Virginia Turfgrass Certification Manual









Virginia Cooperative Extension
Virginia Tech • Virginia State University

Virginia Turfgrass Council

DCR
Virginia Department of Conservation & Recreation

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Chapter 1. Turfgrass Identification

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Why bother identifying what grass you have? It's pretty much all the same isn't it? This is the usual reaction from someone (perhaps your supervisor, a customer, your greens committee chair, athletes using your field) that thinks "if it's all a green color, then you have done a good job". However, this is not always true. What if the "green" is only because of an invasion of short lived grassy weeds? Or because it's a newly planted lawn and the new grass will die soon because it is not adapted to the soil or climate.

Your career as a successful turfgrass manager depends upon you making the best choices in grassing at establishment or renovation. Your goal is to insure you provide a turfgrass area that is safe, vigorously growing, relatively pest free, sustainable and aesthetically pleasing, while being delivered using environmentally and economically sound practices. So much for the perception of being thought of as just a 'grass cutter'.

Knowledge is power is an old saying but it's true. You need to understand the grass you are managing so you can make the best decisions. Each turfgrass area is different and will have its' own "personality" (growing characteristics and requirements) because each will likely have a different mix or percentage of various turfgrasses and will have a different blend of light, soil and air movement. You will learn about these aspects and plenty more while you study this book.

This chapter is a quick overview of how to identify the most common turfgrasses used in the Mid-Atlantic region. It will cover the basic plant structures of the common turfgrasses that let you distinguish each species, the common misidentifications or 'look-a-likes' that can confuse you in identification, and give you the general characteristics to look for so that you can make some identifications from a distance, and others with the naked eye, and others with a hand lens..

First you need to realize that there are two major divisions of grasses based on their performance under different temperature regimens for the grasses that we grow in the Mid-Atlantic. We loosely define these categories as cool season grasses and the warm season grasses. The cool season species such as fescue, ryegrass, bentgrass, bluegrass and weedy grasses like orchardgrass and quackgrass grow best in the two cool seasons of the year –

COOL TRIVIA -

Cool season grasses are commonly called "C3" and warm season "C4". The numbers represent the number of carbon atoms in the first product of photosynthesis from each type of grass.

fall and spring, with an ideal temperature range of 60-75^{o}F. They struggle in the hot months of summer. Warm season species like bermudagrass, zoysia, St. Augustine, seashore paspalum, centipedegrass, and weedy species like crabgrass, goosegrass, and foxtail grow best in the heat and full sun of the summer (temperatures of 80-95^{o}F), but go dormant (or die if they are annuals) during the late fall and don't green again until the following spring. Timing of fertilizer, mowing and other cultural practices will be different for cool season and warm season species. So you need to know what grasses are in your turfgrass areas if you are to make the best decisions!

The Mid-Atlantic is in the "Transition Zone" which means that we can grow both cool season and warm season grasses in our region. It also means that the climate presents challenges for each type of grass when unfavorable seasons arrive. Excess heat and drought can seriously damage and/or kill cool season grasses and very cold winters can damage and/or kill warm season grasses. These conditions occur infrequently and randomly in our region, but often enough to make turfgrass managers worry about their areas each year.

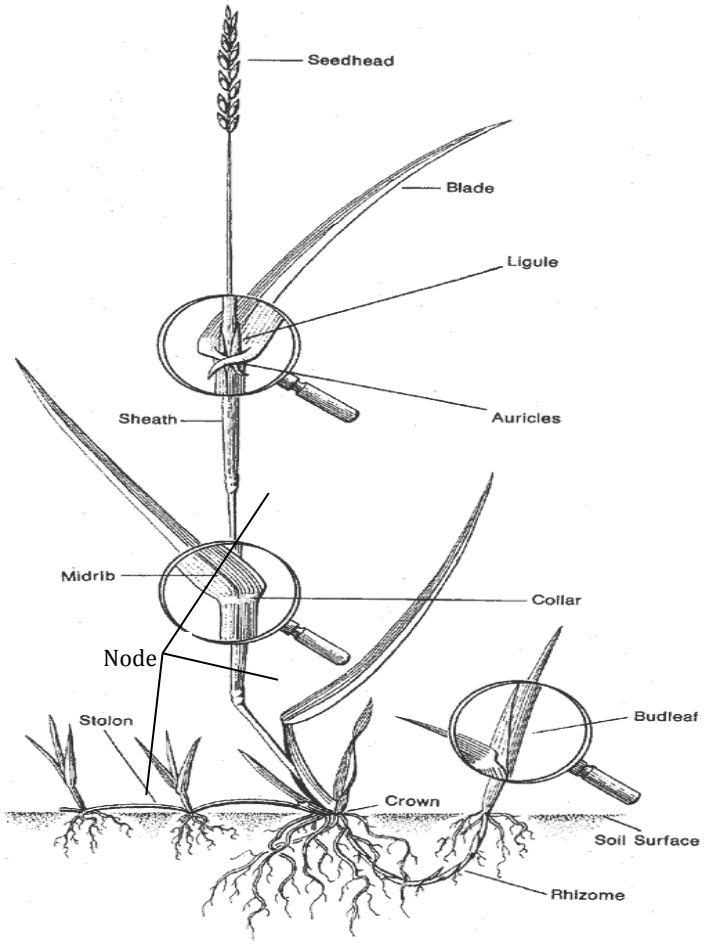


Figure 1. Line drawing for detailed grass plant parts. In many cases these parts are used in identification.

NOTE: Line drawings are used with permission from Scotts Company LLC, unless otherwise noted. Photos are from Sam Doak, unless noted.

The parts of a grass plant are detailed in Figure 1. Let's provide some basic definitions of each of these segments, working from the top of the plant to the bottom, and then more specific pictures and details follow in the text below.

The **seedhead** (also referred to as the **inflorescence**) is a reproductive structure of the plant, typically containing hundreds of tiny packets of growth potential by way of the seeds that are produced. (Note that not all turfgrasses produce viable seeds as some of our highest quality bermudagrasses can only be propagated by vegetative stems). The seedhead forms at the top of a specific stem called a **flowering culm** and is typically formed in response to some combination of temperature, moisture, day length, and/or environmental stress. The seedhead is the ultimate identification tool for grasses and the types of seedheads found on turfgrasses will be discussed in greater detail later.

The next four parts (**blade, ligule, auricle,** and **sheath)** all comprise the part of the plant that we spend the most time managing: the leaf. The blade is the top part of a leaf and the workhorse of the plant because it is what we run on, bounce balls on, clip, etc., as well as serving its role as the most important component of photosynthesis in the plant. It also is the part that gets us the most accolades in its management when it appears *en masse* with thousands of other leaves to form a thick dense canopy. At the juncture of the blade and the **sheath** (the basal portion of the leaf that is attached to the stem) (Figure 10) are two structures that may or may not be found depending on the species of grass. **Ligules** (Figures 6a and 6b) can be missing, membranous (aka plastic-like), hairy, or a combination of membranous/hairy for some species. Not a lot is known about the importance of ligules, but a ligule is an important identification feature. **Auricles** (Figure 7a and 7b) are arm-like extensions of the leaf blade that wrap around the stem. Most grasses either do not have auricles or they are so small they are hard to identify, but for those that do have auricles (annual rygrass and quackgrass), the auricles are an important vegetative identification feature. The picture also shows the location of specific growing points called **nodes** that are at the point of attachment of the leaf sheath to the stem. The area between nodes is called the **internode**, a structure that is very easy to see on lateral creeping stems such as **rhizomes** (below ground) and **stolons** (above ground) (Figure 11).

Two other parts of a leaf identified in the line drawing are the **mid-rib** (formed by a major vein in the leaf that transports water/nutrients in the leaf running horizontally down the middle of the leaf; it is typically prominent in plants that have folded **vernation**, (Figure 5) a term that refers to the arrangement of leaves as they emerge from the growing points) and the **collar** (Figure 8) (found at the junction of the blade and the sheath and typically denoted as being a small band of different colored leaf tissue that spans the width of the blade and sheath). Both of these features are used in the identification of specific grasses. The **crown** is a series of stacked nodes (i.e. growing points) that can give rise to new leaves, seedheads, stems, and roots, depending on the environment, the management of the turf, and the production of internal chemical signals being produced within plant tissues (**hormones,** many produced within the crown**)** that trigger various plant growth responses. Crowns are located at or just below the soil surface. The first leaf to emerge from a crown is called the **bud-leaf** and the leaf for various grasses emerges either by unrolling (referred to as **rolled vernation…** think of a barber pole spinning as a leaf unfurls itself during emergence) or by unfolding itself (referred to as **folded vernation**).

Figure 2. The tillering growth habit of a perennial ryegrass plant.



All grasses can produce stems that develop inside previously formed leaves that are called **tillers** (not pictured in Figure 1, but can be seen in Figure 2). An abundance of tillers leads to a very high density turfgrass canopy. Some grasses can produce either (or both) **stolons** (above ground stems with expanded internodes between growing points that produce leaves, roots, more stems etc; they are essentially vegetative carbon copies of the parent plant) and **rhizomes** (below ground stems that move away from the parent plant and when exposed to sunlight, produce a new shoot). The practical difference between a rhizome and a stolon is its location. If a rhizome is exposed to the light, it essentially becomes a stolon and if a stolon is buried in the soil, it behaves as a rhizome. Not all grasses can produce stolons and/or rhizomes, but those that do can be propagated vegetatively by using the ever growing network of creeping stems they form to provide a dense turfgrass canopy.

Figure 3. The distinct parallel veins of a tall fescue leaf surface (top) and "boat-shaped" tip of Kentucky bluegrass (bottom).



Practical Steps in Turfgrass Identification

First, look at the surface of the leaf blade. Is it smooth or ridged? Does it have parallel veins? Does it have a prominent mid-rib (mid-vein) running the length of the leaf blade? Smooth surfaced leaf blades are more common in grasses than parallel veins, so it is easier to remember which species are NOT smooth. Two species with distinct parallel veins on the surface are tall fescue (Figure 3) and creeping bentgrass.

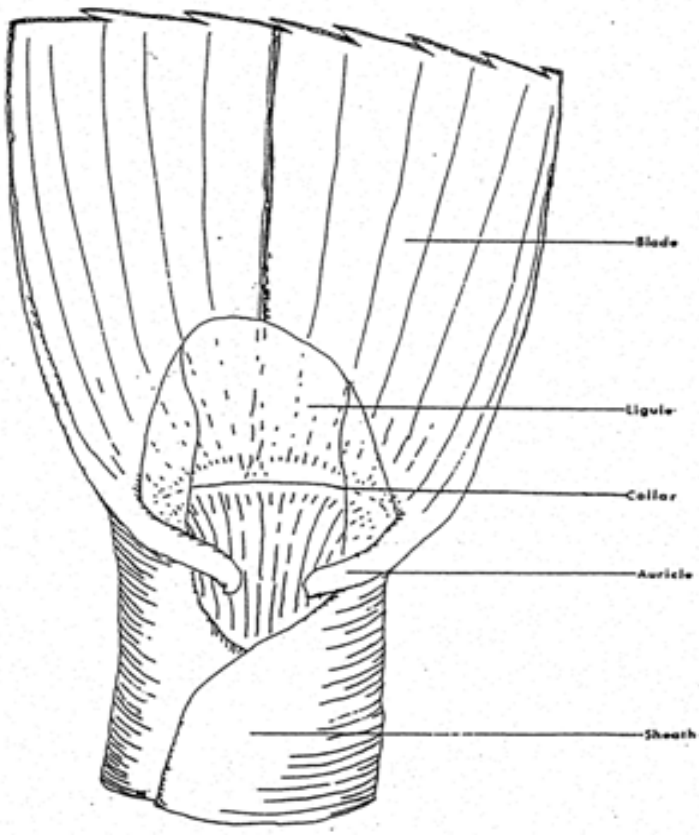
Another part of the leaf blade to examine is the tip of unmowed blades. Is it sharply pointed or is it 'keeled' (i.e. boat-shaped). For instance, Kentucky bluegrass has a very distinct boat-shaped leaf tip, perennial ryegrass comes more to a point, and tall fescue comes to a very distinct point. In the warm-season grasses, St. Augustinegrass has a boat-shaped leaf tip, centipedegrass is rounded but not typically keeled, and zoysiagrass is more distinctly pointed than bermudagrass.

Is the underside [adaxial surface] of the leaf blade shiny? The grasses that have a distinctly shiny underside of the blade are annual and perennial ryegrass.

Is the blade hairy? Most warm season turfgrasses have some level of hairs on their leaf surface and/or ligule, but there are always exceptions]

Seashore Paspalum – smooth surface
Bermudagrass – sparsely hairy
Zoysiagrass – sparsely hairy
Centipedegrass hairs along base and edges of leaf blade
Buffalograss- very hairy
Bahiagrass – sparsely hairy

Several distinct anatomical features provide a good basis for identifying grasses. These regions are: The bud-shoot, the blade, the ligule, the collar, the auricles, the sheath, and the roots. Recognition of these regions, and their variability, can aid in grass identification.



* Text in part from: "Some Grasses of the Northeast." C. E. Phillips. University of Delaware Field Manual no. 2. July. 1972.

Figure 4. Magnified line drawing of the collar region of a grass plant.

-Do the blade edges have a rough or toothy feel? If so, there is a strong possibility that you are looking at tall fescue. If the leaves are very soft to the touch, then you might be looking at creeping bentgrass.

Second, look at the intersection of the blade and the sheath. There are several structures or terms important for identification that occur at the juncture of the leaf blade and the sheath (Figure 4): vernation, collar, ligule and auricles.

VERNATION

Does the leaf blade appear to have a rolled or folded shape as it emerges?

A folded vernation has the leaves folded in a V-shape with the margins meeting, but not overlapping. A rolled vernation has the leaves curled such that the margins are overlapping.

Folded vernation is the standard for most turfgrasses, so it's easier to just remember which turfgrasses are rolled.

Rolled vernation in cool season grasses [C3]
- Tall fescue -other fescues are folded vernation
- Annual ryegrass
- Bentgrasses
- Quackgrass

Rolled vernation in warm season [C4]
- Zoysiagrass
- Seashore paspalum
- Buffalograss

Either **rolled or folded** vernation
- Bermudagrass
- Bahiagrass

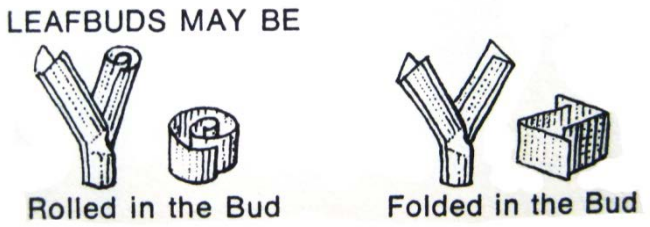


Figure 5. Line drawing depicting leaf vernation: rolled or folded.

Very compressed – very flat, like you took your fingers and flattened and slightly spread the intersection of the leaves and the stem
- Bahiagrass
- Centipedegrass

Also note that many weeds have rolled vernation and can be confused with turfgrasses
-foxtails, fall panicum, crabgrass and dallisgrass to name a few

Triangle shaped vernation means the plant is a **sedge,** not a grass
-sedges and kyllingas have triangle vernation

Ligules

Ligule. A protruding structure from the upper surface of the leaf where the blade and the sheath are joined. This structure may be membranous, a fringe of hairs, or a membrane with hairs. The ligule can vary in both shape and size, and may also be absent.

Absent is the standard

Short

Tall fescue – short to absent
Kentucky bluegrass
Rough bluegrass
Colonial bentgrass
Perennial ryegrass
Fine Fescue – very short

Medium

Annual bluegrass

Tall

Creeping bentgrass

Very Prominent

Orchardgrass

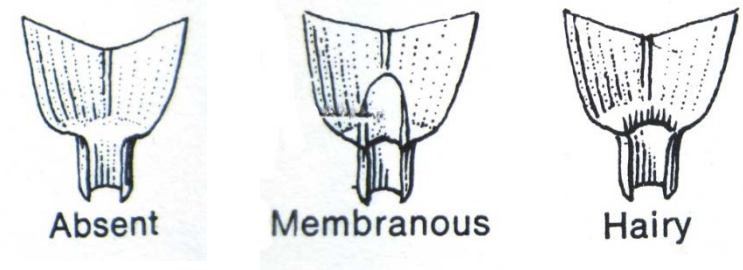
Fringe of hairs only -- C4 grasses

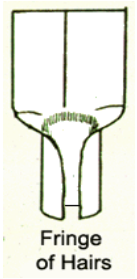
Bermudagrass
Zoysiagrass
Blue grama
Buffalograss
Carpetgrass
St Augustine – very few hairs

Membranous AND Hairy

Seashore paspalum -- key feature
Centipedegrass -- very short membrane

Figure 6a. Magnified line drawing of the collar region of a grass plant showing the presence, location, and shape of the ligule.





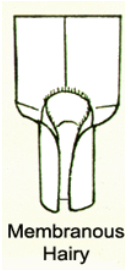


Figure 6b. Side view of a tall, membranous ligule.



Auricles

Auricle. A pair of appendages projecting from the side of the grass leaf at the junction of the blade and the sheath.

Figure 7a. Magnified line drawing of the collar region of a grass plant showing the presence, location, and shape of the auricle.

Absent is standard

Most grasses
All sedges

Claw like

Quack grass

Long

Annual ryegrass
Annual bluegrass
Creeping bentgrass

Short

Tall fescue
Perennial ryegrass

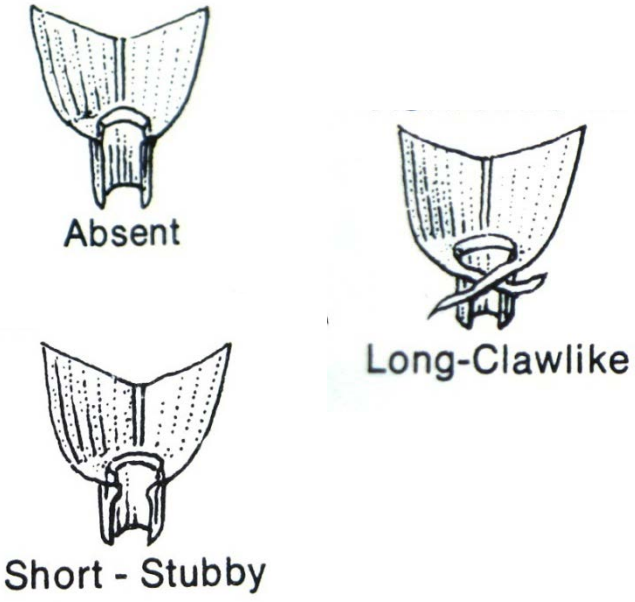




Figure 7b. Clasping or clawlike auricles of quackgrass.

Collar

Collar. The area on the back side of a leaf where the leaf blade and sheath are joined.

Divided
Ryegrasses
Bluegrasses

Broad and continuous
Tall fescue - "conspicuous yellow-green"

Orchardgrass

Continuous and hairy
Most warm season - C4 grasses

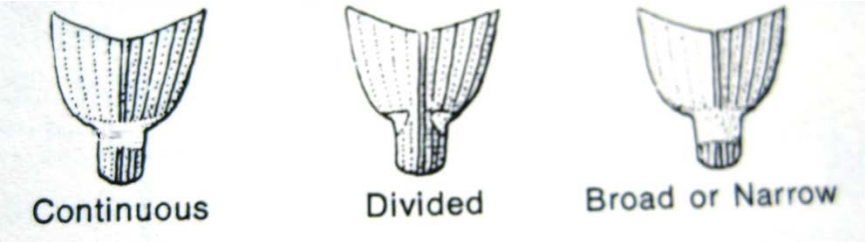


Figure 8. Magnified line drawing of the collar region of a grass plant showing specifically the presence, location, and shape of the collar. The collar occurs at the back of the leaf where the blade and sheath join.

Narrow
Creeping bentgrass
Colonial bentgrass - may be **Divided**
Fine Fescue – narrower than the blade
St Augustine - constricted

Seedhead

The collection of flowering or seeding parts which are arranged in various ways (spike, panicle, etc.)

Panicle
Bluegrasses
Bentgrasses
Orchard grass – distinctive "puffs"

Narrow Panicle
Fescues

Spike
Ryegrasses
Centipedegrass
St Augustine

Raceme
Bahiagrass -- usually 2 branches, a distinctive "V" shape

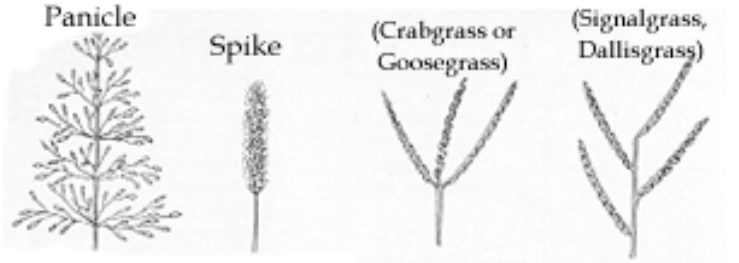


Figure 9. Magnified line drawing of seedhead shapes.

Bermuda – 2-3 branches
Carpetgrass – 2-5 branches
Seashore paspalum – 2 branches

Distinctive – "eyelash"
Blue Grama
Buffalograss -- like a small green ball

Sheath

The basal portion of the grass leaf just below the intersection of the new leaf and the "stem"

Split
Red fescue
Tall fescue
Bermudagrass
Zoysiagrass
Seashore paspalium

Closed
Young bluegrass -- open as it ages
Ryegrass -- reddish at soil level and split as it ages

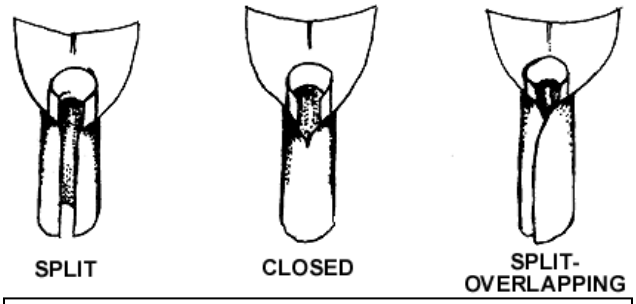


Figure 10. Magnified line drawing of the sheath margins.

Rhizomes and Stolons

Rhizomes -- underground **stems** – "runners"
Kentucky Bluegrass
Some fine fescues
Quackgrass

Stolons -- aboveground **stems** – "runners"
Colonial Bentgrass
Creeping bentgrass
St Augustine
Centipedegrass
Buffalograss
Carpetgrass
Rough bluegrass – *Poa trivialis*

St Augustine

BOTH Rhizomes AND Stolons

Bermudagrass
Zoysiagrass
Seashore paspalum

If a plant has NEITHER rhizomes or stolons is called a "**bunch or clump"** type. They spread by "**Tillering**".

Tall Fescue
Ryegrasses
Orchardgrass
Annual bluegrass



Figure 11. Rhizomes (top) are underground stems and stolons (bottom) are aboveground stems.

Major identification characteristics

Some leaf shape and texture characteristics are oblivious links to certain grasses these include:

Boat shaped tip = bluegrass
Big veins = tall fescue
Thin blades = fine fescue
Bottom shiny = perennial ryegrass
Seedheads in summer = C4 grass

COOL SEASON GRASSES

FESCUES

Tall Fescue

***Festuca arundinacea* (Schreb.)**

-Cool Season - C3, bunch type
-Weakly rhizomatous cultivars are now available
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Most heat tolerant of the major C3 lawn grasses
-Limited cold tolerance
-Adapted to the widest range of soils
-Very deep root system

KEY ID FEATURES:

-Toothed edges on blades [rough edges]
-Distinct parallel veins on upper leaf surface
-Rolled vernation
-Can have reddish crowns [base of the plant]
-Ligules, small to medium
-Can have claw-like to no auricles
    Claw-like on meadow or pasture fescue
    Absent on the turf-type lawn fescue

WEAR TOLERANCE: good

GERMINATION TIME: 7- 14 days

WATER REQUIREMENTS: MEDIUM

DROUGHT RESISTANCE: VERY GOOD
Once established it has deep rooting

FERTILIZER REQUIREMENTS: Medium 2-3.5 lbs nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Widest range of any cool season grass

MAJOR DISEASES: Rhizoctonia blight [brown patch]



Figure 12a. Top and bottom sides of a Tall Fescue leaf.

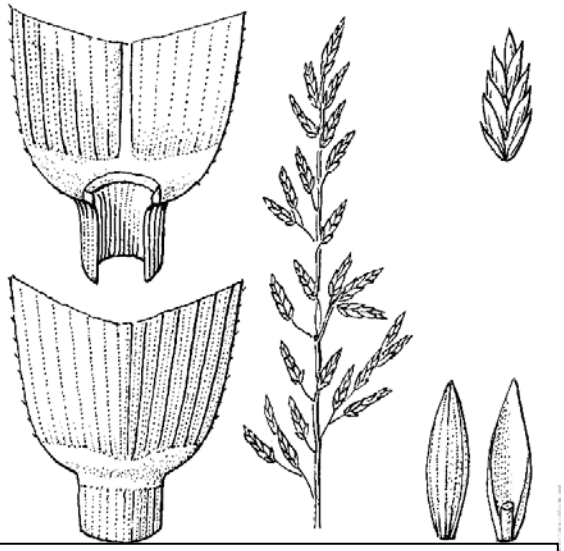


Figure 12b. Tall fescue collar region, seedhead and seed line drawing.

MAJOR INSECTS: none – Especially in the endophyte-enhanced varieties

SHADE TOLERANCE: GOOD

SALT TOLERANCE: Medium

NOTES: Do not feed endophyte-enhanced tall fescue to pregnant horses or cows.



Figure 12c. The compact panicle of a Tall Fescue seedhead.



Figure 12d. Tall Fescue leaf, ligule and auricles.

FINE FESCUES

Fine fescues are the most shade tolerant cool season grasses. In the higher and cooler sections of the Mid-Atlantic, fine fescues will dominate stands of tall fescue. They have generally low fertilizer requirements, in fact too much is harmful. They do not like saturated soils and like most shade tolerant turfgrasses, do not handle traffic well !! -

-Hard fescue
-Creeping Red fescue
-Chewings fescue
-Sheep's fescue

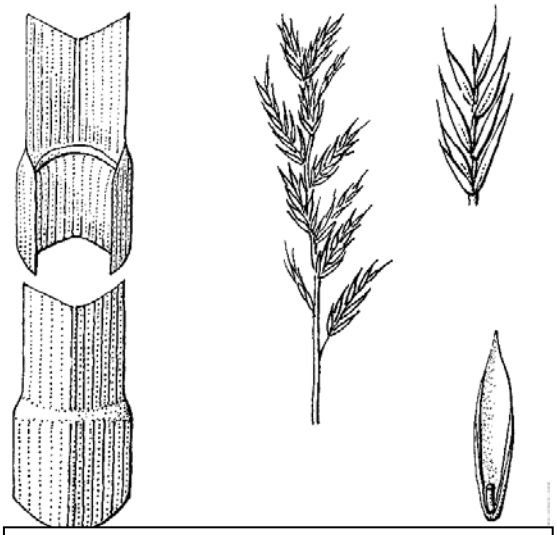


Figure 13a. Fine fescue collar region, seedhead and seed line drawing.

Hard Fescue

***Festuca brevipila* Tracey**

-Cool Season - C3, bunch type
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very shade tolerant
-Tends to persist longer than other fine fescues

KEY ID FEATURES:

-Fine leaf blades
-Blades slightly narrower than the sheath
-Short ligule



Figure 13b. Fine Fescue has a fine leaf texture and often a clump-like growth habit.

WEAR TOLERANCE: Poor to fair

GERMINATION TIME: 14 days

WATER REQUIREMENTS: Low

DROUGHT RESISTANCE: good – better if in the shade

FERTILIZER REQUIREMENTS: Low, 0-1 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Loamy dry soils

MAJOR DISEASES: few

MAJOR INSECTS: none

SHADE TOLERANCE: Excellent

SALT TOLERANCE: Medium

NOTES: Best if not mowed or mowed long [3+ inches]. Not good in warm microclimates. Tends to persist better than other fine fescues in the transition zone.

Creeping Red Fescue

***Festuca rubra* L.**

-Cool Season - C3, moderately rhizomatous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very shade tolerant
-Tends to dominate other fine fescues
-May be more salt tolerant than other fine fescues

KEY ID FEATURES:

-Slender rhizomes
-Fine leaf blades
-Short ligule
-ridged V shape



Figure 13c. The compact panicle of a Fine Fescue seedhead.

NOTES: Best if not mowed or mowed long [3+ inches]. Not good in warm microclimates. Thrives best in cooler areas of the transition zone. There are several sub-species.

Sheeps Fescue

Festuca ovina. L.

-Cool Season - C3, bunch type
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very shade tolerant
-Some cultivars have a distinct blue-gray color
-Similar to other fine fescues in adaption but may be **less tolerant of heat**, cold and wet soils than other fine fescues



Figure 13d. Sheeps fescue typically has a blue-gray hue to the leaves.

Chewings Fescue

***Festuca rubra* L subsp. *Fallax* (Thuill.) Nyman**

-Cool Season - C3, bunch type
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very shade tolerant

-Similar to other fine fescues in adaption but may be **more drought tolerant** than Creeping Red Fescue

RYEGRASSES

Perennial Ryegrass

***Lolium perenne* L.**

-Cool Season - C3, bunch type
-Introduced, perennial grass

KEY ADAPTIVE POINTS:
-Very fast germination
-Quick cover
-Moderate heat or drought resistant
-Sensitive to heat and cold

KEY ID FEATURES:
-Strong mid-vein, "keeled",
V cross section
-Bottom of leaf is "shiny"
-Prominent veins on upper side
- Can have reddish crowns
-Auricles are variable from long to absent

WEAR TOLERANCE: Good

GERMINATION TIME: 5-7 days

WATER REQUIREMENTS: Moderate

DROUGHT RESISTANCE: Fair

FERTILIZER REQUIREMENTS:
Medium 2-3.5 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO:
Loam, pH 6.0 - 7.0

MAJOR DISEASES: Susceptible to most. Gray leaf spot is a fast acting devastating disease

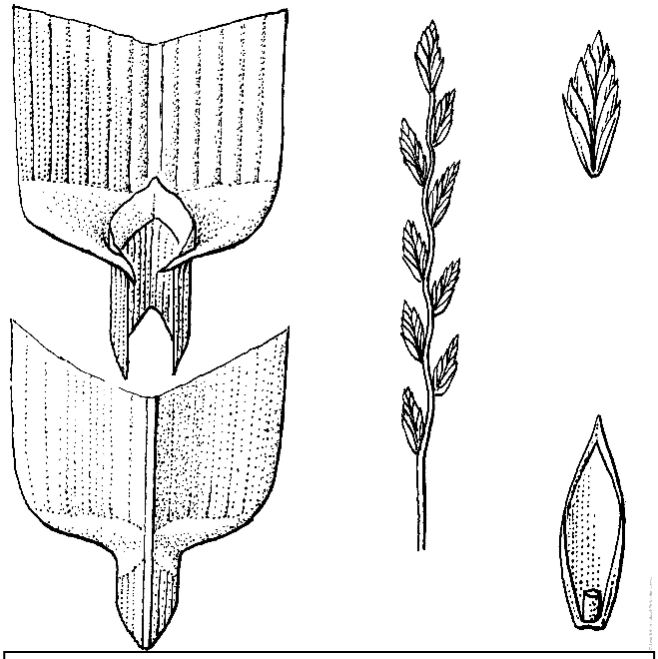


Figure 14a. Ryegrass collar region, seedhead and seed line drawing.



Figure 14b. Perennial ryegrass leaf texture with both a distinct mid-rib and parallel veination.

MAJOR INSECTS: Susceptible to most

SHADE TOLERANCE: Fair

SALT TOLERANCE: Med

NOTES: Newer cultivars are more stress resistant and persist better, especially in moderate temperature areas of the Mid-Atlantic. Perennial Ryegrass is popular for winter overseeding of warm-season grasses.



Figure 14c. The distinct raceme shape of a ryegrass seedhead.



Figure 14d. Ryegrass ligule.

Annual [Italian] Ryegrass

***Lolium perenne* L. subsp. *multiflorum* (Lam.) Husnot**

-Cool Season - C3, bunch type
-Introduced, annual grass

KEY ADAPTIVE POINTS:

-Very fast germination
-Quick cover
-POOR heat or drought resistant
-Very low cost
-Hybridizes freely with L. Perenne and F. arundinacea

KEY ID FEATURES:

-Rolled vernation
-Clasping auricles
-light "apple" green color
-Strong mid-vein, "keeled",
-Bottom of leaf is "shiny"
-Prominent veins on upper side
-Blade much wider then P. Rye
-Like P. Rye can have reddish crown

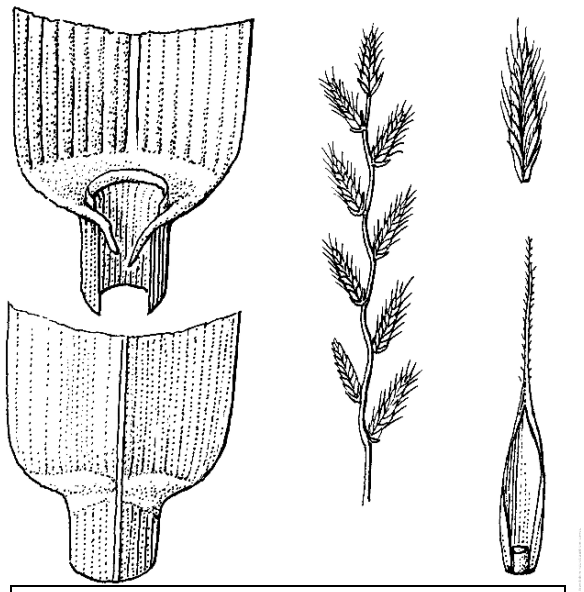


Figure 15a. Annual ryegrass collar region, seedhead and seed line drawing.

WEAR TOLERANCE: Poor

GERMINATION TIME: 5 - 7 days

WATER REQUIREMENTS: High

DROUGHT RESISTANCE: Poor

FERTILIZER REQUIREMENTS: Medium 2-3.5 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Loam, pH 6.0 - 7.0

MAJOR DISEASES: Susceptible to many

MAJOR INSECTS: Susceptible to many

SHADE TOLERANCE: Poor-fair

SALT TOLERANCE: Poor



Figure 15b. Ryegrass collar region, leaf and sheath.

NOTES: Used mainly as a temporary cover. Consider "Contractors blend", a seed mix containing annual ryegrass offered at a low cost.



Figure 15c. The distinct raceme shape of a ryegrass seedhead.

BLUEGRASSES

There are more than 200 Poa species. A few important species are described below.

-Kentucky Bluegrass
-Annual Bluegrass
-Roughstalk or Rough Bluegrass
-Bulbous Bluegrass
-Texas Bluegrass



Figure 16. The distinct "boat-shaped" tip of bluegrasses.

All bluegrasses:

-Have "boat shaped" leaf tips and a distinctive mid vein
-Have a high water requirement
-Are susceptible to most pests and diseases
-High maintenance is required
-Fairly low growing - usually less than 12 inches

Bluegrasses spread in a variety of ways, which can help you identify them.

-Kentucky Bluegrass spreads by rhizomes
-Annual Bluegrass spreads by tillering – a bunch grass; also a prolific seedhead producer at almost any cutting height
-Rough Bluegrass spreads by stolons

Kentucky Bluegrass

***Poa pratensis* L.**

-Cool Season - C3, rhizomatous

-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Low growing
-Shallow root system
-Will go dormant in a drought
-Moderate heat tolerance

KEY ID FEATURES:

-Boat shaped leaf tips
-Smooth leaf surface

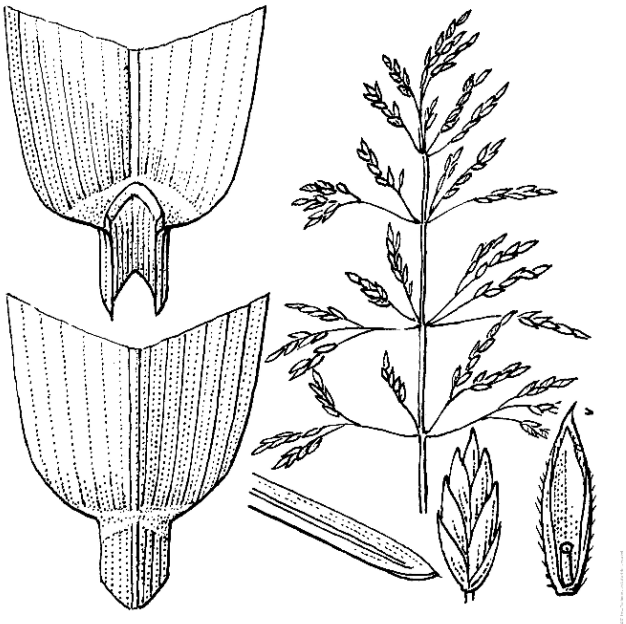


Figure 17a. Ketucky Bluegrass collar region, seedhead, leaf tip and seed line drawing.

-Distinctive mid vein
-Translucent lines parallel to the mid vein
-Short ligules

WEAR TOLERANCE: Good

GERMINATION TIME: 14 - 21 days

WATER REQUIREMENTS: High

DROUGHT RESISTANCE: Fair to good – goes dormant quickly



Figure 17b. The distinct "boat-shaped" tip of Kentucky Bluegrass.

FERTILIZER REQUIREMENTS: HIGH 2-3.5 lb nitrogen per 1000 sq ft per year

SOIL BEST ADADPTED TO: Wide range, prefers pH 6.0 – 7.0

MAJOR DISEASES: Susceptible to most, summer patch a particular concern

MAJOR INSECTS: Susceptible to most

SHADE TOLERANCE: Poor -fair

SALT TOLERANCE: Low



Figure 17c. Kentucky Bluegrass ligule.

NOTES: A major lawn grass in the northeast USA, but the higher temperatures and humidities in most of the Mid-Atlantic means this species is very hard to sustain without irrigation and fungicides.



Figure 17d. Kentucky Bluegrass panicle seedhead.

Annual Bluegrass

***Poa annua* L. (also called "poa anna")**

-Cool Season - C3, bunch type

-Introduced, annual grass – however there are some perennial biotypes

KEY ADAPTIVE POINTS:

-A winter annual generally, however there are a perennial biotypes

-Very high water requirement

-Poor heat and drought tolerance

-Viable seed just a few days after pollination

KEY ID FEATURES:

-Boat shaped leaf tip

-Tall rounded ligule

-Produces seedheads most of its growing season

-Light "apple" green color

-Does not have stolons or rhizomes

-Can have "wrinkles" on the leafs

WEAR TOLERANCE: Poor

GERMINATION TIME: 14 -21 days

WATER REQUIREMENTS: Very high

DROUGHT RESISTANCE: Very poor

FERTILIZER REQUIREMENTS: High, 2-3.5 lb nitrogen per 1000 sq ft per year – to maintain a good stand (usually on golf greens)

SOIL BEST ADAPTED TO: Likes cool moist soil and near neutral pH

MAJOR DISEASES: Susceptible to many

MAJOR INSECTS: Susceptible to many

SHADE TOLERANCE: Fair - good

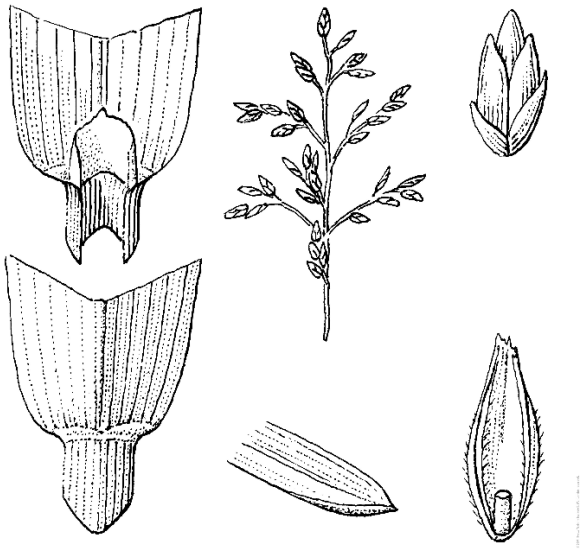


Figure 18a. Annual Bluegrass collar region, seedhead, leaf tip and seed line drawing.



Figure 18b. Annual Bluegrass panicle seedhead in a lawn setting.

SALT TOLERANCE: Very low

NOTES: Is a major weed on golf course greens. *Poa annua* survives at very low mowing heights and still produces a lot of "unsightly" seedheads.



Figure 18c. Annual Bluegrass distinctive leaf crinkle. Photo by Dr. E Ervin & Ms T Bayrer.



Figure 18d. Annual Bluegrass ligule. Photo by Dr. E Ervin & Ms T Bayrer.

