Turfgrass
Trials and Tribulations

J. Bryan Unruh, Ph.D.
Extension Turf Specialist

Loss of turf last spring. . .

- Site visits revealed loss of turf – especially golf course putting greens.
- Very cold winter – was it winterkill?
  - Winterkill is difficult to define.

Cold-Temperature Stress in Grasses

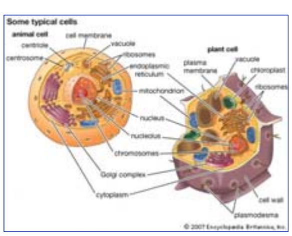
- Cool-Season Grasses
  - Optimum growth range = 60 to 75 °F.
    - Cool-season grass adaptation is limited by the intensity and duration of seasonal heat and drought stresses.
- Warm-season Grasses
  - Optimum growth range = 80 to 95 °F.
    - Warm-season grass adaptation is limited by the intensity and duration of cold temperatures.

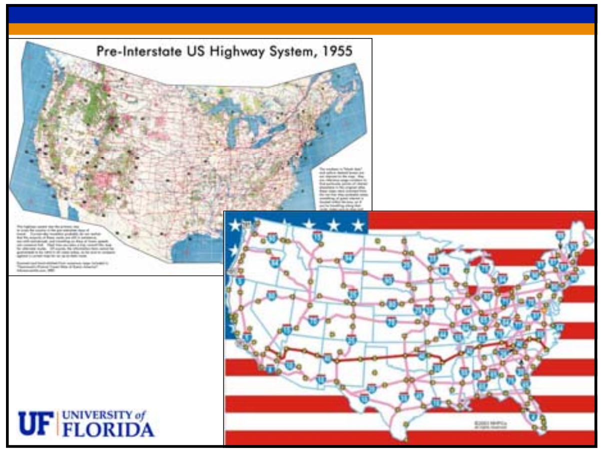
Cold-Temperature Stress in Grasses

- Temperatures do not have to reach freezing before some warm-season turfgrasses begins to experience stress.
  - Freezing Stress
  - Chilling Stress

Plant Physiology

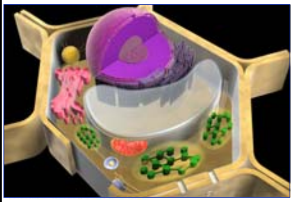
- To understand freezing and chilling stresses in turf, you have to understand cellular structure.
  - Plant cells have a cell membrane AND a cell wall.
    - Cell walls add support – similar to our skeleton.

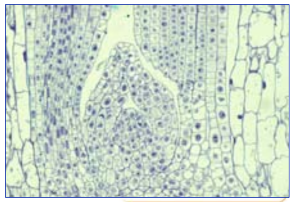




Plant Physiology

- Plants are comprised of rigid cells stacked on top of each other.
  - Each cell is filled with water (intracellular water)
  - Each cell is surrounded by water (intercellular water)





Colligative Properties

- What happens when we add a solute such as sugar or salt to otherwise pure water?
  - The freezing point of the solution decreases;
  - The boiling point increases;
  - The vapor pressure decreases; and
  - The osmotic pressure increases.

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Plant Physiology

- The intracellular space contains the living parts of the plant.
  - All the plant's metabolic processes occur in the intracellular spaces *in water*.
- Intracellular water contains a high concentration of solutes = freezing point decreases.

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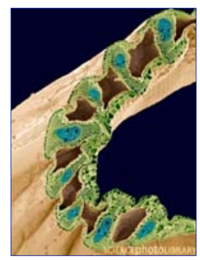
Plant Physiology

- Non-living activity occurs in the intercellular space which is in contact with the vascular system (blue).
  - Xylem transports water and nutrients from the roots throughout the plant.
  - Phloem transports carbohydrates and hormones around the plant.



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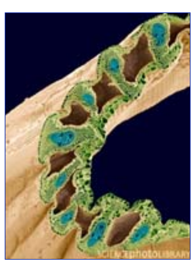
Plant Physiology

- Intercellular water also contains a high concentration of solutes but it is not as high as that of the inside (intracellular) space.
- Intercellular water freezes *before* the intracellular water.



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Freezing Stress in Grasses

- Water is the only known compound that expands when it cools – all other compounds shrink.
  - When intercellular water freezes, the expanding water can cause damage to cell walls.

