Turfgrass
Fertilizers and Management

The 2016 SC Turf School
Feb. 15-18th

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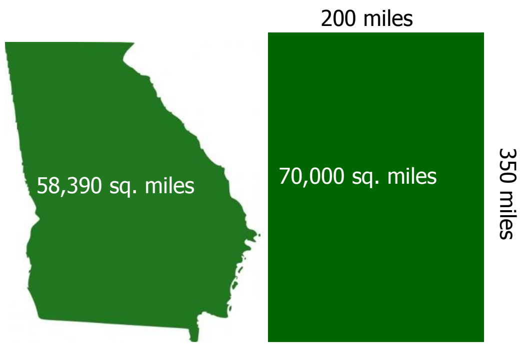
CLEMSON TURFGRASS SCIENCE

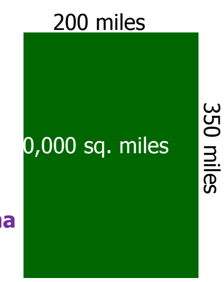
How about to reduce 10% of the total N input to all turf areas in US?

If 10% of total N will be reduced, how many tons nitrate-N free water will be saved?

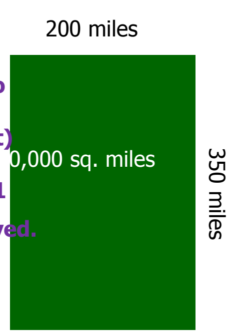


1 sq. mile = 640 acres
70,000 X 640 = 45,000,000 acres
I ha = 2.47 acres
45,000,000/2.47
= 18,220,000 ha

If annual N input is 150 kg/ha (about 3 lb N/1,000 sq. ft)
The total N input is
About 18.22 million x 150
= 27.22 billion kg N!
Or 2.722 million tons of N



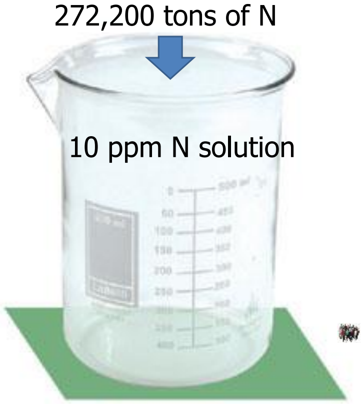
If annual N input reduced to 135 kg/ha
(about 2.7 lb N/1,000 sq. ft)
The total saved N input is
2.722 million tons of N X 0.1
=272,200 tons of N saved.

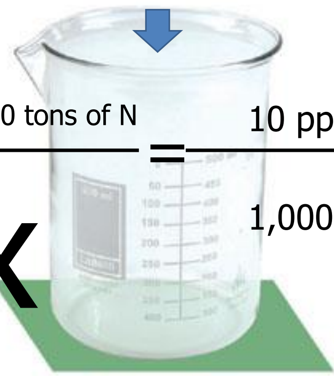


272,200 tons of N

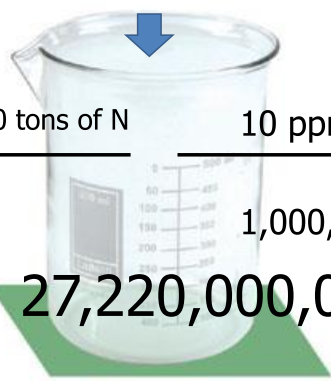
272,200 tons of N

272,200 tons of N





$$\frac{272{,}200 \text{ tons of N}}{X} = \frac{10 \text{ ppm N}}{1{,}000{,}000}$$



$$\frac{272{,}200 \text{ tons of N}}{\quad} \qquad \frac{10 \text{ ppm N}}{1{,}000{,}000}$$

$$X = 27{,}220{,}000{,}000$$

U.S. 322,937,637
(0.322 billions)
The World
7,303,215,319
(7.303 billions)
Feb. 4th, 2016 6:00am

US - 27.22 billion/0.322
= 84.53 tons/year
The World - 27.22/7.303
=3.73 tons/year

What 3.73 tons = ?

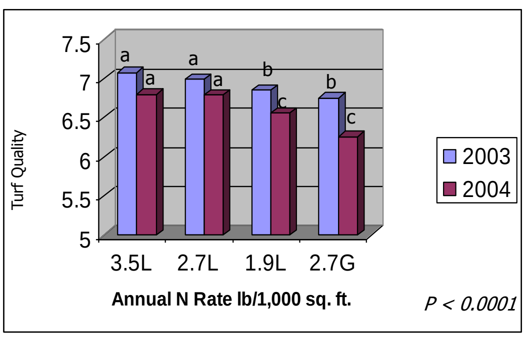
= 6301 bottles of 20 oz water

6301/365 = 17.26 bottles/day

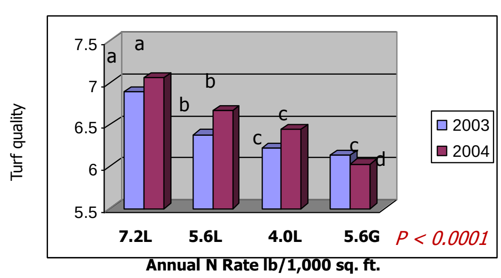
Mississippi River average flowing volume is 18,000 tons/second. 27.22 billions of water equal Mississippi River runs 16 days no stop

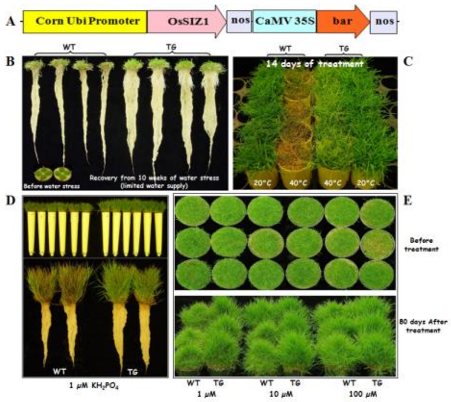
Mississippi River average flowing volume is 18,000 tons/second. 27.22 billions of water equal Mississippi River runs 16 days no stop

L-93 Creeping Bentgrass Turf Quality May to November



TifEagle Bermudagrass Turf Quality June to September



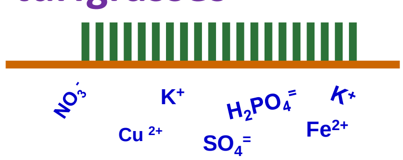


Current P work at Clemson

OBJECTIVES

- Nutrients required by turfgrasses
- Nutrient availability
- Types of turf fertilizers
- Choosing right products
- Application techniques