Rough Bluegrass

***Poa trivialis* L. (also called "poa triv")**

-Cool Season - C3, stoloniferous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very high water requirements
-Poor heat tolerance
-Poor traffic tolerance

KEY ID FEATURES:

-Boat shaped leaves
-Tall pointed ligule
-'Onion skin" sheath
-Light "apple" green color
-A profusion of thin stolons – create mat-like surface on the dirt
-Can have leaf " wrinkles" like annual bluegrass

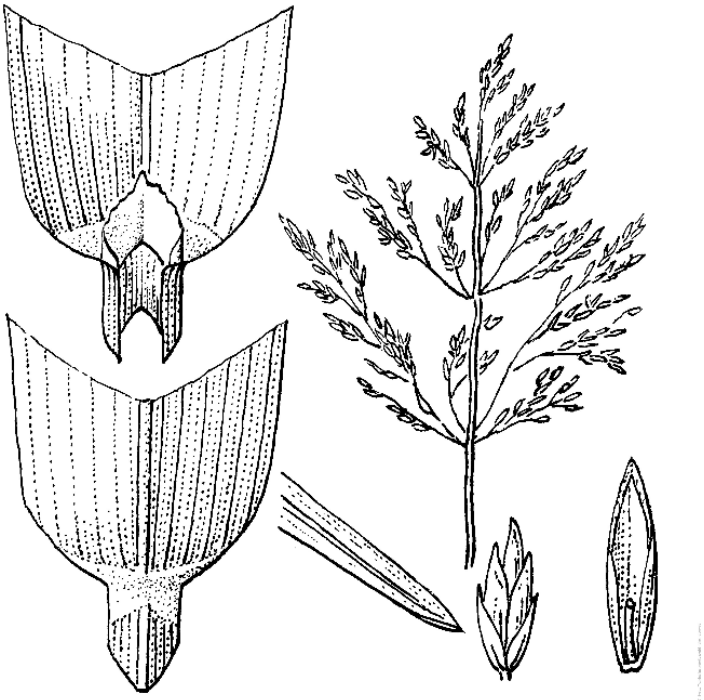


Figure 19a. Rough bluegrass collar region, seedhead, leaf tip and seed line drawing.

WEAR TOLERANCE: Poor

GERMINATION TIME: 14 - 21days

WATER REQUIREMENTS: Very high

DROUGHT RESISTANCE: Very poor

FERTILIZER REQUIREMENTS: High, 2-3.5 lb nitrogen per 1000 sq ft per year to maintain a stand but low (0-1 lb nitrogen per 1000 sq ft per year) to survive as a weed

SOIL BEST ADAPTED TO: Cool wet soil

MAJOR DISEASES: Susceptible to many

MAJOR INSECTS: Susceptible to many

SHADE TOLERANCE: Very Good

SALT TOLERANCE: Low



Figure 19b. Rough bluegrass ligule, leaf and sheath. Photo by Dr. S. Askew.

NOTES: Generally appears as a light colored turf in cool-season athletic fields or golf course fairways. Despite being a "weak" grass it is surprisingly hard to eliminate and will return even if the infested area is resodded.

Bulbous Bluegrass

***Poa bulbosa* L.**

-Cool Season - C3, bunch type
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Found in the warmer areas of the Mid-Atlantic

KEY ID FEATURES:

- Boat shaped leaf tips
-"Swollen" or bulb shape at the base of the stem
-Looks like a circular patch of fine fescue

WEAR TOLERANCE: Good



Figure 20. Bulbous Bluegrass seedhead.

Texas Bluegrass

***Poa arachnifera* L.**

-Cool Season - C3, rhizomatous
-NATIVE perennial grass

KEY ADAPTIVE POINTS:

- Very heat tolerant

KEY ID FEATURES:

-Boat shaped leaf tips

NOTES: Texas bluegrass is often crossed with *Poa pratensis* to produce a generation of "heat tolerant" hybrid bluegrasses. These hybrids typically perform well in the warmer climates of Virginia.



Figure 21. Texas Bluegrass including the panicle seedhead.

BENTGRASSES

Bentgrass

Tolerates very low mowing; some cultivars accept less than 0.125 to 0.1 in. Bentgrass is primarily used on golf course putting greens. It has a shallow root system and reduction of the root length caused by summer stresses require a very high level of maintenance and irrigation in order to keep a good stand.

-Creeping bentgrass
-Colonial bentgrass

Creeping bentgrass

Agrostis stolonifera L* var. *palustris

-Cool Season - C3, stoloniferous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Survives under very low mowing heights
-Dense – many plants per square foot
-Shallow annual root system

KEY ID FEATURES:

-Rolled vernation
-Tall pointed ligule
-Parallel veins on top [abaxial] of the blade
-Narrow blade width

WEAR TOLERANCE: Fair to poor

GERMINATION TIME: 5 - 14 days

WATER REQUIREMENTS: High

DROUGHT RESISTANCE: Poor

FERTILIZER REQUIREMENTS: Medium to High, 2-3 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Loamy, moist, pH 5.5 – 7.0

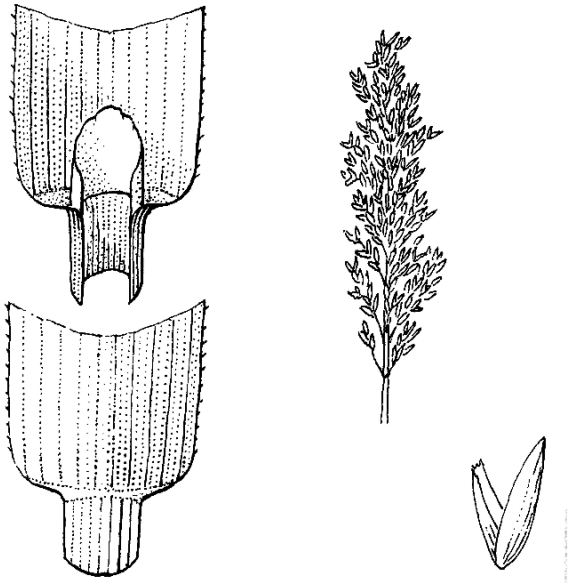


Figure 22a. Creeping Bentgrass collar region, seedhead and seed line drawing.



Figure 22b. Creeping Bentgrass leaf, sheath, and ligule.

MAJOR DISEASES: Susceptible to many. Dollar spot is a major disease of importance in putting green turf.

MAJOR INSECTS: Susceptible to many

SHADE TOLERANCE: Good

SALT TOLERANCE: Low

NOTES: Susceptible to many pests and diseases because of the amount of stress low mowing places on a turfgrass. This vulnerability to many pests makes bentgrass on a putting green extremely high maintenance. Higher mowing heights will reduce the stress and therefore the pest pressure, but bentgrass will still require a high level of care to keep a persistent stand with desirable appearance and playability characteristics.

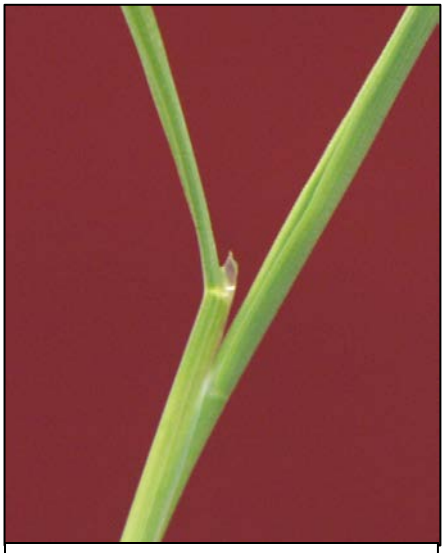


Figure 22c. Creeping Bentgrass ligule. Photo by Dr. E Ervin & Ms. T Bayrer.

Colonial Bentgrass

***Agrostis capillaris* L.**

-Cool Season - C3, mainly stoloniferous but some cultivars are weakly rhizomatous or bunch type

-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very cold hardy

-Does not do well at very low mowing heights

-Better wear than creeping bentgrass at fairway heights

- Fairly shade and drought tolerant. Better than Creeping bent

-Tolerates summer heat fairly well

KEY ID FEATURES:

-Rolled vernation

-Ligule smaller than creeping bentgrass

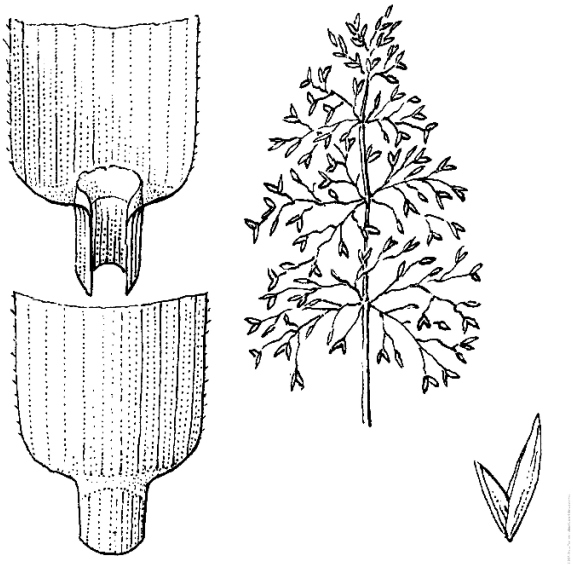


Figure 23. Colonial Bentgrass collar region, seedhead and seed line drawing.

WEAR TOLERANCE: Poor

GERMINATION TIME: 7-14 days

WATER REQUIREMENTS: High

DROUGHT RESISTANCE: Fair

FERTILIZER REQUIREMENTS: Medium, 2-3 lbs nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Wide range, prefers well drained, pH 5.5 – 6.7
May tolerate slightly more acid soils than creeping bentgrass

MAJOR DISEASES: Susceptible to many

MAJOR INSECTS: Susceptible to many

SHADE TOLERANCE: Moderate

SALT TOLERANCE: Low

NOTES: Better at higher mowing heights. Higher dollar spot resistance than creeping bentgrass and some crosses have been made to improve the dollar spot resistance in creeping bentgrass.

WARM SEASON GRASSES

Bermudagrass

***Cynodon dactylon* L. Pers.** also called common bermudagrass or "wire grass"
***Cynodon transvaalensis* Burtt-Davy**, also called "hybrid bermuda"

-Warm Season – C4, rhizomatous AND stoloniferous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

- Fast, aggressive spreading grass
  Covers damage or bare spots quickly during its growing season
-Deep root system
-Seeded and vegetative cultivars available

KEY ID FEATURES:

-Rolled OR folded
-Ligule is a fringe of hairs with hairs around the ligule
-Rhizomes and stolons present
-A few short hairs may be present on blade

WEAR TOLERANCE: Excellent

GERMINATION TIME: 14 - 21 days NOTE: not all varieties can be propagated from seed.

WATER REQUIREMENTS: Low

DROUGHT RESISTANCE: Excellent

FERTILIZER REQUIREMENTS: High, 2-4 lbs nitrogen per 1000 sq ft per year, responds well to high fertility

SOIL BEST ADAPTED TO: Tolerates the widest range soils of most warm season turfgrasses

MAJOR DISEASES: Few, Spring Dead Spot is the most prominent

MAJOR INSECTS: Few

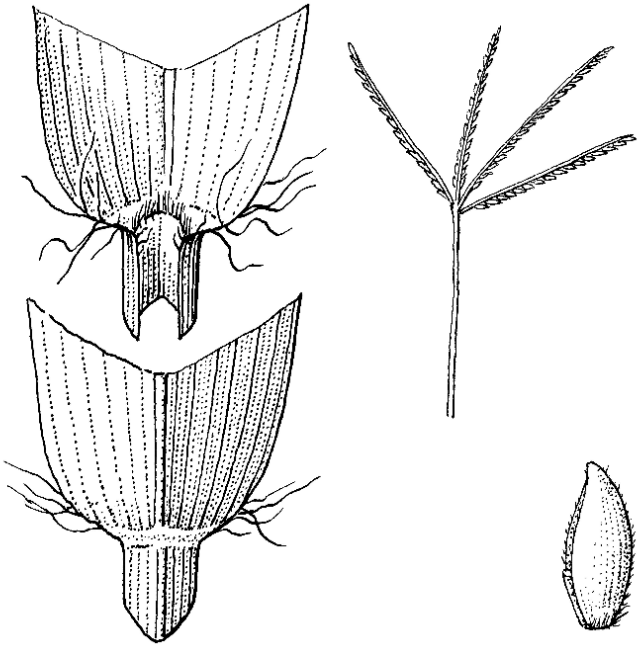


Figure 24a. Bermudagrass collar region, seedhead and seed line drawing.



Figure 24b. Bermudagrass ligule and collar region.

SHADE TOLERANCE: Poor

SALT TOLERANCE: High

NOTES: Requires full sun [like most C4 grasses] to grow. The common *C. dactylon* types are generally more drought tolerant than the hybrid bermudagrasses. One of the best athletic field grasses because of its recuperative ability. It is a very heavy thatch producer.



Figure 24c. Bermudgrass aggressively 'creeps' into neighboring areas by stolons (as shown here) and rhizomes.



Figure 24d. Bermudagrass leaf arrangement at the nodes on a stolon.

Zoysiagrass

***Zoysia japonica* L.**

-Warm Season – C4, Rhizomatous AND stoloniferous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:
-Spreads much slower than bermudagrass
Slower recuperative ability
-More shade tolerant than bermudagrass
-Greens up earlier and goes dormant later than bermudagrass

KEY ID FEATURES:
-Rolled vernation
-Stolons have husks or "sheaths"
-Stolon internode lengths are equal in length
= "goal posts" generally emerging on one side of the stolon
-Long hairs on base of blade [more than bermudagrass]
-May have some hairs on top of blade
-Blades have an upright growth habit
Turfgrass feels stiff
-Leaf tips have more needlelike tips than bermudagrass

WEAR TOLERANCE: Excellent

GERMINATION TIME: 21 - 35 days NOTE: Many varieties do not produce true-to-type seed.

WATER REQUIREMENTS: Low

DROUGHT RESISTANCE: Very good

FERTILIZER REQUIREMENTS: Medium, 1-2 lbs nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Tolerates moderate acidity, likes well drained soils best

MAJOR DISEASES: Large Patch

MAJOR INSECTS: none

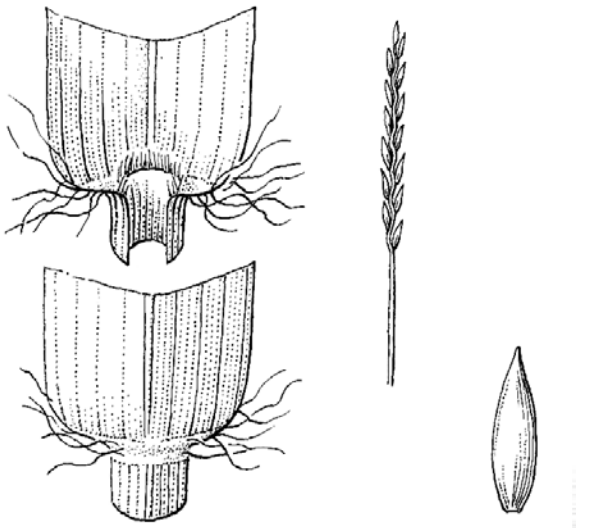


Figure 25a. Zoysiagrass collar region, seedhead and seed line drawing.



Figure 25b. Zoysiagrass shoot arrangement on a stolon.

SHADE TOLERANCE: Fair – good

SALT TOLERANCE: Medium

NOTES: Tolerates cooler temperatures better than most C4 grasses. Very heavy thatch producer. When established, zoysiagrass will crowd out most other grasses and weeds. Some improved seeded varieties are available.



Figure 25c. Zoysiagrass characteristic spike seedhead.

St. Augustinegrass

***Stenotaphrum secundatum* (Walter) Kuntze**

-Warm Season – C4, Stoloniferous

-NATIVE, perennial grass

KEY ADAPTIVE POINTS:

-Most shade tolerant of the C4 turfgrasses

-Thick stolons

-Poor cold tolerance

KEY ID FEATURES:

- Very coarse leaf texture

-Greatly compressed collar

-Rounded leaf tips

-Boat shaped leaf tip

-Opposite leaf arrangement at stolon nodes

WEAR TOLERANCE: Good

GERMINATION TIME: Very limited seeded varieties available

WATER REQUIREMENTS: Low

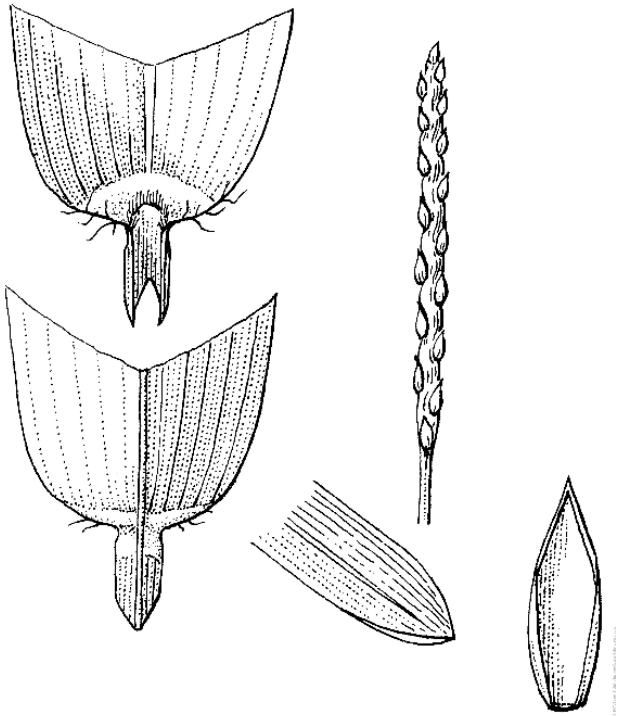


Figure 26a. St. Augustinegrass collar region, seedhead, leaf tip and seed line drawing.

DROUGHT RESISTANCE: Good

FERTILIZER REQUIREMENTS: High, 2-4 lbs nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Wide range of soils and pH, but likes sandy soils; will respond to higher fertility levels but will not compete well with other C4 grasses

MAJOR DISEASES: SAD virus, Gray leaf spot

MAJOR INSECTS: Chinch bug, grubs

SHADE TOLERANCE: GOOD

SALT TOLERANCE: High

NOTES: Sensitive to iron deficiency



Figure 26b. St. Augustinegrass plant showing leaves and seedhead.



Figure 26c. St. Augustinegrass leaf and shoot arrangement at the node.

Bahiagrass

***Paspalum notatum* L.**

-Warm Season – C4, rhizomatous some so shallow they move along the surface and are called stolons

-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Very drought tolerant, deep root system
-Low fertility requirements
-Very deep and extensive root system
-Does not form a tight turfgrass
-Very cold sensitive

KEY ID FEATURES:

-Short membranous ligule
-Compressed - flattened collar
-V shaped seedheads
-Can have very dense stolons
-Some stolons have a purplish "sheath" below the emerging blades



Figure 27b. Bahaigrass leaf and shoot arrangement at the node.

WEAR TOLERANCE: Good

GERMINATION TIME: 21 -35 days

WATER REQUIREMENTS: Very low

DROUGHT RESISTANCE: Excellent

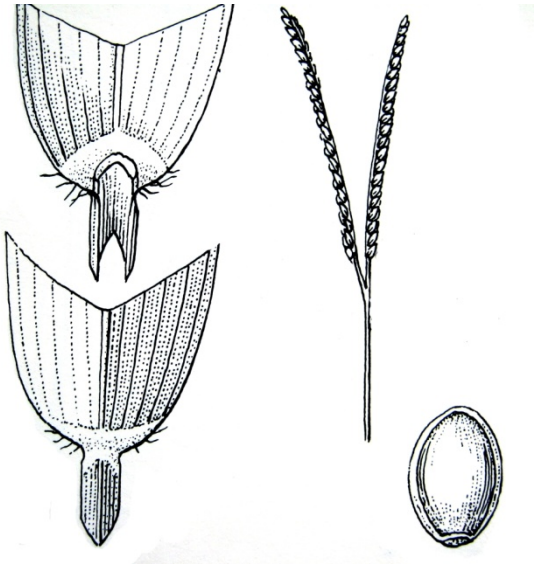


Figure 27a. Bahaigrass collar region, seedhead and seed line drawing.



Figure 27c. Bahaigrass leaf and collar region, including hairy ligule.

FERTILIZER REQUIREMENTS: Low, 0-1 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Best in sandy or poor soils

MAJOR DISEASES: Few

MAJOR INSECTS: Few

SHADE TOLERANCE: Poor

SALT TOLERANCE High

NOTES: Good for a low maintenance lawn in the warmest climates of the region. However it does not produce a good visual turf. Works well on infertile soils. Bahiagrass is very sensitive to iron deficiency especially in low pH soils and sensitive to many herbicides.



Figure 27d. Bahaigrass distinctive 'V'-shaped seedhead.



Figure 27e. Bahiagrass plant.

Seashore Paspalum

***Paspalum vaginatum* Sw.**

-Warm Season – C4, Stoloniferous and weakly rhizomatous
-NATIVE, perennial grass



Figure 28a. Seashore Paspalum leaf and shoot arrangement at the node.

KEY ADAPTIVE POINTS:

-The most salt tolerant of the turfgrasses; Can use salt water for weed control
-Deep root system
-Very poor cold tolerance

KEY ID FEATURES:

-rolled vernation
-Membranous ligule with hairs around it
-Deep mid vein on both sides of the blade
-Stolons have alternate blades



Figure 28b. Seashore Paspalum leaf and ligule.

WEAR TOLERANCE: Good

GERMINATION TIME: 7-10 days

WATER REQUIREMENTS: Low

DROUGHT RESISTANCE: Excellent

FERTILIZER REQUIREMENTS: Low – Medium; 1-3 lbs nitrogen per 1000 sq ft per year, heavy thatch can result from higher fertility.



Figure 28c. Seashore Paspalum leaf arrangement at the node.

SOIL BEST ADAPTED TO: Wide range of soils, will live in sand or boggy areas

MAJOR DISEASES: Fusarium, Large Patch, Dollar spot

MAJOR INSECTS: Few

SHADE TOLERANCE: Fair

SALT TOLERANCE: Exceptionally High

NOTES: Salt tolerance is the key to this grass. Seashore paspalum may be harmed by many herbicides, so pay attention to label restrictions.

Centipedegrass

***Eremochloa ophiuroides* (Munro) Hack.**

-Warm Season – C4, stoloniferous
-Introduced, perennial grass

KEY ADAPTIVE POINTS:

-Requires low fertility
-Slow growth
-High shoot density

KEY ID FEATURES:

-Membranous ligule with hairs on top
-Compressed collar
-"Dog ear" leafs on stolons
-Alternating leafs at stolon nodes
-Can have hairs along leaf edges

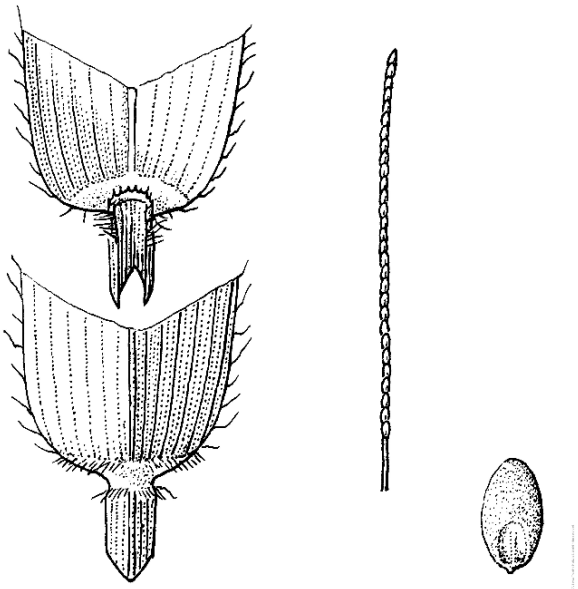


Figure 29a. Centipedegrass collar region, seedhead and seed line drawing.

WEAR TOLERANCE: Fair

GERMINATION TIME: 30 - 45 days

WATER REQUIREMENTS: Low

DROUGHT RESISTANCE: Fair - good

FERTILIZER REQUIREMENTS: Low, 1-2 lbs nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Moist, but likes sandy soils with acidic pH



Figure 29b. Centipedegrass shoot including hairy ligule.

MAJOR DISEASES: Slightly less than Bermudagrass

MAJOR INSECTS: ground pearls

SHADE TOLERANCE: Good

SALT TOLERANCE: Low

NOTES: "Poor man's grass" requiring very low inputs. Will need extra iron and little to no fertility; if you fertilize you will increase the pressure from other grasses and weeds. Centipedegrass is a very good grass for an organic nitrogen program.



Figure 29c. Centipedegrass leaf and shoot arrangement at the node.

Buffalograss

***Buchloe dactyloides* (Nutt) J.T. Columbus**

-Warm Season – C4, Stoloniferous
-NATIVE, perennial grass

KEY ADAPTIVE POINTS:

-Very drought tolerant
-Very heat and cold tolerant
-Does not do well with in wetter climates

KEY ID FEATURES:

-Thin, stiff, twisted, blue-gray leaf blades

WEAR TOLERANCE: Fair

GERMINATION TIME: 14 -30 days

WATER REQUIREMENTS: Very low

DROUGHT RESISTANCE: Exceptional

FERTILIZER REQUIREMENTS: Low 1-2 lb nitrogen per 1000 sq ft per year

SOIL BEST ADAPTED TO: Wide range of soils

MAJOR DISEASES: Few – unless in prolonged moisture conditions

MAJOR INSECTS: none

SHADE TOLERANCE: Poor

SALT TOLERANCE: Low- moderate

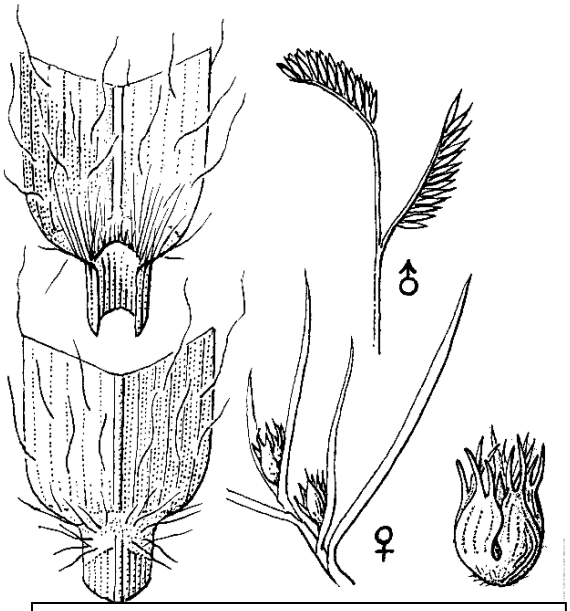


Figure 30a. Buffalograss collar region, seedhead (male and female) and seed line drawing.



Figure 30b. Buffalograss female inflorescence.



Figure 30c. Buffalograss shoots on a stolon.

NOTES: Is native to the arid [9 -14 inches of rainfall] midwestern USA and does poorly under irrigated conditions or in high rainfall years in the Mid-Atlantic

Some common turfgrass identification confusions and key features to distinguish between them:

Warm season grasses

Bermudagrass		**Zoysiagrass**
Usually folded	VERNATION	Rolled
Differing lengths	STOLON INTERNODES	Same length –goal posts
Soft feel	BLADE GROWTH	Stiff feel
Opposite sides	STOLON BUDS	All on one side

Bermudagrass		**Seashore Paspalum**
Fringe of hairs	LIGULE	Membrane with hairs
Dull or same	UNDERSIDE OF LEAF	Shiny
Usually folded	VERNATION	Rolled

Centipedegrass		**Bahiagrass**
Yes	90^{O} BLADES	No
Yes	EVENLY SPACED STOLON NODES	No

COOL SEASON GRASSES

Bluegrass		**Ryegrass**
Yes	BOAT SHAPED LEAF TIP	No
No	SHINY BLADE BOTTOM	Yes
Slightly	MID-VEIN TOP AND BOTTOM	Very prominent

Bentgrass		**Fine Fescue**
Strongly	STOLONIFEROUS GROWTH	Some have weak growth
Soft feel	BLADE FEEL	Stiff – bristle like feel
Generally lighter	BLADE COLOR –GREEN	Generally dark some gray
Wider	BLADE WIDTH COMPARED TO SHEATH	Narrower than sheath

Identification Key to Turfgrass Species From Dr. David Gardner at Ohio State U.- Used with permission

buckeyeturf.osu.edu/pdf/01_**turfgrass_identification**.pdf Modified slightly by Sam Doak Virginia Tech

both couplets or triplets should be read before deciding where to proceed. The key includes common turfgrass, plus some lesser-used species that are often misidentified in the field. Some cultivars or hybrids may exhibit slightly differing characteristics so examine several features before deciding

FOLDED VERNATION

Ligule is membranous -- short or absent

Boat shaped leaf tip

Rhizomatous, leaf blade with translucent midrib = **Kentucky bluegrass (*Poa pratensis*)**

Ligule present

Ligule prominent, sheaths slightly compressed, bunch type, crinkled leaves= **Annual bluegrass (*Poa annua*)**

Ligule abrupt, sheath strongly compressed = **Canada bluegrass (*Poa compressa*)**

Ligule 4 - 6 mm, stoloniferous, fused sheath resembles onion skin = **Rough bluegrass (*Poa trivialis*)**

Pointed leaf tip

Very fine leaves, bunch type, blades smaller than sheathes = ***Festuca spp.* fine fescues**

Very fine leaves, bunch type, blades smaller than sheathes, bluish-green leaf, short ligule, **Sheeps Fescue = (*Festuca ovina)***

Very fine leaves, rhizomatous, medium ligule, prominent veins on upper leaf = **Creeping red fescue (*Festuca rubra)***

Leaves shiny on back, bunch type, red pigment at sheath base =**Perennial Ryegrass (*Lolium perenne*)**

ROLLED VERNATION

Auricle present

Long, claw-like auricle, bunch type = **Annual Ryegrass (*Lolium multiflorum*)**

Auricle difficult to detect or absent

Distinct collar, bunch type, prominent veins on upper leaf, rough leaf edges = **Tall Fescue (*Festuca arundinacea*)**

Ligule evenly truncate, blades rough along edges, bunch type =**Colonial Bentgrass (*Agrostis tenuis*)**

Ligule prominent

Stoloniferous, light green color = **Creeping bentgrass (*Agrostis palustris*)**

Rhizomatous, prominent venation = **Redtop Bentgrass (*Agrostis alba*)**

Swollen base (Haplocorm) = **Turf Timothy (*Phleum pratense*)**

Ligule a membrane with a fringe of hairs

Margins ciliate toward base, thick stolons = **Bahiagrass (*Paspalum notatum*)**

Fine-textured, less aggressive stolons = **Seashore Paspalum (*Paspalum vaginatum*)**

ROLLED VERNATION

Auricle absent

Ligule a fringe of hairs

Light green-gray leaf, surface pubescent on both sides, ray-green color, stiff blades that are twisted = **Buffalograss (*Buchloe dactyloides*)**

Continuous collar, evenly spaced internodes = **Zoysiagrass (*Zoysia japonica*)**

Short rhizomes, no hairs on leaf blades, gray-green color, stiff blades that are twisted = **Blue Grama (*Bouteloua gracilis*)**

FOLDED VERNATION

Unevenly spaced internodes,

Vernation may be rolled, thin collar = **Bermudagrass (*Cynodon dactylon*)**

Evenly spaced internodes

Collar constricted with 90 deg. twist = **St. Augustine grass (*Stenotaphrum secundatum*)**

Collar lacks 90 deg. twist

Hairs on lower 1cm of leaf edge, cottony ligule = **Centipedegrass (*Eremochloa ophiuroides*)**

Pubescent sheath, smooth leaf blade = **Kikuyugrass (*Pennisetum clandestinum*)**

C4 grasses - Stolon leaf arrangement comparison

Bermudagrass:





Zoysiagrass:





Centipede





Bahiagrass:





St. Augustinegrass:





Seashore Paspalum:





Chapter 2. The Adaptation and Primary Uses of Mid-Atlantic Turfgrasses

Michael Goatley, Jr., Professor and Sam Doak, Instructor, Virginia Tech

Much of the mid-Atlantic climate falls into what is commonly termed the **transition zone** of the United States. This region is noted for its hot summers and cold winters and varying levels of moisture. In terms of selecting appropriate turfgrasses, it means that almost any warm or cool-season turfgrass can be grown in much of the region, but not necessarily grown that well given the possible environmental extremes of winter and summer. Most species grown in the mid-Atlantic offer a wide variety of cultivars from which to select. The United States Department of Agriculture's National Turfgrass Evaluation Program (NTEP) presents regularly updated field research data on numerous turfgrass variety trials from around the country (www.NTEP.org). Within the mid-Atlantic, the research efforts of turfgrass scientists at Virginia Tech and the University of Maryland results in an annual Turfgrass Variety Recommendation list that features the top performing cultivars in the region. The current Recommendation List is in the appendix of this training manual and annually updated reports can be found at http://pubs.ext.vt.edu.

Primary cool-season turfgrasses of importance.

The primary cool-season grasses used in this region are Kentucky bluegrass (*Poa pratensis* L.), hybrid bluegrass (*Poa pratensis* x *P. arachnifera*), tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), the fine-leaf fescues of creeping red (*Festuca rubra* L.*)*, chewings [*F. rubra* L. ssp. *fallax* (Thuill.) Nyman], and hard fescue (*F. brevipila* Tracey)], creeping bentgrass (*Agrostis stolonifera* var. *palustris* L.), annual ryegrass (*Lolium multiflorum* L.).

Kentucky bluegrass (Figure 1)**. Description:** a fine to medium-textured grass noted for its dark green color and aggressive lateral growth habit from rhizomes (below-ground stems). **Primary uses:** lawns, athletic fields, golf course fairways, tees, and roughs. Commonly mixed with perennial ryegrass for athletic fields, tall fescue for home lawns and athletic fields, and with perennial ryegrass/tall fescue and fine fescue for sun/shade lawns. **Primary establishment method(s):** seed readily available for many improved cultivars; sod available also, particularly in mixtures with turf-type tall fescues. **Strengths:** excellent cold tolerance; excellent density; rapid recuperation potential due to aggressive lateral growth habit; summer dormancy during drought. **Weaknesses:** poor shade tolerance; 14 to 21 days for seed germination; aggressive

lateral growth habit from rhizomes can make it a weed in plant beds; heavy thatch (an organic layer primarily composed of non-decomposed stems that occurs between the turf canopy and the soil surface) under aggressive maintenance programs; disease and insect pressures can be high under intensive maintenance programs. **Typical seasonal N requirements:** 1 to 2 lbs per 1000 sq feet for low maintenance lawns; 3 to 4.5 lbs per 1000 sq feet for golf and sports turf uses.



Figure 1. Kentucky bluegrass is a highly desirable lawn grass in the cooler regions of the mid-Atlantic, but it requires intensive maintenance to perform as desired.

Hybrid bluegrasses. Similar descriptive and maintenance characteristics as for Kentucky bluegrass but with these grasses potentially having genetic improvements in heat and drought tolerance. Hybrid bluegrasses have traditionally distinguished themselves from standard Kentucky bluegrass varieties in the warmer areas of the transition zone. See more comments below in the section on tall fescue.

Tall fescue (Figure 2)**. Description:** 'turf-type' varieties are fine to medium textured, older varieties are medium to coarse-textured; managed primarily as a bunch/clump-forming grass with little spreading potential but newer varieties with more aggressive rhizome formation are in development; deepest root system of the cool-season grasses. **Primary uses:** the most important lawn and 'all purpose' turf for the mid-Atlantic; low maintenance athletic fields, golf course roughs; turf-type varieties are commonly mixed with either Kentucky bluegrass or hybrid bluegrass in sod production systems. Preliminary research in the warmer, coastal regions of the mid-Atlantic suggest that 90%/10% by weight seed mixtures of tall fescue and hybrid bluegrass provide a more disease tolerant lawn turf than single species plantings. **Primary establishment method(s):** seed readily available for many improved cultivars; sod readily available in the region as well, either as a tall fescue blend or in mixtures with Kentucky or hybrid bluegrass. **Strengths:** excellent drought avoidance by way of a very deep root system; rapid (4-7 days) germination rates; early spring greening; moderate shade tolerance; adapted to a wide range of soils. **Weaknesses:** high mowing requirement during active growing periods; limited to no recuperative potential (with research



Figure 2. A general purpose turf-type tall fescue turf at a business park in Richmond, VA.

efforts being made to develop rhizomatous tall fescus); Rhizoctonia blight is a common disease problem under aggressive spring fertility programs. **Typical seasonal N requirements:** 0.5 to 1 lb per 1000 sq feet for low maintenance lawns; up to 3.5 lbs per 1000 sq feet for higher maintenance lawns and golf/sports turfs.

Perennial ryegrass. Description: a shallow rooted, fine textured, bunch-type grass noted for its dark green color and exceptional visual appeal due to 'striping' when clipped. **Primary uses:** not recommended as a monostand except at elevations above 2000 ft where it can be used for lawns, golf turf, and sports turf; also commonly mixed with Kentucky bluegrass for lawns and athletic fields; primary cool-season grassing option for overseeding bermudagrass for winter color/playability. **Primary establishment method(s):** seed readily available for many improved cultivars. **Strengths:** rapid (4 to 7 days) germination and establishment from seed; exceptional visual appeal due to glossy leaf surface that results in 'striping' by mowing; excellent wear tolerance as a mature turf; tolerates cutting heights as low as 0.5 inch. **Weaknesses:** no recuperative potential; poor cold tolerance; poor drought tolerance; high disease pressure. **Typical seasonal N requirements:** 1 to 2 lbs per 1000 sq feet for low maintenance lawns; 3 to 4.5 lbs per 1000 sq feet for golf and sports turf uses.



Figure 3. A perennial ryegrass overseeding on a bermudagrass base makes for a dramatic spring visual image at Davenport Field at the University of Virginia.

Fine-leaf fescues (Figure 4)**.** Three species of fine-leaf fescues predominate in the mid-Atlantic: creeping red, chewings, and hard fescue. **Description:** All species have exceptionally fine leaf blades commonly described as 'needle-like'. Chewings and hard fescues are bunch-type grasses while creeping red possesses short rhizomes; all are managed as bunch-grasses. **Primary uses:** excellent low maintenance turf with the best shade tolerance of cool-season grasses; often mixed with Kentucky bluegrass as the 'shade component' of sun/shade seed mixtures. **Primary establishment method:** seed available for limited number of varieties; limited sod available in Virginia. **Strengths:** good shade tolerance; excellent cold tolerance; good drought tolerance; minimal



Figure 4. Fine-leaf fescues are ideal for minimal maintenance turfs where limited fertility and mowing are desired.

fertility and liming requirement; reduced mowing requirement compared to other grasses. **Weaknesses:** intolerant of persistently wet soils; poor traffic tolerance and recuperative potential; 10 to 14 day germination from seed. **Typical seasonal N requirements:** 0.5 to 2 lbs N per 1000 sq feet.

Creeping bentgrass (Figure 5)**. Description:** a very shallow-rooted, fine textured grass with an aggressive stoloniferous (above-ground stem) growth habit; many cultivars having a characteristic pale 'blue-green' color. **Primary uses:** almost exclusively for golf turf as bentgrass is the primary grass utilized on Virginia's golf putting greens; also receives extensive use on tees and golf fairways at high maintenance/well-budgeted golf facilities. **Primary establishment method:** seed available for many improved cultivars; sod available from regional producers. **Strengths:** surface smoothness, density, and its tolerance to cutting heights as low as 0.1 inch are predominate reasons for bentgrass use; excellent cold tolerance. **Weaknesses:** very poor heat and drought tolerance; poor traffic tolerance; high disease and insect pressure. **Typical seasonal N requirements:** 2.5 to 4.5 lb N per 1000 sq feet.



Figure 5. Owing to its ability to be maintained at cutting heights of 0.1 to 0.5 inch, creeping bentgrass is a popular grass for golf putting greens, tees, and fairways in the mid-Atlantic.

Annual ryegrass. Description: a bunch-type, medium to coarse bladed grass typically having a very light green color. **Primary uses:** cost effective, temporary soil stabilization either seeded alone or as a nurse grass for perennial species; winter overseeding of lawns or sports fields. **Primary establishment method:** exclusively by seed with most cultivars available having been developed as a temporary forage grass; the first releases of annual ryegrass varieties developed for turfgrass use are now available; there also are **intermediate ryegrass** (*Lolium perenne* x *L. multiflorum*) hybrids for which early releases were of similar quality to annual ryegrass, but later releases are displaying quality characteristics more comparable to perennial ryegrass. **Strengths:** the most rapid germination from seed results in quick establishment and soil stabilization; **Weaknesses:** a very fast growth rate results in a very high mowing requirement; poor cold tolerance; dies quickly the following summer (but note some might consider this a strength when used for winter overseeding and a rapid, natural transition is desired). **Typical seasonal N requirements:** 1 to 2.5 lbs N per 1000 sq feet.

Figure 6 details the seasonal anticipated shoot and root growth and carbohydrate (i.e. stored food) levels across the seasons. Optimal temperatures for cool-season grass growth are 65-75^{o} F, resulting in the primary period for N fertilization being late summer through mid-fall, followed by early to mid-spring. Under the cooling temperatures and shorter day lengths of fall, fertilization optimizes root development and carbohydrate storage rather than excessive shoot growth, and the benefits of fall fertilization continue on into the spring by delivering a steady and sustained spring greening and growth response. During the secondary window for fertilizing cool-season grasses during the spring, limited amounts of N (0.5 to 0.7 lb N per 1000 sq feet total) can support the period when the largest increase in root development occurs. However, as indicated in the figure, spring shoot development very quickly responds to the increasing temperatures and can exceed root development if promoted by heavy N fertilization. Excessive shoot growth, while resulting in a great looking turf for the spring months, promotes a shallow-rooted turf that will struggle in the summer months when environmental extremes are likely. Carbohydrate levels begin to decline in the spring (and continue to decline throughout the summer) as the plant utilizes stored food to support early season root and shoot growth; the decline can be exaggerated by excessive spring N applications. For most purposes, summer N fertilization is discouraged because temperatures exceed optimal growing conditions for the turfgrasses.