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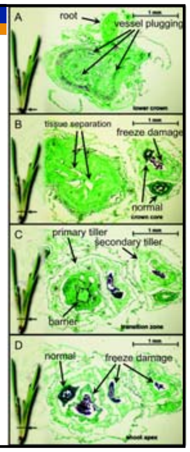
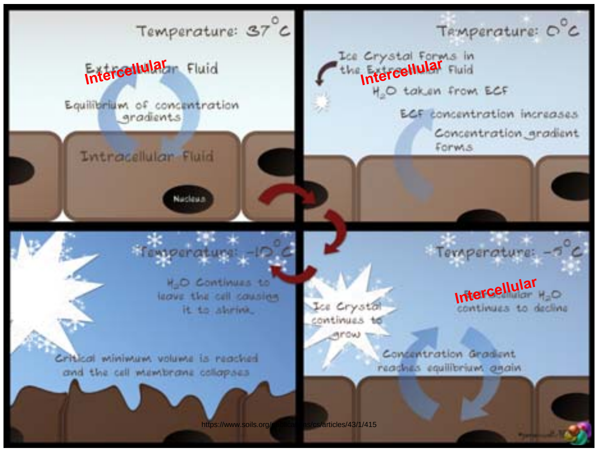
Freezing Stress in Grass

- If the intracellular water freezes the cell nearly always dies.
- It is more likely that the intercellular water will freeze which damages membranes and cell walls or causing cell dehydration.

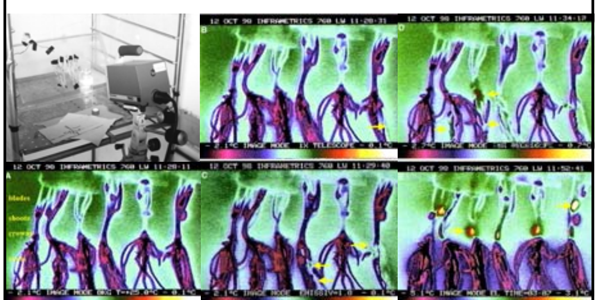




Freezing Stress in Grass

- At 14 °F (-10C), 90% of the osmotically active cellular water will move out of the cell into intercellular spaces (Thomashow, 1998).
- The most common type of freeze injury occurs at relatively high freezing temperatures 24 to 28 °F during late winter/early spring.

Visualization of freezing progression in turfgrasses using infrared video thermography
J. C. Stier, D.L. Filiaulta, M. Wisniewskib, and J.P. Paltaa



https://www.soils.org/publications/cs/articles/43/1/415

Visualization of freezing progression in turfgrasses using infrared video thermography
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- Freezing moved rapidly through roots, progressing several centimeters in <1 to 2 seconds.
  - Freezing proceeded up and down in root tissues and ice crystals were propagated throughout connected roots within seconds.
- The crown consistently provided a barrier for ice propagation between roots which were not directly connected.
  - The crown also provided a barrier which significantly slowed freezing into the upper crown and shoots.
- Freezing occurred only slowly in the crowns, with one to several minutes required for the entire crown to freeze.
  - Once the entire crown was frozen, freezing propagated quickly up the shoots, though not as rapidly as in the roots.
  - Freezing occasionally stopped or slowed at the leaf collar, suggesting some sort of barrier, then proceeded upwards to the leaf tips.

CHILLING STRESS

Chilling Stress in Warm-Season Grasses

- A condition that can occur in warm-season plants when temperatures fall below 50 °F.
- It is defined as low-temperature stress in the absence of freezing temperatures.

Chilling Stress in Warm-Season Grasses

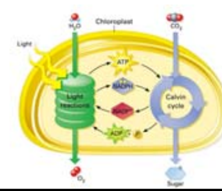
- Cell membrane permeability
  - Cell membranes are primarily composed of phospholipids.
    - Lard *vs* Vegetable Oil
      - Warm-season turfgrass cell membranes contain lipids closer to lard.
      - Cool-season turfgrass cell membranes contain more lipids like vegetable oil.
  - Warm-season membranes can be seriously affected when the weather is cool.

Chilling Stress in Warm-Season Grasses

- Cell membrane permeability
  - Membranes become rigid as temperatures go down.
    - If they become rigid, the selectivity is affected and it permits unwanted compounds to enter or leave cells.
      - This makes it very difficult for the cell to maintain efficient metabolism.
    - Genetics influence this rigidity:
      - Extensive damage to inner chloroplast membranes of bermudagrass but little damage to the more cold-tolerant zosysiagrass.

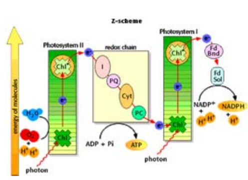
Chilling Stress in Warm-Season Grasses

- Chlorophyll photooxidation
  - As temperature declines, photosynthesis, respiration, and transpiration decline.
    - The chemical reactions in both the z-scheme and the Calvin cycle are affected.



Chilling Stress in Warm-Season Grasses

- Chlorophyll photooxidation
  - Light energy interception by chlorophyll is not affected by temperature.
    - Because the PS system is slow, this excitation energy has nowhere to go.
    - Eventually, some chlorophyll molecules reach an energy level high enough to pass an electron directly to the PSII receptor – this causes damage.



