies.

Relative Water Content(RWC)

Since there as no differences in between 2 Studies, these data are averages of both Studies. Water content of all grasses decreased as drought stress increased.

In our Study, there were differences among grasses at all treatments except 80% ET. 'Floratam' and 'Palmetto' had higher RWC than other grasses at all deficit irrigation treatments as well as 100% ET. No grass had differences between 100% and 80% ET, while there were differences between 60% and 40% ET treatments(Table 4). Internal water holding capacity during drought stress periods can be ranked as following: 'Palmetto'(best) > 'SeaIsle 1' > 'Empire' > 'Floratam' > 'Pensacola'(least).

Lee et al. (2003) showed that 'SeaIsle 1' and 'Floratam' maintained an average RWC of 90% until day 24 without irrigation in greenhouse while soil moisture was gradually decreased and there was significant RWC reduction after day 24. Thus, measuring relative water content of leaves(RWC) is one of valuable methods to investigate drought resistance mechanism. Jiang and Huang(2002) showed that RWC of tall fescue decreased and increased electrolyte leakage(EL) during drought stress.

Table 4. Average relative water content of leaves for warm-season grasses under deficit irrigation treatments.

	RWC				
By ET(%)[y]	SeaIsle 1	Empire	Palmetto	Floratam	Pensacola
100 ET	90.35 a	88.90 a	92.14 a	93.86 a	87.60 a
80 ET	90.17 a	88.24 a	89.72 a	91.35 a	88.16 a
60 ET	73.89 b	73.67 b	79.68 b	81.16 b	82.99 b
40 ET	67.13 c	63.38 c	70.86 c	65.23 c	54.77 c
	***	***	***	***	***
Internal water loss (%)[z]	25.7	28.7	23.1	30.5	37.5

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Column means followed by the same letter are not significantly different ($P < 0.05$).
[y]Evapotranspiration.
[z]Internal wate loss is the percentage of water loss at 40% ET compared to 100% ET.

Chlorophyll Content Index(CCI)

'SeaIsle 1' and 'Empire' maintained comparatively higher CCI than other grasses at 100, 80, and 60% ET in Study 1(Table 5). At 40% ET, 'Empire' and 'Palmetto' had highest CCI. In Study 2, 'Empire' maintained highest CCI at 40%

ET,followed by 'Sea Isle 1'. There was a general trend for CCI to decrease as drought stress increased, although 'Pensacola' had higher CCI at 80% ET than at 100% in both Studies.

Chlorophyll synthesis is inhibited at greater water deficits. Jiang and Huang(2001) found that drought stress to both tall fescue and Kentucky bluegrass reduced chlorophyll content. Lee et al. (2003) concluded that CCI of St. Augustinegrass was highly correlated with soil moisture(r^2 = 0.91, p<0.0001) and was significantly reduced when soil moisture decreased.

Table 5. Average chlorophyll content index for warm-season grasses under deficit irrigation treatments.

By Grass	Study 1				Study 2			
	100 ET[y]	80 ET	60 ET	40 ET	100 ET	80 ET	60 ET	40 ET
Sea Isle 1 Seashore Paspalum	215.28 a[x]	210.69 ab	202.46 a	169.24 b	237.61 a	243.10 a	202.49 a	169.49 b
Empire Zoysiagrass	209.14 ab	216.99 a	197.09 a	171.17 ab	236.47 a	249.17 a	209.84 a	185.80 a
Palmetto St. Augustine	196.83 bc	200.85 b	202.46 a	183.72 a	228.43 a	215.20 b	207.89 a	147.26 c
Floratam St. Augustine	194.03 c	179.38 c	168.82 b	161.36 b	203.15 b	195.63 c	179.87 b	152.03 c
Pensacola Bahiagrass	134.29 d	162.78 c	142.43 c	142.13 c	175.26 c	200.35 bc	159.36 c	147.19 c
	***	***	***	***	***	***	***	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Column means followed by the same letter are not significantly different (P < 0.05).
[y]Evapotranspiration.

Photosynthesis(PS)

Since there as no difference in PS data between 2 Studies, data were averaged. At 100 and 80% ET, 'Sea Isle 1' and 'Empire' had highest PS levels(Table 6). At 40% ET, 'Empire' and 'Palmetto' had highest levels. Lowest PS rates were consistently found in 'Floratam' and 'Pensacola'. Photosynthesis decreased as drought stress

Table 6. Average photosynthesis for warm-season grasses under deficit irrigation treatments in two repeated Studies.