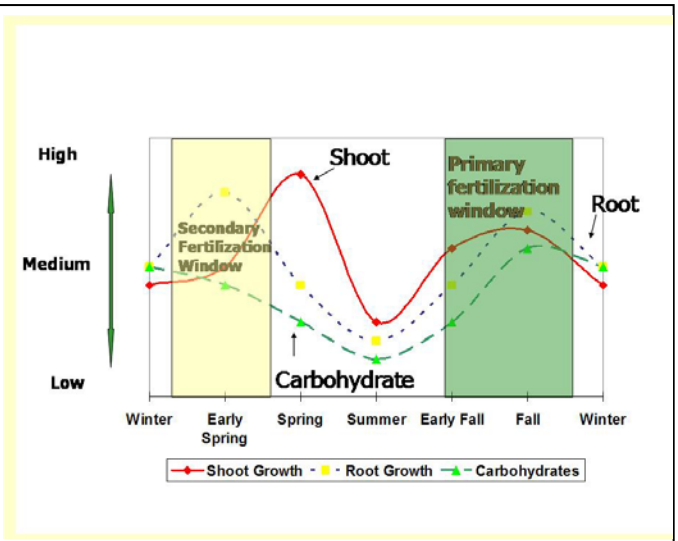


Figure 6. The anticipated seasonal root and shoot growth patterns and carbohydrate levels of

Primary warm-season turfgrasses of importance.

The primary warm-season grasses used in the mid-Atlantic are bermudagrass [*Cynodon dactylon* L., known as 'common bermudagrass' and *C. dactylon x transvaalensis (*Burt.) Davey, known as 'hybrid bermudagrass'], zoysiagrass (*Zoysia japonica* L, known as Japanese lawngrass and *Z. matrella* L., known as manilagrass), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack], and St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze]. Bermudagrass and zoysiagrass can be found throughout the region while centipedegrass and St. Augustinegrass are primarily found in the southern Piedmont and coastal plains. Buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus] has the unique characteristic of being a native turfgrass to

the United States, although its area of adaptation is the Midwestern plains states. Two other limited use turfgrasses are bahiagrass (*Paspalum notatum* L.) and seashore paspalum (*Paspalum vaginatum* L).

Bermudagrass. (Figure 7) **Description:** a highly diverse species with ecotypes varying in leaf textures from very fine to coarse; aggressive lateral growth habit from both rhizomes and stolons. **Primary uses:** an important lawn grass in central to southern Piedmont and coastal regions, with uses ranging from roadside turf to manicured lawns; major advancements in the cold tolerance and quality of seeded (*Cynodon dactylon* L.) and vegetative bermudagrasses (*C. dactylon* x *transvaalensis*) have greatly expanded bermudagrass use throughout the mid-Atlantic, especially on golf and sports turfs; there are now approximately 10 golf courses in Virginia utilizing ultradwarf bermudagrasses for their putting green turf. **Primary establishment method:** improved common varieties now available from seed; vegetative-only cultivars are sterile and can only be established by sod, sprigs (i.e. stems), or plugs. **Strengths:** exceptional heat and drought tolerance; rapid establishment and recuperation rates; exceptional density; cutting heights as low as 0.1 inch for golf green ecotypes, 0.5 to 0.75 inch for golf and fairway uses, to 2.5 inches for lawn use; minimal pest pressure. **Weaknesses:** rapid lateral and foliar growth rates result in high mowing requirement and weed potential in ornamental beds, gardens, etc.; cold tolerance a concern in extreme winter conditions; poor shade tolerance; loss of color due to winter dormancy. **Typical seasonal N requirements:** 1 to 2 lbs per 1000 sq feet for low maintenance lawns and 4 to 6 lbs N per1000 sq feet for intensively maintained golf and sports turfs, higher rates being used for ryegrass-overseeded turf.



Figure 7. Improvements in density and cold tolerance of bermudagrasses, coupled with its rapid recuperative potential and tolerance to close clipping, have made bermudagrass a popular sports turf throughout the mid-Atlantic.



Figure 8. Zoysiagrass provides one of the highest quality, lowest maintenance lawn turfs in the mid-Atlantic, while also being used for golf fairways and tees.

Zoysiagrass (Figure 8**). Description:** an extremely dense, fine to medium textured species that spreads by both rhizomes and stolons. **Primary uses:** lawns, golf fairways and tees. **Primary establishment method(s):** improved cultivars are mostly established by sod, sprigs

or plugs (sod is available throughout the region); a limited number of seeded cultivars now available. **Strengths:** exceptional heat tolerance and moderate drought tolerance; exceptional density; slow vertical and lateral growth rates result in reduced mowing requirement and limited invasiveness; moderate shade tolerance; minimal pest pressure. **Weaknesses:** slow to establish from seed, sprigs or plugs; sod very expensive; loss of color due to winter dormancy; not recommended to overseed zoysiagrass with ryegrass. **Typical seasonal N requirements:** 1 to 2 lbs per 1000 sq feet.

Centipedegrass (Figure 9**. Description:** medium to coarse-textured species with a stoloniferous growth habit. **Primary uses:** lawns and other low maintenance turfs, primarily in the costal regions. **Primary establishment method(s):** seed readily available, sod production primarily limited to the Carolinas . Very limited variety selection. **Strengths:** good quality, low maintenance turf that is well adapted to acidic soils; moderate shade tolerance; slow vertical and lateral growth rates that reduces mowing requirement and its ability to become a weed. **Weaknesses:** poor traffic tolerance; slow to establish; marginal cold tolerance. **Typical seasonal N requirements:** 1 to 2 lbs per 1000 sq feet.



Figure 9. Centipedegrass is an excellent choice for low-input turfgrass sites such as cemeteries in the southern coastal plain of the mid-Atlantic.



Figure 10. St. Augustinegrass is adapted to sun/shade lawns in extreme southeastern VA.

St. Augustinegrass. Description: coarse-textured species with a stoloniferous growth habit. **Primary uses:** lawns and general purpose turf in the Tidewater region of Virginia. **Primary establishment method:** sod or plugs, limited varieties available in the region, with sod primarily coming out of the Carolinas. **Strengths:** best shade tolerance of warm-season grasses; good quality, very dense turf with an aggressive growth rate; good heat and drought tolerance. **Weaknesses:** poor cold tolerance; requires frequent mowing; the most insect and disease pressures of the warm-season grasses. **Typical seasonal N requirements:** 2 to 3.5 lbs N per 1000 sq feet.

Buffalograss . Description: fine-medium leaf texture, stoloniferous species (Figure 11). **Primary uses:** low input, low traffic turf areas across the state. **Primary establishment method:** at this time only from seed. No commercial sod production yet available in the region. **Strengths:** Exceptional cold and drought tolerance, limited mowing requirement. **Weaknesses:** very poor traffic tolerance; concerns with competition with other species better adapted to higher rainfall patterns of this region. **Typical season N requirements:** 1-2 lbs N per 1000 sq feet.



Figure 11. The exceptional cold hardiness of buffalograss is evident in this picture that shows the spring greening of a buffalograss variety trial (left) as compared to a bermudagrass variety trial (top right).

Bahiagrass. Description: medium to coarse leaf textured species with very compressed rhizomes and stolons. **Primary uses:** low input turf areas, including highway rights of way in southeast Virginia. **Primary establishment method:** seed; limited choices in varieties for this area. **Strengths:** good shade, drought, and wear tolerance and is quite tolerant of nematode pressure. **Weaknesses:** average cold tolerance; does not form a dense turf canopy; frequent mowing is required to manage prolific seedhead formation. **Typical seasonal N requirements**: 1-2 lbs N per 1000 sq feet.

Seashore Paspalum. Description: fine to medium leaf texture, rhizomatous and stoloniferous species; **Primary uses:** very limited in Virginia at this time as this species undergoes more extensive evaluation, but anticipated to have uses for lawns, general purpose turf, and possibly golf courses and sports turfs if cultivars prove to have adequate winter hardiness. **Primary establishment method:** at this time only from seed but commercial sod production is available in the southeastern United States. **Strengths:** exceptional tolerance of very high salt concentrations compared to other turfgrasses; **Weaknesses:** cold tolerance is a serious concern in this region; **Typical seasonal N requirements: 1** to 3.5 lbs N per 1000 sq feet depending on its use (which is still being determined and evaluated in southeastern Virginia).

The growth rates for warm-season grasses are optimized at 80-95^{o} F. Their seasonal shoot and root growth patterns and stored carbohydrate levels are detailed in Figure 12. The grasses enter dormancy after frost events in the fall and do not resume active growth until early to mid-spring the following season. Nitrogen fertilization is preferably initiated in the spring after complete greening, but at the least after 50% spring greening for situations where fertilizers are applied in combination with preemergent herbicides in traditional "weed and feed" products. Fertilization can continue through the summer and into early fall during the periods of active growth. As the persistently cool temperatures of fall arrive, N fertilization ceases as the plants prepare for winter dormancy.

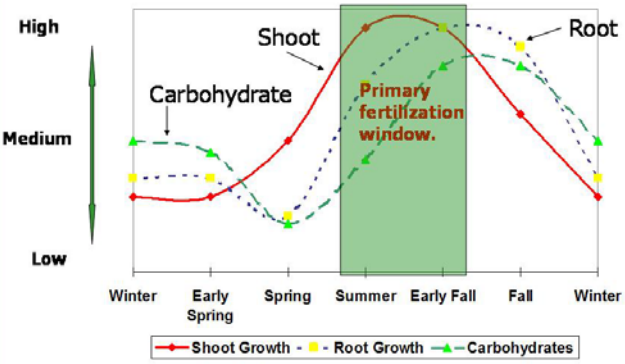


Figure 12. The anticipated seasonal root and shoot growth patterns and carbohydrate levels of warm-season turfgrasses.

Warm-season grasses have inherent advantages in water use efficiency over cool-season grasses, and for this reason alone, their use is growing. However, the winter dormancy period that results in the complete loss of green color (Figure 13) continues to be a primary reason why many homeowners are reluctant to establish and maintain warm-season lawns.



Figure 13. Warm-season grasses have a winter dormancy period ranging from 4 to 5 months in the mid-Atlantic.

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Chapter 3. Turfgrass Growth and Development

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Which came first, the seed or the plant? We may never know the answer to this academic question, but since many of our turfgrasses originate from seed, we feel it logical to begin by discussing the growth and development of seeds. Next, we'll give our attention to the production and use of energy through the processes of photosynthesis and respiration and finish with a thorough presentation of the vegetative growth of turfgrass plants.

Seeds

When we examine a turfgrass seed, we must marvel at how superbly nature has packaged a resting miniature plant. This mini-plant or embryo has an intact food supply called the endosperm to nourish the embryo as it develops into a seedling and can begin to produce its own food through photosynthesis. The embryo and endosperm, surrounded by a tough, protective seed coat, together are referred to as the caryopsis or true seed. The caryopsis is further enclosed by two bracts, the lemma and palea, providing a wrapper that enables the seed to easily be shipped or stored. In some cases, the lemmas and paleas may have been removed naturally during processing (e.g., bentgrass) or mechanically (e.g., hulled bermudagrass seed). At the base of the palea is the rachilla, a short stem-like structure that was originally attached to the seed stalk. Spine-like structures called awns may also be present, coming off the top (e.g., fine fescues) or bottom (e.g., bentgrass) of the bracts.

As with most vegetative material the seed is perishable, but with dry and cool storage (< 55 F), the seed will often survive storage periods of 2-3 years. Storage at room temperature (or above) will often shorten viability to 1-2 years. Because the seed is a living organism, it must respire (burn stored energy (starch) and give off CO_2), just as animals do. If the seed is placed in an environment that slows the rate of respiration,

such as cold storage, starch is consumed at a slow rate and the seed will remain viable for longer periods.

Germination. When seeds are placed in an environment of favorable moisture and temperature (60-75 F), the seed absorbs water and biochemical functions begin the process of germination. Some species, such as zoysia- and buffalo-grasses, have a seed coat that must be scarified (scratched or chemically thinned) before water can be absorbed for active germination. With water imbibition, starch in the endosperm is broken down to simpler sugars and transported to the embryo. Enzymes and hormones are mobilized and signal cells in the embryo to divide, resulting in the first appearance of the coleoptile.

Within the embryo is a minute plant containing primary leaves (plumule) and a primary root (radical). The first organ that appears during germination is the sheath-like coleoptile that protects the plumule as it emerges above the soil. The radical also has a protective sheath called the coleorhiza. Through the inside of the hollow coleoptile, the first leaves emerge and begin to photosynthesize.

Immediately after the coleoptile emerges, the radical begins to develop. A short-lived primary (or seminal) root system then develops. Within a few weeks the primary roots are replaced by fibrous adventitious roots that function as the primary water and nutrient absorbing organs for the shoots. If unfavorable environmental conditions occur during the germination and seedling development process, survival can be poor. Therefore, it is important to plant during recommended date ranges and protect developing seedlings from the vagaries of nature via mulching (or covers) and supplemental irrigation.

Photosynthesis and Respiration

In the transition zone we manage turfgrasses whose photosynthetic metabolism make them best adapted to temperate climates, called cool-season grasses, and those whose photosynthetic metabolism make them best adapted to semi-tropical climates, called warm-season grasses. Cool-season grasses are often referred to as C3 plants

because the first product of photosynthetic carbon fixation is a 3 carbon compound. Photosynthetic carbon fixation in warm-season grasses produces a first product consisting of 4 carbons, hence the term, C4 plants.

These two categories of grasses are also distinguished by having distinct cellular anatomies. C3 plants have leaves consisting of loosely arranged cells called spongy mesophyll. Photosynthesis begins near dawn with the opening of leaf pores called stomates that allow water to transpire out (for leaf cooling) and CO_2 to diffuse in and be fixed by an enzyme called RUBISCO (ribulose bisphosphate carboxylase oxygenase). This process takes place within the chloroplast-filled spongy mesophyll cells via the energy provided by chlorophyll capture and reduction of light energy to chemical energy. Fixed CO_2 is first used to produce the 3-carbon compound phospho-glyceric-acid (PGA), which is quickly converted to 5-carbon sugars such as glucose and fructose that are the main building blocks of carbohydrates.

The open cell arrangement of C3 plants, however, results in less than optimal efficiency of CO_2 fixation due the natural fact that RUBISCO also fixes oxygen in an energy-wasting process called photorespiration. Internal C3 leaf oxygen levels are on the order of 20% relative to those of CO_2 at 0.0035%. RUBISCO, when exposed to such an oxygen-rich environment, will use energy to fix oxygen in a 1:3 ratio to CO_2, resulting in the net consumption of carbon, rather than a net gain as in photosynthesis. As a result of photorespiration, C3 plants grow (produce a net energy gain) more efficiently at cool temperatures, because the relative internal concentration of oxygen increases as temperatures increase.

Warm-season plants evolved a distinct cell anatomy and photosynthetic pathway as they struggled to adapt to warmer tropical climates. They still use RUBISCO for CO_2 fixation, but through a special Kranz anatomy they isolate this enzyme from oxygen exposure. Without exposure to oxygen, no photorespiration occurs and RUBISCO functions only to fix CO_2. Kranz anatomy is characterized by RUBISCO-containing bundle sheath cells that form an air-tight ring that excludes oxygen. In C4 grasses CO_2 diffuses into the leaf mesophyll cells and combines with water to form bicarbonate (HCO_3). Bicarbonate is then fixed by a C4-specific enzyme called PEP carboxylase

(phospho-enol-pyruvate). Fixation results in the production of a 4-carbon compound called oxaloacetic acid. This 4 carbon first product is then transported into the bundle sheath cells and broken down into CO_2 and a 3-carbon compound. RUBISCO, now free from all oxygen exposure, fixes CO_2 and forms the 3-carbon compound PGA, just as in cool-season plants. These differences in anatomy and photosynthetic metabolism make C4 plants approximately 50% more efficient users of water and CO_2 than C3 plants when growing at temperatures of 75 F or more.

The generalized photosynthetic reaction is the same for C3 and C4 plants:

$12H_2O + 6CO_2$ + chlorophyll capture of light $\xrightarrow{\text{RUBISCO (PEP)}}$ $C_6H_{12}O_6 + 6O_2 + 6H_2O$, where $C_6H_{12}O_6$ represents the final carbohydrate product of photosynthesis. Respiration is essentially a reversal of photosynthesis:

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + energy release to fuel growth and maintenance of plant structures at any time during night or day.

Vegetative Growth

As initial root and leaf development proceeds the seed disintegrates and is transformed into a crown (or growing point) at the soil surface. The crown is a compressed stem consisting of stacked nodes and internodes. The location of the crown (a 1 mm high unelongated stem) at the soil surface is why grasses may be mowed frequently without growth stopping. Nodes are regions of cell differentiation from which new organs (e.g., leaves, tillers, stolons, rhizomes, and roots) develop. The apical meristem is located at the tip of the crown. Given proper environmental conditions, cell division and elongation of the apical meristem will result in development of the flowering stem (or culm). Tillers, rhizomes, and stolons develop from axillary buds on the sides of the crown. Each crown contains 3 to 5 miniature (undeveloped) leaves just below the apical meristem. Leaf formation proceeds in an ordered fashion with the second leaf growing through the coleoptile and emerging from within the fold (or roll) of the first leaf. Each succeeding leaf develops from the crown and upward within the older leaves,

much like an expanding telescope. Each succeeding leaf is higher up on the shoot than the previous leaf. A shoot consists of a stem (crown) and attached leaves.

As each leaf develops, two distinct structures emerge, the sheath and the blade. Each has its own region of cell division and elongation at its base called an intercalary meristem. The oldest portion of the leaf is at the tip, while the youngest is at the base of the sheath. Because leaf growing points (intercalary meristems) are at the base, leaf expansion can continue after the top portion of the blade is removed by mowing.

The process by which new aerial shoots emerge from axillary buds is called tillering. Density increases as new tillers arise, form leaves and roots, and separate from the mother shoot. Well-tillered grasses provide dense ground cover, competition with weeds, and excellent aesthetics. Two other ways that certain grasses spread is by development of rhizomes and stolons. Rhizomes are underground stems that develop from crown axillary buds and elongate horizontally through surface soil. New shoots develop from rhizome nodes, break through the soil surface, and begin to photosynthesize. Stolons also arise from crown axillary buds, creeping along the soil surface, rooting at nodes, and developing new shoots. Stolons and rhizomes are of primary importance for low mowing tolerance and recovery from wear.

The flowering portion of the grass shoot is called the inflorescence. Formation of the inflorescence from the apical meristem occurs in three distinct phases. First, the shoot must be mature to respond to environmental conditions (e.g., long days) that promote flowering. Second, for flowering of the mature shoot to be induced, two requirements usually need to be met: induction by vernalization (e.g., exposure to sustained low (< 50 F) temperatures, or winter); and/or a day-length requirement. Many of our common C3 and C4 turfgrass species flower (even under mowing) each spring in response to the lengthening days. Cells divide then elongate rapidly from the apical meristem and the inflorescence emerges from the middle of the existing leaves. Once a shoot has flowered it usually dies, but leaves behind many immature daughter tillers to sustain the life of the lawn.

Turfgrasses produce a fibrous root system. The adventitious roots arise from the lower nodes of the unelongated stem (crown) or on rhizome or stolon nodes. Adventitious roots appear to live as long as the shoot they support. The life span depends on the species, season of development, environmental conditions and management practices. The meristematic region of the root is found at the tip, immediately behind the root cap. The root cap consists of protective cells that slough off as cells divide and the root grows. Behind the meristematic region, cells elongate. As the root cells mature, they differentiate into specific cell types. In this region, the vascular tissue develops. Phloem tissue transports food manufactured in the leaves to the roots for respiratory energy, while the xylem conducts water and nutrients from the roots to other parts of the plant. Also, root hairs develop from the root epidermal cells. Most nutrients and water used by the plant is absorbed by the root hairs. Roots grow most efficiently and profusely in well-aerated and pH-balanced soils.

Cool-season grasses have a bi-modal annual growth pattern. Shoot growth begins with a strong spring flush (at 60-75 F) that eventually slows as flowering occurs (if not clipped) and temperatures increase. As summer progresses, shoot growth slows substantially and may stop given sustained high temperatures of 85 F or above. As fall approaches, moderate vertical growth resumes, followed by vigorous tillering. Maximum root growth occurs at slightly lower temperatures than shoot growth (50-65 F). Thus, maximum root growth occurs in mid spring and fall. Root growth slowly continues through the winter except in areas where long-term soil freezing occurs.

Warm-season grasses have a uni-modal annual growth pattern. They are dormant to semi-dormant through the winter and slowly re-grow shoots and roots from surviving crowns as temperatures increase in mid-spring. Maximum shoot and root growth occurs during summer temperatures of 80-95 F. Growth slows dramatically in the fall as temperatures drop into the 50’s. Leaf senescence and cessation of shoot growth occurs following successive frost events. Most roots die during the winter and must be replaced during spring greenup.

Close attention to the growth and development dynamics of turfgrass species in response to season and weather fluctuations are essential for intelligent programming

of the primary cultural practices of mowing, fertilizing, cultivation, and irrigation. Professional turfgrass managers work with seasonal growth patterns to schedule cultural practices that favor robust growth of roots and shoots for a turfgrass that is stress-tolerant and resource-efficient.

Chapter 4. Irrigation Management Principles

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Introduction

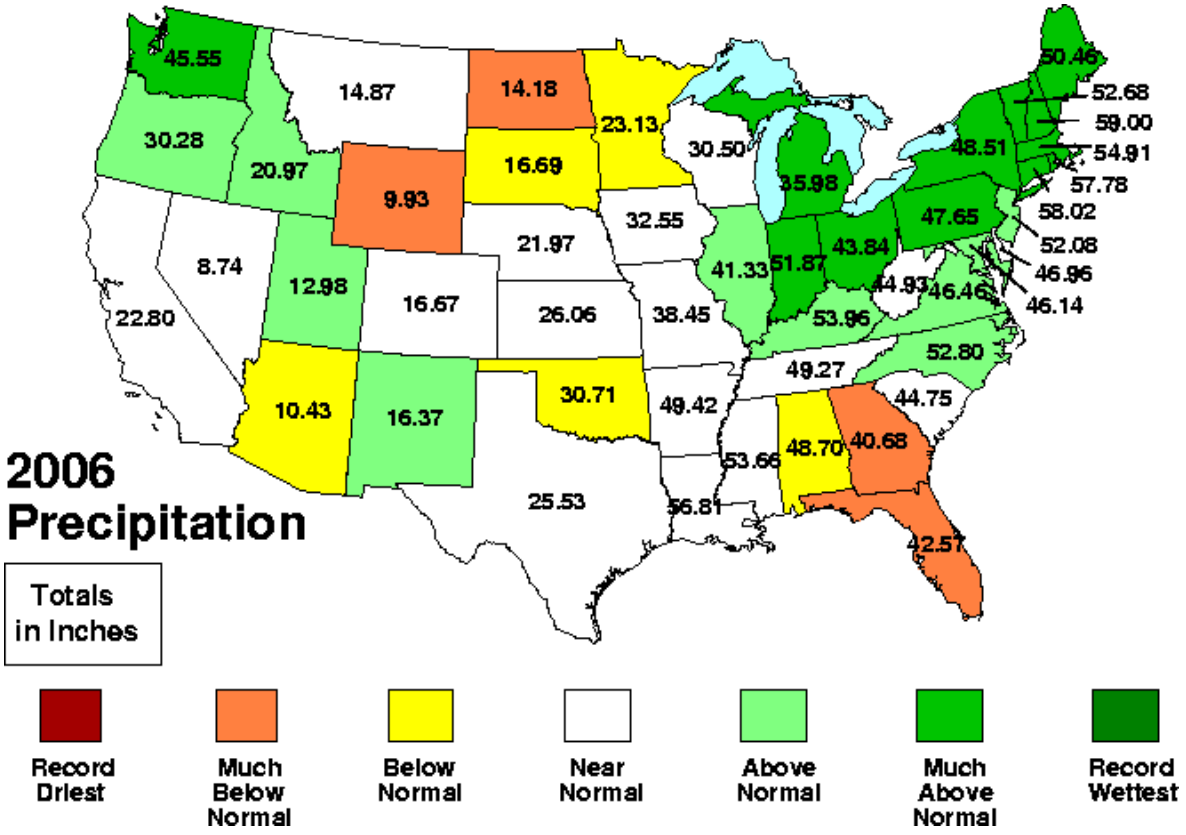
Although very important for efficient delivery of water, this chapter will not discuss irrigation design or installation. At best, a certified irrigation contractor (CIC) should be hired to provide these services. Information regarding these and other landscape irrigation issues can be accessed at the Virginia Irrigation Association website: www.virginiaia.org. Secondarily, a number of irrigation design, installation, and maintenance books and references can be accessed at the national Irrigation Association website: www.irrigation.org.

The focus of this chapter will be on the following topics: Humid-transition zone climates and the need for irrigation; irrigation requirements and drought tolerance of commonly utilized turfgrass species; irrigation scheduling to include system auditing, irrigation amount, frequency, and timing; irrigation water sources and quality issues; and irrigation system components and trouble-shooting.

Humid Transition-Zone Climates

New Jersey, Delaware, Maryland, Virginia, western North Carolina, Kentucky, Tennessee, southern portions of Indiana, Illinois, Missouri, and Kansas, and northern portions of Arkansas, Oklahoma and Georgia, are in a climate zone classified as the Humid Transition-Zone. This zone is characterized as having warm to hot summers and winters with moderate freezing events. Average precipitation within this zone ranges from totals of 30-50 inches (Figure 1). Equally important is when the rainfall typically occurs. Monthly rainfall averages are fairly evenly distributed across months with the wettest months on average being July and August (slightly above 4 inches), but every month typically receives 3 or more inches. Of course, these are averages across a region that possesses great climatic diversity and the first years of the 21st century have provided dramatic swings in rainfall amounts from record droughts (2000-2002; 2007) to record rainfall (2003-2004).

Figure 1. Average annual precipitation for each state in the normal rainfall year of 2006. Data and graphic from the National Climatic Data Center.



Irrigation becomes necessary for maintaining functional turf surfaces especially in those summer months when rainfall events fail to be evenly distributed or occur in afternoon thunderstorm events where runoff exceeds soil recharge.

Irrigation Requirements and Drought Tolerance

In general, turfgrasses will require 1 to 1.5 inches of rainfall or irrigation per week during the summer months to replace what is lost during active growth via evapotranspiration (ET). Given the localized and uneven occurrence of rainfall each growing month, it often becomes necessary to supplement soil moisture availability through properly scheduled irrigation. See Table 1 below for weekly estimates of irrigation required on various surfaces in a typical humid transition zone state. To most accurately schedule irrigation one must be aware of the estimated ET requirements of a particular turfgrass species and the conditions under which it is maintained (e.g., intensity of use, soil type, microenvironment, and mowing height).

For example, warm-season species such as bermudagrass and zoysiagrass require significantly less irrigation than most cool-season grasses because they are more efficient users of water and carbon dioxide in their photosynthetic pathway. This increased efficiency, coupled with their deep-rooting nature, imply the need for 30-50% less irrigation during the summer.

Heavily used turf surfaces need slightly more irrigation to promote wear recovery and will tend to have more compact soil that restricts rooting. These two factors imply that irrigation will need to be applied more frequently in smaller amounts.

ET demand of shaded turfgrasses is often 30-50% less than in full sun. However, low light intensity often results in shallow rooting. These two factors combine to indicate shaded grasses should be watered half as much and half as often as turf in full sun. Consider a tall fescue lawn with one irrigation zone in the sun and one in moderate shade. A general summer recommendation would be to irrigate the sunny area every 3rd or 4th day with 0.7 in. of water, while the shaded area should receive only 0.35 in. every 7th or 8th day without measurable rain.

Table 1. Estimated ET replacement requirement of various turf surfaces in Humid Transition states

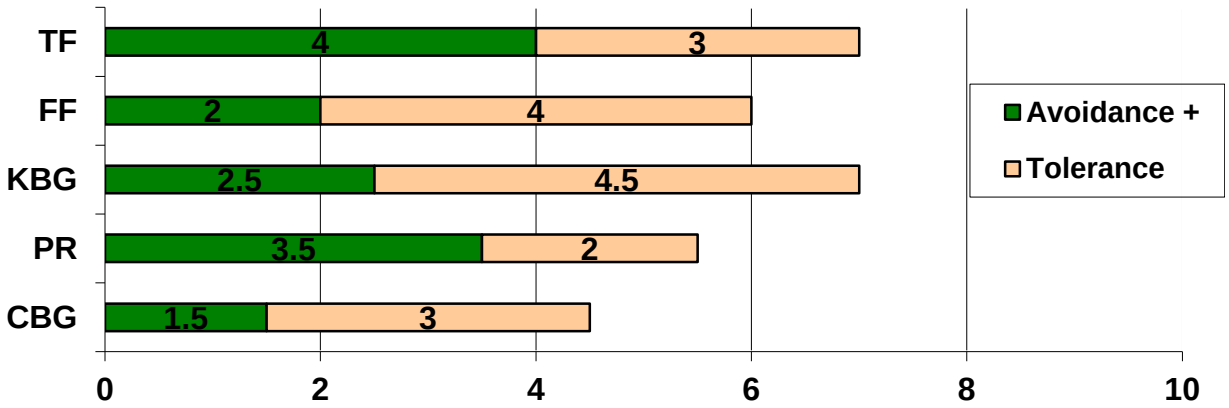
	May	June	July	Aug	Sept
Type of Turf	Estimated ET Requirement (inches per week)*				
C3 Rough	0.60”	1.20”	1.50”	1.30”	0.80”
C3 Shaded Area	0.30”	0.60”	0.75”	0.65”	0.40”
C3 Fairway	0.55”	1.10”	1.35”	1.20”	0.75”
C4 Rough	0.45”	0.85”	1.05”	0.90”	0.55”
C4 Fairway	0.35”	0.75”	0.90”	0.80”	0.50”

* These estimates assume that only 50% of monthly rainfall is effectively soil absorbed and becomes available for plant uptake.

From the table above it is apparent that as mowing height goes from higher lawn or field conditions (2 to 4 inches) to lower golf course fairway conditions (0.3 to 1 inch) ET demand decreases. In general, lower cutting heights reduce leaf area resulting in less overall leaf transpiration. Caution! Do not take this to imply that water can be conserved by mowing lower. As was discussed in the chapter on mowing, lower cutting heights result in shallower rooting and the requirement to mow more frequently to avoid negatively affecting stress tolerance and competitiveness with weeds and other pests. Deep roots are the most important factor in a turf's ability to withstand multiple stresses, especially drought.

Our discussion above was one that assumed irrigation will be practiced, but what of those many turf areas where irrigation will be applied sparingly or never at all? In these cases we need to know which of the turfgrass species are most drought resistant and how to properly manage them to maximize this resistance. Drought resistance encompasses two facets: avoidance and tolerance. Drought avoidance is the ability to stay somewhat green and growing as surface soil dries and drought progresses; it is the facet of drought resistance that is most preferred: green grass even as drought sets in. Drought tolerance is the ability of a turf to keep its growing points alive, not necessarily its leaves green, as drought progresses. In figure 2 below, common turf species are rated in terms of these two facets of drought resistance.

Figure 2. Drought Resistance of cool-season turfgrass species, both drought avoidance and tolerance.



Drought resistance rankings of cool-season turfgrasses; 5 = best for each

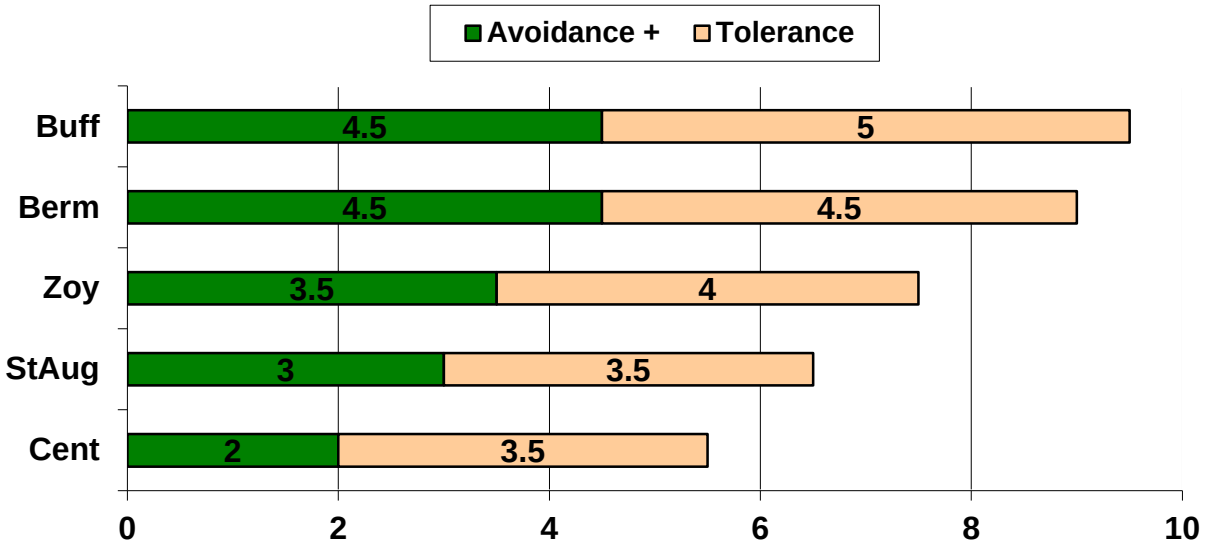
Among cool-season grasses, tall fescue (TF) has the best genetic potential to grow deep roots and avoid drought as surface soil moisture becomes limited. Perennial ryegrass (PR), a close genetic relation to TF, also avoids drought a few days longer than others. However, PR's ability to tolerate drought after exhausting accessible soil moisture is relatively poor. This implies that PR will often exhaust all energy reserves and die almost completely in an extended summer drought of 3 to 5 weeks. Tall fescue tolerates drought a little longer than PR, but will also succumb to an extended summer drought of 4 to 6 weeks. In these situations even the replacement of 25 to 50% of ET via irrigation once weekly will prevent widespread loss of TF and PR. The turf may not be aesthetically pleasing, but this approach will conserve water and money while reducing the need for extensive fall renovation.

Kentucky bluegrass (KBG) and the fine fescues (FF) respond differently to the onset of drought relative to TF and PR. These grasses are more shallow-rooted and respond much sooner to moisture deficits in the upper soil profile by stopping leaf growth and allowing leaves to brown and senesce. The subsequent lack of leaf transpiration allows the very limited root moisture uptake to be used to maintain hydration of growing points at the crown and on rhizome and stolon nodes. In this manner, undeveloped tillers can remain viable and arise from these nodes once drought subsides. During extended summer drought these brown grasses are said to be in drought-dormancy. Every survival mechanism has its limits with KBG and FF usually being able to recover from up to 6 weeks of drought-dormancy. If these areas are subjected to wear during dormancy, this survival limit will be shortened based on the intensity of wear. As opposed to TF and PR, KBG and FF will not respond well to very small irrigation events that do not effectively return soil moisture to field capacity. Such a minimalist approach merely functions to bring some nodes out of dormancy and send out a few new tillers. However, with the quick return of dry soil much of this new growth will perish, leaving less potential tillers for full recovery at the real cessation of drought. With KBG and FF the approach has to be all or nothing: a robust and continued use of irrigation or no irrigation at all.

Creeping bentgrass (CBG), when grown on native soils on golf fairways, is most often shallow-rooted, not having thick roots to penetrate these heavy soils. This, combined with a

growth habit that partitions considerable energy to stolon development, results in a species that has very poor ability to mine deeper soil moisture and avoid drought. While CBG's extensive stolon network provides many growing points for potential recovery from drought, this tolerance mechanism is grossly inadequate for maintaining a functional golf playing surface. Thus, no attempt should be made to maintain CBG in the humid transition zone without irrigation.

Figure 3. Drought Resistance of warm-season turfgrass species, both drought avoidance and tolerance.



Drought resistance rankings of warm-season turfgrasses; 5 = best for each

The water use efficiency of warm-season grasses is often 50% greater than cool-season grasses. This means they can develop 50% more biomass with an equivalent amount of water (Figures 2 and 3). Such a photosynthetic advantage also often translates into plants that are deeper rooted than cool-season grasses. This is especially true for buffalograss as it primarily uses photosynthetic energy to grow deep roots rather than heavy shoot biomass. While this growth habit makes buffalograss very susceptible to wear and weeds, it also makes it the most drought resistant turfgrass used in the U.S. Bermudagrass, a more common humid transition zone grass, rates only slightly behind as it tends to allocate more energy to shoot growth than buffalograss during drought; a fact that can result in some shoot death in prolonged summer drought (over 8 weeks). Drought resistance goes from medium high to medium low as we

proceed from zoysiagrass to St. Augustine to centipedegrass as these three grasses all originate from high rainfall climates and are progressively shallow-rooted, respectively.

Irrigation Scheduling

In the section above we presented some rules of thumb concerning how much to irrigate various turf types. In this section, we will discuss concepts of site-specific irrigation auditing so as to determine the proper approach to applying specific irrigation amounts while being guided by the science-based principle of “deep and infrequent” delivery of water.

Given an unobstructed soil of 12 to 18 inches, research and experience have shown that deep rooting is promoted by applying irrigation to fill soil pores to the depth of roots and not irrigating again until surface soil moisture has been depleted to near the wilting point. Such a deep and infrequent approach encourages roots to explore deeper depths for soil moisture, while promoting gas exchange and soil temperature moderation and discouraging surface soil compaction. Enhanced soil gas exchange also promotes increased rooting density, improving water and nutrient absorption efficiency.

Soil type, effective rootzone depth, and estimated ET demand must be determined as they dictate how frequently irrigation must be scheduled and if soak cycles will be needed. Heavier soils such as silts and clays can only take in irrigation at a rate of 0.25 to 1 inch per hour, while the infiltration rate of sandy soils can be 2 to 20 inches per hour. Soil compaction further restricts permeability, but can be enhanced via regular core aeration. Soil type also determines how much water per inch can be held at field capacity (see table 2).

Table 2. Estimated Plant Available Water (PAW) between Field Capacity and Wilting of various soil textural classes.

Soil Textural Class	Field Capacity	Wilting Point	PAW
	Inch of Water per Inch of Soil		
Sand	0.14	0.06	0.08
Sandy Loam	0.24	0.09	0.15
Loam	0.34	0.13	0.21
Silty Clay Loam	0.40	0.18	0.22
Clay	0.41	0.28	0.13

Effective rootzone depth is defined as that depth to which 90% of the root system penetrates and must be determined on-site with a soil probe or spade. These two factors are then used to estimate the soil water-holding reservoir available to your root system.

Finally, we need to know the precipitation rate of the irrigation system or zone to be used. A system's precipitation rate is most accurately determined by conducting an irrigation audit with catch cans or rain gauges. To conduct an audit place 10 to 20 collection devices in a grid pattern within each irrigation zone (figure 4). Run the heads for 15 to 30 minutes and then determine the amount collected in each. Use these numbers to determine the average precipitation rate of this zone and its Distribution Uniformity (DU).

Figure 4. Example of an irrigation audit being conducted on a putting green with catch cans. Less expensive rain gauges or tuna tins can also be used.



For example, on a tall fescue lawn the heads were run for 15 minutes and the following amounts were collected in 10 rain gauges: 0.30, 0.32, 0.20, 0.25, 0.18, 0.33, 0.40, 0.29, 0.42, and 0.22 inches; the average is 0.29 inches/15 minutes; multiply by 4 and we get a precipitation rate of 1.16 inches/hour. Next, we use the lowest 3 readings to estimate a DU or the lack of 100% uniformity of application of this system.

Percent DU = [((0.20 + 0.18 + 0.25/3)) / 0.29] * 100 = 72%

Well designed, installed, and maintained irrigation zones should have DU's of 70% or higher. If they do not, one should troubleshoot the system and attempt to increase uniformity. Troubleshooting is discussed in a later section. These precipitation rate and DU numbers will be used in the examples below.

The following two examples will serve to illustrate these concepts and put the deep and infrequent irrigation approach into action.

Example 1: Bermudagrass lawn or field on a silty clay loam soil in July

Estimated ET demand:	1.05”/wk = 0.15”/day
Effective rooting depth:	9”
PAW per inch of soil:	0.22”
Estimated infiltration rate:	0.5”/hr
Irrigation zone precipitation rate:	1.16”/hr
Irrigation zone DU:	72% or 0.72

Steps

1. Determine reservoir of water available to the root system at soil field capacity:

Effective rooting depth X PAW per inch = 9” x 0.22” = 1.98” or 2”

2. Next, determine how dry you can safely allow your surface 2 to 4 inches of soil to get. Remember, soil moisture is depleted from shallow depths first, so a good rule of thumb to minimize wilting potential between irrigations is to allow 60% depletion of PAW. So,

Days until 60% depletion of PAW = (2” x 0.60) / 0.15” ET/day = 8 days or run irrigation every 7^{th} and 8^{th} days to apply 1.2 inches of water.

3. Determine irrigation minutes required to replace 1.2 inches of water (on even the driest parts of the zone due to poor distribution) used each 7 to 8 days:

(1.2” / 1.16”) = 1.44 x 60 minutes = 86 minutes

DU of 0.72

4. Finally, determine number of irrigation cycles needed to replace 1.44 inches of water without wasteful runoff. The soil can absorb about 0.5”/hr, so the longest we can run the zone is: (1.16”/hr x 0.50”/hr) x 60 min = 35 minutes

Soak cycles needed to avoid runoff = 86 min / 35 min/cycle = 2.5 cycles

5. One approach to using these numbers would be to schedule one 30 minute cycle every 7 days, followed by two more cycles on day 8, one of 30 minutes, with the third supplying the final 16 minutes.

We have yet to discuss what time of day these cycles would be scheduled. Early morning (2 to 8 am) is the best time of day to space various zonal and soak cycles to take advantage of four factors: first, water pressure is normally highest in the early morning, while wind is low providing more uniform head to head coverage; second, few people are around to be bothered by the irrigation; third, the larger droplets applied via irrigation actually knocks sugary dew off the leaf, reducing a food source and the leaf wetness period required for best disease development; and fourth, evaporative demand from the sun and wind are minimized providing more efficient soil moisture recharge.