Chilling Stress in Warm-Season Grasses

- Chlorophyll photooxidation
  - Most likely to occur on clear cold days when intense light is present, but chemical processes are slow because of cool temperatures.

Chilling Stress in Warm-Season Grasses

- Dehydration
  - As soil temperatures cool, soil water becomes more viscous.
    - The more viscous the soil water becomes, the more difficult it is for plant roots to absorb it.
      - Cool temperatures slow water uptake, water translocation, and transpiration.
    - If the soil water freezes when the turf is still green and active the plants may dehydrate.

What's the difference between SAE30, 10W-30, and 5W-20?

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Cold Acclimation in Turfgrass Plants

- During acclimation, grasses go through a dehydration process – less water is stored.
  - Dry tissue is less likely to freeze than succulent tissue.

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Cold Acclimation in Turfgrass Plants

- As temperatures cool in the fall, turfgrasses begin to "harden off" for the winter.
  - Turfgrasses begin to translocate carbohydrates into their roots and stems.
    - In some grasses, these carbohydrates may be quickly converted to sucrose (sugar), which accumulates in the turfgrass crowns and stems when necessary to prevent freezing.

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Loss of Cold Hardiness

- A plant will lose its cold hardiness at a rate proportional to the degree of hardiness (Laude, 1937).
  - Centipedegrass required ~ 14d to acquire cold hardiness (Fry et al.).
    - Centipedegrass lost is cold hardiness after 48h of growth-conducive weather.
  - St. Augustinegrass lost the majority of its cold hardiness 48 – 72 hours at 77 °F (Reeves and McBee, 1972).

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Cold Acclimation in Turfgrass Plants

- As temperatures cool, shoot growth slows, but photosynthesis continues as long as the leaves are green.
  - The energy produced by photosynthesis and stored in roots and stems for the winter also provides fuel for slowed metabolism.

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Cold Acclimation in Turfgrass Plants

- Turfgrasses also accumulate proteins and other nitrogen-rich compounds that decrease in the spring as the plants de-acclimate.
  - This protein accumulation has been implicated in the greater freeze tolerance of some bermudagrasses and some zoysiagrasses.
  - Warm-season grasses that rapidly accumulate carbohydrates and proteins during cold acclimation are likely to be more cold tolerant.

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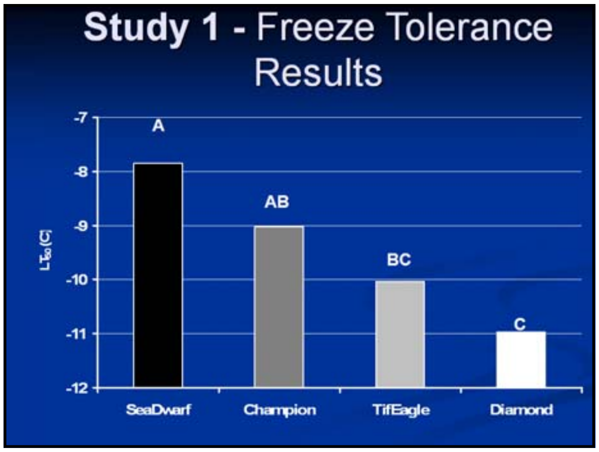
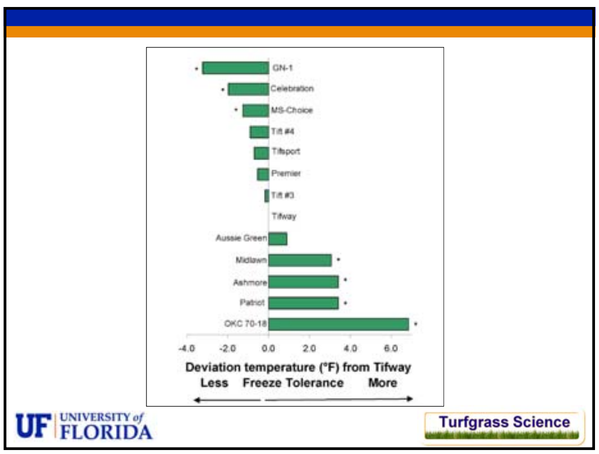

Study 1 - Freeze Tolerance Results
A
AB
BC
C
LT50 (C)
-7
-8
-9
-10
-11
-12
SeaDwarf
Champion
TifEagle
Diamond


Study 1 - Freeze Tolerance Conclusions
Diamond zoysaigrass freeze tolerant to -11 C
Champion and TifEagle not different
SeaDwarf and Champion least freeze tolerant