Nutrients required by turfgrasses



Essential elements

Turfgrasses require
17 essential elements:
The 3 elements from air and water

Carbon	C
Hydrogen	H
Oxygen	O

C + H + O = 95% of the dry weight
The rest 14 elements are from soils

Mineral nutrients

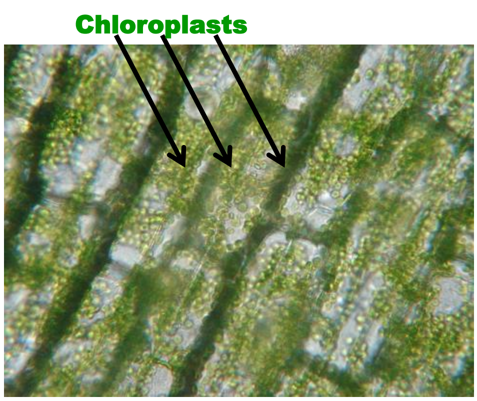
Primary nutrients: 0.2 to 6%
N, P, and K
Secondary nutrients: 0.1 to 1.0%
Mg, Ca, and S
Micronutrients: 0.0001 to 0.05%
Fe, Mn, Cu, Zn, B, Mo, Cl, and Ni

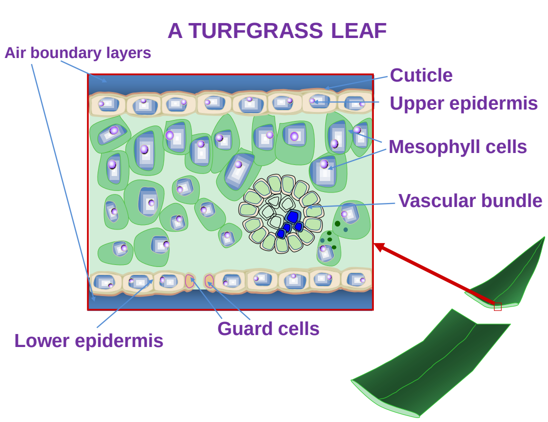
Primary nutrients - 1

Nitrogen:
3 - 6% in dry tissue
NO_3^- , NH_4^+ , and urea
Mobile in turfgrasses and soils
Most frequently deficient
Older leaves turn yellow
and reduced shoot growth

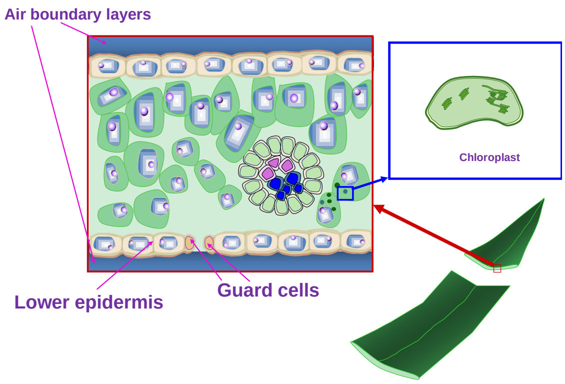
Functions of Nitrogen in Plants

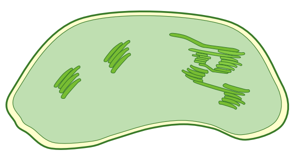
- Chlorophylls
- Proteins
- DNA, RNA
- Hormones
- Secondary metabolites



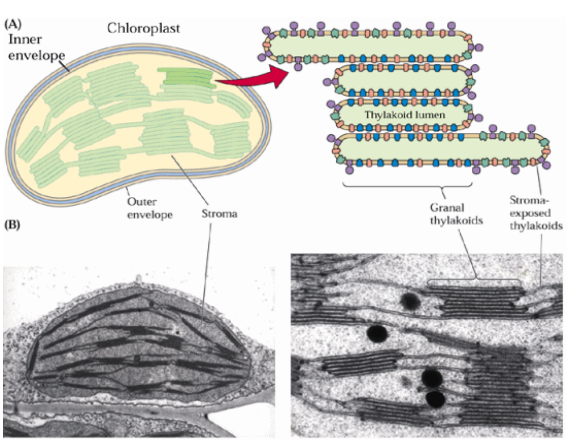


A TURFGRASS LEAF





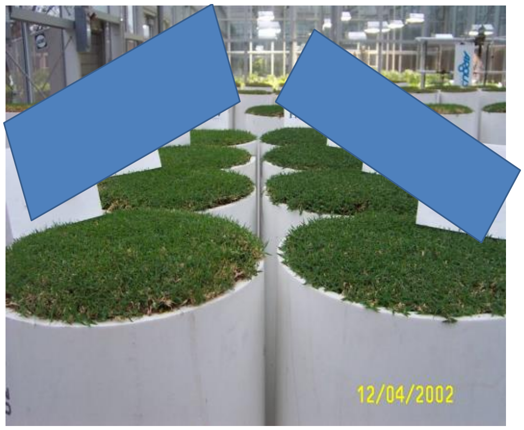
Chloroplast



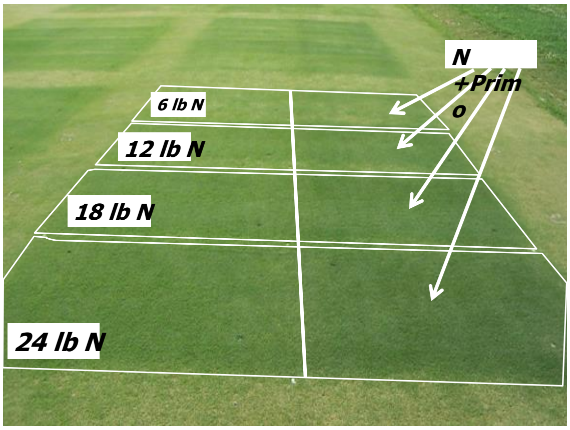
Symptoms of N Deficiency


03/01/2003


N24
N12 +
Primo
03/01/2003


12/04/2002


N6
N12
N18
N24
N24 +
Primo
N18 +
Primo
N12 +
Primo
N6 +
Primo
12/04/2002



Primary nutrients - 2

***Phosphorus*:**

0.2 - 0.6% in dry tissue

$H_2PO_4^-$ and $HPO_4^=$

Mobile in turfgrasses but immobile in soils

Second most frequently deficient

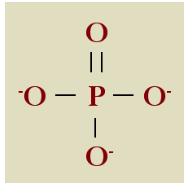
Older leaves turn dark green and purple or reddish

Phosphorus

- **No major gaseous forms**
  - **unlike C, N, and S**
- **Movement of P from terrestrial to aquatic systems is very important ecologically**
- **Humans have greatly altered P cycling**
  - **Mining, application of P fertilizers, manure management, accelerated erosion**

Nomenclature

Ortho-phosphate



phosphates HPO_4^{-2} $H_2PO_4^{-1}$

Phosphite HPO_3^{-}

Nomenclature (continued)