By Grass	Photosynthesis			
	100 ET[y]	80 ET	60 ET	40 ET
Sea Isle 1 Seashore Paspalum	14.0922[z] a[x]	13.13 a	8.56 ab	3.36 b
Empire Zoysiagrass	13.89 a	13.09 a	9.39 a	6.03 a
Palmetto St. Augustine	12.22 b	11.49 b	9.59 a	6.48 a
Floratam St. Augustine	9.42 c	9.25 c	6.16 c	4.04 b
Pensacola Bahiagrass	8.78 c	10.47 bc	7.10 bc	4.22 b
	***	***	***	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Column means followed by the same letter are not significantly different (P < 0.05).
[y]Evapotranspiration.
[z]Unit: umol/m^2/sec.

increased, although rates were the same at 100 and 80% ET, with the exception of 'Pensacola', which had the highest rates at 80% ET. Regression analysis predicted that optimum PS for 'Pensacola' would occur at 85.4% of ET. All other grasses had linear reductions in PS as drought stress increased. 'Floratam' and 'Palmetto' St. Augustinegrass had the same reduction rate as ET treatments decrease, 'SeaIsle 1' showed higher reduction than the other grasses in both Studies(Fig. 2).

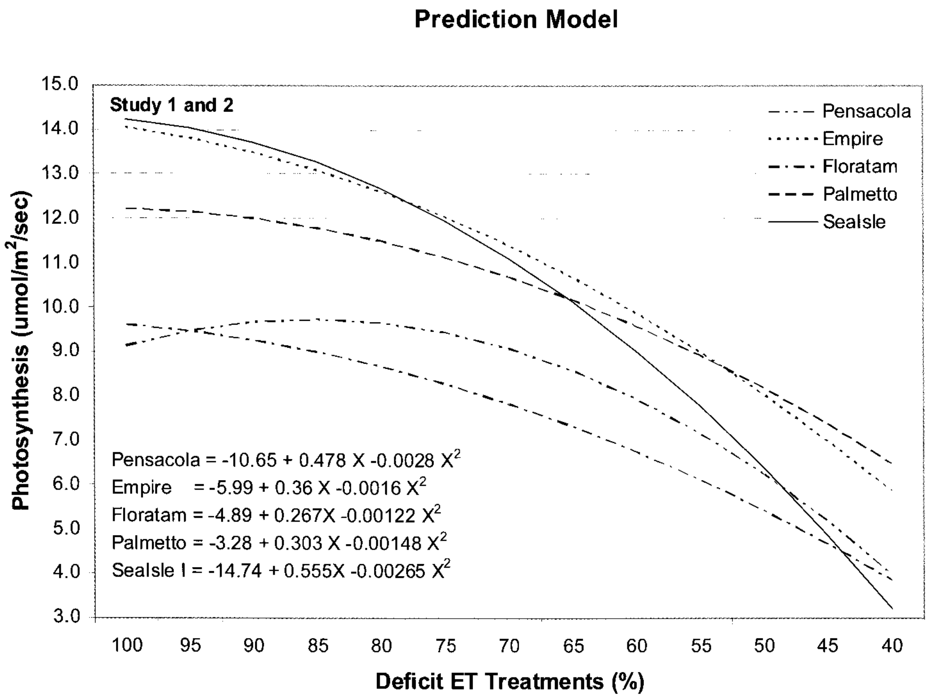

Fig. 2

<u>Water Use Efficiency(WUE)</u>

Under non-stressed conditions, 'SeaIsle 1' had the lowest WUE at all respective deficit irrigation treatments except 40% ET. There as no difference among all the grasses at 40% of ET while all the grasses showed no significant difference at 100% and 80% of ET under stressed condition. 'Floratam' showed higher WUE at 60% ET than the other grasses(Table 7). Also, under non-stressed condition, only 'SeaIsle 1' showed the highest WUE at 40% of ET while this grass showed the lowest WUE under stressed condition. It means that 'SeaIsle 1' is the most drought sensitive grass among these evaluated grasses in this Study. In stressed condition, 'Palmetto', 'Floratam', and 'Pensacola' showed no significant difference among all irrigation treatments. Generally all the grasses showed low WUE when applied ET rate decreased under stressed condition while there were no difference in non-stress condition.

Table 7. Average water use efficiency for warm-season grasses under deficit irrigation treatments drought stress and no drought stress conditions.