GN-1
Celebration
MS-Choice
Tift #4
Tifsport
Premier
Tift #3
Tifway
Aussie Green
Midlawn
Ashmore
Patriot
OKC 70-18
-4.0
-2.0
0.0
2.0
4.0
6.0
Deviation temperature (°F) from Tifway
Less Freeze Tolerance More
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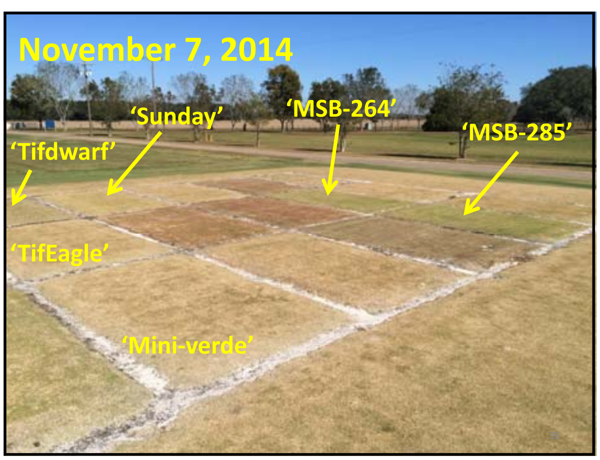
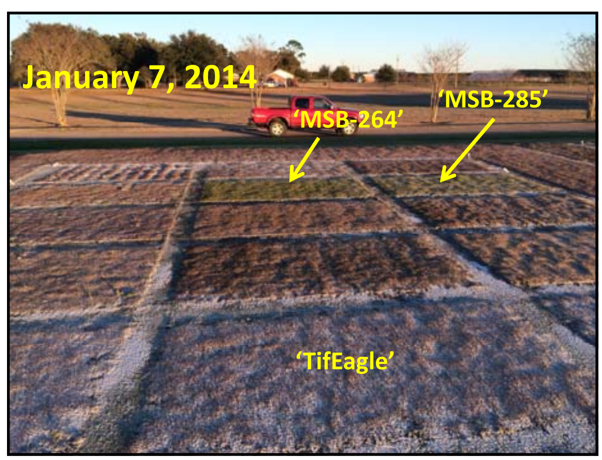
November 7, 2014
TifEagle Bermudagrass
'FAES1301' Zoysiagrass


November 7, 2014
'Sunday'
'MSB-264'
'MSB-285'
'Tifdwarf'
'TifEagle'
'Mini-verde'


January 7, 2014
'MSB-285'
'MSB-264'
'TifEagle'

Frost Injury

- Frost occurs on clear cold nights when turfgrass plants reradiate heat (exothermic reaction).

- As the plant loses heat to the atmosphere the plant leaf cools.
- If the plant is cooler than the air then moisture from the atmosphere will condense on the leaf.
- Should the leaf temperature drop below freezing then the water freezes and frost forms.
- This will occur even if the air temperatures are slightly above freezing.

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Frost Injury

- Frost does not form as readily on cloudy nights because the clouds reflect, or absorb and then reradiate the energy back towards the turf.
- Frost also does not form as readily under conditions where a breeze is present.
  - Mixing air closest to the plant and the atmosphere buffers the leaf temperature drop and promotes evaporation of the water droplets from the leaf.
- Frost will normally form early in the morning before sunrise.
  - This makes sense because if the plants have been reradiating energy throughout the night, the leaf temperature should be the coolest prior to daybreak.

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Frost Injury

- Frost itself does not cause long-term damage.

- Injury does occur when traffic occurs on frosted areas due to the crushing of the leaf blade.
- Frost injury can kill leaves, but if no damage occurs to the crown, recovery will occur from the generation of new leaves.

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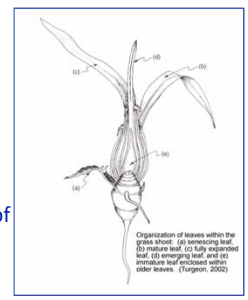
Managing Cold-Temperature Stress

- Soil temperature is more important than air temperature.
  - Dead turfgrass leaves are common in the winter.
  - It is the crowns that determine the life or death of the plant – and crowns are in, or at, the soil surface.



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Managing Cold-Temperature Stress

- Soil Moisture
  - A frozen wet soil is more damaging to turfgrass crowns than a frozen dry soil.
    - A wet soil expands when it freezes and may crush the crowns.
    - Wet soils are less likely to freeze and resist rapid temperature declines than dry soils.

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Managing Cold-Temperature Stress

- Soil Moisture
  - Light irrigation can help prevent freeze damage.
    - A moist soil resists the rapid temperature declines but does not contain enough water to crush the crown should it freeze.
  - Do not apply a soaking irrigation.
    - The dryness of the crown is an important component of resistance to freezing.