Thus, if we return to the above irrigation scheduling example for a bermudagrass lawn or athletic field we would run this zone on day 7 for 30 minutes from 4 to 4:30 am, followed on day 8 by another 30 minute cycle from 4 to 4:30 am, with the remaining cycle being scheduled from 5 to 5:16 am. As with any cultural or chemical practice in turfgrass management, fine-tuning of this program to fit homeowner/clientele needs and maintenance and use patterns will be left to the field observations of the turf manager.

Example 2 is included to re-emphasize the points above and to demonstrate that the deep and infrequent irrigation approach is relative to each turf situation.

Example 2: Kentucky bluegrass lawn on a clay soil in July

Estimated ET demand:	1.50”/wk = 0.21”/day
Effective rooting depth:	4”
PAW per inch of soil:	0.13”
Estimated infiltration rate:	0.25”/hr
Irrigation zone precipitation rate:	1.16”/hr
Irrigation zone DU:	72% or 0.72

Steps

1. Determine reservoir of water available to the root system at soil field capacity:

Effective rooting depth X PAW per inch = 4” x 0.13” = 0.52”

2. Next, determine how dry you can safely allow your surface 2 to 4 inches of soil to get. Remember, soil moisture is depleted from shallow depths first, so a good rule of thumb to minimize wilting potential between irrigations is to allow 60% depletion of PAW. So,

Days until 60% depletion of PAW = (0.52” x 0.60) / 0.21” ET/day = 1.5 days or irrigate every two days in July.

3. Determine irrigation minutes required to replace 0.31 inches of water (on even the driest parts of the zone due to poor distribution) used every two days:

(0.31” / 1.16”) = 0.37” x 60 minutes = 22 minutes

DU of 0.72

4. Finally, determine number of irrigation cycles needed to replace 0.37 inches of water without wasteful runoff. The soil can absorb about 0.25”/hr, so the longest we can run the zone is: (1.16”/hr x 0.25”/hr) x 60 min = 17 minutes

Soak cycles needed to avoid runoff = 22 min / 17 min/cycle = 1.3 cycles

In summary, the deep and infrequent irrigation approach for this shallow-rooted Kentucky bluegrass lawn on a clay soil will be to irrigate every two days with two early morning soak cycles: 4 to 4:17 am and 5 to 5:05 am. This type of summer irrigation schedule does not seem to be very “deep and infrequent”, but it is what is required to maintain health and responsibly apply irrigation to this shallow rooted-species growing on a poor soil. Homeowners and turf managers who are all too often faced with these types of situations should strive to improve the soil (and therefore rooting depth and water conservation) by more frequent core aeration and compost topdressing events.

Irrigation sources and water quality issues

Irrigation Sources. For lawns the principle source of irrigation water is potable municipal water that by its definition is clean of contaminants such as suspended solids, nutrients, salts, or carbonates that could have injurious effects on turfgrass or surrounding ecosystems. The primary drawbacks of municipal water are cost and less than adequate availability during extended drought periods. For larger turfgrass facilities, the four primary sources of irrigation water are groundwater from wells, stationary surface bodies (lakes, reservoirs, ponds), flowing surface bodies (rivers, streams), and of increasing importance, effluent from municipal treatment facilities (for a discussion of reclaimed water for irrigation see VT Cooperative Extension publication 452-014 at http://www.ext.vt.edu/pubs/compost/452-014/452-014.html).

In most areas of the humid transition zone sufficient groundwater exists for the development of wells to serve as a direct irrigation source or to supplement levels of on-

property irrigation ponds. Well water is usually desirable because of freedom from weed seeds, potential pathogens, and suspended solids. Tests to confirm acceptable levels of sodium, carbonates, pH, boron and chloride should be conducted prior to full-scale use for irrigation. In general, wells provide ample water that is consistent in quality. However, water quality problems can arise due to persistent drought where drawn-down inland wells begin to accumulate carbonate and bicarbonate and wells in coastal areas experience saltwater intrusion. Such irrigation water quality issues will be discussed in greater detail below.

Pumping from rivers and streams can be a reliable source of ample irrigation water, but local permitting regulations must be investigated and followed closely. Flowing water often carries suspended solids which must be screened to prevent clogging of irrigation system components. Where practical, imponding can be used to allow settling of suspended solids prior to pumping.

Many facilities can be planned to have small lakes or ponds that are fed by precipitation, surface drainage, or springs and serve as irrigation reservoirs. Management practices must be implemented to prevent these ponds from becoming sedimented, polluted, and contaminated with excess algae and aquatic weeds. Readers interested in pond water quality management can consult Virginia Cooperative Extension Publication 420-251 at www.ext.vt.edu/pubs/fisheries/420-252/420-251.pdf.

Irrigation Water Quality. The suitability of a specific water source for irrigating depends on the type and concentration of substances dissolved or suspended in the water. Irrigation water quality issues that could pose increasing hazards to turfgrass health in the humid transition zone as population pressure on water availability increases are salinity, sodium absorption ratio (SAR) and residual sodium carbonate (RSC).

Salinity is measured as the electrical conductivity (EC) of the irrigation water. Irrigation with water of a high EC can result in the development of physiological drought or the inability of plant roots to absorb water from the soil. As the salt concentration of the soil solution increases, soil osmotic potential becomes so negative as to preclude root water uptake and

widespread wilting can occur. The United States Department of Agriculture (USDA) classifies the salinity hazard of irrigation water as the following:

1. EC < 0.25 dS/m; Low hazard: suitable for landscape irrigation
2. EC = 0.25 to 0.75; Medium hazard: suitable if moderate rainfall leaching occurs.
3. EC = 0.75 to 2.25; High hazard: not to be used on fine-textured soils.
4. EC = 2.25 or more: Very high hazard: not suitable for irrigation.

Use of saline irrigation water can also result in the accumulation of sodium ions in the soil and negatively affect soil physical structure by collapsing pore space, thereby greatly diminishing permeability; this phenomenon is called deflocculation. The relative concentrations of the major cations in irrigation water, Ca, Mg, and Na, determine the sodium absorption ratio (SAR) and subsequent potential to cause deflocculation. The USDA has also developed a hazard classification system for SAR values.

1. SAR = 0 to 10; Low hazard: water suitable for irrigation on all soils.
2. SAR = 10 to 18; Medium hazard: do not use on fine-textured soils; use on well-drained sandy soils should be fine.
3. SAR = 18 to 26; High hazard: harmful effects can be expected in most soils and repeated gypsum amelioration will be necessary.
4. SAR = > 26; Very high hazard: unsuitable for irrigation.

As drought depletes groundwater levels, wells in limestone-based aquifers begin to contain higher concentrations of carbonates and bicarbonates. Carbonates react with Mg and Ca in the soil to form solid Mg- and Ca-carbonates (or lime), leaving soil exchange sites open for Na attachment. Longer-term summer reliance on irrigation water high in bicarbonates on low CEC soils can result in the above-reviewed Na-related problems of physiological drought and deflocculation. The residual sodium carbonate (RSC) test is used to assess the potential of

irrigation water to cause a Na-hazard and is represented by the formula: RSC = (CO_3^{-2} + HCO_3^{-}) – (Ca^{+2} + Mg^{+2}). Sodium hazard levels based on irrigation water RSC values are given below.

1. RSC < 1.25; Low hazard: water suitable for irrigation on all soils.
2. RSC = 1.25 to 2.5; Marginal hazard: appreciable Ca and MG removal due to irrigation water use can occur.
3. RSC > 2.5; unsuitable for irrigation without treatment of water with gypsum or sulfuric acid.

Specific advice should be sought from testing laboratories, private consultants, or state extension personnel if water quality test results indicate hazard potentials due to high EC, SAR, or RSC values.

Irrigation System Components and Troubleshooting

Installed irrigation systems will not continue operating efficiently indefinitely; problems will develop, but many will be correctable. This section walks you through an evaluation of a home-lawn type irrigation system, including the controller, valves, back flow prevention, rainfall sensors, pressure regulators, and the physical condition of system components. We will cover the main categories a specialist would use to evaluate an irrigation system. Working through the procedures described in this section will identify conditions that lead to water waste and higher water bills. If after working through these procedures problems persist, contact a certified irrigation specialist for assistance.

Control system. Find each irrigation controller at your home or facility and evaluate the condition of its components. Look for bad connections, frayed wires, and unreadable indicators. Become acquainted with how to control each valved zone, the flexibility of programming irrigation intervals, and how to implement soak cycles to prevent runoff. Make a list of all the zones that each station controls and keep this “map” in the controller for future reference.

Valve condition. Valves are devices that control the flow of water through the pipes. Typical irrigation valves will be either fully closed or open. To check for leaks turn off all irrigation heads and read the meter. After 12 hours of no water use of any kind, read the meter again. If the meter hand or readout has progressed, begin checking for valve leaks.

Back flow prevention. City codes require that a backflow prevention device be installed on irrigation systems. This prevents any flow from the irrigation system back into the home water system, assuring that drinking water cannot be contaminated.

Rainfall sensors. These sensors can be wired into your controller and set to shut off scheduled irrigations given that a certain user-set rainfall threshold is reached. If you are following the deep and infrequent irrigation approach it is best to set your rainfall shut-off threshold at 50% of your estimated ET-replacement for the irrigation interval you are using. Using the Kentucky bluegrass lawn example from above, approximately 0.42" of ET was to be replaced every two days; thus, we would set our rainfall sensor to shut off irrigation on days where 0.20 to 0.25 inches of rainfall had occurred in the last 24-hr period. For manual verification that your rainfall sensor is reading properly, compare it to a rain gauge placed close by.

Pressure regulators. Static pressures of 80 psi or more on home lawn systems may result in valve malfunctions and will cause water droplets to be too fine for uniform and efficient water delivery from nozzles. Pressure regulators can be installed so as to set the pressure to that specified by the irrigation heads and nozzles being used. Install at least two pressure regulators if the system uses sprinklers for turf and drip emitters for shrubs and flower beds. A pitot tube pressure gauge (purchased from an irrigation supply company) can be used at each head to check for proper operating pressure and for calibrating the pressure regulator.

Hardware problems. Some of the most common hardware problems in an irrigation system are broken components such as risers, improperly spaced heads, use of dissimilar heads or nozzles across a zone, worn nozzles, leaking heads, and sunken or askew heads. Turn the heads on during calm conditions and check for proper head rotation, direction, and throw of spray. Adjust the radius and arc to avoid spraying sidewalks and buildings. As the system ages and the

landscape matures, sprinkler heads sink, are pushed off vertical, stop turning, and become clogged. Properly installed heads should have sufficient riser or swing joint attached to allow flush re-positioning to occur. Clean the sprinkler's trash screen if it has one and check the wiper seal at the base of the head. Water will squirt or seep out of the base if the seal is worn.

Chapter 5. Principles of Soil Science for Turfgrass Managers

Lee Daniels, Greg Evanylo, and Mike Goatley, Professors; Sam Doak, Instructor; Katy Haering, and Jon Dickerson, Staff; Virginia Tech

Introduction

Soil, it's just dirt right? What does soil really do for us anyway?

Soil performs several important functions for plants and plants perform many important functions for us, like produce food and oxygen. Turfgrass produces oxygen; an average lawn produces enough oxygen to sustain a family of four for a year. Turfgrass cools the air, provides great erosion control and is one of the best pollution filters.

Great soil will produce great turfgrass; it is the foundation of your turfgrass management program.

Five important functions of soil:

1) Anchor the plant via roots. This sounds too simple to even discuss but turfgrasses do need a medium on which to grow. The fibrous nature of a turfgrass plant provides excellent erosion control and can trap many pollutants. Roots prevent the plant from being pulled out of the ground during mowing, human and vehicular traffic and times of flooding.

2) Holds available water for plants. Plants are about 80% percent water and humans are 65% water. A small reduction in the amount of water has serious consequences in both plants and animals. Water performs many important functions in plants. **a)** Water is part of the photosynthesis process and releases oxygen to the system. b**)** Water helps metabolic processes within the plant like the transport and distribution of soluble nutrients. **c)** Maintains hydration of the plant which keeps the plant tissues firm. **d)** Water provides an electron source and oxygen for photosynthesis. **e)** Water is used to cool the plants through evaporation and transpiration. The plant uses 99% of the water absorbed for transpiration. Evapotranspiration or ET is the combination of the water lost to the atmosphere from the plant [transpiration] and the water lost from the soil [evaporation]. It is the amount you need to replace to maintain current levels of soil moisture.

3) Serves as a reservoir of plant nutrients. Turfgrass root systems collect most of their water and nutrients from the surrounding soil. The roots use three methods to collect nutrients. The least efficient method is root **interception** whereby the growing root simply encounters a nutrient as the root expands in the soil. The second method is **diffusion**. This method moves nutrients from areas of high concentration to areas of low concentration. Think of two balloons connected by a valve and one balloon is full while the other is empty. What happens when you open the valve? The air from the full one will rush into the empty until a balance or equilibrium is reached. This is the same for diffusion where nutrients will move from areas of high concentration to areas of low concentration. The final method of getting nutrients to the roots is **mass flow,** this method is most critical for root absorption of the macronutrients, the nutrients required in the largest quantities. Nutrients dissolved in the soil water move past or are drawn to the roots as they extract the water required for growth and development of the plant.

4) Serves as a reservoir for air. Root systems must rely upon food (aka energy) produced by the leaves and stems to conduct any energy-requiring biochemical process. Roots use O_2 in the process of respiration (turning stored carbohydrates into other forms of chemical energy that can be linked to biochemical reactions). As roots respire, they also release CO_2 and although this molecule is the basis for photosynthesis by the shoot system, high concentrations of CO_2 in the rootzone are a potentially poisonous gas for root systems. The soil must be able to balance its O_2 and CO_2 levels with the atmosphere. The model soil often detailed in turfgrass textbooks is about one half pore space that holds both water and air. If the soil is extremely compacted or flooded, the open spaces can't exchange CO_2 (and replenish with O_2) fast enough to maintain healthy growth.

5) Soil is home for a tremendously diverse population of micro- and macro plants and animals. Soil microbes (bacteria, fungi, actinomycetes, algae, etc.) are present by the billions in a single pound of soil. Most microbes are highly beneficial organisms that assist in nutrient cycling. However, there are certain fungi and bacteria that can become problematic in a turf management system when their activity results in a turfgrass disease. As a rule of thumb, a healthy soil (proper pH, nutrition, moisture and air levels, etc.) maintains a healthy and desirable microbial population. Similarly, there are a highly diverse population of insects and worm or worm-like creatures (nematodes) that reside in our soils. Most of these animals are beneficial as well, although there are certainly circumstances where their activity can become detrimental to turfgrass health. Your goal as a turfgrass manager is to manage the soil to allow a diverse range of microbes to live and thrive to help produce a very active and healthy soil. Great soils are the foundation for a great turfgrass.

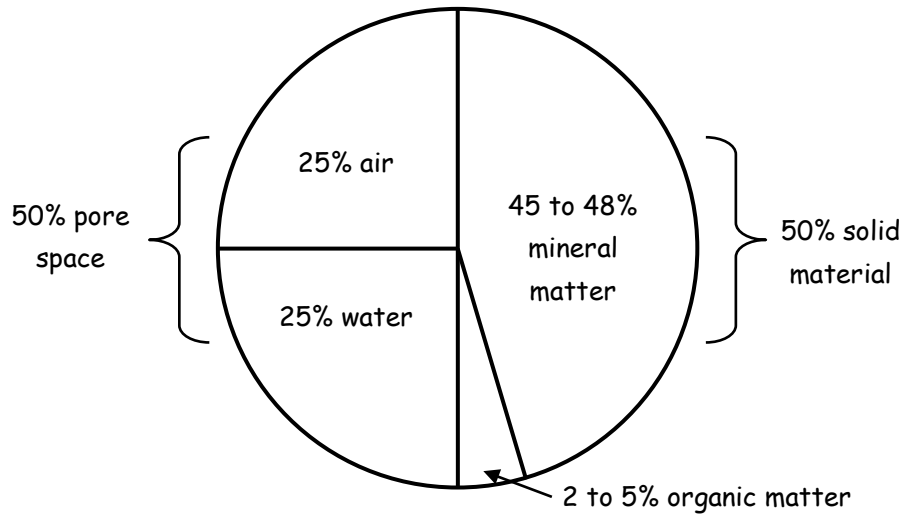
Soil formation and soil horizons

Introduction and soil composition

Soil covers the vast majority of the exposed portion of the earth in a thin layer. It supplies air, water, nutrients, and mechanical support for the roots of growing plants. The productivity of a given soil is largely dependent on its ability to supply a balance of these factors to the plant community.

A desirable surface soil in good condition for plant growth contains approximately 50% solid material and 50% pore space (Figure 1). The solid material is composed of mineral material and organic matter. Mineral material comprises 45% to 48% of the total volume of a typical Mid-Atlantic soil. About 2% to 5% of the volume is made up of organic matter, which may contain both plant and animal residues in varying stages of decay or decomposition. Under ideal moisture conditions for growing plants, the remaining 50% soil pore space would contain approximately equal amounts of air (25%) and water (25%) on a volume basis.

Figure 1. Volume composition of a desirable surface soil.



Soil formation

The mineral material of a soil is the product of the weathering of underlying rock in place, or the weathering of transported sediments or rock fragments. The material from which a soil has formed is called its *parent material*. The weathering of residual parent materials to form soils is

a slow process that has been occurring for millions of years in most of the Mid-Atlantic region. However, certain soil features (such as A horizons, discussed below) can form in several months to years. The more you know about your parent material the better you can plan your grassing and management options for the future. More detail on parent material and soil relationships in our area can be found in http://www.mawaterquality.org/publications/pubs/manhcomplete.pdf.

The rate and extent of parent material and soil weathering depends on:

1. The chemical composition of the minerals that comprise the rock or sediment;

2. The type, strength, and durability of the material that holds the mineral grains together;

3. The extent of rock flaws or fractures;

4. The rate of leaching through the material;

5. The extent and type of vegetation at the surface.

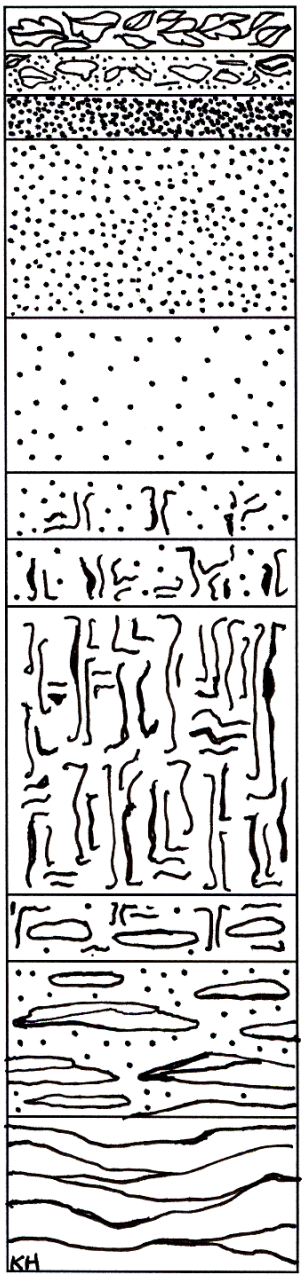
Physical weathering is a mechanical process that occurs during the early stages of soil formation as freeze-thaw processes and differential heating and cooling breaks up rock parent material. After rocks or coarse gravels and sediments are reduced to a size that can retain adequate water and support plant life, the rate of soil formation increases rapidly. As organic materials decompose in the surface soil, the evolved carbon dioxide dissolves in water to form carbonic acid, a weak acid solution which constantly bathes weatherable minerals below. The carbonic acid reacts with and alters many of the primary minerals in the soil matrix to chemically alter and etch the sand and silt fractions and to produce secondary clay minerals. The decomposing organic matter also releases other organic acids (e.g. oxalic, citric and tartaric) that further accelerate weathering (Brady & Weil, 2008).

As soil-forming processes continue, some of the fine clay soil particles (<0.002 mm) are carried, or leached, by percolating water from the upper portions of the soil (topsoil) down into the lower or subsoil layers. As a result of this leaching action, the surface soil texture becomes coarser and the subsoil texture becomes finer as the soil weathers.

Soil horizons

Soils are layered because of the combined effects of organic matter additions to the surface soil and long-term leaching. These layers are called *horizons*. The vertical sequence of soil horizons found at a given location is collectively called the *soil profile* (Figure 2).

Figure 2. Soil profile horizons. Figure by K. Haering.



Oi Loose, easily recognizable, organic debris
Oe Partially decomposed organic materials
Oa Fully decomposed organic materials

A Surface mineral horizon; darker and higher in organic matter. If plowed, will be designated **Ap**

E Eluviated horizon; light colored zone of maximum leaching of clay, iron, aluminum, and soluble organic matter. Often mixed into **Ap**

EB Transition from E to B; more like E than B

BE Transition from E to B; more like B than E

B Subsurface zone of maximum accumulation of clay, iron, etc. Common features include development of blocky and/or prismatic structure, clay coatings on larger particles, red and yellow colors from accumulation of iron oxides

BC Transition from B to C; more like B than C

C Weathered parent material such as saprolite, oxidized sediments, unconsolidated bedrock, etc.

R Hard bedrock; not always seen

The principal master soil horizons found in managed soil systems are:

A horizon or mineral surface soil (if the soil has been plowed, this is called the Ap horizon);

B horizon or subsoil;

C horizon or partially weathered parent material, which is also part of the subsoil;

Rock (R layer) or unconsolidated parent materials similar to that from which the soil developed.

Unmanaged and relatively undisturbed forest soils also commonly contain an organic O horizon (litter layer) on the surface and a light-colored acid leached zone (E horizon) just below the A horizon.

In addition to the master soil horizons which are noted by capital letters (e.g. A or B), soil scientists also assign lower case letters called *subscripts* (e.g. Ap) to describe the nature of the master horizon (Soil Survey Staff, 1993). There are several dozen commonly used subscripts, but the most common ones in urbanized areas of the mid-Atlantic are Ap (plowed topsoil), Bt (clayey subsoil) and Cd (very dense compacted subsoil). Another important combination to recognize is Btg which indicates a clayey subsoil with color features (gleying or gray coloration) indicative of poor internal drainage as discussed later in this chapter.

The surface soil horizon(s) or *topsoil* (the Ap or A+ E horizons) is often coarser than the subsoil layer and contains more organic matter than the other soil layers. The organic matter imparts a tan, dark-brownish, or black color to the topsoil. Soils that are high (> 3%) in organic matter usually have very dark surface colors. The A or Ap horizon tends to be more fertile and have a greater concentration of plant roots than any other soil horizon. In unplowed soils, the *eluviated* (E) horizon below the A horizon is often light-colored or gray, coarser-textured, and more acidic than either the A horizon or the horizons below it because of acid leaching over time.

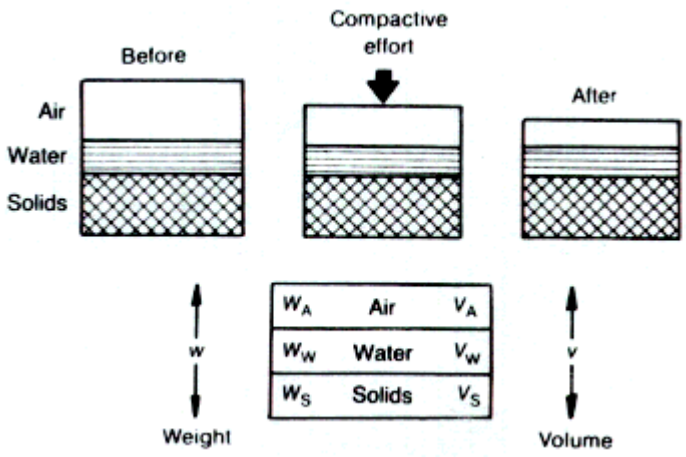
The subsoil (B horizon) is typically finer in texture, denser, and firmer than the surface soil. Organic matter content of the subsoil tends to be much lower than that of the surface layer, and subsoil colors are often stronger and brighter, with shades of red, brown, and yellow predominating due to the accumulation of iron coated clays. Subsoil layers with high clay accumulation relative to their overlying A horizon are described as Bt horizons. If the B is still observed based on color or structural development, but not enriched in clay it is labeled “Bw” by default.

The C horizon is partially decomposed and weathered parent material that retains some characteristics of the parent material. It is more like the parent material from which it has weathered than the subsoil above it. By definition, C horizons are “diggable” with spade or soil auger while R layers cannot be excavated with hand tools. Images with horizon designations for soils typical of our region (Ultisols), along with distribution maps and information links can be found at http://soils.cals.uidaho.edu/soilorders/ultisols.htm.

Soils in the urban landscape are frequently highly disturbed and often contain distinct layering due to cut/fill and grading practices which are quite dissimilar from the natural soil horizons discussed above. It is also quite common for the native topsoil (A horizon) layers to be absent and for deeper subsoil materials (Bt) to appear at the surface. Graded and layered urban soils also commonly contain highly compacted subsoil layers (Cd horizons).

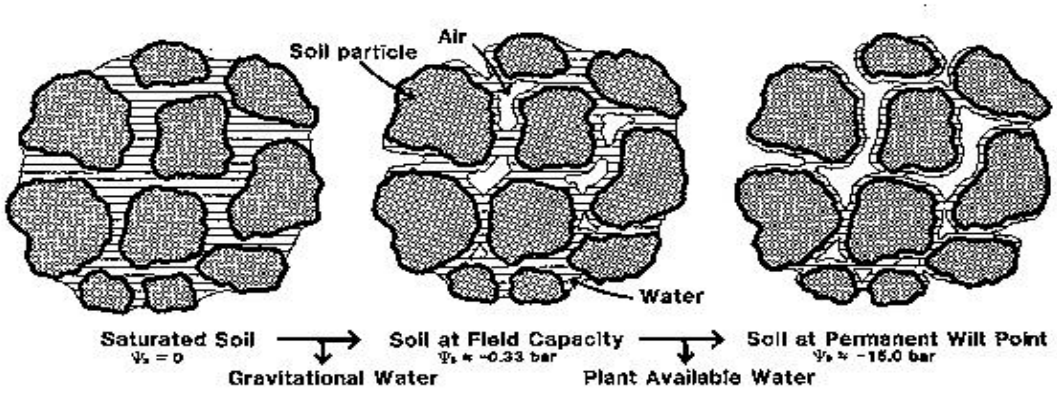
COMPACTION

When a soil becomes **compacted the amount of macropores decreases** so the amount of air in the soil declines and the roots can’t breathe and have a difficult time growing through a hard soil. This one-two punch leads to a reduction in the functioning of the roots which greatly reduces the amount of nutrients and water to the rest of the plant. The whole plant is stressed, struggling and can’t resist traffic or pest problems very well so turfgrass and thins or dies. Just like people when the stress is high their resistance to disease is low and they don’t function well. Compaction is caused by repeated application of force / weight to a soil surface, especially when the soil is wet. We’ve all seen the results from the high traffic areas in sports like football or soccer and the entry and exit points from a field near a gate. The reduction of turfgrass cover is a result of the compaction brought on by concentrated traffic or usage. Yes there is damage to the plant from to tearing of leaves by players and machines, but the plant’s ability to recover is greatly reduced due to the compaction.



Notice that as compaction is increased the difference is the loss of macropores. The solid or mineral portion of the soil does not change while the amount micropores may increase very slightly or stay the same. The big loss is the air holding macropores.

SOIL WATER and AIR

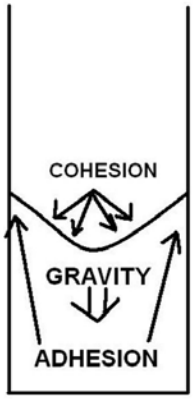


Soil water illustrated above shows **SATURATED SOIL** [on the left] where all the macropores and micropores are filled with water. There is no air in the soil and the roots will drown so the plant will die. A soil at **FIELD CAPACITY** [in the middle] has all the *gravitational water* removed. The soil on the right is at **PERMANENT WILTING POINT**, where all the *plant available water* is removed and the plants will die.

An illustration of soil water is: If you fill a clay plant pot [plant and soil in it] with water and hold your finger over the hole in the bottom what will happen? The soil will produce air bubbles as the pot fills with water until no more water can be put in the pot. All the space is filled with water; there is no air in the soil. This is a SATURATED SOIL. When you remove your finger what happens? The water flows from the hole. What force is pulling the water? Gravity, hence all the water that drains from the pot through the hole is gravitational water. When this water is finished draining the remaining water in the soil, the result is called FIELD CAPACITY.

Why doesn't **all the water** empty from the pot? Water is attracted to the soil particles [or colloids] in the same manner that when a cup that is rinsed and turned upside down there will still be water drops attached to it. This is called **adhesion** or the attraction of water to a solid surface. There is also the attraction of water molecules to other water molecules and this is called **cohesion**. Cohesion causes the water to bead into little balls instead of spreading out and allows a thick film of water to "stick" to the soil particles.

These two forces [adhesion and cohesion] **keep a layer of the water** attached to the soil colloids and this balancing point where the forces of the soil colloids over the water is greater than the force of gravity results in a soil moisture content called field capacity. If you like equations then **Saturated Soil minus Gravitational Water = Field Capacity**. At field capacity is when you should see the "ideal soil" space mix of about 50% air and 50% water (see the previous illustration.



Notice that there is still water at permanent wilting point soil. This is the point where the soil forces [adhesion and cohesion] are greater than the plant root's ability to extract the water molecules off of the soil particles. This is a much thinner layer of water around the colloids than at field capacity.

The difference in water between field capacity and permanent wilting point is the plant available water [water the plant is able to retrieve and use]. This is a key concept and the amount will vary from soil to soil [we will cover in more detail later]. One more equation: **Field Capacity minus Plant Available Water = Permanent Wilting Point.**

Soil physical properties

The physical properties of a soil are the result of soil parent materials being acted upon by climatic factors (such as rainfall and temperature), and being affected by relief (slope and direction or aspect), and by vegetation, over time. A change in any one of these soil-forming factors usually results in a difference in the physical properties of the resulting soil. The important physical properties of a soil are: Texture, aggregation/structure, porosity and bulk density.

Texture

The relative amounts of the different soil sized (<2 mm) particles, or the fineness or coarseness of the mineral particles in the soil, is referred to as soil texture. Mineral grains which are >2 mm in diameter are called rock fragments and are measured separately. Soil texture is determined by the relative amounts of *sand*, *silt*, and *clay* in the fine earth (< 2 mm) fraction.

Sand particles vary in size from very fine (0.05 mm) to very coarse (2.0 mm) in average diameter. Most sand particles can be seen without a magnifying glass. Sands feel coarse and gritty when rubbed between the thumb and fingers, except for mica flakes which tend to smear when rubbed.

Silt particles range in size from 0.05 mm to 0.002 mm. When moistened, silt feels smooth but is not slick or sticky. When dry, it is smooth and floury and if pressed between the thumb and finger will retain the imprint. Silt particles are so fine that they cannot usually be seen by the unaided eye and are best seen with the aid of a strong hand lens or microscope.

Clay is the finest soil particle size class. Individual particles are finer than 0.002 mm. Clay particles can be seen only with the aid of an electron microscope. They feel extremely smooth or powdery when dry and become plastic and sticky when wet. Clay will hold the form into which it is molded when moist and will form a long ribbon when extruded between the fingers.

There are 12 primary classes of soil texture defined by the USDA (U.S. Department of Agriculture; Soil Survey Division Staff, 1993). The textural classes are defined by their relative proportions of sand, silt, and clay as shown in the USDA *textural triangle* (Figure 3). Each textural class name indicates the size of the mineral particles that are dominant in the soil. Regardless of textural class, all soils in the Mid-Atlantic region contain sand, silt, and clay- sized particles, although the amount of a particular particle size may be small.

Texture can be estimated in the field after a moderate amount of training by manipulating and feeling the soil between the thumb and fingers. However, for precise measurement and/or prescriptive use, texture should be quantified by laboratory particle size analysis.

To use the textural triangle:

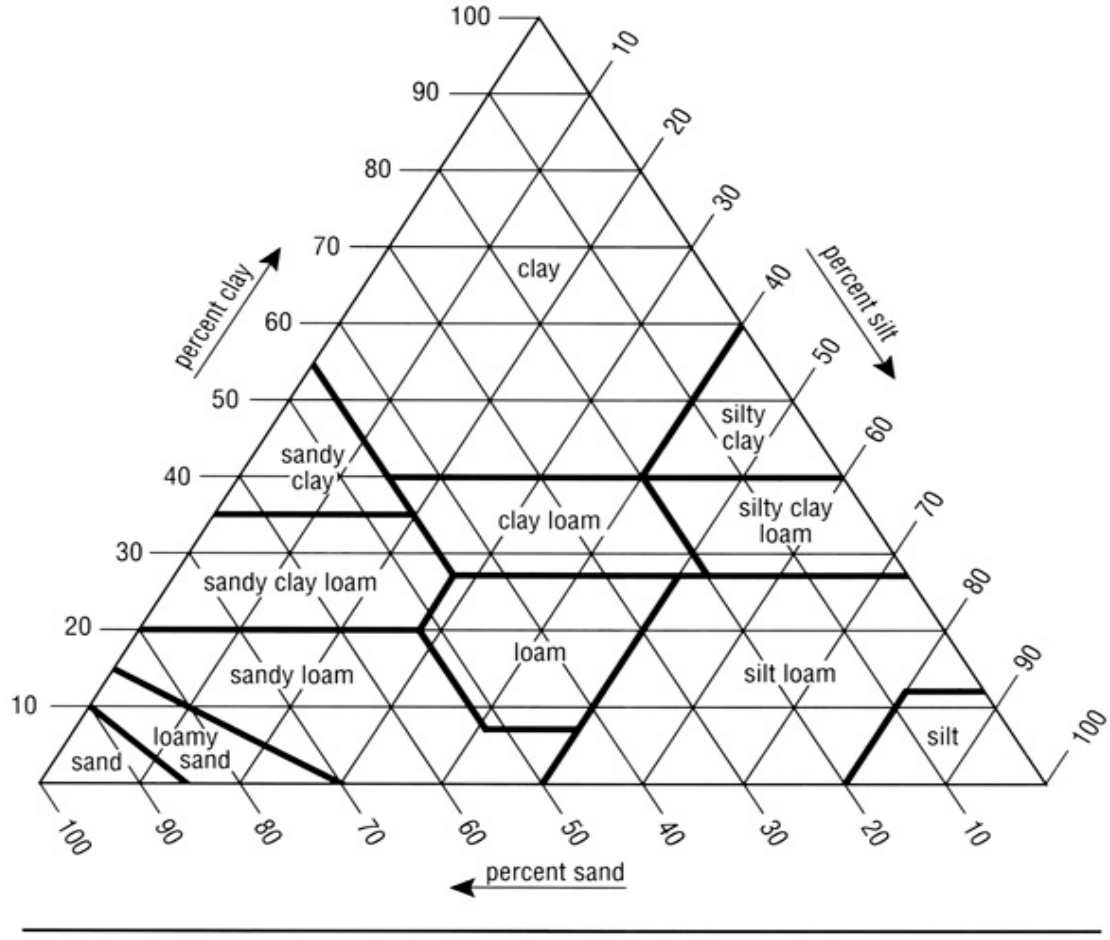
First, you will need to know the percentages of sand, silt, and clay in your soil, as determined by laboratory particle size analysis (commercial or university soil testing laboratories can do this for you for a small fee).

Locate the percentage of clay on the left side of the triangle and move inward horizontally, parallel to the base of the triangle.

Follow the same procedure for sand, moving along the base of the triangle to locate your sand percentage

Then, move up and to the left until you intersect the line corresponding to your clay percentage value.

Figure 3. The percentages of sand, silt, and clay will determine the textural classification of your soil.



At this point, read the *textural class* written within the bold boundary on the triangle. For example: a soil with 40% sand, 30% silt, and 30% clay will be a clay loam. With a moderate amount of practice, soil textural class can also be reliably determined in the field.

When soil textures fall very close to the boundary between two adjacent classes, it is appropriate to name both (e.g. sandy clay loam to sandy clay). Also, within a given textural class, soils with high clay contents are often referred to as "heavy" vs. those low in clay content are called "light". Thus, a "heavy clay loam" indicates a soil texture in the upper portion of that textural class, close to being "clay". This latter convention is **not** defined or formally accepted by USDA, but is commonly used by field practitioners.

If a soil contains 15% or more rock fragments (> 2 mm), a rock fragment content modifier is added to the soil's texture class. For example, the texture class designated as *gravelly silt loam* would contain 15 to 35% gravels within a silt loam (< 2 mm) fine soil matrix. A sample with

>35% gravels would be described as *very gravelly silt loam*, etc. More detailed information on USDA particle size classes and other basic soil morphological descriptors can be found on-line at http://soils.usda.gov/technical/handbook/download.html or in the USDA Soil Survey Manual (Soil Survey Division Staff, 1993).

Effects of texture on soil properties

The clay fraction in soils is charged and relatively minor amounts (10 to 15%) of clay can significantly increase net negative charge which directly influences both water holding and nutrient retention in soils. Water infiltrates more quickly and moves more freely in coarse-textured or sandy soils, which increases the potential for leaching of mobile nutrients. Sandy soils also hold less total water and fewer nutrients for plants than finer textured soils like clays or clay loams. In addition, the relatively low water holding capacity and the larger amount of air present in sandy soils allows them to warm faster than fine-textured soils. Sandy and loamy soils are also more easily tilled than clayey soils, which tend to be denser.

In general, fine-textured soils hold more water and plant nutrients and thus require less frequent applications of water, lime, and fertilizer. Soils with high clay content (more than 40% clay), however, actually hold less plant-available water than loamy soils. Fine-textured soils have a narrower range of moisture conditions under which they can be worked satisfactorily than sandy soils. Soils high in silt and clay may puddle or form surface crusts after rains, impeding seedling emergence. High clay soils often break up into large clods when worked while either too dry or too wet.

It is important to understand the magnitude in differences in particle size between sand, silt, and clay, and to further understand that there are even five classifications of sand. This becomes crucial when one considers specifications for modified sand-based soils. The USDA Textural Classification data are shown in the first two columns of Table 1, and the analogous sizes of the particles are presented in the far right column.

These particle sizes influence soil porosity, water holding capacity, resistance to compaction, and chemical responses. The key is in understanding surface area on a volumetric basis. When comparing one grain of very coarse sand versus one clay particle, there is a huge surface area difference between the particles based on their physical size (the very coarse sand has a very large surface area when comparing particle to particle). However, now consider what happens to the surface area comparison if we compare equal volumes of the sand particle versus the clays. There will be hundreds of thousands of clay particles required to equal the same volume of a single sand particle. Thus, clays have a much greater surface area on a volumetric basis

and are considered to be much more reactive when it comes to both chemical and physical properties.

Table 1. Textural classification of soil particles as defined by the United States Department of Agriculture.

Soil separate	Diameter size (mm)	Particle size analogy
Very coarse sand	2.0-1.0	Ball, 8 feet in diameter
Coarse sand	1.0-0.5	Ball, 4 feet in diameter
Medium sand	0.5-0.25	Medicine ball
Fine sand	0.25-0.1	Basketball
Very fine sand	0.1-0.05	Softball
Silt	0.05-0.002	Golf ball
Clay	<0.002	Popcorn kernels

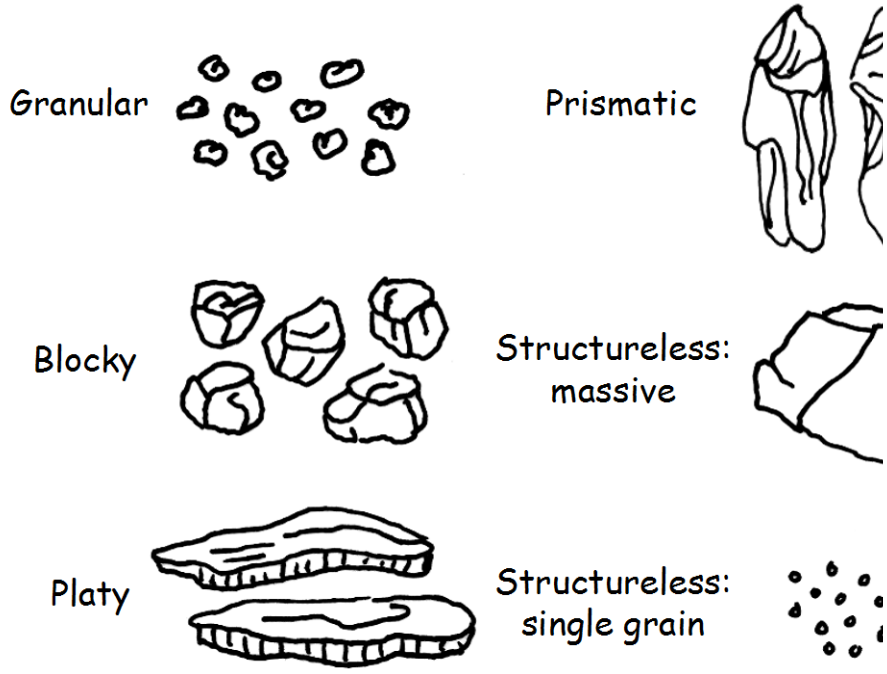
Aggregation and soil structure

Soil *aggregation* is the cementing of several soil particles into a secondary unit or aggregate. Soil particles are arranged or grouped together during the aggregation process to form structural units (known to soil scientists as *peds*). These units vary in size, shape, and distinctness (also known as strength or grade). In topsoils, soil organic matter is the primary material that cements particles together into water stable aggregates. In subsoil, aluminum and iron-oxides play a major role in cementing aggregates as do finer clay particles which due to their charge (discussed later in this chapter) can also bind and stabilize much larger sand and silt particles together. The types of soil structure found in most Mid-Atlantic soils are described in Table 2 and illustrated in Figure 4.

Table 2. Types of soil structure.