H_3PO_4 = phosphoric acid

$H_2PO_4^{-}$ = monobasic

HPO_4^{-2} = dibasic

PO_4^{-3} = tribasic

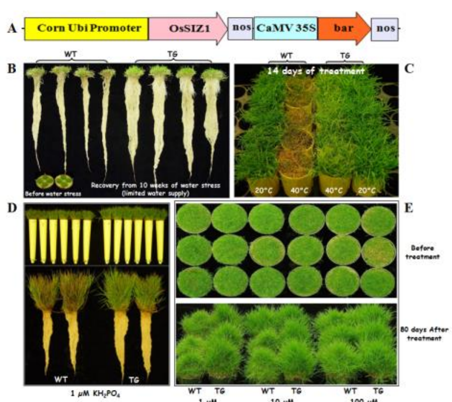
P_2O_5 = phosphorus pentoxide

Phosphorus Function

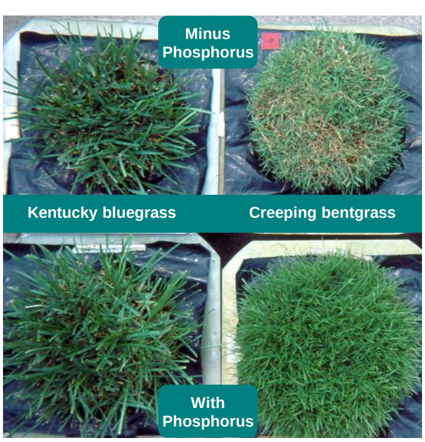
- ATP, ADP- “energy units”
- DNA, RNA -genetic "memory unit"

Phosphorus Sufficiency Levels

▪ Bentgrass	0.30 – 0.60%
▪ Bermudagrass	
Greens	0.25 – 0.60%
Fairways	0.15 – 0.50%
▪ Tall fescue	0.30 – 0.45%
▪ Perennial ryegrass	0.30 – 0.50%



Current P work at Clemson



Primary nutrients - 3

***Potassium*:**

1 - 4% in dry tissue

K^{+}

Mobile in turfgrasses and soils

Third most frequently deficient

Interveinal yellowing on older leaves

Role of Potassium in Plants

- Photosynthesis
- Translocation of photosynthates
- Protein synthesis
- Control of ionic balance
- Regulation of plant stomata and water use
- Activation of plant enzymes (>60)
- Stress resistance enhancement
  - Drought
  - Cold, Heat
  - Salinity
  - Pests …

K regulates stomata opening and closure

Bethea, 2012 unpublished

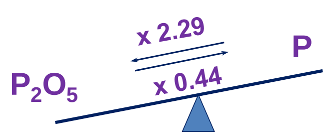
Agricultural Crop K Deficiency Symptoms

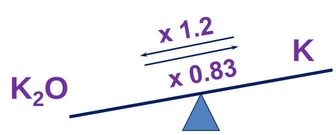
Fertilizer's Analysis

N : P : K - used to be
N: P_2O_5: K_2O - now commonly used

20 - 10 - 10
10 - 10 - 10

Useful Conversions

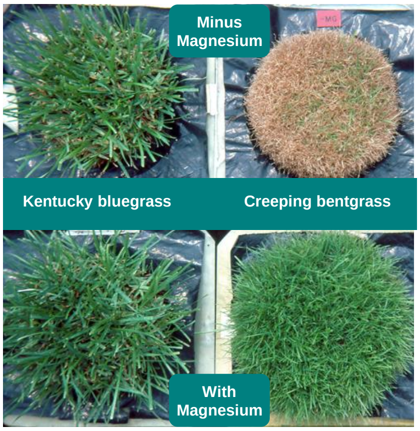




Secondary nutrients - 1

***Magnesium*:**

0.1 – 1.0% in dry tissue
Mg^{2+}
Mobile in turfgrasses and soils
Frequently deficient at low soil pH and low CEC
Red leaf margins and striped chlorosis



Secondary nutrients - 2

***Calcium*:**
0.1 - 0.5% in dry tissue
Ca^{+2}
Immobile in turfgrasses and soils
Frequently deficient at low soil pH and low CEC
Young leaves turn to reddish brown
Excess Ca can cause Mg and K deficiency

Gypsum

$CaSO_4$

$\neq$ pH

Improvement of soil salinity

- Use salt tolerant crops
- Deep Irrigation
- Chemical application: $CaSO_4.2H_2O$ (gypsum)

Clay Na^+ Na^+ Ca^{2+} Mg^{2+} Na^+ $+ Ca^{2+} + SO_4^{2-} =$ Clay Ca^{2+} Ca^{2+} Mg^{2+} Na^+ $+ 2Na^+ + SO_4^{2-}$

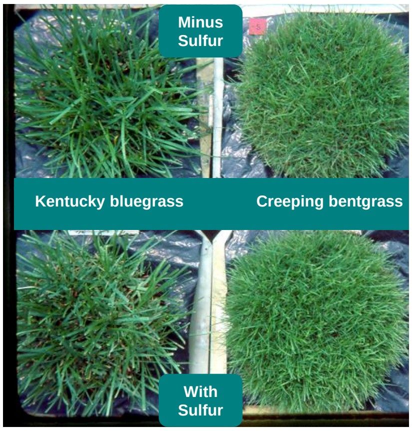
Increase Soil pH - More Alkaline

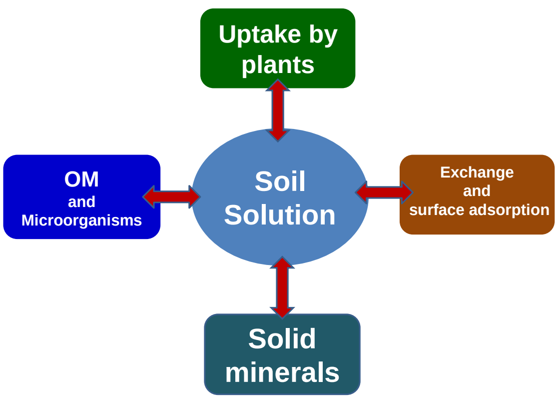
Lime Materials
CaO, $Ca(OH)_2$, $CaCO_3$, $CaMg(CO_3)_2$

$CaCO_3 + 2H^+ = Ca^{2+} + H_2O + CO_2$
$CaO + 2H^+ = Ca^{2+} + H_2O$
$Ca(OH)_2 + 2H^+ = Ca^{2+} + 2H_2O$
$CaMg(CO_3)_2 + 4H^+ = Ca^{2+} + Mg^{2+} + 2H_2O + 2CO_2$

Secondary nutrients - 3

***Sulfur*:**
0.2 - 0.6% in dry tissue
SO^{-2}
Mobile in turfgrasses and soils
Rarely deficient
Yellowing of older leaves similar to N deficiency