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Managing Cold-Temperature Stress

- Soil Moisture
  - Especially important during early cold snaps that occur before the turf has had sufficient time to acclimate.

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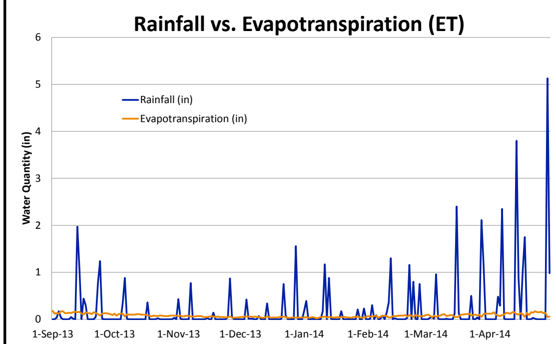

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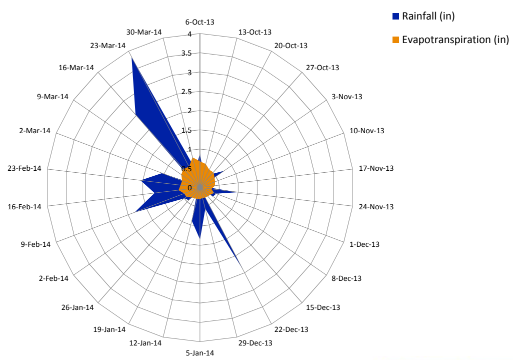

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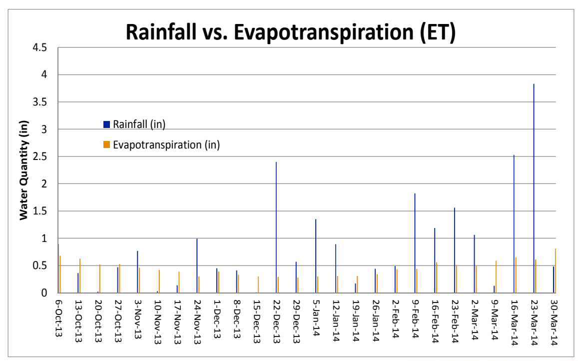

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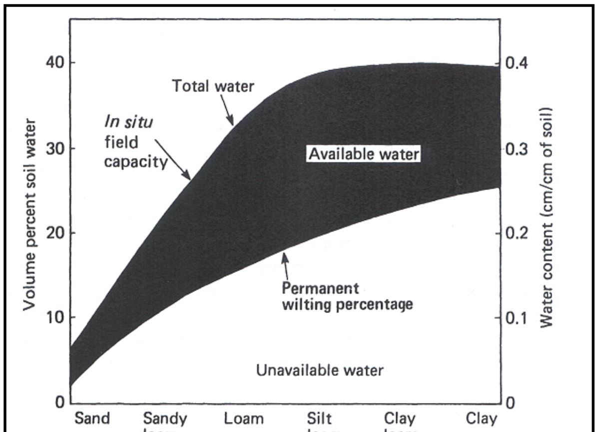

Field Capacity (FC or θ_{fc})

- Soil water content where gravity drainage becomes negligible.
- Soil is not saturated but still a very wet condition.
- Traditionally defined as the water content corresponding to a soil water potential of -0.1 (sands) to -0.33 bar.

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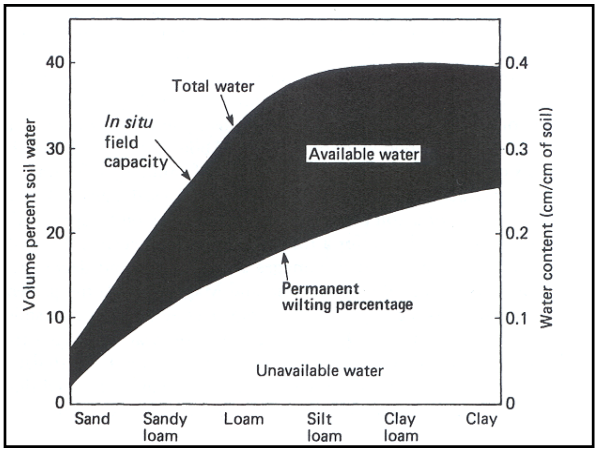
Permanent Wilting Point (WP or θ_{wp})

- Soil water content beyond which plants cannot recover from water stress (dead)
- Still some water in the soil but not enough to be of use to plants
- Traditionally defined as the water content corresponding to -15 bars of SWP

Plant Available Water

- Water held in the soil between field capacity (θ_{fc}) and permanent wilting point (θ_{wp}).
  - "Available" for plant use
- Available Water Capacity (AWC)
  - AWC = $\theta_{fc} - \theta_{wp}$
  - Units: depth of available water per unit depth of soil, "unitless" (in/in, or mm/mm)
  - Measured using field or laboratory methods