Structure type	Description
Granular	Soil particles are arranged in small, rounded units. Granular structure is very common in surface soils (A horizons) and is usually most distinct in soils with relatively high organic matter content.
Blocky	Soil particles are arranged to form block-like units, which are about as wide as they are high or long. Some blocky peds are rounded on the edges and corners; others are angular. Blocky structure is commonly found in the subsoil, although some eroded fine-textured soils have blocky structure in the surface horizons.
Platy	Soil particles are arranged in plate-like sheets. These plate-like pieces are approximately horizontal in the soil and may occur in either the surface or subsoil, although they are most common in the subsoil. Platy structure strongly limits downward movement of water, air, and roots. Platy structure may occur just beneath the plow layer, resulting from compaction by heavy equipment, or on the soil surface when it is too wet to work satisfactorily.
Prismatic	Soil particles are arranged into large peds with a long vertical axis. Tops of prisms may be somewhat indistinct and normally angular. Prismatic structure occurs mainly in subsoils, and the prisms are typically much larger than other typical subsoil structure types such as blocks.
Structureless	Either: • *Massive*, with no definite structure or shape, as in some C horizons or compacted material. Or: • *Single grain*, which is typically individual sand grains in A or C horizons not held together by organic matter or clay.

Figure 4. Types of soil structure. Figure by Kathryn Haering.



Effects of soil structure on soil properties

The structure of the soil affects pore space size and distribution and therefore, rates of air and water movement and overall root proliferation. Well-developed structure allows favorable movement of air and water, while poor structure retards movement of air and water. Since plant roots move through the same channels in the soil as air and water, well-developed structure also encourages extensive root development. With respect to rooting, the size of the pores and their degree of interconnection are also critically important. In general, the penetration of air, water and roots through soils is favored by macropores ($\geq$ 0.05 mm or sand-sized) that are physically interconnected, particularly vertically. In general, soil productivity is favored when water, air and roots can move readily down through the soil. It is also important that soil metabolic gasses (e.g. CO_2) be able to diffuse back up to the atmosphere.

Water can enter a surface soil that has well-developed (strong) granular structure (particularly fine-textured soils) more rapidly than one that has relatively weak structure. Surface soil structure is usually granular, but such granules may be indistinct or completely absent if the soil is continuously tilled, the soil is very coarse, or if organic matter content is low.

The size, shape, and strength of subsoil structural peds are particularly important to soil productivity. Sandy soils generally have poorly developed structure relative to finer textured soils, because of their lower clay content. When the subsoil has well developed blocky structure, there will generally be good air and water movement in the soil. If platy structure has formed in the subsoil, downward water and air movement and root development in the soil will be slowed. Distinct prismatic structure is often associated with subsoils, but those larger prisms will usually break down into primary blocky peds. Very large and distinct subsoil prisms are also commonly associated with *fragipans (Bx horizons)*, which are massive and dense subsoil layers.

Porosity and Bulk Density

Soil *porosity*, or pore space, is the volume percentage of the total soil that is not occupied by solid particles. Pore space is commonly expressed as a percentage:

% pore space = 100 - [bulk density ÷ particle density x 100]

Bulk density is the dry mass of soil solids per unit volume of soils, and *particle density* is the density of soil solids, which is assumed to be constant at 2.65 g/cm^3. Bulk densities of mineral soils are usually in the range of 1.1 to 1.7 g/cm^3. A soil with a bulk density of about 1.32 g/cm^3 will generally possess the ideal soil condition of 50% solids and 50% pore space. Bulk density varies depending on factors such as texture, aggregation, organic matter, compaction/ consolidation, soil management practices, and soil horizon. In general, root penetration through soils will be limited in sandy soils when the bulk density approaches 1.75 g/cm^{3}and in clayey soils at 1.40 g/cm^3 (Brady & Weil, 2008). However, water, air and roots can penetrate high bulk density soils that have well developed structure with interconnected macropores as discussed above. Macropores (> 0.05 mm) allow the ready movement of air, roots, and percolating water. In contrast, micropores (< 0.05 mm) in moist soils are typically higher in water content and poorly interconnected, and this does not permit much air movement into or out of the soil. Internal water movement is also very slow in micropores. Thus, the movement of air and water through a coarse-textured sandy soil can be surprisingly rapid despite its low total porosity because of the dominance of macropores.

Under field conditions, the total soil pore space is filled with a variable mix of water and air. If soil particles are packed closely together, as in well-graded surface soils or compact subsoils, total porosity is low and bulk density is high. If soil particles are arranged in porous aggregates, as is often the case in medium-textured soils high in organic matter, the pore space per unit volume will be high and the bulk density will be correspondingly low.

Fine-textured clay soils, especially those without a stable blocky (Bt) or granular (Ap) structure, may have reduced movement of air and water even though they have a large volume of total pore space. In these fine-textured soils, micropores are dominant. Since these small pores often

stay full of water, aeration, especially in the subsoil, can be inadequate for root development and microbial activity. The loosening and granulation of fine-textured soils promotes aeration (gas exchange) by increasing the number of macropores.

Soil organic matter

Soil organic materials consist of plant and animal residues in various stages of decay. Primary sources of organic material inputs are dead roots, root exudates, litter and leaf drop, and the bodies of soil animals such as insects and worms. Earthworms, insects, bacteria, fungi, and other soil organisms use organic materials as their primary energy and nutrient source. Nutrients released from the residues through decomposition are then available for use by growing plants.

Soil *humus* is fully decomposed and stable organic matter which is primarily derived from the bodies of soil microbes and fungi. Humus is the most reactive and important component of soil organic matter, and is the form of soil organic material that is typically reported as "organic matter" on soil testing reports. Soil organic matter in Virginia soils typically ranges between 0.5 and 2.5% in A horizons and can approach 5% in heavily enriched garden soils or soils with poor drainage. Higher levels are typically only found in wetlands. Soil organic matter is so reactive (charged) that when it exceeds 12 to 20% by weight it dominates soil properties and we refer to it as "organic soil material".

Factors that affect soil organic matter content

The organic matter content of a particular soil will depend on:

Type of vegetation: Soils that have been in grass for long periods usually have a relatively higher percentage of organic matter in their surface. Soils that develop under trees usually have a low organic matter percentage in the surface mineral soil, but do contain a surface litter layer (O horizon). Organic matter levels are typically higher in a topsoil supporting perennial hay, pasture, or forest than in a topsoil used for cultivated crops.

Tillage: Soils that are tilled frequently are usually lower in organic matter. Plowing and otherwise tilling the soil increases the amount of oxygen in the soil, which increases the rate of organic matter decomposition. This detrimental effect of tillage on organic matter is particularly pronounced in very sandy well-aerated soils because of the tendency of frequent tillage to promote organic matter oxidation to CO_2.

Drainage: Soil organic matter is usually higher in poorly-drained soils because of limited oxidation, which slows down the overall biological decomposition process.

Soil texture: Soil organic matter is usually higher in fine-textured soils because soil humus forms stable complexes with clay particles and fine textured soils limit the penetration of atmospheric oxygen in and CO_2 out of surface soils.

Effect of organic matter on soil properties

Adequate soil organic matter levels benefit soils in several ways. The addition of organic matter improves soil physical conditions, particularly aggregation and macropore space. This improvement leads to increased water infiltration, improved soil tilth, and decreased soil erosion. Organic matter additions also improve soil fertility, since plant nutrients are released to plant-available mineral forms as organic residues are decomposed (or *mineralized*) and soil humus is highly charged and retains nutrients against leaching as discussed later.

A mixture of organic materials in various states of decomposition helps maintain a good balance of air and water components in the soil. In coarse-textured soils, organic material bridges some of the space between sand grains, which increases water-holding capacity. In fine-textured soil, organic material helps maintain porosity by keeping very fine clay particles from packing to closely to one another, thereby enhancing macroporosity.

One of the most cost effective and efficient ways to increase the organic matter content of soils and gain the subsequent benefits from the addition is to develop a program that utilizes **compost.** Composting is the controlled, aerobic, thermophilic, biological decomposition of organic materials that results in a stable end product that can be used as a soil amendment termed “compost.” Compost contains essential plant nutrients in low concentrations and is typically applied as a soil conditioner or mulch.

Compost is used primarily as a soil conditioner and, secondarily, as a supplier of nutrients; thus, the properties of compost that are usually tested and listed include those that improve soil conditions for plant growth and environmental effects (e.g. water quality) (Table 3). Composting is a pH-neutralizing process; therefore, most high quality composts have pH values near 7. Stabilized organic matter tends to buffer soil pH, so addition of compost to soil often reduces the need for frequent liming. Only where acid-loving plants are grown are such compost application effects not desirable.

Electrical conductivity (EC) can vary greatly in compost depending on the source of the feedstock(s) (Table 3). Composts produced primarily from animal manures are usually higher in soluble salts and, hence, EC than yard and woody waste-based composts (Table 3). High soluble salts and EC can impair the growth of sensitive plants, particularly seedlings; thus, it is important to limit the portion of high soluble salt-containing compost mixed with soil when seeding or transplanting will occur shortly after soil amending.

Table 3. Typical and preferred values of compost properties.

Property	Typical	Preferred
pH	5.0-8.5	6.0-7.5
EC (dS/m)	1.0-10	≤ 5.0
Organic matter (%)	30-70	≥ 50
Water holding capacity (%)	75-200	≥ 100
Moisture content (%)	30-60	40-50
Bulk density	700-1200	800-1000
Nutrients	0.5-2.5% N 0.2-2.0% P 0.3-1.5% K	No minimum required for ideal compost.
Inorganic trace elements		As, Cd, Cu, Hg, Mo, Ni, Pb, Se, and Zn must meet 40 CFR USEPA Part 503 pollutant concentration limits.
Stability		Should be measured as stable to highly stable by appropriate tests.
Growth screening		Should pass seed germination and plant growth assays.

The higher the concentration of organic matter in compost, the greater will be the beneficial soil physical and chemical property effects. The water holding capacity of the compost can vary depending on the quality and particle size distribution of the organic matter (Table 3). The compost's water holding capacity is directly proportional to the water holding capacity of compost-amended mineral soil. Bulk density of the compost is an indirect measure of the proportion of organic to mineral matter in the compost (mineral matter having a higher specific density than organic matter) and particle size distribution. An intermediate bulk density will have a balance between coarse and fine particles.

Because the primary purpose of compost used in landscapes is as a soil conditioner, there are no ideal concentrations of nutrients. Normal landscape application rates of compost do, however, provide considerable amounts of nutrients, even at the low concentrations that

typically occur in compost (Table 3). For instance, one inch of compost (3 cubic yards or approximately 1350 lbs dry matter per 1,000 ft^2) having an N-P-K ratio of 1-1-1 will provide 13.5 lbs of each N, P, and K per 1,000 ft^2. Only a small portion of the N, but most of the P and K will be plant available. Carbon to nitrogen ratios can provide useful information (e.g., potential degree of N mineralization or immobilization) about compost and other organic waste by-products although, by themselves, they are not good indicators of compost quality. Most stabilized composts that are produced from well-designed starting recipes have C:N ratios between 12:1 and 20:1.

One to two inches of a quality compost pre-plant incorporated into the top 4 inches of a heavy textured soil is a highly beneficial soil remediation step that preemptively addresses the concerns of what is anticipated to be a 'poor' soil. For turfgrass maintenance applications, Penn State University research has shown that as little as one or two ¼" depth compost topdressings to an existing turf provides excellent soil remediation over a 3-5 year period, and the benefits are enhanced if the compost is applied in conjunction with core aeration. One area for which the use of compost is typically discouraged is as a topdressing component on modified sand-based athletic fields. The compost can quickly reduce the desired infiltration and percolation levels associated with the installation of a modified sand-based soil system (discussed later in this chapter).

Soil-water relationships

Water-holding capacity

Soil water-holding capacity is determined largely by the interaction of soil texture, bulk density/pore space, and aggregation. Sands hold little water because they have little net charge and their large intergranular pore spaces allow water to drain freely from the soils. Clays adsorb a relatively large amount of water, and their small pore spaces retain it against gravitational forces. However, clayey soils hold water much more tightly than sandy soils, so that much of the water retained (>40%) is unavailable to growing plants. As a result, moisture stress can become a problem in fine-textured soils despite their high total water-holding capacity. In turfgrass management systems we often add soil conditioners designed to either hold and/or release water at prescribed rates. For instance, consider the soil conditioners used to improve both the drying and wetting characteristics of a skin infield on a baseball or softball diamond. Soil conditioners allow the sports turf manager to greatly reduce the dust of these surfaces AND improve their overall playability. Sometimes amendments are added to soils (either at construction or as part of topdressing or 'drill and fill' operations to both improve drainage and increase water available to the plant. This leads us to the concept of understanding your soil

conditioner's selection in terms of **plant available water (PAW).** An amendment that increases water holding capacity might not increase plant available water.

Field capacity and permanent wilting percentage

Let's take these concepts further. The term *field capacity* defines the amount of water remaining in a soil after downward gravitational drainage has stopped. This value represents the maximum amount of water that a soil can hold against gravity following saturation by rain or irrigation. Field capacity is usually expressed as percentage by weight (for example, a soil holding 25% water at field capacity contains 25% of its dry weight as retained water). On a volumetric basis, values for field capacity range from 8% in a sand to 35% in a clay (Brady & Weil, 2008).

The amount of water a soil contains after plants are wilted beyond recovery is called the *permanent wilting percentage*. Considerable water may still be present at this point, particularly in clays, but is held so tightly that plants are unable to extract it. The amount of water held by the soil **between** field capacity and the permanent wilting point is our previously detailed *plant- available water* (PAW) and is maximized in loamy textured soils. The volumetric PAW for sand is typically less than 5%, but may approach 25% volumetric water for a well aggregated loamy soil (Figure 1).

Tillage and moisture content

Soils with a high clay content are sticky when wet and form hard clods when dry. Tilling clayey soils at the proper moisture content is thus extremely important. Although sandy soils are inherently droughty, they are easier to till at varying moisture contents because they do not form dense clods or other high-strength aggregates. Sandy soils are also far less likely than clays to be compacted if cultivated when moist or wet. However, soils containing high proportions of very fine sand or coarse silts may be compacted by tillage when moist.

Soil drainage

Soil scientists commonly use the term s*oil drainage* to describe the rate and extent of vertical or horizontal water movement and internal soil saturation during the growing season.

Important factors affecting soil drainage class are:

1. Slope (or lack of slope);

2. Depth to the seasonal water table;

3. Texture of surface and subsoil layers, and of underlying materials;

4. Type and strength of soil structure;

5. Problems caused by improper tillage or grading, such as compacted subsoils or lack of surface soil structure. These problems are inherent in housing construction in particular.

Another definition of drainage refers to the removal of excess water from the soil to facilitate agriculture, forestry, or other higher land uses. This is usually accomplished through a series of surface ditches or the installation of subsoil drains, something that is not at all uncommon in the world of fine turf management.

The movement of water into the soil is defined as *infiltration* and the movement of water through the soil is termed *percolation.* Having adequate drainage is an important part of the installation and maintenance of turf at many levels, ranging from modified sand-based soils for golf and sports fields, to a properly drained home lawn. Modified soil systems come with their own specifications for infiltration and percolation rates (often termed 'perc rates') for their respective soil systems. As discussed earlier in the section on soil texture, the surface area differences due to varying particle size of soil components have a great deal of effect on what is called *saturated hydraulic conductivity* that is frequently tested for modified soils (Table 4). You can see the dramatic differences in saturated hydraulic conductivity just within four classifications of sands based on their particle sizes.

Table 4. Typical soil saturated hydraulic conductivity levels on the basis of soil particle size either as single component or mixtures.

Soil separate and particle size diameter	**Inches/hr**
Coarse sand (1-0.5 mm)	216.5
Medium sand (0.5-0.25)	59.1
Fine sand (0.25-0.1)	17.7
Very fine sand (0.1-0.05)	5.1
Sand/organic mix meeting USGA putting green specifications	6-12

Surface drainage

No matter how extensive of a subsurface drain system is installed, it is still very possible that the key to success in moving the largest amounts of excessive water off of fine turf systems is by way of surface drainage (aka, water that flows across the surface by gravity). This concept even applies to artificial turf systems. It is pertinent in final grading events prior to grassing to ensure that surface drainage promotes as much movement of water away from the site as

warranted for the situation. Sports fields typically have a 1-2% crown. Golf greens have one or more directions for which surface water moves laterally away from the playing surface, with the surface humps and ridges providing the dual purpose of surface drainage and delivering a challenging putting surface. When considering surface drainage think about where the water ends up and how far it has to go to get there. Many times, the end point of surface drainage is complemented with the installation of catch basins that feature large drainage pipes that move water away from the site in rapid fashion.

Subsurface drainage

To enhance playability of golf and sports surfaces, subsurface drains are often installed either at construction or as a remediation step. Most modified sand-based soil systems also contain a set pattern and recommended spacing of sub-surface drains that are connected to a primary exit point away from the playing surface. The key to success with most subsurface drains still revolves around utilizing the force of gravity to channel water away, although there are vacuum-pump systems that are used in modified soils of both golf and sports turfs to accelerate the movement of water through the soil. A very simple (but effective method if surface disruption/smoothness is not a concern) type of subsurface drain called a 'french drain' is often nothing more than a trench backfilled with a specific size gravel or sand and an appropriate slope to move water away from the site as it gathers in the trench. The rate and direction/control of the water movement in the trench can be greatly enhanced by the inclusion of various sizes and/or shapes of drain tile, pipe, etc. that collect and deliver the water to a prescribed exit point. Remember that without the suction created by a vacuum pump system, there really is no reason for water to enter a drain line. Remember that without the suction created by a vacuum pump system, typical subsurface drain lines offer no reason for water to enter the drain line. They are nothing more than a huge pore space that has no attraction for water at all. But the way the design works is that water fills into the trench and eventually enters that large pore space (the drain line), and if it is properly installed to take advantage of gravity, the water will be quickly moved away in the pipe. Subsurface drainage lines that are simply installed in an existing heavy-textured without the inclusion of properly sized pea gravel or sand will effectively remove subsurface water that moves up in the profile (perhaps a wet weather spring?), but are very ineffective at removing water that moves through the soil. Again, what would be the attraction of water to enter that piece of pipe?

Inherent Soil Color as an Indicator of Drainage

The nature of internal soil drainage in relatively undisturbed soils is usually indicated by soil color patterns and color variations with depth. A basic understanding of this (as well as the ability to identify particular plant species growing on a site) can be very valuable in decisions about where to build homes, sports complexes, golf courses, etc. Clear, bright red and/or yellow subsoil colors indicate well-drained conditions where iron and other compounds are

present in their oxidized forms. A soil is said to be well-drained when the *solum* (A+E+B horizon) exhibits strong red/yellow colors without any gray coloration (mottles or redox depletions). The term "mottle" is used generically to describe any differences in coloration within a given soil horizon. When those differences in coloration are due to wetness, however, the correct term is *redoximorphic features.*

When soils become saturated for significant periods of time during the growing season, these oxidized (red/yellow) forms of iron are biochemically reduced to soluble forms and can be moved with drainage waters. This creates a matrix of drab, dominantly gray colors which are described as *redox depletions*. The iron that is mobilized is typically reprecipitated locally into contrasting red/yellow features that are called *redox concentrations*. Subsoil zones with mixtures of bright red/yellow and gray colors are indicative of seasonally fluctuating water tables, where the subsoil is wet during the winter/early spring and unsaturated in the summer/early fall. Poorly drained soils also tend to accumulate large amounts of organic matter in their surface horizons because of limited oxidation and may have very thick and dark A horizons.

Soils that are wet in their upper 12 inches for considerable amounts of time during the growing season and that support hydrophytic vegetation typical of wetlands and exhibit redoximorphic features are designated as *hydric soils*. Further information on Mid-Atlantic hydric soils and redox features can be found on-line at http://www.epa.gov/reg3esd1/wetlands/hydric.htm.

Interpretation of soil redox features can be highly complicated in an urban environment due to the fact to effects of soil layer mixing via the cut/fill and grading process and changes in internal soil drainage due to ditching and pavement interception of normal infiltration.

Drainage classes

The *drainage class* of a soil defines the frequency of soil wetness as it limits agricultural practices, and is usually determined by the depth in soil to significant gray redox depletions. The soil drainage classes in table 5 are defined by the USDA-NRCS (Natural Resources Conservation Service). They refer to the natural drainage condition of the soil without artificial drainage.

Table 5. Soil drainage classes.

Drainage Class	Soil Characteristics	Effect on Cropping
Excessively drained	Water is removed rapidly from soil.	Will probably require supplemental irrigation.
Somewhat excessively drained		
Well drained	Water is removed readily, but not rapidly.	No drainage required.
Moderately well drained	Water is removed somewhat slowly at some periods of the year.	May require supplemental drainage if crops that require good drainage are grown.
Somewhat poorly drained	Water is removed so slowly that soil is wet at shallow depths periodically during the growing season.	Will probably require supplemental drainage for satisfactory use in production of most crops.
Poorly drained		
Very poorly drained	Free water is present at or near the surface during the growing season.	

Soil chemical properties

The plant root obtains essential nutrients almost entirely by uptake from the soil solution. The chemistry and nutrient content of the soil solution is, in turn, controlled by the solid material portion of the soil. Soil chemical properties, therefore, reflect the influence of soil minerals and organic materials on the soil solution.

Soil pH

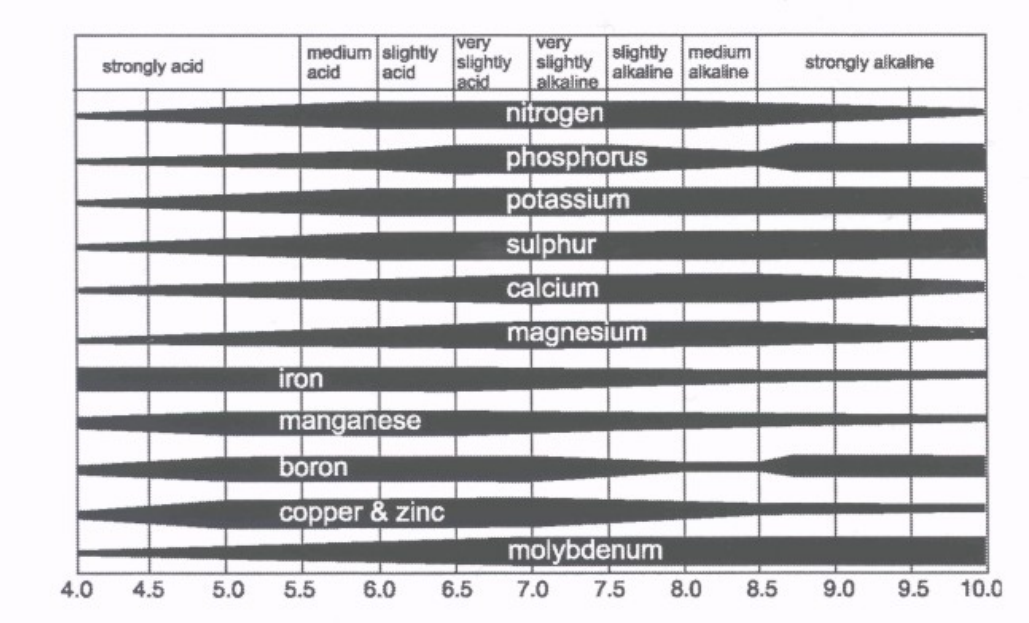
Soil pH defines the relative acidity or alkalinity of the soil solution. It is important to note that pH can only be measured in soil solution that has equilibrated with soil solids; you cannot measure the pH of a solid. The pH scale in natural systems ranges from 0 to 14. A pH value of 7.0 is neutral. Values below 7.0 are acid and those above 7.0 are alkaline, or basic. Many agricultural soils in the Mid-Atlantic region have a soil pH between 5.5 and 6.5. Any soil pH value less than 4.0 is indicative of acid-sulfate influenced soils and these are of extreme concern for both construction and landscaping/grassing operations. As population centers continue to grow, acid-sulfate soils are being exposed more frequently, especially in central and northern Virginia.

Soil pH is a measurement of hydrogen ion (H^+) activity in soil solution, or effective concentration, in a soil and water solution. Soil pH is expressed in logarithmic terms, which means that each unit change in soil pH amounts to a tenfold change in acidity or alkalinity. For example, a soil with a pH of 6.0 has 10 times as much active H^+ (or is 10x more acidic) as one with a pH of 7.0.

Soils become acidic when basic cations (such as calcium, or Ca^{2+}) held by soil colloids are leached from the soil, and are replaced by aluminum ions (Al^{3+}), which then hydrolyze to form aluminum hydroxide ($Al(OH)_3$) solids which then liberate H^+ ions to solution as water hydrolyzes (splits into H^+ and OH^- ions). This long-term acidification process is accelerated by the decomposition of organic matter which also releases acids to soil solution. Most soils of the Mid-Atlantic were formed under high rainfall with abundant vegetation, and are considerably more acidic than soils of the midwestern and western United States. In fact, very few soils in Virginia were > pH 6.0 when the settlers first arrived in the 17th century.

The importance of soil pH from a basic turfgrass management perspective is its relationship on the availability (or lack thereof) of the essential elements required for plant growth and development. As can be seen in Figure 5, either extremely low or high pHs result in either nutrient deficiencies or toxicities. For most turfgrasses, slightly acid pHs (6.3-6.7) are deemed ideal for plant growth and development (as well as the health of soil microbes etc.).

Figure 5. Plant nutrient availability as affected by soil pH.



Cation exchange capacity (CEC), our measure of soil charge and reactivity

The net ability of a soil to hold, retain, and exchange *cations* (positively charged ions) such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH_4^{+}), aluminum (Al^{3+}), and hydrogen (H^{+}) is called *cation exchange capacity,* or *CEC*. All soils contain clay minerals and organic matter that typically possess negative electrical surface charges. In modified sand-based systems sometimes used for golf greens, tees, and athletic fields, organic matter and perhaps small amounts of topsoil containing clay are added to boost CEC. In all these systems, the negative charges are present in excess of any positive charges that may exist, which gives soil a net negative charge.

Negative surface charges attract positively charged cations and prevent their leaching. These ions are held against leaching by electrostatic positive charges, but are not permanently bound to the surface of soil particles. Positively charged ions are held in a "diffuse cloud" within the water films that are also strongly attracted to the charged soil surfaces. Cations that are retained by soils can thus be replaced, or *exchanged*, by other cations in the soil solution. For example, Ca^{2+} can be exchanged for Al^{3+} and/or K^{+}, and vice versa. The higher a soil's CEC, the more cations it can retain.

There is a direct and positive relationship between the relative abundance of a given cation in solution and the amount of this cation that is retained by the soil CEC. For example, if the predominant cation in the soil solution of a soil is Al^{3+}, Al^{3+} will also be the predominant exchangeable cation. Similarly, when large amounts of Ca^{2+} are added to soil solution by lime dissolving over time, Ca^{2+} will displace Al^{3+} from the exchange complex and allow it to be neutralized in solution by the alkalinity added with the lime.

The CEC of a soil is expressed in terms of moles of charge per mass of soil. The units used are *cmol+/kg* (centimoles of positive charge per kilogram) or *meq/100g* (milliequivalents per 100 grams; 1.0 $cmol^{+}/kg$ = 1.0 meq/100g). Soil scientists have used the former unit in publications since the early 1980's while the latter unit (meq/100 g) is commonly used by other disciplines. Numerically, they are the same, however. You will typically see meq/100g on your soil test reports if you have CEC tested. Soil CEC is calculated by adding the charge equivalents of K^{+}, NH_4^{+}, Ca^{2+}, Mg^{2+}, Al^{3+}, $Na^{+,}$ and H^{+} that are extracted from a soil's exchangeable fraction.

<u>Sources of negative charge in soils</u>

The mineralogy of the clay fraction and the soil's humus content greatly influence the quantity of negative charges present. One source of negative charge is *isomorphous substitution*, which is the replacement of a Si^{4+} or Al^{3+}cation in the clay mineral structures with a cation with a lower surface charge. For example, Si^{4+} might be replaced with Al^{3+}, or Al^{3+} with either Mg^{2+} or Fe^{2+}. Clay minerals with a repeating layer structure of two silica sheets sandwiched around an aluminum sheet (2:1 clays, such as vermiculite or smectite), typically have a higher total

negative charge than clay minerals with one silica sheet and one aluminum sheet (1:1 clays, such as kaolinite). Soil humus is also highly charged due to a large number of chemically reactive sites called "functional groups".

Soil pH also has a direct relationship to the quantity of negative charges contributed by organic matter and, to a lesser extent, from mineral surfaces such as iron oxides. As soil pH increases, the quantity of negative charges increases due to the reactions of exposed organic matter functional groups and similar reactions that occur on the surfaces of Fe+Al oxides and the edges of clays. This *pH dependent charge* is particularly important in highly weathered topsoils where organic matter dominates overall soil charge.

It is important to point out that while we use CEC as our measure of net charge or reactivity in soils, all soils contain a certain amount of positive charges as well. These positive charges are important in retained anions like NO_3^-, Cl^- or SO_4^{2-} against leaching in certain soils as well. In particular, highly weathered soils that are high in aluminum and iron (very red) and low in pH (<5.5) may actually have more positive charges on their surfaces than negative charges. These soils also have a very strong affinity to bind (or fix) P in very tight complexes.

Cation retention and leaching in soils

The negatively charged surfaces of clay particles and organic matter strongly attract cations. However, the retention and release of these cations, which affects their mobility in soil, is dependent on several factors. Two of these factors are the relative retention strength of each cation and the relative amount or mass of each cation present.

For a given cation the relative retention strength by soil is determined by the charge of the ion and the size, or diameter of the ion. In general, the greater the positive charge and the smaller the ionic diameter of a cation, the more tightly the ion is held (i.e., higher retention strength) and the more difficult it is to remove that cation and leach it down through the soil profile. For example, Al^{3+} has a positive charge of three and a very small ionic diameter and thus moves through the soil profile very slowly. Potassium (K^+), on the other hand, has a charge of one and a much larger ionic radius, so it leaches much more readily. This difference in cation retention has important soil fertility implications which will be discussed in the nutrient management chapter.

If cations are present in equal amounts, the general strength of adsorption that holds cations in the soil is in the following order:

$Al^{3+} >> Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$

Effect of CEC on soil properties

A soil with a **low CEC value** (1-10 meq/100 g) may have some, or all, of the following characteristics:

high sand and low clay content

low organic matter content

low water-holding capacity

low soil pH

will not easily resist changes in pH or other chemical changes

enhanced leaching potential of plant nutrients such as Ca^{2+}, NH_4^+, K^+

low productivity

A soil with a **higher CEC value** (11-40 meq/100g) may have some or all of the following characteristics:

low sand and higher silt + clay content

moderate to high organic matter content

high water-holding capacity

ability to resist changes in pH or other chemical properties

less nutrient losses to leaching than low CEC soils

Base saturation

Of the common soil-bound cations, Ca^{2+}, Mg^{2+}, K^+, and Na^+ are considered to be *basic cations*. The *base saturation* of the soil is defined as the percentage of the soil's CEC (on a charge equivalent basis) that is occupied by these cations. A high base saturation (>50%) enhances Ca, Mg, and K availability and prevents soil pH decline. Low base saturation (<25%) is indicative of a strongly acid soil that may maintain Al^{3+} activity high enough to cause phytotoxicity.

Buffering capacity

The resistance of soils to changes in pH of the soil solution is termed *buffering*. In practical terms, buffering capacity for pH increases with the amount of clay and organic matter. Thus, soils with high clay and organic matter content (high buffer capacity) will require more lime to

increase pH than sandy soils with low amounts of organic matter (low, or weak, buffer capacity).

One laboratory measure of the acid buffering capacity (or lime demand) of a given soil is called "buffer pH" as will be discussed in more detail later in Chapters 4 and 5. It is very important to realize, however, that buffer pH is quite different from conventional soil:water pH as discussed above.

Essential Elements for Plant Growth

Higher plants and the microbial biomass in soils need a wide array of essential elements to sustain them and build biomass. The soil biota take C, H and O from soil air and water, so these are not considered soil supplied nutrient. Six essential elements (N, P, K, S, Ca and Mg) are taken up by plants from the soil in relatively large amounts and these are referred to as *macronutrients*. All of the essential elements are taken up primarily as dissolved ions from solution and Table 6 lists their common forms and sources. The ionic form (e.g. cation vs. anion) of each nutrient and its specific charge characteristics directly control its relative sorption and availability from the soil. Higher plants also require a wide range of other elements (B, Cl, Co, Cu, Fe, Mo, Mn, Ni, and Zn) in much smaller amounts and these are referred to as *micronutrients*.

Table 6. Soil supplied macronutrients, sources and ionic forms for plant uptake.

Nutrient	Primary Sources	Dominant Form in Soil Solution
Nitrogen (N)	Organic matter, manures, fertilizers (N-P-K), legumes	NH_4^+ - Low pH or wet NO_3^- - Moderate pH and oxidized
Phosphorus (P)	Organic matter, fertilizers	$H_2P0_4^-$ - Between pH 5 and 7
Potassium (K)	Plant litter, fertilizers, soil minerals (micas & feldspars)	K^+
Calcium (Ca)	Limes, plant litter, soil minerals (feldspars & carbonates)	Ca^{2+}
Magnesium (Mg)	Dolomitic limes, soil minerals	Mg^{2+}
Sulfur (S)	Atmospheric & gypsum additions, soil sulfides	SO_4^{2-}

Limiting Factors to Plant Growth

Higher plants rely on the soil for a wide range of services in support of their growth. Physically, the soil must be deep and strong enough to support the plant, hold and supply sufficient plant available water, moderate extreme air temperatures and allow for adequate exchange of gasses between the root zone and the atmosphere. Chemically, the soil must maintain an adequate pH and soluble salt environment for locally adapted plants and supply all of the soil nutrients detailed above in adequate amounts to meet the plant's demand. The overall productivity of the plant community will be controlled by that soil factor that is present in the lowest relative amount, regardless of the adequacy/availability of the rest of important soil physical and chemical factors. This concept is known as the "*The Law of the Minimum*". For example, overall plant growth in urban soils is commonly directly limited by compaction and associated lack of rooting volume, regardless of the adequacy of soil pH and nutrient levels. Once you loosen these soils to provide adequate rooting depth, plant growth will increase until it becomes limited by the next limiting factor (e.g. low soil pH or P). Therefore, the overall guiding principle underpinning appropriate soil management is that we must manage all important plant growth factors together to maintain adequate plant growth over time.

Principles in Soil Modification

Complete modification

Intensively trafficked golf and sports turf venues often utilize complete soil modification that emphasizes specified sand source in order to gain an increase in drainage, an improvement in soil structure, and an increased in resistance to compaction from foot and/or vehicular traffic. Such modifications obviously have significant costs given how costly it can be to locate and pay for specific soil materials that perform as desired as a growing medium.

Complete modifications typically have these goals: a) allow for play during or soon after extreme rain events, b) improve surface playability characteristics, and c) improve the safety of sports fields. It is most common to remove existing topsoil and install a totally new coarse textured soil material (typically something high in medium textured sand) that might be supplemented with some organic material such as reed sedge or sphagnum peat. It is desirable that a modified root zone has high rates of water infiltration and percolation, resists compaction, high nutrient and water holding capacities, and low maintenance requirements. Unfortunately, some of these properties must be sacrificed in order to obtain a rapidly draining soil that resists compaction. The sacrifices are these fields have very low nutrient and water holding capacities.

Sand size, depth, bridging/interlocking properties and all of the physical and chemical interactions with added organic or inorganic amendments have to be considered for a modified soil to perform as desired. It is money well spent to have all possible soil components thoroughly tested by a reputable lab before making final purchasing decisions and installation of a completely modified soil. The specifications for some typical modified soil systems are presented in table 7.

Partial modification

There is nothing attempted more frequently that fails to deliver than partial modification of soils. The norm is to try to improve the drainage of heavy-textured, predominantly clay soils by adding sand to the existing clay. Unfortunately, the result of a little sand mixed in with a lot of clay is a brick. Depending on the sand-size, it typically takes 60-70% by volume of the sand in order to make appreciable improvements in the macroporosity (aka drainage) of a clay soil that is being modified with the sand to a 4 inch depth. The reason is that unless sand particles are touching sand particles to create the macropores, there are no increases in macroporosity possible. Again, the only way to really know how much sand material would be added to an existing soil to gain the desirable physical and chemical characteristics would be to submit samples to a soil testing lab that does physical analyses.

This discussion is not intended to entirely discourage the use of sands and/or organic matter in partical modification. Topdressing with small amounts of sand or compost (especially in conjunction with core aeration) is a great way to slowly but surely modify the physical nature of a soil. And another common thought in what works when doing partial modifications to soil is that in general, adding something 'larger' in size to something 'smaller' tends to 'work' (e.g. topdressing with small amounts of sand, say 1/8 to ¼" depth, on a heavy textured soil, is fine). On the contrary, if managing a completely modified sand-based putting green or athletic field, be wary of topdressing with compost as the small particles can effectively serve to clog the macropores of the predominantly sand system. Organic matter levels in completely modified soils that are intended to improve water and nutrient holding capacity are best adjusted BEFORE the field is installed, and not after.

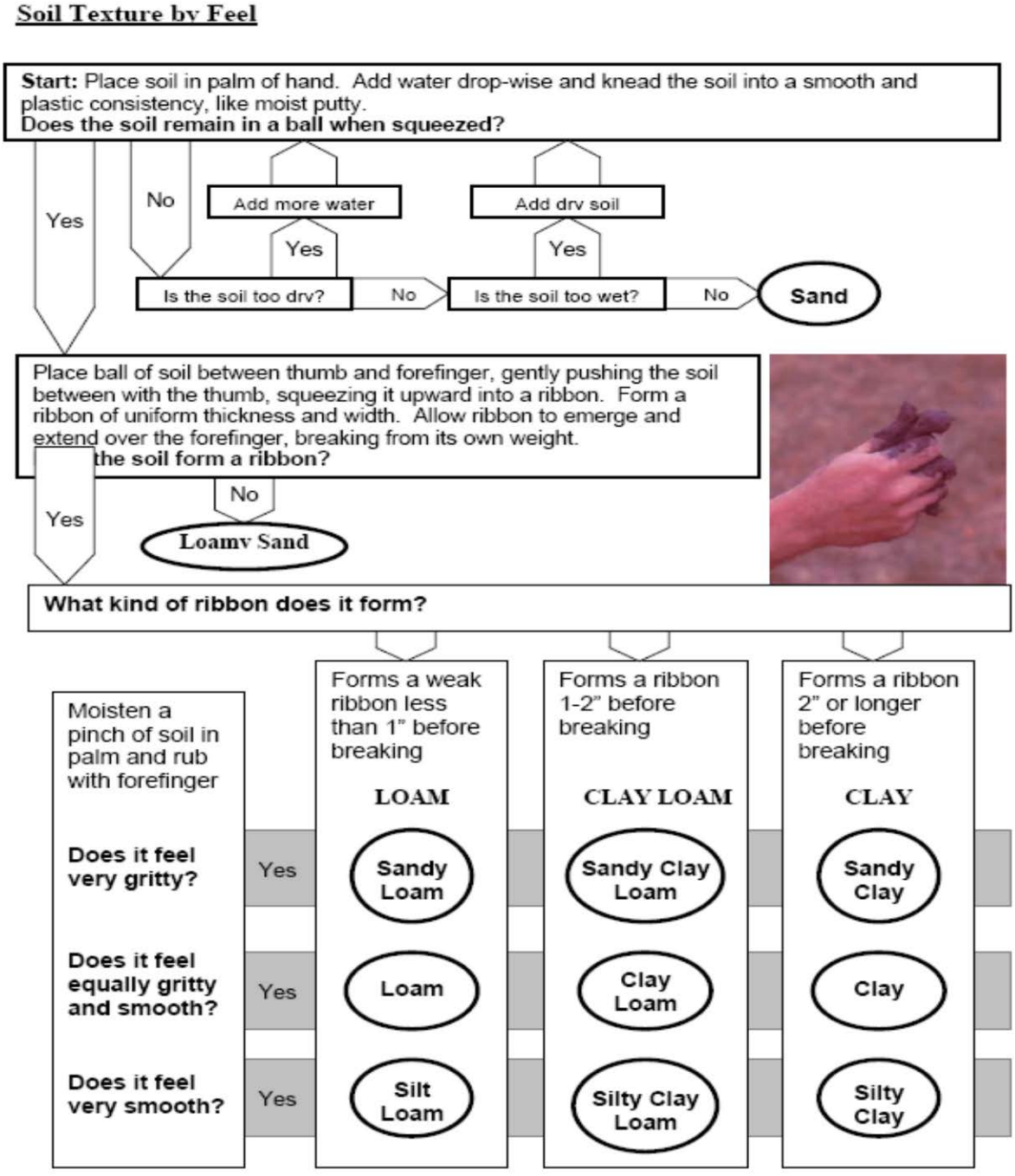
Table 7 Recommended particle size distributions for modified sand-based athletic fields and golf putting greens (table adapted from *Sports Fields: Design Construction, and Maintenance,* 2nd Edition, 2010, John Wiley and Sons, Inc., Hoboken, NJ).

Name	Fine Gravel >2 mm	Very Coarse 1–2 mm	Coarse .5–1 mm	Medium .25–.5 mm	Fine .1–.25 mm	Very Fine .05–.1 mm	Silt .002–.05 mm	Clay <.002 mm
Penn State[a]		95%*						
Penn State[b]	<10%	<10%	50–75%		<25%	<10%	<15%	
Univ. Minn.[c]	3% max		60% min		3% max			
USGA[d]	3% max	7% max	60% min		20% max	5% max**	5% max**	3% max**
Univ. Calif.[e]	<10%		82% min			8% max		
Pac. NW[f]	30% max		70% min		15% max	10% max	5% max	
Miss. State[g]	15% max		>60%		25% max		12% max	
PAT[h]	3% max	10% max	60–80%		5–20%	5–10%	6% max	6% max

APPENDIX I.