Micronutrients

		Available form being taken up by plants	Dry wt. ppm
Chlorine	Cl	Cl^-	100-200
Iron	Fe	Fe^{2+}, Fe^{3+}	100-200
Boron	B	$B(OH)_3$ (Boric acid)	20-40
Manganese	Mn	Mn^{2+}	30-70
Zinc	Zn	Zn^{2+}	20-50
Copper	Cu	Cu^{2+}	5-20
Molybdenum	Mo	MoO_4^{2-}	0.1-2
Nickel	Ni	Ni^{2+}	0.01-10

The above 8 elements are micro-nutrients for plants.
Crops often do not require application of micro-nutrients

Micronutrient Concentrations In Plants and Soil

		Dry wt. in plants ppm	In Soils ppm
Chlorine	Cl	100-200	50-500
Iron	Fe	100-200	20,000-50,000
Boron	B	20-40	20-200
Manganese	Mn	30-70	500-5,000
Zinc	Zn	20-50	17-160
Copper	Cu	5-20	5-50
Molybdenum	Mo	0.1-2	0.8-3.3
Nickel	Ni	0.01-10	5-100

Micronutrients

		Available form being taken up by plants	Dry wt. ppm
Iron	Fe	Fe^{2+}, Fe^{3+}	100-200
Manganese	Mn	Mn^{2+},	30-70
Zinc	Zn	Zn^{2+}	20-50
Copper	Cu	Cu^{2+}	5-20
Nickel	Ni	Ni^{2+}	0.01-10
Chlorine	Cl	Cl^-	100-200
Boron	B	$B(OH)_3$ (Boric acid)	20-40
Molybdenum	Mo	MoO_4^{2-}	0.1-2

The above 8 elements are micro-nutrients for plants.
Crops often do not require application of micro-nutrients

Micronutrients - 1

***Iron*:**

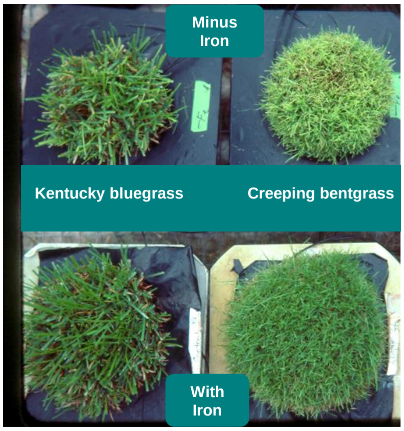
0.005 - 0.05% in dry tissue

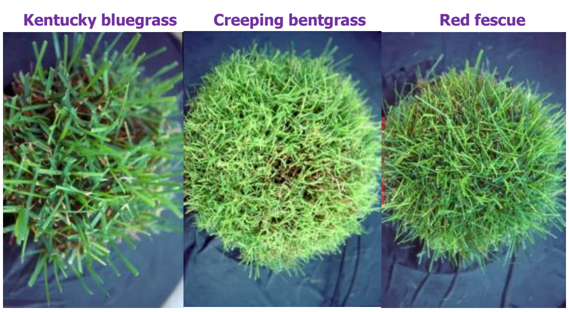
Fe^{3+} and Fe^{2+}

Immobile in turfgrasses and soils

Frequently deficient after N, P, and K and at high soil pH

Young leaves turn yellow





Iron Deficiency of Three Cool Season Turfgrasses

Micronutrients - 2

***Manganese*:**

< 0.01% in dry tissue

Mn^{+2}

Immobile in turfgrasses and soils

Rarely deficient

Young leaves turn yellow

Micronutrients - 3

***Zinc*:**

< 0.01% in dry tissue

Zn^{+2}

Mobile in turfgrasses and soils

Rarely deficient

Growth stunted and thin leaves

Micronutrients - 4

Boron	B	$H_2BO_3^-$
Copper	Cu	Cu^{2+}
Molybdenum	Mo	$MoO_4^=$
Chlorine	Cl	Cl^-
Nickel	Ni	Ni^{2+}

<0.001% in dry tissue

Rarely deficient

Nutrient availability

Nutrient availability

Soil conditions
- pH
- CEC
- C:N ratio (50:1)
- Salinity

Mobility of nutrients

Turfgrasses

Types of turf fertilizers

Types of turf fertilizers - 1

- Quick-release N fertilizers
- Slow-release N fertilizers
- Coated fertilizers
- Natural organics
- Fertilizer/pesticide combinations

Types of turf fertilizers - 2

Quick-release N fertilizers

Ammonium nitrate	33 - 0 - 0
Ammonium sulfate	21 - 0 - 0
Calcium nitrate	16 - 0 - 0
Diammonium phosphate	20 - 50 - 0
Potassium nitrate	13 - 0 - 44
Urea	46 - 0 - 0

Types of turf fertilizers - 3

Slow-release N fertilizers

Urea formaldehyde (UF)	38 - 0 - 0
Methylene urea (MU)	40 - 0 - 0
Isobutylidene diurea (IBDU)	31 - 0 - 0

Types of turf fertilizers - 4

Coated fertilizers

Sulfur-coated ureas (SCU)

Polymer-coated ureas (PCU)

Stabilized urea (SU)

Types of turf fertilizers - 5

Natural organics

Sewage-based materials
- Milorganite

Animal by-products
- Sustane

Plant by-products
- Corn gluten meal

Types of turf fertilizers - 6

Fertilizer/Pesticide

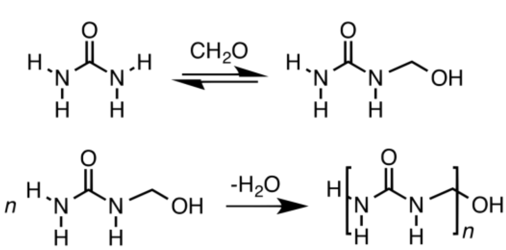
Herbicides

Insecticides

Fungicides

*Timing!!!

Urea-formaldehyde (UF)



Urea formaldehyde (UF)

- Urea formaldehyde
- Insoluble organic
- 38% N; 65-71% WIN
- Biological N release
  - Rate influenced by soil temperature

Urea formaldehyde (UF)

- UF was first synthesized in 1939 but did not become popular until the mid-1950's.
- The nitrogen contained in UF can be separated into three groups based on solubility.

Different Carbon Chain Lengths

Methylene Urea

N-C-N

N-C-N-C-N-C-N

Urea Formaldehyde

N-C-N

N-C-N-C-N-C-N-C-N-C-N

N-C-N-C-N-C-N-C-N-C-N-C-N-C-N

N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N

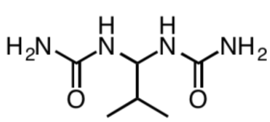
N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N-C-N

Slow Release N Fertilizer Activity Index

- The UF material is generally rated by an activity index (AI)
- The higher the AI, the more rapidly nitrogen is solubilized
- The AI should be 40% or greater

$$AI = \frac{CWIN - HWIN}{CWIN \times 100}$$

Isobutylidene Diurea IBDU ($C_6H_{14}N_4O_2$)



Isobutylidene diurea IBDU

- Only a single chemical product is formed, not a bunch of different molecules. 31% N, 90% WIN
- Different sized granules available
- IBDU differs from the UF in that the molecule is uniform.
- IBDU is only slightly influenced by temperature, and the lack of solubility is primarily dependent on particle size.