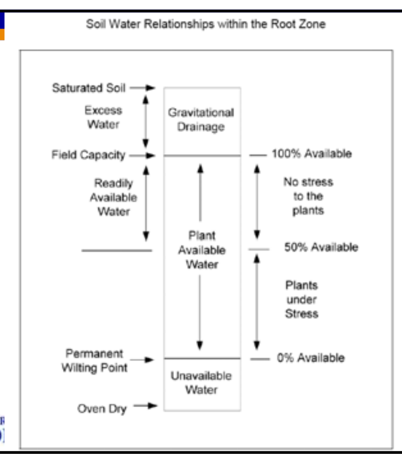


Soil Hydraulic Properties and Soil Texture

Table 2.3. Example values of soil water characteristics for various soil textures.*

Soil texture	θ_{fc}	θ_{wp}	AWC
	---------- in/in or m/m ---------		
Coarse sand	0.10	0.05	0.05
Sand	0.15	0.07	0.08
Loamy sand	0.18	0.07	0.11
Sandy loam	0.20	0.08	0.12
Loam	0.25	0.10	0.15
Silt loam	0.30	0.12	0.18
Silty clay loam	0.38	0.22	0.16
Clay loam	0.40	0.25	0.15
Silty clay	0.40	0.27	0.13
Clay	0.40	0.28	0.12

* Example values are given. You can expect considerable variation from these values within each soil texture.



Effective Root Zone

- The Effective Root Zone is the depth of soil from which plants can draw nutrients and water.
  - A tree or shrub may have an effective root zone of several feet.
  - A bermudagrass turf may have only 4" of an effective root zone.
    - Greens-height bermudagrasses may have only 1 – 2" of an effective root zone.

Total Available Water (TAW)

- TAW = total available water capacity within the plant root zone, (inches)
  - TAW = (AWC) (Rd)
    - AWC = available water capacity of the soil, (inches of H_2O/inch of soil)
    - Rd = depth of the plant root zone, (inches)

Total Available Water (TAW)

- Example: Bermudagrass growing on sand.
  - TAW = (AWC) (Rd)
  - TAW = (0.08) (4")
  - TAW = 0.32" water in the rootzone.

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Clay	0.40	0.28	0.12

* Example values are given. You can expect considerable variation from these values within each soil texture.

Management Allowable Depletion (MAD)

- MAD is the maximum percentage of Total Available Water (TAW) that the irrigation manager allows to be extracted (depleted) from the soil (ET) before irrigation is applied.

Soil Texture Class	MAD without Plant Stress
Clay	30%
Silty Clay	40%
Clay Loam	40%
Loam	50%
Sandy Loam	50%
Loamy Sand	50%
Sand	60%*

*Any value of MAD greater than 50% should be tried with a small area before being applied site-wide

Allowable Depletion

- Allowable Depletion (AD) is the desired amount of TAW to be depleted from the root zone before applying irrigation.

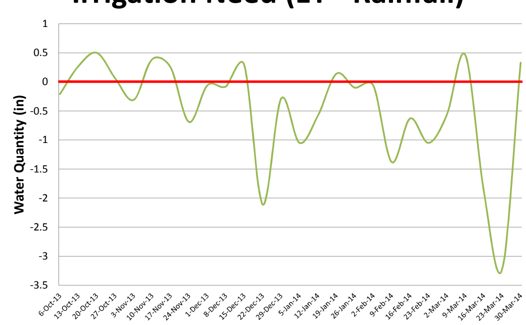
$$AD = TAW \times \left(\frac{MAD}{100}\right)$$

Allowable Depletion

- Example:
  - What is the AD for bermudagrass growing on a 4" sand root zone, and with no stress to the plants?
  - TAW = (AWC) (Rd)
    - TAW = (0.08) (4")
    - TAW = 0.32" water in the root zone
    - MAD = 50%

$$AD = 0.32'' \times \left(\frac{50}{100}\right) = 0.16''$$

Irrigation Need (ET - Rainfall)



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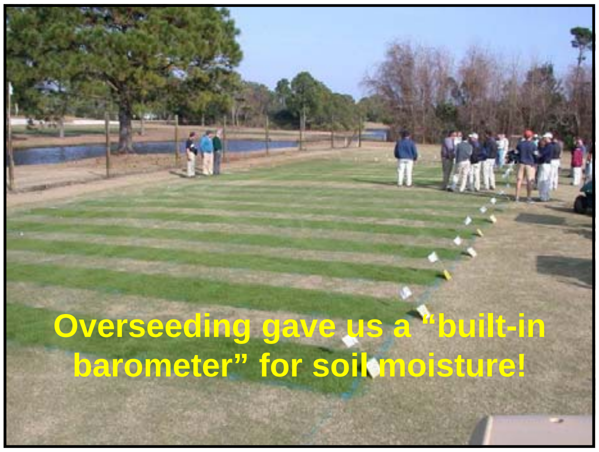

Field Scout TDR 300

- Based on proven time-domain measurement technology, these portable units accurately measure soil moisture across the full range of soil moisture conditions.
  - Probes are 3", 5", or 8" to suit your desired depth measurement.
  - Install PVC access tubes and take readings deeper in the soil profile.
  - $1,065.00 (+ rods) from Spectrum Technologies.