HOW CAN YOU TELL WHAT TYPE OF SOIL YOU HAVE?

You can send samples to soil labs that perform soil textural test or you can do some simple in house tests that will give you a rough idea of the soil you are dealing with. The following examples are from the Colorado State University extension.



Identifying Soil Texture by Measurement

1. Spread soil on a newspaper to dry. Remove all rocks, trash, roots, etc. Crush lumps and clods.
2. Finely pulverize the soil.
3. Fill a tall, slender jar (like a quart jar) ¼ full of soil.
4. Add water until the jar is ¾ full.
5. Add a teaspoon of powdered, non-foaming dishwasher detergent.
6. Put on a tight fitting lid and shake hard for 10 to 15 minutes. This shaking breaks apart the soil aggregates and separates the soil into individual mineral particles.
7. Set the jar where it will not be disturbed for 2-3 days.

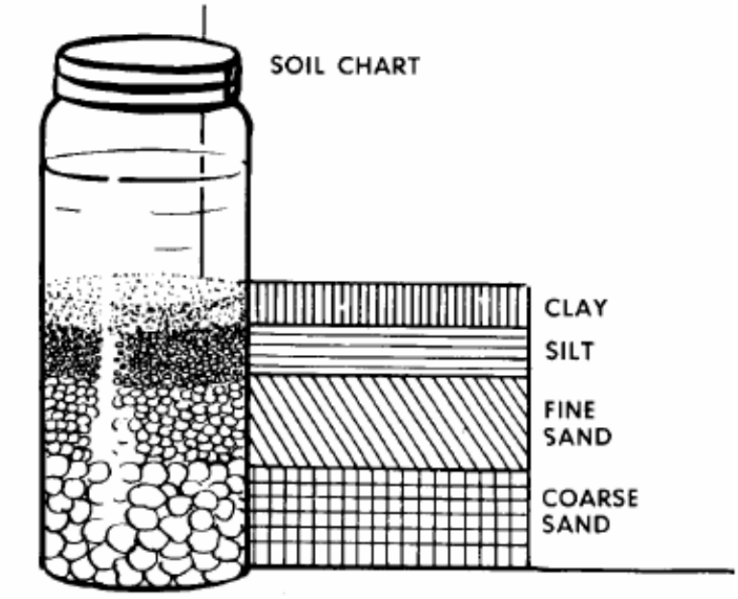
8. Soil particles will settle out according to size. **After 1 minute,** mark on the jar the depth of the sand.

9. **After 2 hours,** mark on the jar the depth of the silt

10. **When the water clear**s mark on the jar the clay level. This typically takes 1 to 3 days, but with some soils it may take weeks.

11. Measure the thickness of the sand, silt, and clay layers.
    a. Thickness of sand deposit ____
    b. Thickness of silt deposit ____
    c. Thickness of clay deposit ____
    d. Thickness of total deposit ____

12. Calculate the percentage of sand, silt, and clay.



[clay thickness]
---------- = ___ percent clay
[total thickness]

[silt thickness]
---------- = ___ percent silt
[total thickness]

[sand thickness]
---------- = ___ percent sand
[total thickness]

13. Turn to the soil texture triangle and look up the soil texture class.

Chapter 6. Turfgrass Nutrient Management: Strategies and Programming for Establishment and Maintenance

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This chapter will detail the concepts of water quality protection as well as the concepts in developing a nutrient management program that delivers a healthy, functional turf in an environmentally responsible fashion.

Water Quality and Nonpoint Source Pollution

Protecting water quality is a vital part of our social well being, but in areas with adequate year-round precipitation, water is sometimes taken for granted. Water provides us with specific services, but a water source's quality can become impaired to the point it is unable to provide that service. We rely on water for drinking water supplies, supporting aquatic life, production of edible and marketable fish and shellfish, as well as wildlife and recreational uses including, swimming, boating, fishing and shellfish harvesting. Water quality standards were developed to protect our water sources.

Although there are many ways water quality can become impaired, one of the more common impairments is from nonpoint source pollution, especially from excess nutrients and sediments. Nonpoint source pollution occurs when rain runs off agricultural, suburban and urban landscapes and into our waterways. The runoff containing pollutants is referred to as a nonpoint source because it does not come from a single source like a wastewater treatment or industrial discharge pipe.

Excess nitrogen, phosphorus and sediments are the three main pollutants that can impair our waters. Specifically, eroded sediments can collect in bodies of water and cause flooding issues and clouding of water during and shortly after heavy rain events. If suspended sediments stay in surface waters for extended periods of time they can also be detrimental to sub-aquatic vegetation by blocking sunlight to plants. Nitrogen and phosphorus are nutrients that help support animals and plants to live and growth. Some amounts of these

nutrients are normally found in water to help support aquatic plants and animals, but when excess levels exist they can cause a phenomenon known as eutrophication (Figure 1).

Eutrophication occurs when excess nitrogen and phosphorus are used by algae to bloom. The algae bloom itself can block sunlight to sub-aquatic vegetation, but the real threat to water quality occurs when the algae die and decompose at the bottom of the body of water. When this occurs the dissolved oxygen in the water is depleted to low or hypoxic conditions that can kill fish and other aquatic animals. These blooms can reoccur each year if the nutrient sources are left unchecked and continue to make their way into our waterways. Proper nutrient management can help reduce the amount of nutrients that reach ground and surface waters and help improve overall water quality.



Figure 1. An algae bloom in a pond on a golf course suggests mismanagement of fertilizer applications.

Pathways of Nutrient loss

A goal of responsible fertilization is that nutrients are effectively utilized by the turfgrass system we are managing. Unfortunately, nutrient management systems (and especially

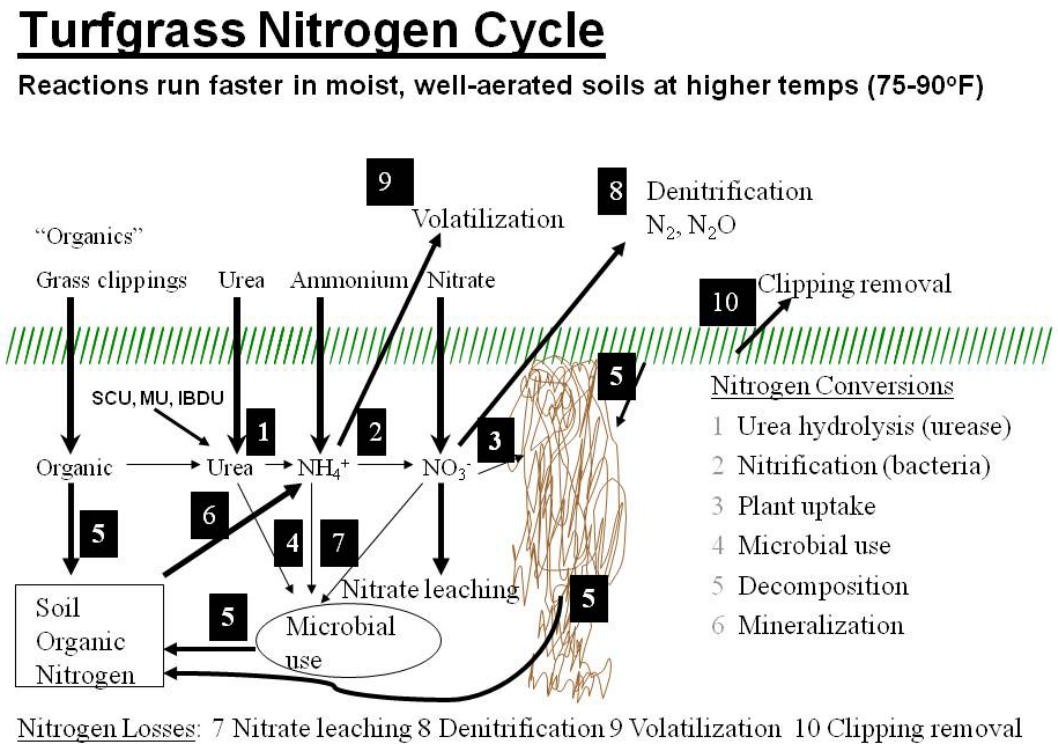


Figure 2. The Turfgrass Nitrogen (N) Cycle detailing the many ways that N is transformed, utilized, and lost.

that for N) have inherent challenges in losses. Figure 2 (provided by Dr. Beth Guertal, Auburn University) details a standard N cycle of turfgrass systems for review of all the possible interactions and transformations of N. Nutrients can be lost to the environment through several different pathways. Each pathway affects how nutrients should be managed in the landscape and losses can be minimized by using proper nutrient management practices. Nitrogen is considered to be very mobile because of its chemical properties and how it reacts in soil environments. Nitrogen can be lost to the environment through leaching, volatilization, denitrification, runoff and erosion.

Nitrogen is found in three main forms: Organic-nitrogen, nitrate-nitrogen (NO_3^-) and ammonium-nitrogen (NH_4^+). Each form is subject to different chemical reactions in soil environments if conditions are right. These reactions make nitrogen more available to plants, but also more susceptible to loss. Nitrate nitrogen because of its negative charge (NO_3^-), and the weakly negative charge of soils, is not bound to soil and can readily be leached below the rootzone if enough water is passing down through the soil profile. The greatest risk of nitrate leaching is when plants are not actively growing. Most nitrogen is leached from soils in winter when there is excess precipitation compared to plant needs and there is nitrate-nitrogen present in the soil that was unused from the warmer growing season. Leaching can occur on any soil type if conditions are right, but sandier soils are usually the most susceptible.

Both volatilization and denitrification require a specific form of nitrogen to be present in specific environmental conditions. Volatilization occurs when ammonium nitrogen (NH_4^+) is applied when air temperatures are hot and the soil is dry. In these conditions the reaction results in a proton (H^+) being taken from the ammonium molecule, turning it into ammonia (NH_3) which is a gas that is released to the atmosphere. Alkaline surface soil conditions will increase volatilization. Denitrification occurs when nitrate-nitrogen (NO_3^-) is present in water-logged soils when soil temperatures are warm. Soil bacteria will reduce (remove oxygen) nitrate-nitrogen (NO_3^-) into nitrous oxide (N_2O) or elemental nitrogen (N_2) that is released to the atmosphere.

Nitrogen loss through runoff and erosion also occur in very specific situations. When water-soluble nitrogen (NO_3^-, NH_4^+) is applied and is not incorporated (with either light irrigation or rainfall) it can be subject to runoff. Runoff from landscaped areas can occurs during large rain events or during smaller events where impervious surfaces direct flow across a landscape. Nitrogen loss through soil erosion occurs when runoff passes over bare or poorly stabilized soil and soil attached nitrogen, usually found as organic nitrogen is transported to nearby waterways.

Phosphorus is generally considered to be a very immobile nutrient because soluble phosphorus, regardless of its form, readily forms insoluble aluminum, iron or calcium

phosphates in soil environments; but loss to the environment can still occur though through erosion, runoff and leaching. Phosphorus loss through soil erosion is the most prevalent form of phosphorus loss. Soil erosion from bare or poorly stabilized soils can transport sediments and tightly bound phosphorus elements directly to waterways. Phosphorus loss by runoff and leaching is minimal and mainly occurs on soils that have extremely high phosphorus concentrations. These phosphorus-saturated soils allow more phosphorus to become water-soluble and be lost to the environment. Runoff can pass over soil and solubilize phosphorus and water that leaches down through the soil profile can carry phosphorus with it as well.

Nitrogen and Phosphorus, because of their unique loss pathways, are managed differently when they are applied to the landscape. In general, nitrogen is highly mobile. To minimize its loss the timing, placement and application rate should be closely managed. Phosphorus on the other hand is typically seen as immobile and found as an insoluble compound in soil. To minimize its loss placement should be closely managed. Only apply phosphorus when needed and be sure to correct any bare or poorly stabilized soil issues as they occur.

Nutrient Management and Fertility Recommendations

Successful turfgrass establishments are closely linked to responsible nutrient management programs, regardless of the turfgrass and its use. These nutrient management recommendations were developed in a cooperative effort between the turfgrass faculty at Virginia Tech and representatives of the Virginia Department of Conservation and Recreation that ultimately resulted in the Virginia Nutrient Management Standards and Criteria (2014). Fertility recommendations for establishment consider that the following criteria are met: 1) the selection of an appropriate grass for the climate and its intended use and 2) establishment occurs under optimal planting conditions.

Nutrient management strategies for new plantings will vary widely depending on the grass and its intended use. For instance, consider the inherent differences in growth rates between grasses, even within the groupings of cool-season and warm-season species. Bermudagrass and St. Augustinegrass (warm-season grasses) or tall fescue and perennial ryegrass (cool-season grasses) are noted for quick establishment, whereas zoysiagrass and centipedegrass (warm-season) or Kentucky bluegrass and fine fescue (cool-season) are very slow. Similarly, consider differences in establishment challenges between roadside vegetation being seeded on cut and fill soils high in B or C-horizon material versus seeding on completely modified sand-based systems for golf and sports turfs. Regardless of the site characteristics, the newly established sites planted from seed, sprigs (i.e. rhizomes or stolons) plugs, or sod have immature root systems that are limited in both size and depth. These limitations in initial root development place an even greater importance on the need for soil testing in order to correct chemical deficiencies, especially pH, and plant-available P

and N. Consult with a certified nutrient management planner or local cooperative extension office personnel in the development of a suitable nutrient management program for turf establishment in your area.

Establishment fertility programs

Phosphate and potash recommendations

Soil testing is appropriate for adjusting soil phosphorus and potassium levels prior to planting. The following table details general phosphate and potash recommendations for turfgrass establishments:

Table 1. Phosphorus (P_2O_5) and potassium (K_2O) levels applied at turfgrass establishments on the basis of soil testing.

	Nutrient needs (lbs per 1000 sq ft)	
Soil Test Level[z]	(P_2O_5)	(K_2O)
Low	3 to 4	2 to 3
Medium	2 to 3	1 to 2
High	1 to 2	0.5 to 1
Very High	0	0

[z]For low soil test levels within a category (e.g. L-), use the higher side of the range of nutrient needs and for high soil test levels (e.g. H+) use the lower side of the range of nutrient needs.

Research in Maryland (Turner, 2005) has demonstrated that there are limited advantages in turfgrass establishment at seeding from utilizing traditional high P-analysis "starter fertilizers" (e.g. 5-15-5, etc.), with the advantages being realized primarily when soil temperatures are sub-optimal for establishment. Similarly, the same advantages in the use of starter fertilizers can apply to overseeding, spot renovations, and sodding as well but their importance are minimal on soils with adequate P and optimal temperature and moisture conditions for establishment.

Nitrogen recommendations

Establishing turfgrasses in an environmentally responsible manner is a challenge in any situation. When possible (or affordable) establishing by sod provides immediate soil stabilization; sediment loss is essentially negated. However, seed, sprig or plug establishments present the challenge of applying relatively large amounts of water and

fertilizer to promote quick establishment (i.e. reduce sediment loss), but not at the expense of leaching or movement of the fertilizer into nearby water sources.

Nitrogen amounts during grow-in will vary depending on the turfgrass, the water solubility of the N source, the soil characteristics, and the timing of the establishment. At establishment, there are at least three factors that require fertility programs to be adjusted for the specifics of a planting situation: 1) all new establishments, even sod, lack a fully developed root system to efficiently utilize nutrients and water soon after planting, 2) the requirement for frequent irrigation during turf establishment to sustain the emerging root and shoot systems increases the potential for nutrient loss, and 3) with seed, plug, or sprig establishments, the lack of a dense turf canopy increases water quality concerns due to the potential lateral movement of nutrients and sediment. Immediate soil coverage is an inherent advantage in sod establishments and even where complete installation is not possible due to cost, using sod strips in predominantly seed establishments is often an affordable way to slow the speed of water on slopes and reduce soil loss (Figure 3).



Figure 3. Adding single strips of sod to seed establishments on sloped sites is a highly effective means of reducing soil erosion potential.

One N fertility strategy that promotes the development of newly established turfgrasses with less potential impact on water quality is to utilize "slowly available nitrogen" (SAN) sources during grow-in. The Virginia Department of Conservation and Recreations' Nutrient Management Training and Certification Regulations (4 VAC 50-85) define SAN "as sources that have delayed plant availability involving compounds which dissolve slowly, materials that must be microbially decomposed, or soluble compounds coated with substances highly impermeable to water such as polymer coated products, methylene urea, isobutylidene diurea (IBDU), urea formaldehyde based (UF), sulfur coated urea, and natural organics". Ideally, these sources should contain 50% or greater SAN in order to realize the full benefits of sustained N feeding with little N loss potential. Such sources should be the focal point of grow-in programs on sand-based soils. However, it is possible (and sometimes desirable due to cost or desired rate of turf coverage) to utilize predominantly water soluble N (WSN) sources during grow-in by way of frequent, low-level (0.25 to 0.5 lb N per 1000 sq feet) N applications. Many times, a successful grow-in program that combines both desirable turfgrass coverage and quality, with environmental protection is one that employs a range of N sources with varying degrees of water solubility.

Grow-in strategies for lawns and general turf. Nitrogen applications for establishments of homelawns and general turf areas should not exceed 0.9 lbs of total N per 1000 sq feet at planting for cool-season grasses or 1 lb of total N per 1000 sq feet at planting for warm-season grasses, followed by one or two applications initiated at 30 days after planting, not to exceed a total of 1.8 lbs N per 1000 sq feet for cool-season grasses or 2 lbs N per 1000 sq feet for warm-season grasses for the establishment. Slow-release N sources containing 15% or greater SAN will reduce leaching potential and should be used whenever possible for establishments on sand-based soils. Split applications of WSN at 0.25 to 0.5 lbs per 1000 sq feet per application on 1 to 2 week intervals will further improve N-use efficiency but consider that these applications can be difficult given the likelihood of wet soils during the grow-in period.

Grow-in strategies for golf course, athletic field, or sod production systems. With the wide range of grasses that can be used and the diversity in soils found across the mid-Atlantic region, there is a great deal of variability in fertilization strategies for turfgrass establishments. Successful establishments are best achieved by planting grasses during their optimum establishment windows (late summer to early fall for cool-season grasses and late spring through mid-summer for warm-season grasses). For any grass on any soil type, utilize a soil test to determine lime, phosphorus, and potassium needs and incorporate all needed amendments into the top 4 to 6 inches of the soil profile prior to planting.

First, consider N-based establishment fertility programs for cool- or warm-season grasses on heavier textured, predominantly silt/clay soils. These programs apply to most soils used for golf fairways and roughs, athletic fields, and sod farms in the region. Up to 0.9 lbs N per 1000 sq feet for cool-season grasses or 1 lb N per 1000 sq feet for warm-season grasses can be applied in a single application at planting with a 15% or greater SAN source that will feed the turf for up to 4 weeks. For sources containing predominantly WSN, apply no more than 0.7 lbs N per 1000 sq feet over the first 4 weeks by splitting the applications into regular intervals. At 4 weeks after planting, apply 0.25 lbs WSN per 1000 sq feet per week for the next 4 weeks, or if using a 15% or greater SAN source, up to 0.5 lbs SAN can be applied every two weeks, not to exceed 2 lbs N per 1000 sq feet for the establishment.

Next, consider N-based establishment fertility programs for cool- or warm-season grasses on naturally occurring or modified sand based soils. In these highly leachable soils, it is important to use a 15% or greater SAN source at up to 0.9 lbs N per 1000 sq feet for cool-season grasses or 1 lb N per 1000 sq feet for warm-season grasses for the first 4 weeks of establishment. For warm-season grasses, apply 0.25 lbs WSN per 1000 sq feet per week for the next 4 weeks. On cool-season grasses, apply up to 0.25 lbs N per 1000 sq feet per week (or 0.5 lbs of a 15% or greater SAN source every 2 weeks) after germination is complete for the next 8 weeks.

Large scale grow-ins on golf courses are sometimes achieved with fertigation systems (the application of low levels of nutrients through an in-ground irrigation system). For a properly installed and functioning irrigation system, fertigation is an extremely efficient method of nutrient delivery through the irrigation water.

Maintenance fertility programs

Phosphorus and potassium recommendations

Applications of phosphorus and potassium in maintenance application programs for cool and warm-season turfgrasses should be based on soil tests. Soil tests should be conducted at least every 3 years on high silt/clay soils and every year on high sand content soils. The following are recommended fertilization levels for phosphate and potash:

Table 2. Phosphorus (P_2O_5) and potassium (K_2O) levels applied to established turf on the basis of soil testing.

	Nutrient needs (lbs per 1000 sq feet)	
Soil Test Level[z]	(P_2O_5)	(K_2O)
Low	2 to 3	2 to 3
Medium	1 to 2	1 to 2
High	0.5 to 1	0.5 to 1
Very High	0	0

[z]For low soil test levels within a category (e.g. L-), use the higher side of the range of nutrient needs and for high soil test levels (e.g. H+) use the lower side of the range of nutrient needs.

Nitrogen

As detailed previously in this chapter describing the predominant grasses of the region and their uses, the annual nitrogen requirement varies greatly depending on the species of grass being grown, the site characteristics, the intended use of the grass and expectations of the clientele growing the turf. The following tables detail general seasonal N fertilization strategies for both cool- and warm-season turfgrasses.

Table 3. General seasonal nitrogen fertilization strategies for cool-season turfgrasses.

Time of Year	Relative N rate per application per growing month	Comments
Early Spring	None to low (0.25 lb N per 1000 sq feet)	-Never apply to frozen ground -if following aggressive fall fertilization, probably not necessary
Mid-late spring	Low to Medium (0.25 to 0.5 lb N per 1000 sq feet)	-have been shown to benefit root growth with responsible applications -exceeding these levels promotes shoots at expense of roots
Summer	None to low (0.25 lb N per 1000 sq feet)	-in general, refrain from N fertility, but small amounts can aid recovery from stress/pest pressures… avoid applications during high heat/drought pressures
Late summer thru early winter	Medium to high (0.5 to 1 lb N per 1000 sq feet)	-Promotes recovery from summer stress with early fall applications -Continue program (while grass is still green without much shoot growth) to promote roots, color, turf density and carbohydrate levels.

Table 4. General seasonal nitrogen fertilization strategies for warm-season turfgrasses.

Time of Year	Relative N rate per application per growing month	Comments
Early Spring	None to low (0.25 lb N per 1000 sq feet) pending emergence from winter dormancy	-Never apply to frozen ground -Ideally wait until complete greening, but strategy doesn't fit standard weed and feed products designed for PRE crabgrass control
Mid-late spring	Low to Medium (0.25 to 0.5 lb N per 1000 sq feet)	-excessive levels promote shoots at expense of roots -be aware of average "last frost" dates for the area
Summer	Medium to High (0.5 lb to 1 lb N per 1000 sq feet)	-primary season for fertilization, but still wise to avoid applications under severe environmental stress
Late summer to winter dormancy	Low (0.25 to 1 lb N per 1000 sq feet)	-maintaining active growth until dormancy promotes late season rooting and carbohydrate storage but N applications terminated prior to first frost date

Lawns and commercial turf. Cool-season grasses can receive up to 3.5 lbs N per 1000 sq ft on an annual basis. Warm-season grasses can receive up to 4 lbs of N per 1000 sq ft. Applications of water soluble N should not exceed 0.7 lbs of N per 1000 sq ft every 30 days and when using WSN on sandy soils, split applications to no more than 0.35 lb N per 1000 sq ft every 15 days. Slowly available N sources (defined as any N source containing 15% or greater SAN) can be applied up to 0.9 lbs N per 1000 sq ft for cool-season grasses or 1 lb N per 1000 sq ft for warm-season grasses per application. SAN sources can be applied at up to 2.5 lbs N per 1000 sq ft per application if the source is used in such a way that it does not release more than 0.7 lbs N in 30 days and the total annual N rates are reduced by 20%. Remember that the seasonal requirements of varying species are highly variable and some of the region's turfgrasses would actually decline in health and/or quality if aggressively fertilized. Table 6.8 details typical seasonal N requirements to achieve anticipated levels of desirable turfgrass performance.

Table 5. Seasonal nitrogen requirements to deliver satisfactory levels of turfgrass performance for cool- and warm-season lawns.

2.5 to 4.0 lbs N per 1000 sq feet annually	1 to 2 lbs N per 1000 sq feet annually
Kentucky/hybrid bluegrass	Fine leaf fescues
Creeping bentgrass	Centipedegrass
Bermudagrass*	Zoysiagrass
Tall fescue*	Bermudagrass*
Perennial ryegrass	Tall fescue*
St. Augustinegrass*	St. Augustinegrass*

*Certain varieties within species perform well under either annual N program.

Golf courses. Golf turf is some of the most intensively managed grass grown, requiring maintenance cutting heights as low as 0.1 inch for some putting greens with expectations to deliver a thick, dense, smooth playing surface. Furthering the need for additional nutrition is that clippings are collected on all greens, most tees, and even some fairways. For sand-based greens and tees, care especially needs to be taken regarding the potential for leaching loss of nitrates and phosphates due to the sandy soil and the likelihood that the greens contain subsurface drains that likely channel leachate to a water source. When greens are mature and healthy, nitrate and phosphate leaching concerns are minimal. When greens are immature (i.e. being grown-in) or are stressed due to pest or environmental pressures, the potential for nutrient loss is greatly increased. Table 6.9

presents general seasonal N applications for all aspects of golf turf management. Consider that while the total annual N rates stay the same, the maximum N rate per application (and therefore, the number of applications) might vary when 15% or greater SAN sources are used. Also consider that SAN sources can be applied at up to 2.5 lbs N per 1000 sq ft per application if the source is used in such a way that it does not release more than 0.7 lbs N in 30 days and the total annual N rates are reduced by 20%.

Table 6. General seasonal N strategies for golf turf management.

Turf use	Grass type	Maximum WSN rate per application in lbs per 1000 sq feet	Total Annual N rate (lbs per 1000 sq feet)[z]
Greens[y]		0.7	3 to 6
Tees[y]		0.7	2 to 5
Fairways (standard management) [x]	Cool-season	0.7	2-3
	Warm-season	0.7	2-4
Fairways (intensive management) [w]	Cool-season	0.5	3-4
	Warm-season	0.5	3.5 to 4.5
Overseeding fairways[v]	Warm-season	0.5	1.25
Roughs[y]		0.7	1 to 3

[z]Use the higher levels for intensively managed turf where accelerated growth and/or rapid recovery are required; use lower rates for maintenance of lesser used areas.

yPer application timing must be a minimum of 30 days between applications. Using a 15% or greater SAN source, up to 0.9 lbs N per 1000 sq ft for cool-season grasses or 1 lb N per 1000 sq ft for warm-season grasses may be applied with each

application.

[x]Standard management fairways may or may not have irrigation and likely are mowed at heights of 0.75 to 1.25 inch one to two times per week. Using a 15% or greater SAN source, up to 0.9 lbs N per 1000 sq ft for cool-season grasses or 1 lb N per 1000 sq ft for warm-season grasses may be applied with each application.

[w]Intensively managed fairways are irrigated and are likely mowed at heights ≤ 0.75 in. three or more times per week. Using WSN application timing must be 15 days between applications. Alternatively, using a 15% or greater SAN source, up to 0.9 lbs N per 1000 sq ft for cool-season grasses or 1 lb N per 1000 sq ft for warm-season grasses may be applied with each application.

[v]Initiate N applications of no more than 0.5 lb N per 1000 sq feet after ryegrass is well established and bermudagrass has entered dormancy. In spring, up to two applications of N not to exceed 0.75 lb N per 1000 sq feet can be used in February or March if growth and color enhancement are required.

Athletic fields. There is likely no turf management situation more challenging than maintaining a safe, high quality playing surface on an athletic field. A fertility program is only one component of a successful management program as appropriate cultivation, irrigation, and field use management strategies have similar importance. However, applying fertilizer at the appropriate levels and timing pending the grass, the soil, and the field use is critical to sustain turf coverage and encourage its recovery. The following tables (adapted from Goatley et al., 2008, and the 2014 DCR Standards and Criteria) provide general recommendations for N fertility strategies on cool-season athletic fields in this region. As stated previously, the maximum N rate per application (and therefore, the number of applications) might vary when 15% or greater SAN sources are used on heavier textured (predominantly clay or silt soils) and levels of up to 2.5 lbs N per 1000 sq feet can be applied in a single application if the source is used in such a way that it does not release more than 0.7 lbs N in 30 days and the total annual N rates are reduced by 20%. The application timing and frequency would be adjusted accordingly.

Table 7. Suggested nitrogen (N) fertility programs for a cool-season athletic field.

	Maintenance program[z]		
	Normal (predominantly silt/clay soil)	Intensive (predominantly silt/clay soil)	Sandy or modified sand soil[x]
Application timing	----------Lbs WSN per 1000 sq feet----------		
After August 15	--	0.5	0.5
September	0.7[y]	0.7[y]	0.7
October	0.7[y]	0.7[y]	0.7
November	0.5	0.7[y]	0.7
April 15 to May 15	0.5	0.5	0.5
June 1 to June 15	--	0.5	0.5
Seasonal N total	Up to 3 lbs	Up to 4.5 lbs	Up to 4.5 lbs

[z]Intensively managed native soil and sand-based fields require supplemental irrigation.

[y]Using a 15% or greater SAN source, up to 0.9 lbs N per 1000 sq ft may be applied with each application.

[x]On sand based systems, where WSN is used, levels should not exceed 0.35 lbs per 1000 sq feet every 15 days. Using a 15% SAN source, applications of 0.5 lbs N per 1000 sq feet can be made every 15 days. Using a 50% SAN source, applications of 0.9 lbs N per 1000 sq feet can be made every 30 days.

Table 8. Suggested nitrogen (N) fertility programs for a bermudagrass athletic field.

	Maintenance program[z]	
	Predominantly silt/clay soil	Sandy or modified sand soil[x]
Application timing	----------Lbs WSN per 1000 sq feet----------	
April 15 to May 15	0.5 to 0.7[y]	0.5 to 0.7[y]
June	0.7[x]	0.7[y]
July	0.5 to 0.7[x]	0.7[y]
August	0.5 to 0.7[x]	0.7[y]
Sept 1 to Sept 15[w]	0.5 to 0. 0.7[y]	0.7[y]
Seasonal N total for non-overseeded fields	3 to 5	Up to 5
	If overseeded with ryegrass[v]	
October through November	0.5 to 1.0	0.5 to 1.0
February through March	0.5 to 1.0	0.5 to 1.0
Seasonal N total for overseeded fields	4 to 6	4to 6

[z]Intensively managed native soil and sand-based fields require supplemental irrigation.

[y]Where WSN is used, levels should not exceed 0.35 lbs per 1000 sq feet every 15 days. Using a 15% SAN source, applications of 0.5 lbs N per 1000 sq feet can be made every 15 days. Using a 50% SAN source, applications of up to 1.0 lb N per 1000 sq feet can be made every 30 days.

[x]Using a 15% or greater SAN source, up to 1.0 lbs N per 1000 sq ft may be applied with each application.

[w]The September application is suitable only if anticipated first fall killing frost

date is after October 20.

[v]Use the higher N levels on intensively trafficked fields only. Do not exceed 1.0 lb N per 1000 sq feet for overseeded ryegrass applications. All applications should be made using a 15% or great SAN source.

Sod production systems. Growing sod is quite simply a specialized form of 'production agriculture', with a similar goal (i.e. yield) of any other crop. A harvestable sod of acceptable turf quality (high density, dark green and uniform color, pest-free, etc.) is the sign of a successful 'crop'. Revenues are optimized by achieving rapid coverage of the turf, and to accelerate harvest, it is common to net the sod either prior to planting or at harvest. As for any growing system, proper timing and appropriate application levels of nutrients are crucial to optimize nutrient use efficiency. Prior to seed or sprig establishment, soil tests should be performed to adjust pH and supplemental nutrient requirements (P and K etc.) at planting using the standard guidelines presented in Table 6.1. Netted sods can likely be produced within a calendar year, whereas non-netted sods will likely require some portion of a second growing season to complete establishment. Recommended N levels at the establishment of both cool- and warm-season turfgrasses were presented earlier in this chapter. Tables 6.12 and 6.13 detail seasonal nitrogen levels in the production of cool-season or warm-season sods.

Table 9. Recommended nitrogen levels for production of a cool-season turfgrass sod.

Timing of planting	Actual N (lbs per Acre)
At seeding[z]:	30 to 40[y]
In seeding year of fall planting[x]	
Nov. 15 – Dec. 15	30 to 40[y]
First full year of establishment	
April 1 – June 15	20 to 40[y]
Aug. 15 – Oct. 1	30 to 40[y]
Nov 1 to Dec. 1	40[y]

Second year[w]:	20 to 40[y] per growing month as needed to complete coverage

[z]Fall planting dates are optimal for rapid establishment; for spring plantings continue first season fertility in Aug of that year.

[y]Apply no more than 30 lbs of water soluble N per Acre in any single application; for levels greater than 30 lbs, use materials that are 15% or greater SAN.

[x]Do not apply fertilizer to frozen soil.

[w]Second year fertilization likely only required for non-netted sod.

Table 10. Recommended nitrogen levels for production of bermudagrass or zoysiagrass sods.

	Bermudagrass	Zoysiagrass[z]
Timing of application	Lbs N per Acre[z]	
Establishment by seed or sprigs in late spring/early summer	30-40	30-40
June	40	
July	40	40
August	40	

[z]Apply no more than 30 lbs of water soluble N per Acre in any single application; for levels greater than 40 lbs, use materials that are 15% or greater SAN.

Chapter 7. Mowing Principles and Practices

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By definition a turf-grass is any plant that can persist under regular clipping and wear. Turfgrasses tolerate mowing because leaf tissue is removed, but shoot meristems (growing points) are not. While frequent removal of photosynthetic area is a stress on plant energy resources, done properly, mowing has benefits that create a beautiful and functional surface.

Mowing Height. The height at which a turf can be mowed is primarily dictated by the growth habit, leaf texture, and tiller density of the species (or cultivar) that is being managed. Those species that spread horizontally along the ground with stolons, have a very fine leaf texture, and high tiller density, such as hybrid bermudagrass or creeping bentgrass, can tolerate the lowest mowing heights. Upright-growing, bunch-type species with wide leaf blades such as tall fescue are best maintained at higher heights. Most of the other seven or so turfgrass species commonly used in the humid transition zone are best maintained at medium mowing heights. Table 1 is presented below for comparison and future reference.

Mowing height can be varied seasonally for a number of reasons, but should never be lowered or raised more than 33% of the “healthy” or regular mowing height at one time. For example, one commonly accepted practice in the early spring before active shoot growth begins is to mow turf-type tall fescue lawns at 2.5” or 30% below the intended spring maintenance height of 3.5”. This removes the upper brown leaf tissue and better exposes the newer green growth to incoming radiation, enhancing soil warming and speeding lawn greenup. As the spring shoot growth spurt begins, mowing height should be returned to 3.5”. As the flush of shoot growth subsides and the heat of summer is looming, consider raising the height to 4” to better insulate the crown from high temperature stress and increase late spring rooting potential for improved summer drought avoidance. With cooler temperatures of

October, the height can again be lowered to 3 or 3.5 inches to encourage lateral growth and more efficiently mulch tree leaves into the canopy.

Table 1. Recommended mowing height ranges of 11 turfgrass species used in the humid transition zone

Turf species	**Growth habit**	**Leaf texture**	**Mowing height range**	**Healthy* mowing height**
Creeping bentgrass	Prostrate	Very fine	0.10 - 0.60”	0.50”
Hybrid bermudagrass	Prostrate	Very fine	0.12 – 1.00”	0.60”
Common bermudagrass	Prostrate	Fine	0.50 – 2.00”	1.25”
Zoysiagrass	Prostrate	Medium-fine	0.50 - 2.00”	1.50”
Seashore Paspalum	Prostrate	Medium-fine	0.10 – 2.00”	1.25”
Centipedegrass	Prostrate	Medium	1.00 - 2.00”	1.50”
Perennial ryegrass	Upright	Medium-fine	0.50 – 3.00”	2.50”
Kentucky bluegrass	Semi-prostrate	Medium	0.75 – 3.00”	2.50”
Fine fescues	Upright	Fine	1.50 – 4.50”	3.00”
St. Augustine grass	Semi-prostrate	Coarse	2.50 – 3.50”	3.00”
Turf-type tall fescue	Upright	Medium-coarse	2.00 – 4.00”	3.50”
K-31 tall fescue	Upright	Coarse	2.50 – 4.50”	4.00”

*Healthy mowing height is relative to the intended or most common use of each species in the humid transition zone. For creeping bentgrass and hybrid bermudagrass the intended use is a golf course fairway; common bermudagrass, an athletic field; and a lawn for the remainder. Seashore paspalum is still being evaluated for cold tolerance,

For warm-season lawns or sports fields the recommended approach is slightly different. The first spring mowing should occur at the lower end of the scale to enhance soil warming and the rate of spring greenup. In the case of a bermudagrass lawn this might be an initial 1" mowing height. Given 100% greenup, move the height up slightly to a summer maintenance level of 1.5". As fall approaches and shoot growth slows, consider allowing the bermuda to reach 1.75 or 2 inches to promote greater carbohydrate storage for improved winter hardiness.

Maintaining a proper mowing height that matches the species of turf not only provides health benefits, but can also act as a weed deterrent and help rebound from damage caused by diseases. Research from multiple locations has shown a decrease in crabgrass cover as the mowing height of cool-season turfgrasses are increased (Figure 1). The increased height of the turfgrass shades out any germinating weed seedlings searching for sunlight, as well as out competing the young weeds for vital water and nutrients.

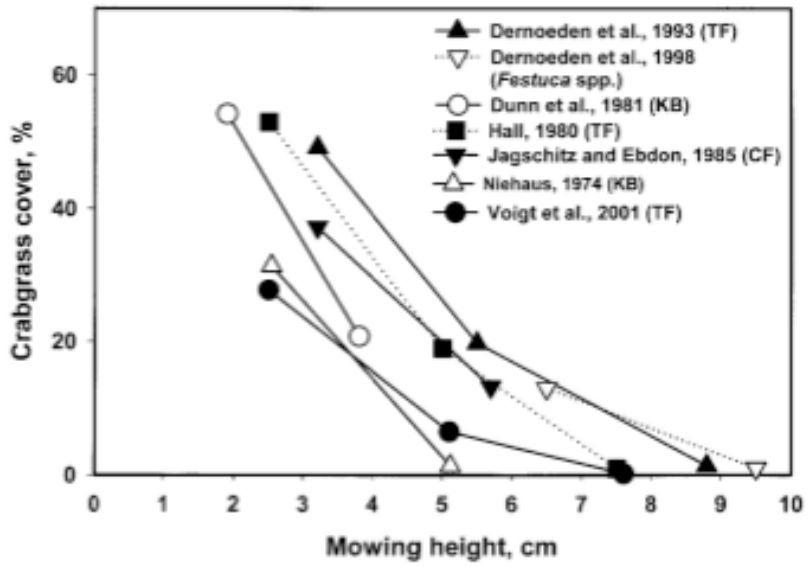


Figure 1. Research showing mowing height of various cool-season grasses versus crabgrass cover (Busey, 2003)

Cool-season grasses are naturally more susceptible to diseases while under stress caused by the heat of the summer. If these grasses are maintained at a higher mowing height, increased leaf area will provide more energy capturing chlorophyll, which would be needed to recover from any damage caused by diseases. The longer leaf blades would also suppress the spread of

the disease infection as the fungus must move over a greater leaf area before moving on to the next leaf. Higher mowing heights can also hide the damage from a disease infection due to a greater presence of healthy leaf blades (Figure 2).



Figure 2. Tall fescue mowed at 2”(left) versus 4”(right). Brown patch (*Rhizoctonia solani*) has infected both sides, but the higher mowing height is less noticealbe, and will recover faster. The lower mowing height is not only more noticable, but is also being overrun by crabgrass.

Mowing frequency. How often a turfgrass needs to be mown is dictated by leaf growth rate when maintained at a specific mowing height. Maximum mowing frequency is required in the spring for cool-season grasses and in the summer for warm-season grasses. Turfgrass research at Virginia Tech in the 1950’s was partly responsible for development of the 1/3-rule: Do not remove more than 30 to 40 percent of the leaf blade with any mowing. In the genetic programming of most turfgrasses, shoots have priority over roots for carbohydrate allocation so as to constantly maintain enough leaf area for photosynthetic energy production. Repeated removal of more than 40 percent leaf area initially stops energy from being stored in the roots and eventually stops root growth and maintenance altogether. Such poor mowing practices, coupled with summer stress, often results in shoot thinning, weed invasion, and sometimes, death. If rainfall or absence has resulted in turf of excessive height between clips, lower the height of cut in 0.5 to 1.0 inch increments, waiting two to three days between mowings, until turf is again at the desired height. Recommended mowing frequency intervals during active

shoot growth based on the 1/3 rule can be determined with a ruler and this simple formula: Divide the intended mowing height by 2 and then add this length to the mowing height. For example, grass that is cut to 2 inches should be mowed when it is 3 inches tall: Step 1: 2”/2 = 1” Step 2: 2” + 1” = 3”

The lower a turf is mowed the more frequent it will need to be cut so as to protect healthy growth and not break the 1/3 rule (Table 2).

Table 2. Mowing frequency required during active growth to conform to the 1/3 rule based on various mowing heights.

Mowing height	1/3 rule height	Frequency
0.12”	0.18”	Every 1-2 days
0.25”	0.37”	Every other day
0.50”	0.75”	Every 2-3 days
1.00”	1.50”	Every 3-4 days
1.50”	2.25”	Every 4-5 days
2.00”	3.00”	Every 5-6 days
3.00”	4.50”	Every 6-7 days
4.00”	6.00”	Every 7-8 days

Time of Day, Sharpening, and Clippings. The best time of day to mow is after the turf has dried. This allows for a cleaner cut of the leaf blades that reduces mowing stress on the plant and minimizes clumping of clippings. Mowing with a dull blade not only leaves an unsightly brown cast to the leaf tips, but depletes energy reserves that are better used to avoid drought and fight disease. Leaf blades should be checked periodically for tearing and mower blades sharpened if needed (Figure 3). Homeowners should sharpen their blades 1 to 3 times per year while those mowers that are used almost daily by lawn care operators and sports turf managers may need sharpening on a weekly to monthly basis.