Isobutylidine diurea IBDU

- Plant-available nitrogen of IBDU results from chemical rather than microbial hydrolysis of the carrier.
- Low pH and high moisture favor solubilization.

Choosing right products

Choosing right products

Factors need to consider

- Turfgrasses
- Soil conditions
- Salty or acidifying fertilizers
- Costs
- Equipments
- Timing

Nitrogen needs of Warm-season Turfgrass species

Bermudagrass
St. Augustinegrass
Zoysiagrass
Seashore paspalum
Centipedegrass
Bahiagrass
Buffalograss

High

Low

Application techniques

Liquid Fertilization – Foliar Applications

- **Quick correction of nutrient deficiency**
- **Lower potential of leaching losses**
- **Lower potential of losses picked up by next mowing**

Fertigation – Foliar Applications

Application techniques -1

- Rates
- Timing
- Liquid application
- Fertigation
- Granular application

Application techniques -2

- 2 to 6 lbs N/1000 sq. ft./year
- Never apply more 1 lb N/1000 sq. ft. per application
- N: P: K = 4:1:3
- Do not fertilize cool-season turf in the middle of summer
- Do not fertilize warm-season turf in the late fall
- Spoon-feeding

Poor Fertilizer Application

Poor Fertilizer Application

Poor and uneven Fertilizer Application


Excessive urea input

Importance of Tissue Testing

Tissue testing is a process to analyze various nutrient concentrations of plant samples collected at a specific time during the growing season.

For turfgrasses, the tissue samples are often clippings.

Comparisons of

Soil testing	Tissue testing
Predictive	Diagnostic
Nutrient supply	Nutrient uptake
Fertilizer need	Problem solving
Monitoring	Monitoring

Soil testing and tissue testing are complementary but can not replace each other

Necessity of Tissue Testing

Tissue testing will determine:

- **Each nutrient concentration in plants**
- **Nutrient deficiency**
- **Element toxicity**
- **Potential nutrient deficiency**
- **Performance of the applied fertilizer**
- **Future fertilization recommendation**

Essential components of a successful tissue testing program:

- **Representative samples**
- **Proper sample preparation**
- **Accurate analysis**
- **Correct interpretation of the results**
- **Complementary with soil testing**
- **Proper recommendations**

A reel mower with a basket is used for clipping collection

The basket should be thoroughly cleaned between samples

Clippings should be carefully put into paper bags

Lunch bag is perfect for the job

Items needed to clean clipping samples

Put the clipping samples in the container with clean water added

A jar can be used to float the clippings for 30 seconds to let sand particles precipitated to the bottom. Then carefully screen the samples to let the sample dry.

Times and Frequency of Tissue Testing

- Two to three times a growing season
- Warm-season turfgrasses:
  May –Early September
- Cool-season turfgrasses:
  April, July, and October

NUTRIENT SUFFICIENCY LEVELS FOR BERMUDAGRASS

N(%) 3.0 - 4.0	Ca(%) 0.25-0.50
P(%) 0.20-0.40	Mg(%) 0.15-0.30
K(%) 1.8-2.25	S(%) 0.15-1.30
Zn(ppm) 15-70	Fe(ppm) 50-250
Cu(ppm) 5-20	Mn(ppm) 20-300
B(ppm) 6-60	

A few facts

- Cool-season turfgrasses tend to have higher nutrient concentrations Than warm-season turfgrasses
- Spring seasons tend have higher nutrient concentrations than other seasons
- Younger tissues tend to have higher nutrient concentrations than older tissues.

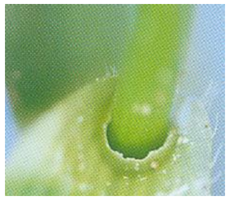
Major factors affecting tissue testing results

- Fertilization input
- Fertility level of the soil
- Turfgrass species or cultivars
- Sample handling
- Accuracy of analysis
- Seasons of growth
- Management practices

A few things to consider when collecting and submitting tissue samples

- Make sure there is no contamination
- Make sure the collected tissues are not affected by other pests
- Keep tissues dry
- Collect more than one samples (normal and an abnormal one)
- Make sure to have enough samples
- Use paper bags
- Label the bag clearly

Tall Fescue
(*Festuca arundinacea*)



Tall fescue distribution in the USA

Tall Fescue
- Identifying characteristics

Vernation:	Rolled
Ligule:	Membranous, very short (1 mm)
Collar:	Broad, continuous
Auricles:	very short
Leaf Blades:	Flat and rough (5 to 10 mm), pointed tip
Stem:	bunch
Seed head:	Compressed panicle

Tall fescue
-Cultivars

Common Cultivars

Kentucky 31, Alta

Tall fescue
-Cultivars

Turf-type Cultivars

Avanti, Rebel II, Silverado, Rebel Jr., Jaguar, Guardian, Mustang, Olympic, Olympic II…

Tall fescue

Future Improvement

Resistance to diseases

- Brown patch
- Rhizomatous

Heat resistance

Tall fescue affected by pythium blight

Tall fescue affected by brown patch

Tall fescue
Turf Appearance in May

A =urea	B =Nitamin	Control	C = NitaminF
B = Nitamin	Control	C = NitaminF	A = urea
C = NitaminF	A = urea	B = Nitamin	Control

Tall fescue Turf Appearance in June

A =urea	B =Nitamin	Control	C = NitaminF
B = Nitamin	Control	C = NitaminF	A = urea
C = NitaminF	A = urea	B = Nitamin	Control

Tall fescue Turf Appearance in July

A =urea	B =Nitamin	Control	C = NitaminF
B = Nitamin	Control	C = NitaminF	A = urea
C = NitaminF	A = urea	B = Nitamin	Control

Tall fescue Turf Appearance in July + Aug.

A =urea	B =Nitamin	Control	C = NitaminF
B = Nitamin	Control	C = NitaminF	A = urea
C = NitaminF	A = urea	B = Nitamin	Control

Tall fescue Turf Appearance in July, Aug. and Sept.