By Grass	No Drought Stress				Drought Stress		
	100 ET[y]	80 ET	60 ET	40 ET	100 ET	80 ET	60 ET
Sea Isle 1 Seashore Paspalum	0.10[z] c[x]	0.09 b	0.11 b	0.20 a	0.19 ab	0.19 b	0.06 b
Empire Zoysiagrass	0.19 a	0.25 a	0.23 a	0.22 a	0.29 a	0.28 ab	0.15 b
Palmetto St. Augustine	0.16 ab	0.17 ab	0.20 ab	0.14 a	0.28 a	0.26 ab	0.14 b
Floratam St. Augustine	0.21 a	0.23 a	0.28 a	0.21 a	0.28 a	0.29 a	0.28 a
Pensacola Bahiagrass	0.12 bc	0.18 a	0.13 b	0.15 a	0.13 b	0.21 ab	0.13 b
	**	*	*	NS	NS	NS	**

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Column means followed by the same letter are not significantly different ($P < 0.05$).
[y]Evapotranspiration.
[z]Water use efficiency is calculated as shoot dry matters are divided by actual ET($g/ml^{-1} \cdot day^{-1}$).

Root Distribution

There as no difference in the top 23 cm of root mass at 100 or 80% ET in all grasses(Table 8). At 60% ET, lower mass occurred in 'Floratam' and 'Pensacola', while 'Floratam' had lower mass than 'Sea Isle 1', 'Empire', and 'Pensacola' at 40%. When root mass was weighed from 23 to 46 cm, 'Sea Isle 1' consistently was in the highest mass ranking at all treatment levels. Also in the top mass categories were 'Palmetto'(80 and 60% ET) and 'Pensacola'(80% ET). Ability to root deeply into the soil profile is considered a drought avoidance mechanism that is enhanced by water deficit. This occurs because cell expansion may be more sensitive to water deficit than to photosynthesis. Reduced leaf area increases the proportion of photosynthate that can be translocated to the root. Huang et al. (1997) found that superior drought resistance to surface soil drying for 'PI 509018' paspalum(*Paspalum vaginatum* Swartz.) and 'TifBlair' centipedegrass(*Eremochloa ophiuroides*(Munro)Hack) were associated with enhanced root growth.

Table 8. Root distribution of warm-season grasses at root zone 0-23cm and 24-46cm under deficit irrigation treatments.

Grass	Root Top (0-23cm)				Root Bottom (24-46cm)			
	100 ET[y]	80 ET	60 ET	40 ET	100 ET	80 ET	60 ET	40 ET
Sea Isle 1 Seashore Paspalum	8.147[z] a[x]	7.94 a	8.74 a	7.09 a	4.00 a	4.03 a	4.99 a	5.49 a
Empire Zoysiagrass	9.58 a	7.66 a	9.24 a	6.44 a	1.66 b	1.56 bc	1.50 b	1.04 c
Palmetto St. Augustine	9.62 a	9.73 a	9.80 a	5.35 ab	1.95 b	3.07 ab	4.45 a	1.63 c
Floratam St. Augustine	5.72 a	6.18 a	4.97 b	3.58 b	0.83 b	1.15 c	1.52 b	1.37 c
Pensacola Bahiagrass	7.88 a	7.22 a	5.92 b	5.89 a	2.22 b	4.11 a	2.50 b	3.18 b
	NS	NS	**	*	*	*	**	***

***, **, * Significant at the 0.001, 0.01, and 0.05 probability levels, respectively. NS = not significant.
[x]Columnmeans followed by the same letter are not significantly different ($P < 0.05$).
[y]Evapotranspiration.
[z]Dry weight (g)

Correlations

Photosynthesis was strongly correlatedwith visual measurements such as visual turf quality(r^2 = 0.61), leaf firing(r^2 = 0.60), leaf rolling(r^2 = 0.64), and RWC(r^2 = 0.60) in both Studies. Photosynthesis was highly correlated with RWC(r^2 = 0.60)(Table 13). Soil moisture had strong correlations with visual turf quality(r^2 = 62), leaf firing(r^2 = 0.64), leaf rolling(r^2 = 0.70), and RWC(r^2= 0.61) in both Studies(Table 9). RWC was also strongly correlated with leaf firing(r^2 = 0.61~0.78) and leaf rolling(r^2 = 0.68~0.83) in all grasses(Table 10). These results agree with Lee et al. (2004) who found that soil moisture was highly correlated with turf quality(r^2= 0.67~0.82) and leaf rolling(r^2 = 0.80~0.87) in 'Floratam' St. Augustinegrass and 'SeaIsle 1' seashore paspalum.