If proper mowing frequency is maintained clippings do not need to be removed, except for specialized areas such as golf greens where they will disrupt aesthetics or playability. Clipping return recycles plant nutrients such as nitrogen, phosphorus, and potassium. Nitrogen (N) return is especially important as clippings containing approximately 4% N will return up to 2 lbs of N per 1000 ft^2 per year to your turf. Clipping return can play a major role in allowing you to maintain a quality lawn while only fertilizing with 2 to 3 lbs of supplemental N per 1000 ft^2 per year. Clippings are 75 to 85% water and are not lignified so numerous research tests have shown that they do not contribute to thatch accumulation if the 1/3-rule is followed. Widely-available mulching mowers make clipping return easy and efficient. Twice weekly mowing in the fall can even allow you to mulch tree leaves into your lawn without excess thatch buildup if the leaves are 1.5 inches or less in depth.



Figure 3. Close-up of torn and damaged leaf blades caused by clipping with a dull mower. Photo credit: E.H. Ervin

Mowing Equipment. For every situation where turfgrass is grown, there is an optimal way to mow that turfgrass. Rotary mowers are the prevalent cutting units for the most acreage because they are generally inexpensive to both purchase and maintain. Rotary units clip grass by spinning a metal blade with a sharpened edge at high speed underneath a stationary deck (Figure 4). The cut is actually more of a "tear" as the grass blades are removed simply by the impact of a solid object striking the leaf blade at a high speed. Maintaining a sharp and properly balanced blade is crucial to maintaining high turf quality and plant health. Mowing with a dull blade creates jagged wounds in the leaves that result in a low quality turf that has increased potential for disease and environmental stress (Figure 3). A downside of rotary mowers is the higher risk of injury from flying debris when the blades strike objects. Scalping is another issue with rotary mowers when used on uneven surfaces. For this reason, rotary mowers are recommended at heights of 1.5" and above, with the greater heights being used on the more uneven surfaces.



Figure 4. Cutaway of a rotary mower deck.



Figure 5. Flail mower blades (top) and walk-behind flail mower on steep terrain.

Flail mowers have multiple levered blades on a spinning horizontal shaft (Figure 5). The blades are not intended to be sharpened and are designed to "give" if they hit a solid object and the deck is fully self-contained with no discharge point. Flail units are popular in maintaining unimproved turf areas such as highway rights of way where turf quality is not critical.

The cutting unit that provides the highest quality of cut is the reel unit that features a cylinder of curved blades that gathers and pinches leaves between the blade and a stationary, sharpened bedknife, (Figure 6), much like a set of scissors. Reel units are used on the highest

quality turf where cutting heights less than 1 inch are desired and the highest level of surface smoothness is required. Maintaining properly adjusted and sharpened blades and bedknives is crucial blade to achieving the high quality cut desired with this type of cutting unit.

Along with maintaining a properly adjusted reel unit, the number of blades is important. The lower the cutting height, the more blades are necessary to maintain a quality cut (Table 3). Having the proper number of blades matching the height of cut helps prevent the washboard/rippling effect (Figure 7).

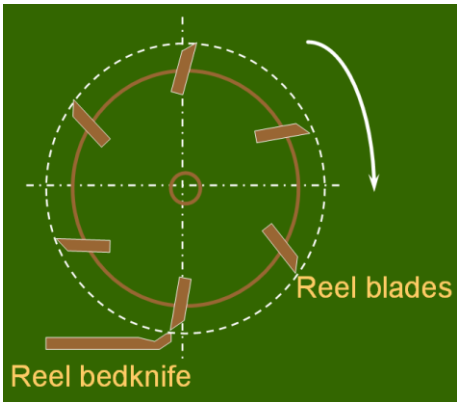


Figure 6. Reel unit, with blades and bedknife.

Table 3. Proper number of blades on the reel at the differing mowing heights required to achieve highest quality of cut.

Height of Cut	# of Blades on Reel
1-2”	5
½” – 1”	6
Less than ½”	7-11



Figure 7. Washboard/rippling effect caused by improperly adjusted reels, reels with the too few blades, or a mowing speed that does not match the height of cut.

More specialty pieces of equipment are used for both high and low maintenance areas where a larger pieces of equipment will not fit, including around fence lines, on narrow bunker faces, and even steep hill faces. These specialty pieces of equipment include string trimmers and hover mowers. String trimmers use thin (0.095-0.120 inch), plastic filaments attached to a rotating head. The cutting action of a string trimmer is similar to that of a rotary mower. A string trimmer, though, does not have the filament fully contained under a deck housing like rotary mowers (Figure 8a). This allows string trimmers to get cut right up against an object, such as rock walls, fence lines, and fence post (Figure 8b-d). Since the cutting element is also a plastic filament, as it strikes these hard surfaces, the filament either bends or breaks without damaging the machine or the surface it hits. The open side of the string trimmer also allows for trimming excessively high turf down to a reasonable height. A standard rotary mower would become bogged down with the cut turf inside of the deck. However, since the filament is not contained like a rotary mower, when it strikes an object like a small rock or twig, these objects can become dangerous projectiles capable of hitting and damaging nearby people or windows.



Figure 8. a) Straight-shaft string trimmer. String trimmer used up against a rockwalls (b), fence lines (c), and around fence post (d).

Hover mowers, like string trimmers, are a specialty-type of mower used in situations or areas where a standard rotary or reel mower may not be able to cut the turf effectively. Hover mowers are primarily used on golf courses that have steep banks, thin strips of grass such as around bunkers, greens, tee boxes, or around water features (Figure 9a). Standard equipment is either too large or unsafe to use for these areas, but the turf still needs to be maintained. Hover mowers cut the turf just as rotary mowers and string trimmers, i.e. a horizontal impact of blade and turf at high speed (Figure 9b). Unlike conventional rotary mowers, hover mowers do not have wheels. Instead, the same engine used to turn the cutting blades, also creates a down draft that lifts the entire unit, allowing the operator to easily glide the mower from side to side. The hovering, coupled with a handle that allows an operator to almost dangle the mower from the edge, gives turf care managers a safe and effective tool for maintaining the height of the turf in unconventional locations.



Figure 9. (a)Hover mower used for cutting around bunkers, water features, and any other steep turfed area. (b) The underside of a hover mower showing the cutting blades.

Clipping management. Returning clippings is desirable whenever possible and the only situation where clippings are recommended for collection is in putting green management for golf turf where they would disrupt playability of the putting surface. Clippings are essentially controlled release fertilizer, containing approximately 4%N, 0.5 to 1% P, and 2% K by weight. A common misconception is that clippings contribute to thatch, a layer comprised primarily of slow to decay stems that forms between the turfgrass canopy and the soil surface. Thatch is primarily comprised of stems (rhizomes, stolons, and crowns) that resist microbial degradation. Therefore, all grasses capable of lateral growth by way of rhizomes and/or stolons can become thatchy, especially if they are aggressively fertilized. If properly mowed (i.e. following the 1/3rd rule of leaf removal) clippings readily degrade and do not contribute to thatch. However, if mowing is sporadic and the turf is allowed to produce seedheads, thatch build-up is likely to occur over multiple seasons. Another tempting reason to collect clippings is to reduce the potential of spreading weeds or diseases throughout the lawn. However, research has shown that the advantages of returning clippings far exceed any concerns with promoting weed or disease pressure in the turf. It is now common that many versions of the standard rotary mowers can serve as 'mulching mowers' by way of modifications of their decks and blades (Figure 10a). The ability to chop clippings into very small leaf pieces accelerates leaf decomposition in the soil, thus improving lawn appearance and promoting a healthy soil microbial population (Figure 10b). If the 1/3rd rule can not be followed for a mowing event and piles of clippings remain on the lawn (Figure 11), it is important to remove these because they block sunlight and encourage disease potential due to the elevated temperature and moisture under the pile. In all cases where clippings are collected, they should be properly composted rather than piled in waste areas and/or bagged for deposition in landfills.

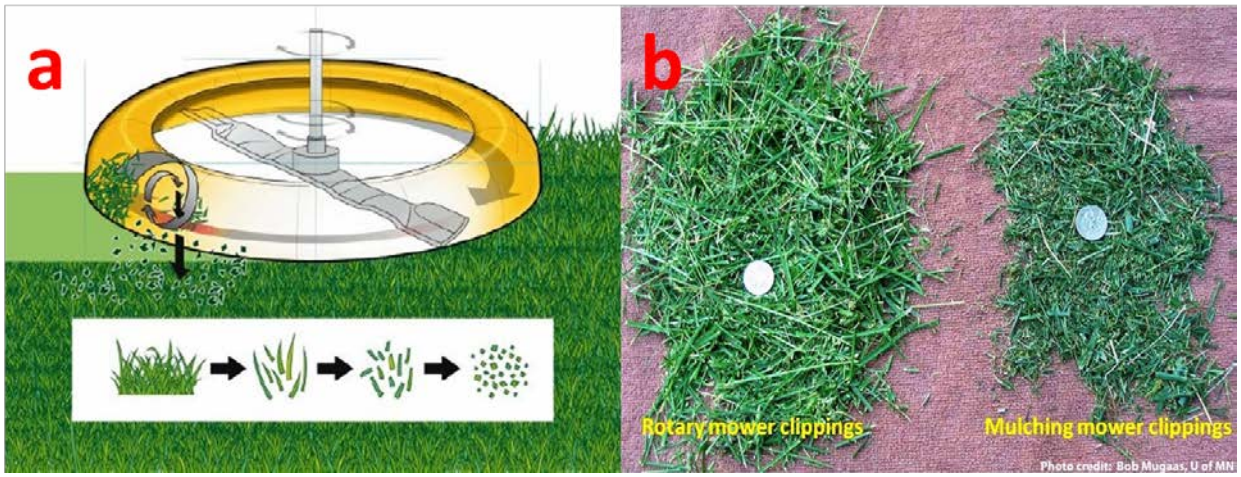


Figure 10 . (a) A mulching mower chops turfgrass clippings into fine particles that are quickly decomposed by microbes in the soil. (b) A side-by-side comparison of lawn clippings from a standard rotary mower (left) versus a mulching mower



Figure 11. When the '1/3rd mowing rule' is violated it is important not to leave the piled clippings on the lawn as they can damage the underlying turf. Collect and compost this material.

Mowing directions, striping, and patterns. Varying the direction in which the turfgrass is mowed provides many benefits. Changing the direction of mowing will keep the turf from lying in the same position. This will allow the entire leaf surface to be utilized for photosynthesis. When the same area is not trafficked the same direction every time an area is

mowed, less compaction will occur. Finally, changing the direction will give an area the "checker-board" pattern.

The striping patterns are the result of reflection of the light off the leaf surface. The striping is also a matter of perspective. When mowed in opposite directions, the stripe mowed towards your eyes is reflecting the light away, and appears darker due to the shadows from the leaf blades. The stripe mowed away from your eyes will reflect the light towards the viewer and appear lighter. The pattern can be mowed in a variety of ways as long as the contrasting stripes are adjacent to each other (Figure 12). Also, different turfgrass species stripe better than others, with perennial ryegrass being the best "striper," and bermudagrass being the worst.

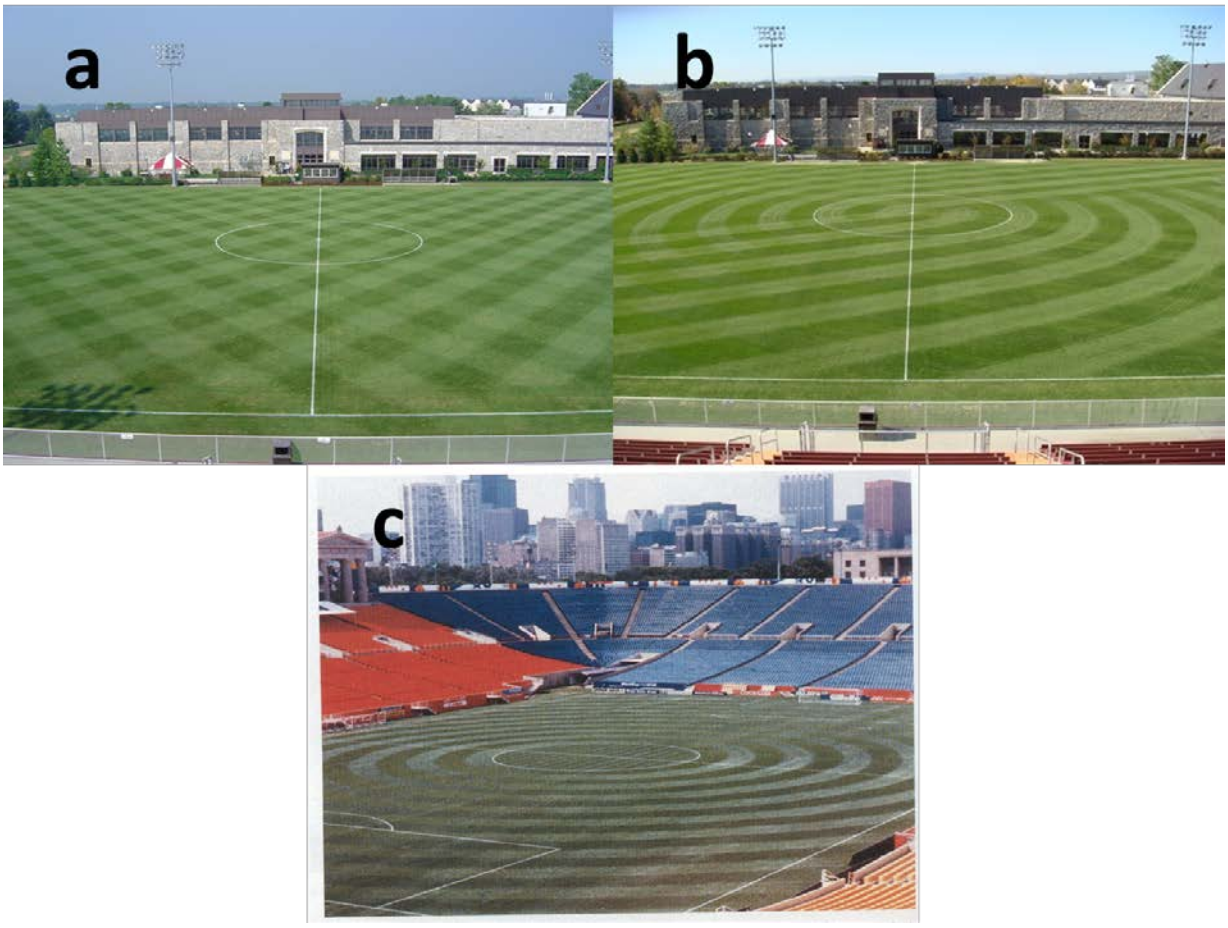


Figure 12. Mowing patterns can vary based on design. (a) Checkerboard. (b) Swirling checkerboard. (c) Bull's eye.

Chapter 8. Turfgrass Establishment

J. Michael Goatley, Professor, Virginia Tech

Soil preparation

Whether it is a new establishment or a spot renovation it is important to ensure that soil physical or chemical properties are suitable for turfgrass establishment and long-term success. If a turf stand has failed, is it possibly due to the soil? For native soils, conducting a soil test is an inexpensive and logical preventative maintenance step that should accompany almost any establishment scenario, especially if a soil test has not been conducted for the past three years. Applying recommended levels of lime and fertilizer will ensure the turf has maximum opportunity to establish.



Figure 1. Stockpile topsoil prior to construction for later distribution before turf and landscape planting.

For new establishments in many urban settings, the physical properties of the existing soil (often a B horizon subsoil remaining after construction) are an immediate limitation to turf establishment (see Chapter 5 for a complete discussion on the challenges of urban soils). Whenever possible, stockpile the top 4 to 6 inches of the topsoil before construction begins for later redistribution across the site after construction is complete (Figure 1). Unfortunately, stockpiled topsoil is often not available in urban settings and what remains is a nutrient deficient, compacted, poorly drained subsoil material that is to be used for turf and landscape plant establishment. Far too often, the unsuitable soil is masked by a sod installation that provides immediate cover, but ultimately fails as environmental extremes (heat, cold, drought, or saturated conditions) arrive. No amount of water, fertilizers, and pesticides can overcome an unsuitable soil, and the potential for turfgrass management to impact water quality is exaggerated as homeowners attempt to overcome the soil limitations with excessive water and chemical inputs. And instead of utilizing the benefits of turfgrass as a filter and soil stabilizer to protect water quality, the end result is a declining stand of turfgrass that negatively impacts water quality by the likely movement of sediment and unused nutrients during heavy rainfall events.

Remove and dispose of all rocks and construction debris (brick, piles of gravel, lumber, spilled concrete, electrical wire, etc.) from the site – do not bury it in the soil. Any utility, irrigation, drainage, or sewer lines for the site should be installed well before the

installation of turf or ornamentals and be sure to confirm that these lines have been installed to appropriate depths such that they won't be hit by tillage equipment during final soil preparation. Ensure that the grade on the property is suitable so that surface drainage moves water away from buildings, sidewalks, etc. This is also the time to consider the feasibility (and/or design and install) of rain gardens or other stormwater retention systems.

Conduct soil tests for the lawn and ornamental beds in order to address any chemical limitations (pH and nutrient levels) of the growing medium. Recommended lime and fertilizer materials should then be pre-plant incorporated into the top 4-6 inches of the soil. This will also be the time to incorporate any organic or inorganic amendments recommended to improve the soil (discussed in Chapter 4). Thoroughly till the soil but do not attempt to turn the lawn seedbed into a fine powder typically equated to a garden soil – some clods are fine for a turf establishment! The soil can then be smoothed and firmed with a lightweight roller prior to planting, but avoid extensive surface compaction. If additional construction traffic occurs prior to planting, conduct another light tillage to remove surface compaction.

Little or no soil preparation of thinning or degraded turf areas most often leads to failed turfgrass establishment even though it might seem logical that sowing seed or installing sod into/on a sparse turf canopy could work. Seed applied into thin turfs usually germinate but many of the newly emerging roots do not adequately penetrate the soil such that the new plant persists. For spot seed renovations, it is recommended to core aerate the soil in multiple directions, seed, and then drag the cores back into the area after seeding to improve soil to seed contact. For sod installations, success is usually achieved through complete soil preparation.

Timing

The optimum period to seed cool-season grasses is late summer to early fall across the mid-Atlantic. This timing optimizes root development and carbohydrate storage in the young plants because of more favorable environmental conditions that maximize plant development before summer arrives. Early to mid-spring is the secondary window for seed establishments. Seed readily germinates as the soil warms, but the root system is rarely developed sufficiently to ensure survival during a hot, dry summer season. Seed is readily available for all cool-season grasses.

For seeded warm-season grasses, the ideal establishment period is mid-spring to early summer. These grasses perform optimally during hot weather conditions as long as they receive adequate moisture to maintain growth. The first winter survival of plants established from seed later than mid-July can be greatly reduced in extreme winters; the

more mature a warm-season turf is, the better its chance of surviving the first winter. There are seeded varieties for bermudagrass, zoysiagrass, and centipedegrass but not all varieties of these grasses are available from seed (i.e. they must be established vegetatively by sprigs, plugs, or sod). St. Augustinegrass is almost exclusively established from sod or plugs (seed are viable but of limited availability since they cannot easily be extracted from the seedhead). Sprigging (inserting vegetative stems into a prepared seedbed) establishments should follow these same timing guidelines.

Sod establishments are much more flexible in terms of timing success but the ideal establishment period follows the previous guidelines for both warm and cool-season grasses. However, both warm and cool-season sods can be successfully established as long as they are not applied to frozen soils. The key to success is to remember that these sods, while having reduced moisture needs, still require some water to prevent desiccation of the newly emerging roots. Dormant sods of warm-season grasses should have minimal moisture requirements but should be checked regularly during abnormally dry winters. Establishing cool-season sods in the summer is possible but requires regular monitoring and applications of soil moisture since evapotranspiration losses are so high. No N fertilizer should be applied to sods when established outside their optimal establishment window.

Establishment methods and planting strategies

Seed provides the most popular means of establishment because of the availability of improved cultivars for many species and relative affordability of the seed. However, many improved varieties of bermudagrass do not produce viable seed and must be established vegetatively. Seed is readily available for many improved varieties of cool-season turfgrasses. Select certified (blue-tag) seed whenever possible as this ensures that what is indicated on the tag is what is in the bag. Apply fertilizers and lime for grow-in programs as detailed in Chapter 5 utilizing the results from soil tests to correct deficiencies.

Seeding

For lawns, seed at the recommended levels detailed in Table 1, using the higher seeding levels during suboptimal establishment periods.

Table 1. Recommended seeding levels for turfgrasses used in home lawns.

Grass	Seeding level (lbs pure live seed per 1000 sq feet)
Fine-leaf fescue	3 to 5
Kentucky bluegrass	2 to 3
Perennial ryegrass	3 to 5
Tall fescue	6 to 8
Perennial ryegrass	3 to 5
Bermudagrass	0.5 to 1
Centipedegrass	0.25 to 0.5
Zoysiagrass	2 to 3
Cool-season mixtures? Dependent on % of individual species in mix.	Use recommendations on the bag. As an example, a 90/10 (% by weight) mixture of tall fescue/Ky bluegrass is seeded at 3 to 4 lbs per 1000 sq feet.

For golf and sports turfs, these seeding levels are recommended:

Table 2. Recommended establishment levels for specific uses of grasses for golf and sports turfs.

Grass and use	Seeding level (lbs pure live seed per 1000 sq feet)
Creeping bentgrass (golf putting greens and tees)	0.5 to 1
Creeping bentgrass (golf fairways))	0.25 to 0.5

Kentucky bluegrass (golf fairways and tees, sports fields)	2 to 3
Perennial ryegrass (golf fairways and tees, sports fields))	3 to 5
Perennial ryegrass/Kentucky bluegrass mixtures (90%/10% by weight, golf fairways and roughs, sports fields))	2 to 4
Tall fescue (golf roughs)	4 to 6
Tall fescue (sports fields)	6 to 8
Tall fescue/Kentucky bluegrass mixtures (90/10, % by weight used for roughs).	2 to 4
Tall fescue/Kentucky bluegrass mixtures (90/10, % by weight, used for athletic fields)).	3 to 5
Bermudagrass (golf fairways and tees, athletic fields)	0.5 to 1
Bermudagrass (golf rough)	0.25 to 0.5
Zoysiagrass (fairways or tees)	2 to 3

<u>Tools for seed establishments.</u> The most common equipment to deliver seed in surface applications to prepared seedbeds is either rotary (often referred to as broadcast or centrifugal) or drop (gravity-fed) spreaders. A ground-driven rotary spreader can be used for large scale plantings as it can cover a lot of ground in a short period of time, but there are also many types of hand-held rotary spreaders that are used for small seeded grasses and/or small areas (Figure 2). One challenge with any rotary spreader is that uniform seed distribution can be disrupted on windy days. Drop spreaders allow for precision in seed application as the seed falls precisely over the area covered by the spreader. Seed distribution is not affected by the wind but this delivery method takes a great deal more time because it covers a much smaller area in a single pass. Apply seed in at least 2 directions (especially with drop spreaders) to avoid skips. The previously mentioned method of hydroseeding is an excellent means of rapidly covering large areas of prepared soil with a seed, fertilizer, and mulch slurry using water as a carrier. There also are a host of mechanized seeders that slice or lightly till the soil in front of a seed hopper that drops the seed into the soil, thus ensuring soil to seed contact. The primary concern with mechanized planters is being sure the seed is not planted so deep in the soil that it can not emerge. Smaller seeded grasses (bluegrass, bermudagrass, bentgrass, zoysiagrass, centipedegrass) should be planted on or just below the soil surface. Larger seeded grasses (tall fescue, perennial ryegrass, fine-leaf fescues) can be planted into the top 0.5 inch of the soil.



Figure 2. A hand-held rotary spreader being used to deliver zoysiagrass seed.

Sodding.

Sod provides almost instant customer gratification by way of transforming a barren soil into a green lawn in just a matter of minutes. While more expensive as an establishment method as compared to seeding, there is also a lot of value in sod for its ability to quickly stabilize the soil and minimize erosion. As compared to seeding, an inherent advantage of sodding is that the soil attached to the sod serves as a nutrient and moisture reservoir to aid in establishment. However, a common mistake in sod installation is improper or inadequate soil preparation as the lure of simply rolling out the sod onto an existing site of ill-prepared soil or failing turf provides the installer a temporarily great looking surface that will ultimately fail. Soil preparation for sod installation is the same as if the site was being prepped for seeding and soil tests are critical to determine lime, phosphorus, and potassium needs. Ideally any needed amendments are applied and incorporated into the prepared soil. However, fertilizers can also be applied post establishment to the sod itself.

Roll the sod after planting to ensure soil to plant material contact and to level the surface. Sod still requires supplemental moisture for establishment, but it offers significant advantages in lower water requirements and watering frequency as compared to seed establishments. Water frequently enough to maintain a moist, but not saturated sod. Periodically check for rooting by lifting on the sod to see how well it is tacked to the soil and reduce irrigation frequency and amount after establishment is complete.



Figure 3. Adding single strips of sod to seed establishments on sloped sites is a highly effective means of reducing soil erosion potential.

Many times areas for establishment are simply so large that sod installations are cost prohibitive. However, it is possible to take advantage of the soil stabilization benefits of sod along with seeding. Figure 3 shows how sod was installed in single strips across a slope in order to slow the speed of water (and reduce erosion), while the rest of the area was seeded with the same varieties used in the sod. The sod producer is often very happy to sell you the same seed used in their crops, so that makes this type of establishment both relatively affordable and environmentally proactive.

Plugging or sprigging.

Any grass that produces lateral stems (rhizomes and/or stolons) can be established by plugging or sprigging (planting stems directly into the soil, Figure 4). However, due to the ready availability of seed for many cool-season grass varieties and their slower lateral growth rates, only warm-season grasses are commonly established by plugs or sprigs. Plugs of 2" to 4" in diameter are planted on 6 to 12 inch centers. Rapidly spreading grasses like bermudagrass and St. Augustinegrass can be planted on 12 inch centers and will achieve complete coverage within one summer growing season; faster coverage rates of 30-60 days is likely with plugging on 6 inch centers. Slow spreading grasses like centipedegrass and zoysiagrass should be planted on 6 inch centers and even then might



Figure 4. Bermudagrass sprigs (i.e. shredded stems) planted in rows on a sand-based athletic field.

not cover within one growing season. Plugs have the advantage of usually being fully rooted and therefore require less intensive irrigation management during establishment.

The shredded stems used as sprigs require regular and frequent irrigation until the growing points on the stems have produced a functioning rooting system. The moisture requirement for sprigs is very high during the first 7 to 14 days of establishment and for those that have never established turf in this manner, the first impression is that the stems have died as most of the leaf material at planting browns and decays. Be persistent with providing the regular irrigation events during this 7-14 day window and new leaves and roots will emerge. Logically, the more plant material used at establishment, the quicker the establishment rate. Sprigging levels of 10 to 25 stems per sq foot are typical planting levels, but higher levels of up to 50 stems per sq foot will likely be required to establish slower growing grasses such as zoysiagrass or centipedegrass in one growing season (Table 3). It is common for sprigging specifications to be presented in units of **bushels** of sprigs per acre**.** However, there is no clear definition of what constitutes a bushel. As a point of reference, numerous custom planting company personnel equate 25 stems per sq foot to a planting rate of 500 bushels per acre and typical planting rate specifications fall somewhere in the 500 to 1000 bushels per acre range. Specifying a precise number of stems per square foot is the easiest way to quantify a vegetative planting rate of stems per unit area.

Table 3. Vegetative planting recommendations for various grasses and their respective uses.

Grass and intended use	Stems per sq ft
Bermudagrass (lawns)	10 to 25
Bermudagrass (golf fairways)	10 to 50
Bermudagrass (golf greens)	35 to 50
Zoysiagrass (lawns)	25 to 35
Zoysiagrass (fairways and tees)	35 to 50

Winter overseeding.

Winter overseeding is defined in this publication as the early to mid-fall seeding of an adapted cool-season turfgrass into an existing warm-season turfgrass for the purpose of winter color and possibly improved playability of sports fields. Note that overseeding is sometimes used as a general term to describe any general seeding or renovation event that is conducted on existing stands of turfgrass, and can include the seeding of cool-season grasses into existing cool-season stands.

Most often, the choice in cool-season turf for winter overseeding is an annual, perennial, or intermediate ryegrass and for most purposes, only bermudagrass is recommended to be overseeded as other warm-season grasses are generally not viewed as being competitive enough the following season to outcompete the winter overseeding. The bermudagrass might be lightly vertical mowed or slightly scalped prior to overseeding in order to enhance seed movement through the canopy to the soil. This obviously is potentially detrimental to the bermudagrass and the level of vertical mowing should be kept at a minimum and not used as a dethatching event late in the bermudagrass growing season. Optimum soil to seed contact can be achieved by topdressing the overseeded grass with sand or similar topsoil material. For winter overseeding of bermudagrass, homelawns are seeded at 5 to 10 lbs of pure live seed per 1000 sq feet. Athletic fields or golf turf fairways and tees are typically seeded at 10 to 20 pounds of pure live seed per 1000 sq feet, and levels can go even higher on heavily trafficked fields that require regular reseeding to maintain desirable levels of density

Fertilization strategies for overseeded turfs can be problematic in trying to balance the needs of the germinating cool-season grass seedlings with those of a warm-season grass that will soon be entering winter dormancy. Overly aggressive N fertilization during fall overseeding periods can reduce ryegrass establishment by promoting excessive late-season bermudagrass competition, and high N levels can also reduce the winter hardiness of the bermudagrass. Using reduced N application levels of 0.25 lb N per 1000 sq feet per week during establishment allow the manager to maintain control of the growth rates of bermudagrass and the establishing ryegrass seedlings. Nitrogen fertilization levels totaling from 0.5 to 0.7 lb available N per 1000 sq feet per month in early September should suffice to feed the germinating ryegrass seedlings and not excessively stimulate the bermudagrass. Apply an additional 0.5 lb N per 1000 sq feet in October or November after the bermudagrass has entered dormancy and then again in February or March of the following year. These levels should suffice to promote ryegrass growth with limited effects on the bermudagrass turf.

While overseeding is generally considered to negatively affect the health and quality of warm-season grasses, there are inherent advantages to its use in grassing systems. Color and playability of golf and sports turfs might warrant the necessity of winter overseeding in some golf and sports turf situations. Another possible reason to overseed is if the turf is irrigated with reclaimed water. The ryegrass can effectively serve as a sink for nutrients applied in the reclaimed water that the dormant bermudagrass turf otherwise would not utilize.

Water management strategies for establishments.

Light and frequent irrigation is required for optimal seed establishments. Keep the seedbed moist but don't apply so much water that the seed might drown or be washed away. A somewhat more aggressive initial watering strategy is required for sprig establishments as these tissues are particularly prone to rapid desiccation. Initiate irrigation as soon as possible on newly planted sprigs and keep the sprigs moist but not saturated. Excessive watering can drown plants and promote losses of fertilizer either due to run-off or leaching loss. Even with immediate irrigation, anticipate a possible total loss of color due to leaf desiccation on the sprigs, but don't let this deter watering as healthy sprigs will almost always rapidly initiate new roots and shoots if their planting is appropriately timed and irrigation and fertility requirements are met. As establishment progresses, gradually reduce irrigation to a deep and infrequent strategy recommended for established turf.

Sod and rooted plugs provide more flexibility in supplemental irrigation requirements for establishment, not requiring nearly as much attention as seed or sprig plantings. As a rule of thumb, sod installations during optimal establishment periods should receive up to one inch of water (either from irrigation or rainfall) during establishment. However, the ideal water management approach is to keep the soil moist and not saturated and during periods of low evapotranspiration, supplemental water needs will be greatly reduced. Roots require both water and oxygen to establish properly and overwatering of sod greatly reduces establishment. Periodically tugging on the sod or plugs to assess root development is a good way to monitor moisture needs, and as rooting progresses, reduce supplemental irrigation to a deep and infrequent strategy as one would for an established turf.

An important way to conserve moisture and reduce soil erosion potential for seed establishments (and it could work for sprig plantings as well) is to mulch the seedbed. Small grain (wheat, barley etc.) straw is an ideal mulch for seed establishments (Figure 5). A general application level is one bale of straw per 1000 sq ft and it can be applied by hand or by power equipment that chops and blows the straw. Avoid using hay as a mulch source; a clean (weed free) wheat straw is a preferred mulching material. Straw can simply



Figure 5. Mulching newly seeded areas with weed-free straw is very effective in conserving moisture for seed establishments.

be mulched right back into the canopy as the new grass establishes and any of the small grain seed that germinates can be mowed and will die during the first summer season.

There are numerous paper-based and wood-fiber mulches available for mulching as well. Shredded paper mulch is very popular when turf is established by 'hydroseeding', a motorized pump-driven planting strategy that applies a fertilizer, seed, mulch and tackifier slurry to a prepared seed bed. There also are a wide variety of erosion control blankets that are primarily designed for vegetation establishments on sloped sites.

Chapter 9. Turfgrass Insect Management

Rod Youngman, Tom Kuhar, Professors; Sudan Gyawaly, Ph.D. Candiate; Curt Laub, Staff Department of Entomology, Virginia Tech; and Shaohui Wu, Post-Doctoral Associate, Rutgers University

What are insects?

Insects are a class of invertebrate animals within the arthropod phylum. Insects typically have a chitinous exoskeleton, three main body regions (head, thorax and abdomen), three pairs of jointed legs, compound eyes and one pair of antennae. They are among the most diverse groups of animals on the planet, with more than a million described species, representing over half of all known living organisms.

The life cycles of insects vary but most insects hatch from eggs that are typically deposited on plants, debris, or in the soil. Insect growth is constrained by the hard exoskeleton and thus, development involves a series of molts in which the exoskeleton is shed and replaced by a larger one. Many types of insects, such as moths, beetles, flies, and wasps undergo complete metamorphosis during their development, in which the insect undergoes four stages(egg, larva, pupa and adult). The egg hatches to produce a larva, which is generally worm-like in form (i.e., grubs, caterpillars, and maggots). The larva grows through several molts and eventually becomes a pupa, a stage marked by reduced movement and often sealed within a cocoon. Adults (often bearing wings as well as sexual organs) emerge from the pupa to complete the development. Other insect groups such as grasshoppers and bugs undergo incomplete metamorphosis in which nymphs emerge from eggs. Nymphs typically have a full set of legs and resemble adults, only smaller. With each successive molt, the immature nymph starts to resemble the adult until it ultimately molts into an adult with fully functional wings. In this chapter, the term 'instar' refers to a phase between molts during the immature stage (larva or nymph) of an insect.

The vast majority of insects are not injurious to humans or their commodities, but rather are an essential part of the ecosystems in which we live. However, several insect species feed on turfgrass or build nests in the turf, which cause them to become pests. This chapter presents insects of primary importance in Virginia turfgrass management.

Annual White Grubs

Order: Coleoptera

Family: Scarabaeidae

Complete development: egg, grub (=larva), pupa, adult

Distribution

The term 'annual white grub' is used to describe the larval stage of a complex of species of scarab beetles (Fig. 1), many of which annually cause serious damage in cool-season turfgrass in Virginia. Species known to occur in Virginia are the Asiatic garden beetle, *Maladara caestanea* (Arrow), green June beetle, *Cotinis nitida* (Linnaeus), Japanese beetle, *Popillia japonica* Newman, northern and southern masked chafers, *Cyclocephala borealis* Arrow and *C. immaculata* (Olivier), and the oriental beetle, *Anomala orientalis* Waterhouse. Of these, the Japanese beetle, green June beetle, and masked chafers are some of the most common white grubs infesting turfgrass in Virginia. The Japanese beetle is an introduced pest from Japan, and was first detected in the U.S. in 1916 in New Jersey. At present, the Japanese beetle is commonly found in most states east of the Mississippi River, extending from Maine to Georgia. The northern masked chafer and the green June beetle are native to the eastern U.S.

Figure 1. Annual White grubs commonly found in VA.

The species of most white grub immatures can be determined by looking at the arrangement of setae (stout hairs) on the raster (Fig. 2). The raster is located on the underside of the abdomen immediately after the last abdominal segment. A 10x power (or higher) hand lens is recommended for viewing the pattern of spines on the raster.

Figure 2. Grub species can be determined using raster pattern (stout hairs).



The Japanese beetle, masked chafers, and green June beetle will be the subject of further discussion. There are many similarities in the annual white grub seasonal life cycle, life stages,

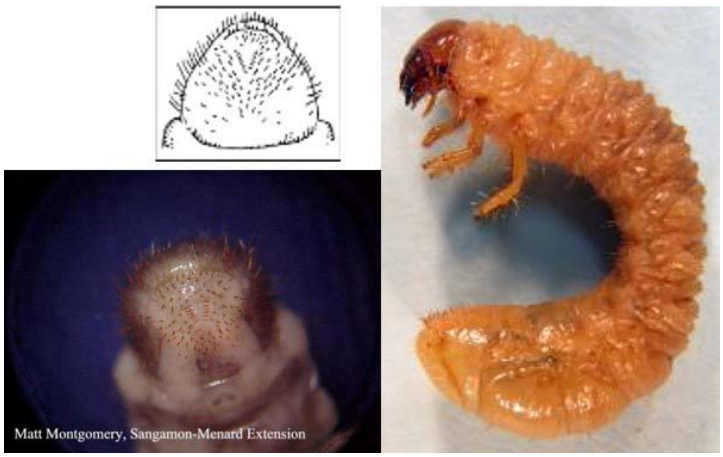
feeding injury, and control options. However, there are some specific differences that will be addressed.

Japanese beetle

Life cycle

The adults emerge about mid-June and begin feeding on landscape plants and fruit bearing trees and shrubs. Adults emit aggregation and sex pheromones that attract other adults. After mating, the female burrows down 2-4 inches into the soil and begins laying eggs in loose clusters of 1-7 eggs. Egg-laying occurs over a 2-3 week period starting about mid-July. The egg capacity for a female is about 60-70, and peak egg-laying is typically completed by early- to mid-August in Virginia. The eggs hatch after about two weeks, and the immature white grubs begin feeding on fine root hairs just below the soil surface. As the first instar increases in size it will shed its skin two more times. The third instar can be detected in turfgrass from mid-late summer to spring of the following year. In late fall, the third instar responds to decreasing soil temperatures (< 60°F at 1 inch soil depth) to stop feeding and begin moving down in the soil profile to spend the winter. After finding a stable 50°F temperature zone about 5-6 inches deep, the grub stops moving and will not return to the root zone until soil temperatures at the 50°F zone begin to rise the following spring. Research in Virginia and elsewhere indicates that about 30% mortality occurs in overwintering white grub populations. In the spring, the grub moves back to the root zone and resumes feeding until late May-early June. The grub then forms a soil cell about 1-3 inches deep, stops feeding, changes into a prepupa, and then pupates. Adults begin to emerge from the soil after ~2 weeks.

Figure 3. Japanese beetle grub raster pattern.



Life stages

The egg is pearly white, ovoid at first then becoming rounder over time. Newly laid eggs are about 0.06 inch in diameter, and nearly double in size just before hatching. The Japanese beetle white grub has a brown to orange-brown head capsule that bears chewing mouthparts and three pairs of well-developed brown legs on the thorax immediately behind the head. The abdomen is generally white to grayish white, with a distinct gray area at the end of the abdomen. The mature third instar grows to about 0.75 inch in length. All three instars exhibit a distinct 'C' shaped aspect, which flattens

out when crawling. The grub can be differentiated from other white grubs on the basis of the 'V'-shape pattern of flattened spines located on the raster on the underside of the last abdominal segment (Fig. 3). The mature grub (third instar) transforms into a prepupa initially. The prepupa is white and grub-like in appearance, and eventually transforms into the pupa. The pupa is light reddish-brown and about 0.5 inch long. Well-defined legs, head capsule, and wing pads are clearly visible on the pupa. The adult is about 0.5 inch in length, and when viewed from above, the adult head and thorax are shiny green. The elytra (wing covers) are shiny rusty brown and have five tufts of white hairs protruding from each side along the lower edge of the elytra, as well as two tufts at the tip of the abdomen (Fig. 4).

Figure 4. Japanese beetle.



Northern and Southern Masked chafers

Life cycle

The masked chafer life cycle is very similar to that described for the Japanese beetle. One of the main differences is that, unlike Japanese beetle adults, the northern and southern masked chafer adults do not feed. Also, the setal arrangement on the raster cannot be used to differentiate these two chafer species. The adult stage is necessary to determine the species of the northern and southern masked chafer.

Life stages

Newly laid eggs of the northern masked chafer are similar in appearance to the Japanese beetle egg; however, they remain about 0.067 inch in diameter throughout their development. The mature grub reaches a length of about 1 inch (Fig. 5), and then transforms into a pre-pupa, which is grub-like in appearance. Over time, the pre-pupa changes in color from white to reddish brown. The new reddish brown pupa has well-defined legs, head capsule, and wing pads, which turn dark brown before the adult emerges. The adult is about 0.5 inch in length. It has a black head capsule, and shiny, 'coppery' brown thorax and elytra.

Figure 5. Masked chafer grub.