A =urea	B =Nitamin	Control	C = NitaminF
B = Nitamin	Control	C = NitaminF	A = urea
C = NitaminF	A = urea	B = Nitamin	Control

A Golf Course Putting Green Micronutrient – Nickel, It's Significance and Potential

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- Cliffs Communities
- USGA Green Section
- Carolinas Golf Course Superintendents Association

USGA

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Acknowledgments

- Dr. Hong Luo, Dr. Sam Sparace, and Dr. Zhigang Li for the enzymatic work in their labs and their helps
- Dr. Richard Hull for his input and consulting on the subject
- Dr. Christian Baldwin at Mississippi State, and Dr. Travis Gannon at NCSU for soil sample collections
- Many superintendents and industry's support on the subject

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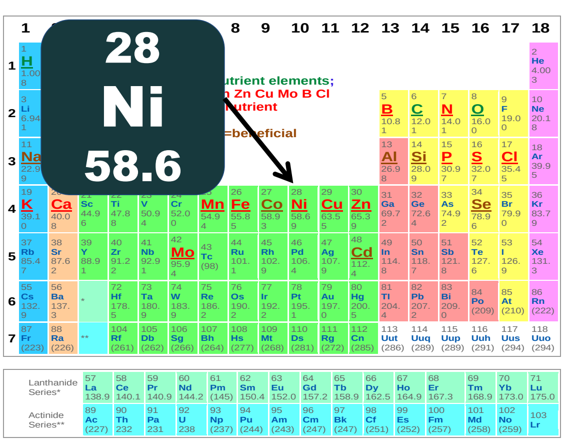
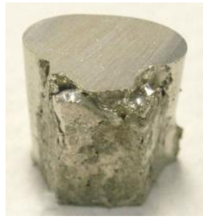
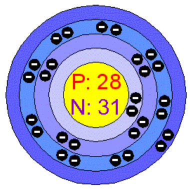


Nickel

Symbol: Ni
Atomic Number: 28
Atomic Mass: 58.6934 amu
Melting Point: 1453.0 ° C (1726.15 K, 2647.4 ° F)
Boiling Point: 2732.0 ° C (3005.15 K, 4949.6 ° F)
Number of Protons/Electrons: 28
Number of Neutrons: 31
Classification: Transition Metal
Crystal Structure: Cubic
Density @ 293 K: 8.902 g/cm^3
Color: white





Ni Functions in Plants

- Nickel is a functional constituent of seven enzymes.
- Among the seven, urease (i.e., urea amidohydrolase) is extremely important to N metabolism in plants.
- Urease assists in the hydrolysis of urea.
- Nickel works as a cofactor to enable urease to catalyze the conversion of urea into the ammonium ions, which plants can use as a source of N to start N assimilation regardless of foliar or root absorbed urea.

Nickel Nutrition

- Nickel (Ni) is an essential nutrient for plants
  - 25- 100 µg kg $^{-1}$ depending on N source and species (Gerendas and Sattelmacher, 1997b,1999)
- An important component of many enzymes
- Ni uptake is transported in transpiration stream
  - Chelated
- Ni in the environment is commonly found in the form of nickelous ion Ni^{2+}
  - Hydrated form Ni $(H_2O)_6^{2+}$ most abundant in soil solution
- Ni deficiency in natural soils is not common

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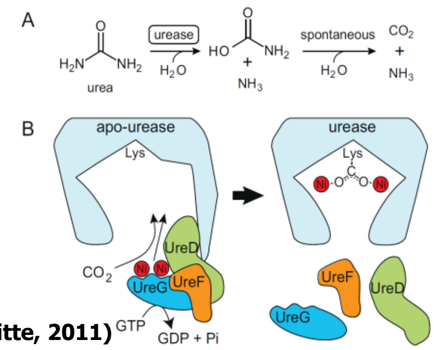

(Witte, 2011)

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Micronutrient Concentrations In Plants and Soil

		Dry wt. in plants ppm	In Soils ppm
Chlorine	Cl	100-200	50-500
Iron	Fe	100-200	20,000-50,000
Boron	B	20-40	20-200
Manganese	Mn	30-70	500-5,000
Zinc	Zn	20-50	17-160
Copper	Cu	5-20	5-50
Molybdenum	Mo	0.1-2	0.8-3.3
Nickel	Ni	0.01-10	5-100

Micronutrients

		Available form being taken up by plants	Dry wt. ppm
Chlorine	Cl	Cl^-	100-200
Iron	Fe	Fe^{2+}, $/Fe^{3+}$	100-200
Boron	B	$B(OH)_3$ (Boric acid)	20-40
Manganese	Mn	Mn^{2+}	30-70
Zinc	Zn	Zn^{2+}	20-50
Copper	Cu	Cu^{2+}	5-20
Molybdenum	Mo	MoO_4^{2-}	0.1-2
Nickel	Ni	Ni^{2+}	0.01-10

Severe leaflet tip necrosis due to nickel deficiency in nitrogen-fixing plants

Patrick Brown, University of California, Davis

+Ni **-Ni**

cowpea seedlings

Patrick Brown, University of California, Davis

Pecan Ni deficiency

M. L. Wells, University of Georgia,

Pecan (*Carya illinoinensis)*

(Bai et al.

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Pecan Ni deficiency

Bruce Wood, USDA-ARS, Byron, GA

In 1987, Ni was first established as a nutrient essential for completion of plant life cycle. Ni deficiency decreased the capacity of barley to develop viable seeds because of hindered embryo growth. The embryonic root developed poorly or even stayed undeveloped; in addition, several anomalies were reported in endosperm development together with declined dehydrogenase activities. The critical Ni concentration in barley tissues that reduced the yield by 15% was 90 ± 10 ng/g dry wt. (90 ppm)

Brown, P.H., Welch, R.M., and Cary, E.E., Nickel: A Micronutrient Essential for Higher Plants, Plant Physiol. , 1987, vol. 85, pp. 801–803

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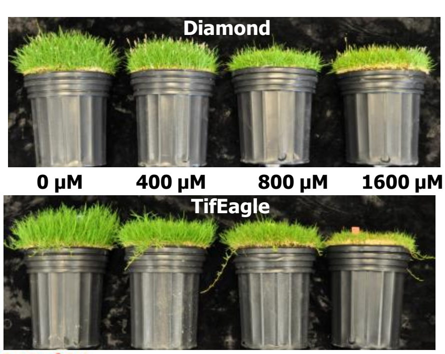
Brown, P.H., Welch, R.M., and Cary, E.E., Nickel: A Micronutrient Essential for Higher Plants, Plant Physiol. , 1987, vol. 85, pp. 801–803

Turfgrass Ni deficiency photos

???