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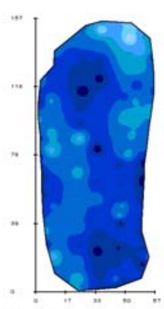
Spatial Variability

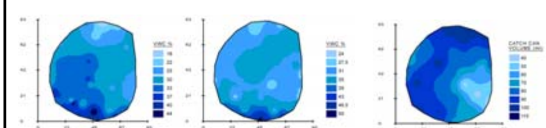


Your Field Name: Tam 1024 No.1a
File Upload Name: TDR Practice Moisture 10-24 1.txt
Sensor Model: TDR 300
Sensor Type: Soil Moisture

Color Legend				Count
29.7	to	31.5	VWC	1
31.5	to	33.3	VWC	2
33.3	to	35.0	VWC	4
35.0	to	36.8	VWC	22
36.8	to	38.6	VWC	26
38.6	to	40.3	VWC	23
40.3	to	42.1	VWC	23
42.1	to	43.9	VWC	9

Application Slide: Comparison of soil moisture map before and after irrigation of a putting green. Third chart is map of catch can volumes collected during irrigation. Catch can locations the same as SM measurement locations.

Irrigation Audit
SpecMaps & TDR 300



Soil Moisture Before Irrigation — Soil Moisture After Irrigation — Catch Can Results

Audit Type	DU_{lq}	DU_{h}	RTM_{lq}	RTM_{h}
CC	64.0	80.2	1.6	1.2
TDR1	81.5	86.7	1.2	1.1
TDR2	83.1	88.5	1.2	1.1

Turf-Tec Digital Moisture Sensor

- Adjustable foot allows you to determine moisture at the 1", 2", 3" or 4" depths.
- Designed to work in all soil types and salinity ranges.
- The Turf-Tec Digital Moisture Sensor uses a newly designed electrical conductivity sensing circuit that gives quick and reliable readings of soil moisture.

www.turf-tec.com
$600.00

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Managing Cold-Temperature Stress

- Soil Fertility
  - It is widely believed that warm-season plants should not be fertilized with nitrogen for a month or more before freezing temperatures.
    - The succulence normally encouraged by nitrogen could counteract the dehydration of the plant tissue as the grasses harden off.

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Managing Cold-Temperature Stress

- Soil Fertility
  - Late-season potassium applications helps warm-season grasses resist chilling and freezing stress.
  - Research suggests that high phosphorus levels may interfere with the cold-protection qualities enhanced by potassium.
    - Potassium may not be utilized fully unless sufficient nitrogen is also present.
    - At NCSU, bermudagrass with a 4-1-6 (N-P-K) ratio in the tissue was the most cold tolerant.
    - A high P:K ratio in St. Augustinegrass resulted in increased winter injury.

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Managing Cold-Temperature Stress

- Soil Fertility
  - Iron applications can also be beneficial because they encourage chlorophyll synthesis.
    - This, in turn, encourages carbohydrate production and storage.
  - Iron promotes aesthetic color without causing and increase in succulence.

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Managing Cold-Temperature Stress

- Mowing Height
  - Raising the mowing height on warm season turfgrasses during the fall will provide more some protection to the growing point during freezing temperatures.
- Field Drainage
  - Provide drainage for removal of water from excessively wet areas.
  - During freeze/thaw cycles the presence of excessive moisture can enhance freeze injury.
- Thatch
  - A significant thatch layer results in the plant's growing point to lose contact with the soil as it elevates into the thatch layer.
  - This will expose the plant more readily to freezing temperatures.

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Why DLI?

- Greenhouse light transmittance
  - 30-75% (Both and Faust, 2004)
- Ease of measurement
- Changes in light intensity
  - Seasonal
  - Regional
  - Latitudinal

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DLI Requirements – Summer Avgs.