In Conclusion, deficit irrigation enhanced deep root system in some grass types such as 'SeaIsle 1' and 'Palmetto'. Deficit irrigation of 80% of ET was able to reduce water use while grasses keep acceptable turf quality. Optimal physiological conditions such as RWC, CCI, and photosynthesis were maintained at this rate. Further Study is needed to investigate the correlation between shoot and root growth rate when turfgrasses are maintained at different soil moisture conditions.

국문 요약

본 연구는 전 세계적으로 물 부족 현상으로 인한 물의 사용에 대한 관심이 증가함에 따라 네 종류의 난지형 잔디에 각기 다른 비율의 적자관수를 함으로써 식물의 생리학적인 반응, 즉 시각적 품질, 잎의 물 함량, 엽록소 함량, 광합성, 물 이용효율 등이 어떤 반응을 보이는지를 이해하고 그에 따른 상관관계를 분석해보고자 했다. 결론적으로 20% 정도 적자 관수를 했을 때 식물은 약간의 스트레스를 받는 상태에서도 적자 관수를 하지 않은 식물과 비교했을 때 광합성량의 차이가 없었으며 가장 이상적인 생리학적인 반응을 보였다. 뿌리 발육 부분에 있어서도 적자관수를 통한 건조스트레스는 깊은 뿌리 생육을 촉진하는 관리방법으로 작용되었다. 다음 연구는 잔디가 각기 다른 토양 수분상태에서 일정하게 유지되었을때 지상부와 지하부의 생육에 따른 생리학적인 반응에 대한 연구로 확대되어야 할 것이다.

주요어 : 가뭄스트레스, 광합성, 난지형 잔디, 물 사용효율, 소량관수, 엽록소 함량

REFERENCES

1. Barrs, H.D. and P.E. Weatherley. 1962.A reexamination of the relative turgidity techniques for estimating water deficits in leaves. Aust. J. Biol. Sci. 15:413-428.
2. Bray, E.A. 1997. Plant responses to water deficit. Trends in Plant Science 2(2):48-54.
3. Davies, W.J. and J. Zhang. 1991. Root signals and the regulation of growth and development of plants in drying soil. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42:55-76.
4. Fry, J.D. and J.D. Butler. 1989. Responses of tall and hard fescue to deficit irrigation. Crop Science 29:1536-1541.
5. Huang, B. and H. Gao. 1999. Physiological responses of diverse tall fescue cultivars to drought stress. HortScience 34:897-901.
6. Huang, B., R.R. Duncan and R.N. Carrow. 1997. Drought-resistance mechanisms of seven warm-season turfgrasses under surface soil drying: I. shoot response. Crop Science 37:1858-1863.
7. Huang, B., R.R. Duncan and R.N. Carrow. 1997. Drought-resistance mechanisms of seven warm-season turfgrasses under surface soil drying: II. Root aspects. Crop Science 37:1863-1869.
8. Huang, B. and J.D. Fry. 1998. Root anatomical, physiological, and morphological responses to drought stress for tall fescue cultivars. Crop Science 38:1017-1022.
9. Iturbe-Ormaetxe, I., P.R. Escuredo, C. Arrese-Igor and M Becana. 1998. Oxidative damage in pea plants exposed to water deficit or paraquat. Plant Physiol. 116:173-181.
10. Jiang, Y. and B. Huang. 2001. Drought and heat stress injury to two cool-season turfgrasses in relation to antioxidant metabolism and lipid peroxidation. Crop Science 41:436-442.
11. Jiang, Y. and B. Huang. 2002. Protein alterations in tall fescue in response to drought stress and abscisic acid. Crop Science 42:202-207.
12. Kim, K.S. and J.B. Beard. 1988. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics. Crop Science 28:328-331.
13. Lee, J.H., L.E. Trenholm and J. B. Unruh. 2003. Technology for irrigation scheduling for St. Augustinegrass. Proc. Fla. State Hort. Soc. 116:319-321.
14. Lee, J.H., L.E. Trenholm and J. B. Unruh. 2003. Evaluating methods of predicting irrigation needs of warm-season turfgrasses. The Florida Green. Spring. p.57-58.
15. Meyer, J.L., V.A. Gibeault and V.B. Youngner. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: Determining crop coefficient of turfgrasses. In F. Lemaire(ed.) Proc. 5thInt. Turfgrass Res.Conf., Avignon, France. 357-364.
16. Shackel, K.A., B. Lampinen, S. Southwick, W. Olson, S. Sibbett, W. Krueger, J. Yeager and D. Goldhamer. 2000. Deficit irrigation in prunes : maintaining productivity with less water. HortScience 35(6):1063-1066.