Ni Toxicity Symptoms = 400uM of Ni =23.44 ppm of Ni



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Ni Toxicity Symptoms

Ni toxicity symptoms on leaf tissue of Diamond and TifEagle under1600 μM Ni treatments

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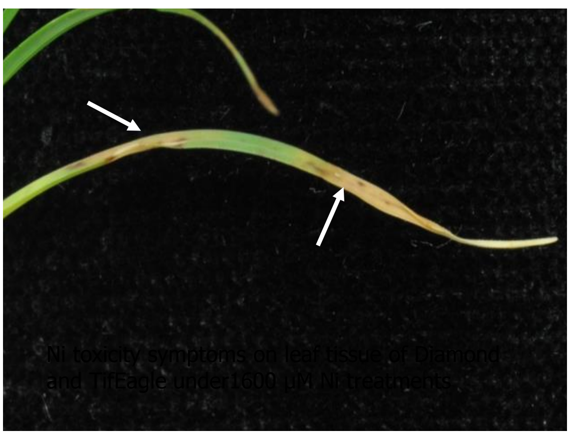

Three Putting Greens Soil Ni levels

TifEagle (established in 2002)
 0.6 ppm
Champion (established in 2002)
 0.9 ppm
Miniverde (established in 2004)
 0.7 ppm

The average CEC < 5 meq/100g

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Facts for warm-season putting green turfgrass nitrogen management

- Urea is the dominant foliar applied N form
- Internal urease must be active to hydrolyze urea before N assimilation for the taken up urea
- Nickel is the co-factor of urease, directly affect urea use efficiency for turfgrasses regardless of the flocculation of Ni in the environment
- Sand soil based greens lack of Ni
- Ni uptake is an active uptake (against

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Hypotheses

- Ni will enhance urase activity
- Ni will enhance the total amino acid content in two warm-season putting green turfgrasses
- Among USGA or pure sand putting greens, with low CEC, Ni is not sufficient and additional Ni application particularly with urea as a main N source (on-going)

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Experimental Design and Analysis

Greenhouse study

- Two turfgrass species
- Three Ni levels using hydroponic culture

Field Study

- TifEagle green more than 10 years old
- Four Ni levels and three urea levels

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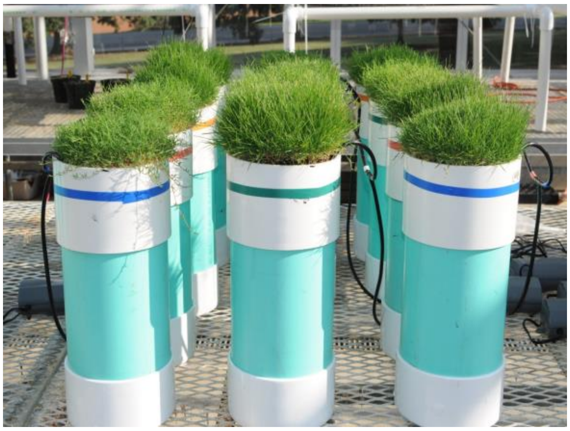

Parameters Measured

- Urease activity
- Amino acid content
- Turf Quality
- Chlorophyll Content

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Results and Discussion

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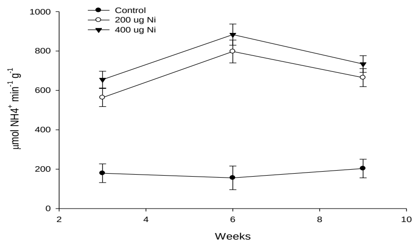
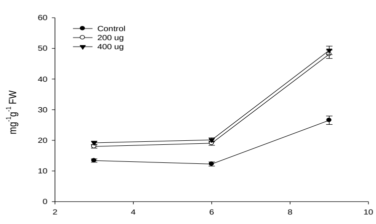
Urease activity of two turfgrasses



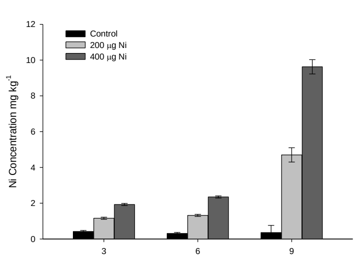
Urease activity (µmol NH_4^+ min^{-1} g^{-1}) in leaf tissue of 'Diamond'zoysiagrass and 'TifEagle' bermudagrass as influenced by Ni level in the Clemson University greenhouse research

Amino Acid Content of two turfgrasses



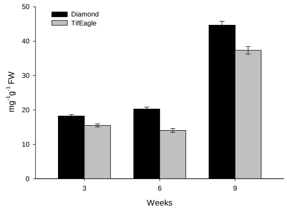
Total amino acid content (mg g^{-1} FW) in leaf tissue of 'Diamond' zoysiagrass and 'TifEagle' bermudagrass as influenced by Ni level in the Clemson University greenhouse research

Ni Concentration in Leaf Tissue



Ni concentration (mg kg^{-1}) in leaf tissue of 'Diamond' zoysiagrass and 'TifEagle' bermudagrass in the Clemson University greenhouse research complex over three harvest dates during 2011. Means were separated at P≤0.05 by protected LSD.

Amino Acid Content and Nitrogen Concentration in leaf tissue



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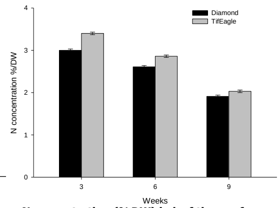
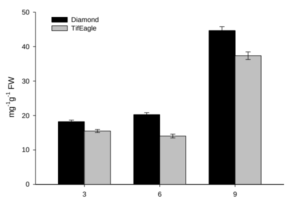


N concentration (%DW) in leaf tissue of 'Diamond' zoysiagrass and 'TifEagle' bermudagrass in the Clemson University greenhouse research complex over three harvest dates during 2011. Means were separated at P≤0.05 by protected LSD.

Amino Acid Content and Nitrogen Concentration in leaf tissue



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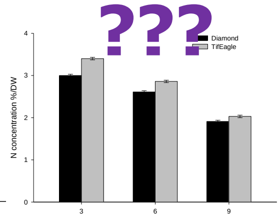

N concentration (%DW) in leaf tissue of 'Diamond' zoysiagrass and 'TifEagle' bermudagrass in the Clemson University greenhouse research complex over three harvest dates during 2011. Means were separated at P≤0.05 by protected LSD.

Effects of Urea and Nickel on TifEagle Bermudagrass Putting Green Performance in the Transition Zone

2014 TifEagle Tissue Ni Concentrations

Urea (kg N/ha)	Nickel (kg/ha)	Ni (ppm) July	Ni (ppm) Aug.	Ni (ppm) Sept.
85	0	7 e	6 d	4 g
	3	26 d	24 c	57 f
	6	36 c	41 b	110 d
	12	53 a	67 a	217 a
170	0	7 e	5 d	5 g
	3	22d	26 c	59 f
	6	35 c	40 b	102 de
	12	49 a	62 a	200 b
255	0	7 e	4 d	4 g
	3	24 d	23 c	53 f
	6	32 c	40 b	93 e
	12	43 b	60 a	176 c
Urea		*	NS	***
Nickel		***	***	***
Urea*Nickel		NS	NS	***

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Turf quality for TifEagle bermudagrass treated with Urea and Nickel from June to September, 2014.