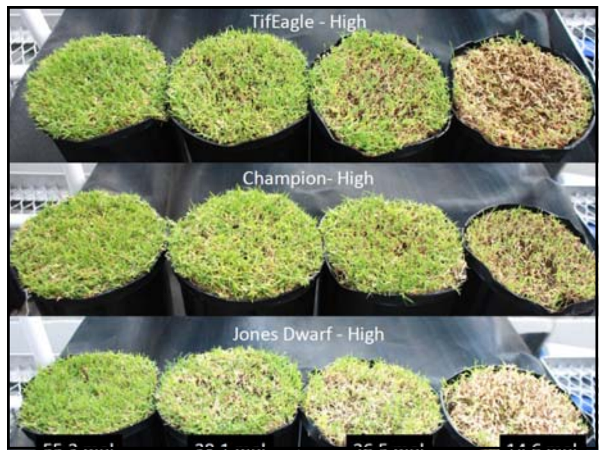
Turfgrass Cultivar	DLI requirement (mol m^{-2} d^{-1})
Tifway bermudagrass	22.4
Celebration bermudagrass	19.5
TifGrand hybrid bermudagrass	18.6
Argentine bahiagrass	15.3
Tifblair centipedegrass	13.5
SeaDwarf seashore paspalum	13.2
Floratam St. Augustinegrass	11.8
Palisades zoysiagrass (japonica)	11.3
Diamond zoysiagrass (matrella)	11.3
Captiva St. Augustinegrass	10.9
Pristine zoysiagrass (matrella)	10.9
JaMur zoysiagrass (japonica)	10.0

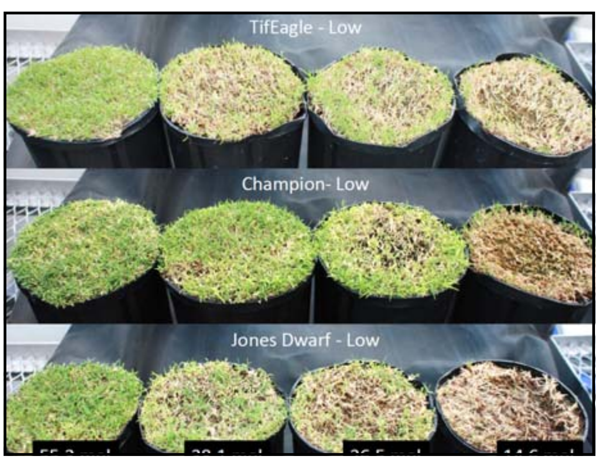
Cultivars

		Mowing Height (mm)	
Species	Cultivar	Low	High
Hybrid bermudagrass - *Cynodon spp.*	TifEagle	3.2	4.8
	Champion	3.2	4.8
	Jones Dwarf	3.2	4.8
	Tifway	12.7	38.1
Common bermudagrass - *Cynodon dactylon*	Celebration	12.7	38.1
Seashore paspalum - *Paspalum vaginatum*	SeaDwarf	12.7	38.1

Experimental Design

- Supplemental lighting
  - HPS with 1000 W bulbs, .9 m above canopy
  - Photoperiod of 12 h d^{-1}





DLI Requirements

	DLI requirement (mol m^{-2} d^{-1})*	
	Mowing Height	
Turfgrass Cultivar	High	Low
Jones Dwarf hybrid bermudagrass	39.8	47.3
TifEagle hybrid bermudagrass	33.7	38.5
Champion hybrid bermudagrass	30.6	31.9
Tifway hybrid bermudagrass	23.3	32.6
Celebration common bermudagrass	18.5	26.4
Seadwarf seashore paspalum	15.6	27.0

*Reduced to 93% observed DLI

Summary

- Increased DLI requirements at lower mowing height
  - Green height
    - 4.5 mol m^{-2} d^{-1} needed between heights (12% increase)
    - 2.8 mol/mm
  - Fairway height
    - 9.5 mol m^{-2} d^{-1} needed between heights (52% increase)
    - 0.4 mol/mm







Six Weeks After Treatment
Untreated Control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Turfgrass Science

On the horizon. . .

- Downhole steam generator
  - Oil field technology
  - The advantage to this technology is that it does not use a steam boiler and is not affected by water hardness.

On the horizon. . .

- Allyl isothiocyanate (AITC) (Dominus™)
  - When Basamid and Vapam react with water, they form MITC (methyl isothiocyanate) which is the biocide.
    - AITC is analogous to MITC and was a central constituent in Vorlex – a very old fumigant.

On the horizon. . .

- In my original GCSAA funded project, I tested a fumigant that I called MBA #300.
  - I recently disclosed that MBA #300 was Vorlex.
  - Vorlex was a mixture of AITC, 1,3-dichloropropene (Curfew/Telone), and chloropicrin.

On the horizon. . .

- AITC is considered “organic” and has a food crop label.
  - AITC does not require Fumigant Management Plans to be in place – but, they will be required if 1,3-D or PIC is added.
- We plan to continue evaluation of this material.

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J. Bryan Unruh, Ph.D.
West Florida Research and Education Center
University of Florida/IFAS
jbu@ufl.edu