Urea (kg N/ha)	Nickel (kg/ha)	Turf Quality[z] July	Turf Quality[z] August	Turf Quality[z] September
85	0	5.58 e[y]	5.17 f	5.42 g
	3	6.17 bcd	6.33 de	6.67 ef
	6	6.17 bcd	6.33 de	6.83 def
	12	5.58 e	6.16 e	6.33 f
170	0	6.58 abc	6.83 cd	6.92 cdef
	3	6.08 cde	6.75 cd	6.92 cdef
	6	6.50 abc	7.42 ab	7.58 ab
	12	5.92 de	7.17 bc	6.75 ef
255	0	6.92 a	7.58 ab	7.50 abc
	3	7.00 a	7.92 a	7.75 a
	6	6.67 ab	7.25 bc	7.08 bcde
	12	6.08 cde	7.92 a	7.42 abcd
LSD[x]		0.58	0.57	0.62
Source of variation				
Urea		***	***	***
Nickel		**	**	**
Urea*Nickel		NS	**	***

, * Significant at 0.01, 0.001 probability levels.
[z]Turf quality was rated weekly on a 1-9 scale with 9 being dark green turf and 1 being dead turf with >6 being acceptable.
[y]Values within a column followed by the same letter are not significantly different at P≤0.05 by protected LSD.
[x]Fisher's protected least significant difference at P≤0.05.
Notes: Urea and Nickel combined solutions were applied bi-weekly from June 19th, 2014 in total of 7 times.

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170	0	6.58 abc	6.83 cd	6.92 cdef
	3	6.08 cde	6.75 cd	6.92 cdef
	6	6.50 abc	7.42 ab	7.58 ab
	12	5.92 de	7.17 bc	6.75 ef
255	0	6.92 a	7.58 ab	7.50 abc
	3	7.00 a	7.92 a	7.75 a
	6	6.67 ab	7.25 bc	7.08 bcde
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Chlorophyll index for TifEagle bermudagrass treated with Urea and Nickel from June to September, 2014.

Urea (kg N/ha)	Nickel (mg/kg)	Chlorophyll Index[z]		
		July	August	September
85	0	201.25 d[y]	253.75 f	246.75 f
	3	250.75 bc	302.75 e	309.00 de
	6	254.25 bc	309.25 e	322.75 cde
	12	253.00 bc	298.50 e	321.25 cde
170	0	240.25 c	317.75 de	301.25 e
	3	247.50 bc	323.50 cde	323.50 cde
	6	271.25 ab	361.25 ab	352.00 ab
	12	261.50 bc	342.00 bcd	342.50 abc
255	0	257.75 bc	349.25 bc	323.75 cde
	3	270.50 ab	366.50 ab	330.50 bcd
	6	256.75 bc	354.50 b	330.50 bcd
	12	290.50 a	390 a	363.00 a
LSD[x]		28.00	28.86	25.21
Source of variation				
Urea		***	***	***
Nickel		***	***	***
Urea*Nickel		NS	*	**

*, **, *** Significant at 0.05, 0. 01, 0.001 probability levels.

[z]Chlorophyll index was measured monthly using a Field Scout CM 1000 Chlorophyll Meter with a 0-999 scale of total amout of chlorophyll in the plant tissue.

[y]Values within a column followed by the same letter are not significantly different at P≤0.05 by protected LSD.

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	3	247.50 bc	323.50 cde	323.50 cde
	6	271.25 ab	361.25 ab	352.00 ab
	12	261.50 bc	342.00 bcd	342.50 abc
255	0	257.75 bc	349.25 bc	323.75 cde
	3	270.50 ab	366.50 ab	330.50 bcd
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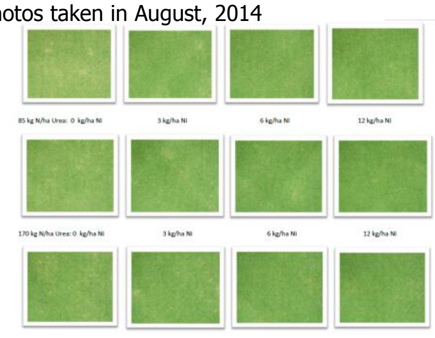
Photos taken in August, 2014



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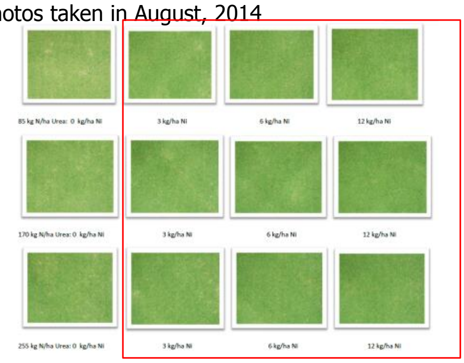

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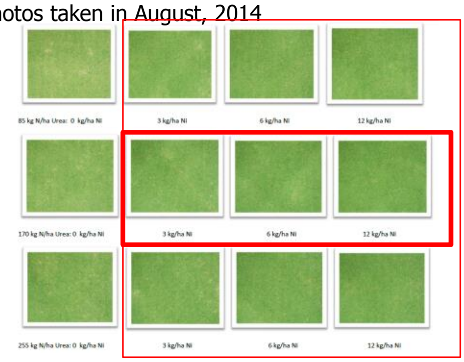

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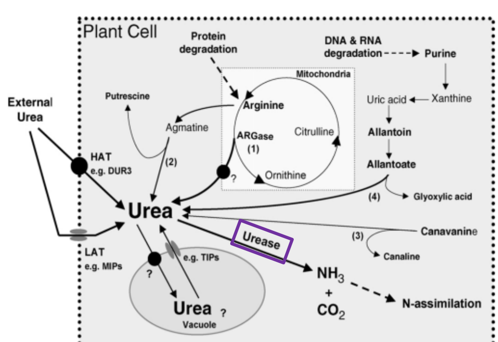

(Wang et al., 2

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Conclusions

- Urease activity and N status in turfgrass
  - An overall decrease in N content in leaf tissue was observed over the course of the nine week study hydroponically
  - This finding could be the result of utilizing urea as the sole N source which can result in reduced growth and symptoms of N starvation in hydroponic cultures
- Ni supplementation
  - Increase in urease activity and amino acid content
  - Improve chlorophyll and turf quality
  - It should not be only based on soil test of Ni, it should be based on N forms applied to the turfgrasses.
- Repeated Ni supplementation in multiple years
  - Increase in urease activity and amino acid content, chlorophyll, and TQ
  - N content decrease in tissues was not found under field conditions with urea as the single N form
  - Glutamine synthetase activity will be monitored as well

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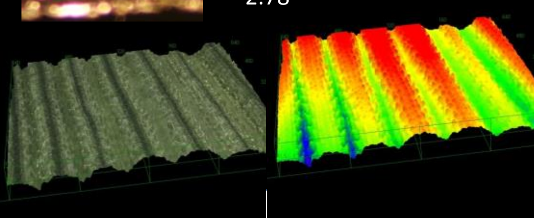
Hybrid Bermuda: TifEagle

- 1 uM (1/1000 ml) water droplet Contact Angle: 126.6º
- Leaf Surface Roughness: 2.78



Thank you very much! Questions?