Green June beetle

Life cycle

The green June beetle deserves special mention because of marked differences in behavioral and physical characteristics. It is the largest white grub (1.6 inches long) of all Virginia species of annual white grubs found in turfgrass, yet has the shortest legs for its size (Fig. 6). Unlike other species of white grubs, which crawl on their front side (ventral) using their three pairs of legs in the process, the green June beetle grub crawls on its back side (dorsal) with its three pairs of legs pointing upward. Also unlike other white grubs, the green June beetle immature stage does not enter into a true hibernation (diapause). In addition to tunneling horizontally like other white grubs, the green June beetle third instar tunnels vertically leaving an opening to the surface. On warm-winter nights, the third instar will come to the surface to feed on well-decayed mulch and vegetation, as well as turfgrass roots. The adults lay an average of 20 eggs at a time in small clusters of soil and bodily secretions. Egglaying occurs over a 2-3 week period starting about mid-July.

Figure 6. Green June Beetle grub.



Life stages

The female lays an average of 20 eggs at a time in small clusters of soil and bodily secretions. The egg is round and varies from translucent to white in color. The grub is similar to other white grubs; however, it differs in that its underside is distinctly flatter. Also, its legs are small for its body size and are no longer used for movement. The backside of the grub is used for locomotion. The third instar grub is about 1.6 inches long and 0.44 inch wide. The pre-pupa is light reddish brown and grub-like in appearance. The pupa is a mix of yellowish tan and brown colors in addition to having well-defined legs, head capsule, and wing pads. The pupa is about 0.5 inch wide and 1.0 inch long. The adult is a somewhat large and showy beetle that is about 0.5 inch wide and just under 1.0 inch long. When viewed from above the color of the adult varies from slightly shiny green to flat green.

Damage

The main food source of the immature stage of the masked chafers, Japanese beetle, and green June beetle, is roots of cool-season turfgrass. However, the masked chafer will feed on organic

debris, and the green June beetle will leave its burrow to feed in well-decayed mulch beds. Also, the third-instar of the green June beetle aggressively makes horizontal and vertical tunnels in the soil. This action loosens the soil, which causes uprooting in the turfgrass. Damage can be especially severe under periods of drought. If unchecked, high numbers of white grubs can kill turfgrass.

Scouting and control

Monitor white grubs by using a flat shovel to remove a one-square foot section of turf several inches deep, then pull apart this section of turf and soil to expose the grubs. Also count the grubs laying on the soil below the removed section of turf. White grub control is largely pesticide based, but there are biological control agents, insect killing fungi, molting mimics, and newer pesticides that are not only highly efficacious, they are extremely safe to humans. Most insecticides provide the best control when used against early instar (smaller) grubs present from early-mid-August. Numbers high enough to warrant treatment are 8-10 grubs per square ft or higher on well-maintained turf, and 4-6 grubs per square ft or higher on unthrifty turfgrass. White grubs stop feeding in late September or October, so control during fall often does not prove successful. Reducing the thatch layer to ≤ 0.5 inch will help increase the penetration of any soil-applied pesticide to turfgrass. Also, avoid soil-applied pesticide applications to waterlogged soil.

Pest Management Guide (PMG)

For the latest information on chemicals, biological, and pest management control options, please consult the Virginia Cooperative Extension PMG web site: Horticultural and Forest Crops: http://pubs.ext.vt.edu/456/456-017/456-017.html

(From the homepage, go to the attachments column on the right-hand side and select: "Turf (full section) (PDF)" or "Turf: Insects (PDF)".

Black Turfgrass Ataenius White Grub

Distribution

. The black turfgrass ataenius (BTA), *Ataenius spretulus* (Haldeman), is native to North America. The BTA is not classified as an annual white grub because it completes 2-3 generations a year in Virginia. However, like the annual white grubs, the BTA is in the same family and mainly feeds on roots of cool season turfgrass. Of all the white grub species that are pests of turfgrass in Virginia, the BTA is the smallest.

Life cycle

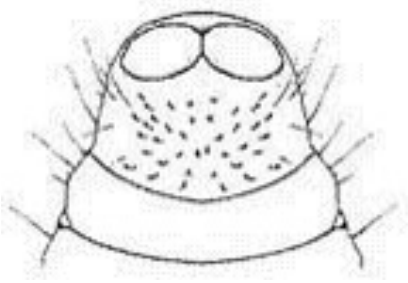
Black turfgrass ataenius completes 2-3 generations per year in Virginia. The adult beetles overwinter in the thatch layer of the rough next to fairways or in wooded lots. The adults become active from mid-April to early May, which coincides with the blooming stages of red

bud and spring crocus. The adults begin laying clusters of 10-15 eggs in shallow soil cavities. These eggs hatch into first generation grubs in May. First generation (new) adults are actively laying eggs in July. Second generation grubs are present from about mid-July to early-August. In the fall, second generation grubs complete development, pupate, then transform into the overwintering adult stage.

Life stages

The mature egg is white, and about 0.02 inch wide and slightly less than 0.03 inch long. The BTA grub resembles other white grubs that infest turfgrass in Virginia. It molts two times producing three instars. The mature third instar is 0.33 inch long. All three instars have a brown to orangish-brown head capsule, which bears chewing mouthparts. Immediately following the head capsule is the thorax, which has three pairs of well-developed, reddish-brown legs. The abdomen is generally grayish white, with a distinct gray area at the end. In addition, there is a pencil thin dark line that runs length-wise down the middle of the grub backside. All three instars exhibit a distinct 'C' shaped aspect that flattens out when crawling. The grub stage can be identified to species by observing the paired, somewhat round structures at the hind end of the abdomen, in front of the anal slit (Fig. 7). When it is time to pupate, the mature third instar stops feeding and moves down in the soil about 0.5-3.0 inches deep. It transforms into a prepupa that is very grub-like in appearance. It then transform into a pupa. The pupa is very light rusty brown with well-defined legs, head capsule, and wing pads visible. The mature pupa is about 0.10 inch wide and 0.20 inch long. The new adult is about the same size as the mature adult (0.09 inch wide by 0.20 inch long). However, the new adult, when viewed from above, has a black head capsule and leg covering followed by light-tan colored elytra that have noticeable, length-wise ridges. The mature adult is entirely shiny black, with similar length-wise ridges on the elytra.

Figure 7. Black turfgrass ataenius.



Damage

Like annual white grubs, the BTA grub is the most damaging stage to turfgrass roots. Thresholds for BTA are not firm, but turfgrass with grub numbers of 20-30 per square foot can show damage, with serious damage reported from ≥ 50 grubs per square foot.

Scouting and control

A springtime application targeting the overwintering adults after they become active (early April), but before peak egg laying has occurred, can provide effective control of not only the adults but, indirectly, the first generation of new grubs. Applications targeting adults should

not be watered in because the adults are in the thatch layer. Also, reducing the thatch layer to ≤ 0.5 inch will help increase the penetration of any soil-applied pesticide to turfgrass. Avoid soil-applied pesticide applications to waterlogged soil. (See PMG for control recommendations).

Annual bluegrass weevil

Order: Coleoptera

Family: Curculionidae

Complete development: egg, larva, pupa, adult

Distribution

The annual bluegrass weevil, *Listronotus maculicolis* (Dietz), (formerly *Hyperodes anthracinus*), is a major pest of annual bluegrass, *Poa annua,* and creeping bentgrass, *Agrostis stolonifera*, and until 2007 was not known to occur in Virginia. In May 2007, damaging infestations of annual bluegrass weevil larvae were found on a golf course in eastern Virginia.

Life cycle

In early spring when *Forsythia* is in full bloom, annual bluegrass weevil adults leave their overwintering sites in pine duff or other types of leaf litter and walk to annual bluegrass-infested bentgrass greens and fairways. The full bloom stage of the flowering dogwood typically marks the end of adult migration. The adults feed in the grass foliage above the thatch and can be easily detected upon close inspection. Two or three eggs are laid within leaf sheaths just above the crown. The life cycle from egg to adult takes about 50-60 days in New England states, but may require fewer days in Virginia. Also, depending on location, annual bluegrass weevil is capable of completing three - four generations per year. In the fall, annual bluegrass weevil adults fly from golf greens and fairways to overwintering sites.

Life stages

The annual bluegrass weevil egg is oblong and pale yellow when first laid, which eventually turns dark gray before hatching. It is about 0.03 inch long by 0.01 inch wide. The larva is legless, has a brown head capsule, creamy white body, and is round at the head end and slightly pointed at the hind end. The larva passes through five instars before pupating. The first instar is about 0.03 inch long, whereas the fifth instar reaches a final length of 0.20 inch. Pupae begin off-white and gradually darken to rusty brown. The pupa width is 0.08 inch with a length of about 0.15 inch. The pupa resembles the adult, having visible legs, snout, and wing pads. The new adult initially is light tan, which, after a few days, becomes mottled reddish-brown in color, and finally grayish-black as the scales wear off. The length of the adult varies from 0.125 –

0.156 inch, and the antennae are elbowed and attached near the tip of the snout where the chewing mouthparts are located.

Damage

Newly hatched larvae feed within the leaf sheath and then move into the crown and roots where the most serious damage occurs (N. Rothwell and P. J. Vittum 2003). High populations of larger larvae (4th and 5th instars) can kill bentgrass greens and fairways, turning them light brown despite adequate moisture.

Scouting and control

Knowing the seasonal development and identity of important life stages is critical to making one or two well-timed applications early rather than six or eight applications from May through August to control overlapping populations of annual bluegrass weevil life stages. The main problem in managing annual bluegrass weevil is not the lack of effective insecticides, but information on insecticide timing. It is critical that spring applications targeting the adult female be timed well before peak egg laying. Reducing the thatch layer to ≤ 0.5 inch will help increase the penetration of any soil-applied pesticide to turfgrass. Also, avoid soil-applied pesticide applications to waterlogged soil. (See PMG for control recommendations).

Billbugs

Order: Coleoptera

Family: Curculionidae

Complete development: egg, larva, pupa, adult

Distribution

Two species of billbug that occur in Virginia are important turf pests. The bluegrass billbug (*Sphenophorus parvulus*) is found in all states within the continental U.S., except California and Nevada, and prefers cool-season grasses, such as bentgrass and Kentucky bluegrass. The hunting billbug (*Sphenophorus venatus vestitus*), one of five subspecies, is found in the southeastern region of the U.S., from Kansas to Washington, D.C. to Florida and west from southern Kansas to eastern Texas. It has also been introduced into Hawaii. In addition to cool-season grasses, the hunting billbug will feed on warm-season grasses, like Bermudagrass and zoysiagrass.

Life cycle

Both billbugs share a similar life cycle. However, one difference in their life cycles is the life stage that overwinters. The bluegrass billbug overwinters in the adult stage, whereas the hunting billbug overwinters as adults and larvae. Also, the bluegrass billbug has one generation per year, while the hunting billbug may have multiple generations in the southern regions of

the U.S. Both species becomes active in late March to early April from overwintering sites in weedy vegetation or debris near the turfgrass host. Their emergence occurs as the soil temperature at a 1-inch depth warms to 67-69° F. Adults feed for a brief period before the females start laying eggs between the leaves and within the stems of the grass. Larvae hatch in about 6 days and begin feeding within the plant stems. Over a period of 35-55 days larvae grow and shed their skins four times, eventually moving down to feed on the crown and roots of the plant. The larvae then pupate within the soil and emerge as new adults after about 10 days.

Life stages

Billbug eggs are small (0.02 inch wide x 0.06 inch long), off-white, and bean shaped. Larvae (Fig. 8) are legless, soft-bodied, and off-white with the exception of hardened head capsules, which turn from yellow to rusty brown as the larvae mature. They range from 0.19-0.25 inch long. Pupae begin off-white and gradually darken to rusty brown, with a length of about 0.33 inch. They somewhat resemble the adult, having visible legs, snout, and wing pads. The bluegrass and hunting billbug adults both have oval-shaped, elongate bodies, long slender snouts, and elbowed antennae, which have clubs on their ends. They differ from each other, however, in size and in the patterns present both behind their heads (the area called the pronotum) and on the wing coverings. Bluegrass billbug adults are smaller (0.25-0.31 inch long), have tiny, uniformly spaced pits on the pronotum, and chain-like markings running along the wing coverings. Hunting billbug adults are 0.25-0.44 inch long and have a pattern on the cover behind the head, that when viewed from above looks like a “V” or “Y” bordered by parentheses. The wing coverings have less-distinct lines running down them. (See PMG for control recommendations).

Figure 8. Bluegrass billbug.



Fall Armyworm

Order: Lepidoptera

Family: Noctuidae

Complete metamorphosis: egg, caterpillar, pupa, adult

Distribution

Fall armyworm (*Spodoptera frugiperda*) originates from the tropical regions of Central America, South America and the West Indies.

The fall armyworm typically overwinters in southern Florida and Gulf coast states, and moves north in spring and early summer. In Virginia, fall armyworm begins its activities in early July, and peaks in the late summer and fall. Although this pest has a wide host range, it prefers to feed on grass including various turf grasses as well as small grain and grass crops. Susceptible turfgrass species include both warm-season grasses (Bermudagrass, St. Augustine grass) and cool-season grasses (bluegrass, ryegrass, fescue and bentgrass).

Life cycle

Fall armyworm has 2-3 generations per year in Virginia, depending on temperature and region in the state. Moths reach Virginia in early July, and lay eggs on light-colored surfaces. Females may lay up to 1000 eggs in masses of 50 to several hundred over their lifetime. The eggs hatch within 2-10 days. Newly hatched larvae feed on the remains of the eggshells, and then drop down to the turfgrass on silken threads. The larvae may feed at any time of the day, but the most intensive feeding occurs in the evening continuing on into the early morning hours. During the following 2-3 weeks, the larvae develop through six instars, and then burrow about 0.8 inch into the soil to pupate. The adults emerge from the pupae after 10-14 days. After completing 1-2 more generations the moths fly south to overwinter.

Life stages (Fig. 9)

Fall armyworm eggs are small, circular-shaped, and about 0.03 inch wide. Freshly laid eggs are greenish white, but darken to nearly black prior to hatching. The eggs are laid in clusters covered with hair-like scales from the abdomen of the moth. The larvae have a variety of colors, ranging from light tan or green to brown to nearly black. They have an inverted "Y" marked prominently on the front of the head, and have three light stripes running throughout the body length, with four dark spots on the dorsal side of each abdominal segment. Fully grown larvae are about 1.5 inches long. Fall armyworm pupae are about 0.5 inch long, reddish-brown initially, that darkens to almost black before adult emergence. Moths have a wingspan of about 1.5 inches. The forewings are dark gray, and mottled with lighter and darker markings. In addition, there is a whitish blotch at the tip and near the center of each forewing. The markings on the forewings are more distinct in males.

Figure 9. Fall armyworm egg mass, larva, 'Y' pattern on head of larva, adult






Damage

Fall armyworm larvae feed on the foliage of grasses, and move as a group. Damage often starts on a turfgrass border, and is usually is associated with lush, green, well-fertilized and irrigated grasses. The moths are attracted to lights to lay eggs, and an infestation may start nearby. The smaller larvae feed on the tender tissues of turfgrass leaves and generally are not as serious as the more mature larvae, which consume most or all of the foliage. Early damage appears as the discoloration of the grass blades. If untreated, however, the turfgrass becomes defoliated and turns brown in heavily infested areas. Bermudagrass might recover from fall armyworm feeding early in the season, but would suffer from winterkill if feeding occurs late in the fall. For cool season grasses, damage caused by high infestations can kill the turfgrass, especially if the growing tips are fed on.

Scouting and control

Special attention should be paid to the newly seeded sod and sprigged turfgrass areas, which are generally more susceptible to fall armyworm damage. Grayish, discolored turfgrass may indicate a fall armyworm infestation. Careful examination and scouting are often necessary to determine the pest status. A detergent-water drench is used to reveal fall armyworm, sod webworm, and cutworm larvae.

Mix 3-4 tablespoons of dishwashing liquid in 2 gallons of water. Pour evenly over 1 square yard of turf. Watch the area for 10 minutes, counting the caterpillars as they rise to the surface. Treatments might be required to prevent further damage if the sampled numbers exceed 6-8 fall armyworm larvae per square yard. If using entomopathogenic (i.e., insect killing) nematodes, apply late in the day and water before and after application. Plant endophyte enhanced fescue and ryegrass. Turfgrass ≥ 2.5 inches in height requires less treatment for armyworms. (See PMG for control recommendations).

Sod webworm

Order: Lepidoptera

Family: Crambidae

Complete development: egg, caterpillar, pupa, adult

Distribution

Sod webworm is often called "lawn moth". It typically feed on cool season grasses, e.g., bluegrass, fine fescue, perennial ryegrass and bentgrass. Plant injury results from larvae chewing the turfgrass blades.. Early damage appears as a general thinning of the turfgrass, but irregular brown patches are observed if the damage is severe. In Virginia, there are about 14 species of sod webworms, and most of them are native to North America. Among these species, bluegrass webworm, *Parapediasia teterrella* (Zincken), has the most abundant distribution. It will serve as the model for further discussion on the life cycle, life stages and control strategies in Virginia.

Life cycle

The life cycle varies with species. Sod webworms are either single generation or have many generations. Bluegrass webworm has two generations per year, and the summer generation of larval feeding causes the most damage in Virginia. Like most sod webworms, bluegrass webworm overwinters in the soil as nearly full-grown larvae. When temperatures rise in the spring, the caterpillars resume feeding for a short period and then pupate in a silken cocoon in the thatch in late May-early June. The pupae emerge into adults within 1-2 weeks. During the day, adult moths are relatively inactive and hidden in sheltered areas, but start to fly over the turfgrass at dusk. The adults mate within 2-3 days after emergence, and lay eggs in about 2 weeks. The female moth randomly drops her eggs onto the turfgrass. Female moths of *P. teterrella* may produce up to 200 eggs in their lifetime. Egg incubation takes about a week. Bluegrass webworm has about 7 larval instars, which feed from July to early August to complete their development. Like the adult moths, the caterpillar activities are nocturnal. They feed on turfgrass blades and shoots during the night, and retreat into silken tunnels during the day. Adults of the second generation appear in late July through August. Eggs are laid, and then hatch into caterpillars, which feed through late September and then overwinter.

Figure 10. Sod web worm.



Life stages

Figure 11. Adult sod webworm moth.



Sod webworm eggs are oval to elliptical shaped, and have distinct longitudinal ridges. The freshly laid eggs are opaque white, and gradually turn yellow, then brown, then orange before hatching. The caterpillars have a brown head and dark, circular spots and coarse hairs scattered over the body. The body varies from green or gray to beige or brown (Fig. 10). A distinctive character of the caterpillar is that they curl into a ball when disturbed. Fully-grown larvae are about 0.75 inch long. The newly formed pupae are about 0.5 inch long, pale yellow colored, and turn brown before emerging into adults. Adult moths of sod webworm are easily recognized by the snout-like projections arising from the front of the head, and their wings, which fold above the body at rest. Bluegrass webworm moths are relatively small, being about 0.5 inch long with a wingspan of 0.75-1 inch. Their front wings are generally whitish, dull gray to brown, with stripes running from the base to the margin, and their hind wings are mostly white or grayish (Fig. 11). The moths are usually noticed flying a few feet above the turfgrass. They fly in a jerky, zigzag pattern dropping eggs as they fly. If disturbed, they will hide in the turfgrass.

Figure 12. Sod webworm damage.



Damage

Sod webworm damage in turfgrass is most noticeable under high-maintenance conditions where turfgrass is kept short. Initial damage symptoms are brown patches of turfgrass about 5-6 inches in diameter (Fig. 12). Upon close inspection, one notices the leaves have been chewed back. If unchecked, the brown patches will increase in size and eventually kill the turfgrass.

Scouting and control

Careful examination of the turfgrass is often necessary to determine pest status. If numbers are high, a urine odor may be detected. A detergent-water drench (see fall armyworm section above) can be used to monitor sod webworm larvae. Densities of 15 per square yard warrant treatment. Young larvae, which are most susceptible to treatment, can be expected in turfgrass about 2 weeks after adults are present; usually late June and again in early September. Spring and early summer treatments may be effective against the larvae that have overwintered. Do not mow for 1-3 days after treatment. Also, plant endophyte enhanced

fescue and ryegrass. If using entomopathogenic (insect killing) nematodes, apply late in the day and water before and after application. Damage is seldom noticed in turfgrass ≥ 2.5 inches in height. (See PMG for control recommendations).

Black cutworm, *Agrotis ipsilon (Hufnagel)*

Order: Lepidoptera

Family: Noctuidae

Complete development: egg, larva, pupa, adult

Distribution

The distribution of the black cutworm is worldwide. Cutworms are medium-size, stout-bodied moths, many of which are important pests of turfgrass in Virginia. The moths are nocturnal and can be observed flying around porch lights in the evening during the spring and summer months. Several of the more important species common to Virginia are the black cutworm, *Agrotis ipsilon* (Hufnagel), granulate cutworm, *Agrotis subterranean* (Fabricius), variegated cutworm, *Peridroma saucia* (Hubner), and bronzed cutworm, *Nephelodes minians* Guenee. The black cutworm will be the subject of further discussion.

Life cycle

The black cutworm completes 3-4 generations per year in Virginia beginning in April and ending in November. They typically overwinter as pupae in the gulf coast states, with new moths flying northward each spring. They are strong fliers and are capable of laying from 1200-1500 eggs over a 5-10 day period. The moths prefer to lay eggs in the taller grass next to golf greens. Upon hatching, the young larvae crawl to nearby greens and feed throughout the night. The 4th and 5th instars are the most active and cause the most damage to turfgrass (Fig. 13)..

Figure 13. Black cutworm adult, eggs, and larva in turf.



Life stages

The black cutworm egg is about 0.02 inch wide and 0.017 inch in height. It is white when first laid, smooth and mostly round except for a small flat area on the side that contacts the surface.

Over time, the egg darkens and is nearly black prior to hatching. The black cutworm larva has few hairs and is dark gray and greasy looking in appearance. A fully mature larva grows to about 1.5 inches in length. The larva undergoes 5 molts, producing 6 instars. The final instar serves as the non-feeding pre-pupa stage. The mature pupa, which has been described as resembling a torpedo, is dark, reddish brown in color. The length of a black cutworm pupa varies from 0.5 to 1.0 inch. Cutworm adults are generally drab in appearance. The body and wings lack prominent coloration; however, the forewings do have distinguishing marks, which can be useful in separating one species from another. Wingspan varies from 1.0 t- 2.0 inches. The moth body from the front of the head to the tip of abdomen varies from 0.5-1.0 inch in length.

Damage

Cutworm larvae are semi-subterranean and can be very damaging to golf greens and athletic fields. The name 'cutworm' reflects the larval habit of cleanly severing plant matter. The cut plant material may be pulled into a burrow or aeration hole to feed on during the day. The larva remains in its burrow during the day and only emerges to feed openly after dark.

Scouting and control

Cutworm numbers of 3-8 worms per square yard may warrant treatment. To sample for cutworms, use a detergent drench flushing technique (see fall armyworm section above). Most insecticides used for cutworms are stomach poisons. Because the larvae feed at night, apply insecticides in the early evening for best results. Unless specified on the label, do not water or mow for 24 hours after treating. Cutworms are highly mobile, so treated areas are likely to become re-infested from surrounding areas. Plant endophyte enhanced fescue and ryegrass. Turfgrass ≥ 2.5 inches in height requires less treatment for cutworms. Cutworm populations can be reduced if turfgrass clippings are removed during mowing because cutworm moths lay their eggs at the tip of turfgrass blades. If using entomopathogenic (i.e., insect killing) nematodes, apply late in the day and water before and after application. (See PMG for control recommendations).

Hairy chinch bug

Order: Hemiptera

Family: Lygaeidae

Incomplete development: egg, nymph, adult

Distribution

Chinch bugs have piercing-sucking mouthparts and suck sap from stems and crowns of grass. Chinch bugs commonly found in North America belong to the *Blissus leucopterus* complex. The

Blissus leucopterus complex consists of three species: the hairy chinch bug, *B. leucopterus hirtus*, the common chinch bug, *B. leucopterus leucopterus*, and the southern chinch bug, *B. insularis*. Among them, the hairy chinch bug and the common chinch bug are known to occur in Virginia. The common chinch bug feeds on several species of turfgrass from both cool-season to warm-season turfgrass. However, Kentucky bluegrass and bermudagrass are not the preferred hosts of the common chinch bug. The common chinch bug is generally not considered as significant a pest as the hairy chinch bug. The hairy chinch bug can be a serious pest of zoysiagrass and cool-season turfgrass including perennial ryegrass, Kentucky bluegrass, bentgrass and red fescue. The hairy chinch bug will be used for all further discussion on describing the life cycle, life stages, damage, and scouting and control options.

Life cycle

The hairy chinch bug has 2 generations per year in Virginia, and overwinters as an adult in pine bark mulch or other types of leaf litter. When the temperature reaches 44.6 °F in the spring, adults emerge from their overwintering sites to feed and mate over a two-week period, after which egg laying begins. The female lays about 20 eggs per day over a 2- 3-week period. Eggs are laid either in leaf sheaths or on roots of host turfgrass. The nymphs start feeding upon hatching. Egg hatch takes up to 4 weeks in spring and 1 week in summer, depending on the temperature. The nymphs develop through 5 instars, which takes 4-6 weeks in summer. The most active time for the fifth instar occurs from early to mid-July. Then, new adults mate and females begin laying eggs from mid-July to late-August. Eggs hatch into second generation nymphs, which develop into adults from late summer to early fall. These adults search for suitable sites to overwinter.

Life stages

Figure 14. The stages of incomplete metamorphosis of the Chinch bug.



Hairy chinch bug eggs are elongated with a length of less than 0.04 inch (Fig. 14). Newly laid eggs are white in color, then become yellow to bright orange before hatching into nymphs. The hairy chinch bug nymphs pass through distinct color changes during development. First and second instars are bright red, with the first two abdominal segments marked with a distinct white band. The third instar is orange and it is this stage when wing pads first appear. The fourth

instar darkens to orange brown, with the wing pads extending over the first abdominal segment. Fifth instars are black and closely resemble adults except for the wing pads, which extend to the second abdominal segment. During the development of 5 instars, the nymphs grow from 0.009-0.038 inch in width, and from 0.035-0.117 inch in length. The adult is slightly larger than the fifth-instar, with a width of 0.04 inch and a length of 0.12-0.14 inch. Female adults typically are larger in size than males. There are two adult forms of the hairy chinch bug, a short-winged type, and a long-winged type that flies. Typical characteristics of the adult include) a black body, red to yellowish red legs, and shiny white wings with a conspicuous black spot on each forewing.

Damage

The hairy chinch bug usually occurs in turfgrass grown in sunny areas with heavy thatch buildup and droughty conditions. Injury is caused by the aggregative feeding of adults and nymphs that suck sap from stems and crowns of grass. Initial damage appears as a small yellowish patch in turfgrass, the center of which is turning brown. This damage can resemble drought stress or sunscald. If not controlled, these patches will increase in size eventually killing the turfgrass.

Scouting and control

Chinch bugs are rarely a problem in turfgrass that is maintained with appropriate levels of water and nutrients. Chinch bugs may be sampled by floatation. Drive an approximate 4-inch diameter cylinder with open ends on both sides into the turfgrass. Then pour in water at a rate that maintains the water level in the cylinder about 1 inch above the turfgrass for 5-10 minutes. Chinch bugs will float to the surface where they can be easily counted. Insecticide treatment is often effective, but because chinch bugs are highly mobile, the area may be quickly re-colonized. Therefore, an application in April or May followed by 1 to 2 additional applications at 2-3-week intervals are recommended for the first generation. Significant damage can be caused if chinch bug numbers reach 15-20 nymphs per square foot. Also, plant endophyte enhanced fescue and ryegrass, reduce the use of fine-red fescue in sunny areas, reduce the thatch layer, and for spring fertilization, avoid using a high nitrogen content. (See PMG for control recommendations).

Northern mole cricket *(Neocurtilla hexadactyla)*

Order: Orthoptera

Family: Gryllotalpidae

Incomplete development: egg, nymph, adult

Distribution

The northern mole cricket (Fig. 15) is native to the US and can be found from New England to Florida and west to the Great Plains. This species prefers moist, but unsaturated, soil with abundant organic material on which to feed. The soil must also be of appropriate texture for burrowing. Three introduced species of mole cricket (the tawny, southern, and short-winged mole crickets) are destructive turfgrass pests in the south; however, the northern mole cricket prefers sandy soils, such as are found in the eastern region of Virginia.

Figure 15. Mole cricket. Note the massive front legs used for digging on the mole cricket.



Life cycle

The northern mole cricket takes 2 years to develop from egg to adult in Virginia, and both the adult and nymph are present year-round as generations overlap. In late May through June, the second-year female lays a single clutch of approximately 30–60 eggs in an underground burrow, and may remain with the egg clutch. First-year nymphs emerge from mid-June to July, overwinter in the nymphal stage, and molt 8–10 times before reaching adulthood the following summer. Second-year crickets mate in the fall, marked by the mate-calling of males from mid-summer to late fall, and overwinter as adults. Eggs develop within the female in the spring, and the cycle is repeated.

Life stages

As the name suggests, mole crickets superficially resemble their mammalian counterparts and are well-suited for their subterranean lifestyle. Northern mole cricket adults have cigar-shaped, 1.25–1.375-inch long bodies, with a slight narrowing of the waist between the thorax and abdomen. They are winged, dark brown and have a long pair of cerci (tails). Their front legs are short, stout, and shovel-like, ideal for digging. The nymphs look like smaller, wingless adults.

Damage

The northern mole cricket is a sporadic pest of turfgrass grown on sandy soil. It feeds on earthworms, roots, and insect larvae. However, the main damage to turfgrass is caused from horizontal burrowing, which leads to uprooting the grass and hastening the desiccation process. Adult control is difficult to achieve in the spring as areas may be continually infested by the

flying adults. Areas that experience heavy adult pressure in the spring may warrant treating with maximum labeled rates and additional applications immediately prior to peak egg hatch.

Scouting and control

Summer treatments targeting the first-year mole cricket nymphs are usually more effective in knocking down populations. The smaller size of the young nymphs (relative to the adults) makes them much more susceptible to insecticides. In addition, given that the nymphs must actively feed close to the surface to grow and develop, their exposure time to the insecticide is greatly increased. As soils dry out, mole cricket nymphs and adults will burrow down into the soil profile to remain in contact with moist soil. If the soil is dry at the time of application, it must receive enough water before treatment to provide favorable conditions to drive the nymphs and adults to the surface. (See PMG for control recommendations).

Types of insecticides registered for use on turfgrass

A wide range of insecticides are registered for use on turfgrass. Many of them are nerve toxins, which have broad spectrum of activity on most insects and also have activity on vertebrates at higher concentrations. These include organophosphates, carbamates, and pyrethroids.

Organophosphates (OPs), which include insecticides like chlorpyrifos (Dursban), acephate (Orthene), trichlorfon (Dylox), diazinon, and the nematicide fenamiphos (Nemacur) are one of the older classes of insecticides. They inhibit the enzyme acetylcholinesterase (AChE), which causes accumulation of acetylcholine at neuromuscular junctions causing rapid twitching of voluntary muscles and eventually paralysis. These insecticides have a broad-spectrum of activity, and are generally the most toxic of all pesticides to vertebrates.

Carbamates, which include carbaryl (Sevin), methomyl (Lannate), and carbofuran (Furadan) have a similar mode of action as organophosphates, except that the inhibition of AChE is reversible. They are broad spectrum in their activity. Some carbamates such as carbofuran can be quite toxic to vertebrates.

Pyrethroids, which include bifenthrin (Talstar) and lambda-cyhalothrin (Scimitar) act by keeping open the sodium channels in nerve membranes leading to a hyper-excitable state causing such symptoms as tremors, incoordination, hyperactivity and paralysis. They are active on a wide range of insects, and are extremely toxic to fish.

Other types (or classes) of insecticides have a more narrow spectrum of activity, typically making them safer for the applicator and integrated pest management programs because they are less disruptive to natural enemies and other beneficial insects.

Neonicotinoids, which include imidacloprid (Merit), thiamethoxam (Meridian), clothianidin (Arena), and dinotefuran (Safari) act on the central nervous system causing irreversible blockage of the postsynaptic nicotinergic acetylcholine receptors. They are effective on a wide range of beetles (and their larvae) and sucking insects, and have generally low toxicity to mammals, birds and fish.

Spinosyns including spinosad (Conserve) act by disrupting binding of acetylcholine in nicotinic acetylcholine receptors at the postsynaptic cell. They are derived from a soil actinomycete and are particularly effective against lepidopteran, coleopteran, and thrips pests.

Indoxacarb, the active ingredient in the ant and cricket bait Advion, blocks the sodium channels on nerve membranes.

Chlorantraniliprole, the active ingredient in Acelepryn, belongs to the novel group of insecticides called anthranilic diamides. These insecticides act on the ryanodine receptor on muscles disrupting muscular contraction. They are extremely safe for mammals, pollinators, and natural enemies. They are highly toxic to white grubs and lepidopteran larvae.

Several **biorational and biological insecticides** are also registered on turfgrass including insect growth regulators (IGR) such as halofenozide (Natural Guard Grub Control), which inhibit insect molting, bacterial spores such as *Bacillus popillae*, which are specific on Japanese beetle grubs, entomopathogenic nematodes, and entomopathogenic fungi such as *Metarhizium anisopliae*.

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Chapter 10. Weed Management in Turfgrass

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Overview:

The key to successful weed management in turfgrass systems is to remember that healthy turfgrass kills more weeds on your property than weed management inputs. The first step in any turfgrass weed management program is to identify the problem that is limiting growth, density, and competition of the desirable turfgrass. By following the steps in Table 1 in order, one can eliminate a weed problem from turf and keep the weeds from returning. By way of outcompeting seedling weeds for light, water, nutrients, etc., a high quality lawn grass will kill seedling weeds and prevent establishment of large weed stands that tend to decrease turf aesthetics. Simply killing weeds is not enough. Without a healthy turf, weeds will continually return and invade the area. High quality turfgrass areas do not happen by accident. Quality turf depends on many factors such as soil type, turfgrass variety, fertilization, irrigation, mowing, and pest management. The most important of these is good soil. As soil quality increases, the number of inputs required for a quality turf (fertilizers, water, and pesticides) decrease. So improving poor soils is among the most important factors to increase turf quality and achieve maximum weed prevention from the turfgrass. Your weed management program should start with a soil test; conduct these tests every 3 to 4 years to ensure that soil pH and nutrient levels can provide for optimum turfgrass growth.

Table 1. Four steps to successful turfgrass weed management.

Step 1	Identify the source of poor turfgrass growth or canopy loss
Step 2	Identify the weed species
Step 3	Control the weed
Step 4	Fix the problem that is limiting turfgrass competition

Turf aesthetic value is in the eye of the beholder. Wild plants that would be appreciated by one person will be considered weeds by another. Some weeds may only be visible above the turf canopy for a few weeks each year while others will persist and even expand their population. So, the next step to turfgrass weed management is to identify the suspect weed. After knowing a little about the weed life cycle (when it emerges, when it flowers, how long it will live, etc.), an intelligent decision can be made regarding inputs to fix the problem now and in the future.

General Cultural Controls:

Since healthy turfgrass is the most powerful weed prevention available, practices that promote turfgrass health are required for successful weed management in turf. In fact, most weed problems in Virginia lawns can be attributed to a single mistake made by most homeowners: mowing the lawn too short. No other cultural input for turfgrass exceeds the effort given to mowing, so mowing correctly is critical for optimal turfgrass health and performance. Most lawns in Virginia are tall fescue or other cool-season grasses like Kentucky bluegrass, perennial ryegrass, and fine-leaf fescues. Optimal mowing heights for these grasses vary somewhat depending on the species but a minimum of 3 inches is a good rule of thumb for most situations. If you are growing cool-season grasses in the warmer climates of Virginia, the single most important thing you can do to promote a higher quality lawn is to raise your cutting height to 3-4 inches in mid-late spring, prior to the onset of summer stress periods. This promotes a deeper root system and provides more leaf canopy to conduct photosynthesis (i.e. make food). If the recreation or functional use of your turfgrass requires lower mowing heights, accept the fact that your turf will requires more water, pesticide, and fertilizer to maintain health and prevent weeds. Follow the turfgrass management practices outlined elsewhere in this publication to avoid a slow conversion from turfgrass to weeds in your managed area. The information in table 2 details the most important steps in delivering a healthy turf that resists weed invasion.

Table 2. Cultural practices that promote turfgrass ability to suppress weeds or prevent weed introduction and expansion in cool-season and warm-season turf.

Cultural practice*	**Cool-season lawns (tall fescue, Kentucky bluegrass, perennial ryegrass, fine-leaf fescues, etc)**	**Warm-season lawns (bermudagrass, zoysiagrass, centipedegrass, St. Augustinegrass)**
Mow height	Mow tall fescue at 3 to 4 inch, others at 2.5 to 3.5 inch.	Mow St. Augustinegrass at 3 to 4 inches, others at 1 to 2 inches
Mow frequency	Follow "one-third rule", mow every 4 to 5 days in spring and fall and 7 to 10 days in summer.	Follow "one-third rule", mow every 4 to 5 days in summer and 7 to 10 days in spring and fall.
Mower	Keep blades sharp; blades should be sharpened every 4-6 weeks during the mowing season. Zoysiagrass and tall fescue turfs require more frequent sharpening than others.	
Soil	Conduct periodic soil tests (every 3-4 years) and improve poor soils by adding compost or topsoil, core aeration, adjusting pH to 6.3 to 6.8	
Fertility	Depending on the grass, an annual amount of 2 to 3 lbs nitrogen per thousand sq ft is applied, mostly in the fall. Do not	Depending on the grass, an annual amount of 1 to 4 lbs nitrogen per thousand sq ft is applied, primarily in late spring

	apply more than 1 lb of water soluble N in a single application. Excessive spring N applications reduce summer stress tolerance and can increase weed and disease pressure. Apply phosphorus (P)and potassium (K) as indicated by soil test results. Avoid applying P & K when weeds are expected to germinate.	thru mid-summer. Do not apply more than 1 lb of water soluble N in a single application. Apply phosphorus (P) and potassium (K) as indicated by soil test results.
Irrigation	If supplemental irrigation is available and/or desired, irrigate deeply and frequently, providing at least 1 in. of water per week (including rainfall) during summer stress periods. . Irrigate in early morning hours in order to minimize leaf wetness periods (i.e. reduce disease pressure) and avoid supplemental irrigation during periods when weeds are expected to germinate. If no irrigation is available, allow lawn to go dormant during drought	
Clipping management	Return clippings as they essentially serve as 'slow release fertilizer' to your lawn, providing up to one-third of its annual nutrient needs. Do not worry about returning weed seed in clippings to the lawn as indigenous seed in the soil far outnumber weed seeds deposited by mowing. .If clippings are removed, use the higher range of recommended fertility programs. Compost collected clippings with other lawn and garden debris and return the compost to the lawn in order to improve soil tilth.	
Variety selection	Choose adapted varieties, refer to www.ext.vt.edu and search "recommended list" for latest variety suggestions. Change turfgrass species or variety in different environments such as shade.	
Aeration	Test soil one day after rain by inserting a knife or screwdriver. If difficult to insert, that area of lawn needs aeration. Aerate cool-season lawns in spring and/or fall. Aerate warm-season lawns in summer.	
Exclusion	Prevent weeds from entering new areas. Inspect soil, manure, or any organic additives for invasive weeds. Target creeping weeds outside the lawn or develop strategies that limit invasion into the lawn. Use only certified grass seed that is free of weed seed.	
Improve conditions	Fix drainage problems, trim low tree limbs, try to increase light quantity and wind movement where turfgrass is growing.	
Choose sites	Don't grow turfgrass in an area where it is not adapted. Deep shade or extremely poor soils are best suited to an inorganic mulch or plant species commonly used as ground covers that are better adapted to the environment.	
*There are numerous Virginia Cooperative Extension publications that provide extensive detail in overall lawn care best management practices available at www.ext.vt.edu.		

The Most Common Weeds

About 90 plant species account for over 95% of the weeds encountered in Virginia turfgrass. To indentify these weeds, one must learn to recognize characteristics such as ligule and vernation for grasses and leaf arrangement and leaf type for broadleaf weeds. These characteristics are described in Table 3. Tables 4 and 5 show descriptive characteristics for broadleaf and grassy weeds, respectively. In order to use these tables effectively, one must understand how to locate and differentiate the identification characters.

Table 3. Characteristics that aid in identifying common broadleaf and grassy weeds of turfgrass.

Term	Definition
Life cycle	Perennial (P) and biennial (B) plants will typically have underground storage structures such as taproots, rhizomes, tubers, or bulbs and often sprout and grow more quickly than annual plants in early season. Winter annuals (WA) germinate in fall and will mature in spring, while summer annuals (SA) germinate in spring and mature in fall.
Cotyledon	The first leaf of a plant, often called the seed leaf, is a cotyledon. They will have consistent shapes that can aid in plant identification; especially young seedlings. After a plant reaches the 2 to 4 leaf stage, cotyledons often fall off. Grass cotyledons are separated based on relative length to width and overall size. It is important to note that all cotyledons increase in size as the plant ages so one must consider the number of true leaves on the plant when assessing cotyledon size.  **Short Fat** Large crabgrass **Short Thin** Smooth crabgrass **Long Thin** Dallisgrass

	 **Oval** Black medic **Oblong** Common purslane **Round** Field bindweed **Lance** Smooth pigweed  **Needle** Buckhorn plantain **Spoon** Mouseear chickweed **Spatula** Persian speedwell **Heart/Kidney** Wild mustard
Habit	The canopy architecture of a weed can be an identification clue. By knowing a plant is a vine, one can quickly limit the number of species under evaluation.  **Prostrate** Prostrate knotweed **Upright** American burnweed **Vine** Field bindweed
Leaf type	Different plants create different forms of leaves. The leaf type is often consistent regardless of environment but some species have multiple leaf types depending on maturity level.  **Palmate** Virginia creeper **Pinnate** Longstalk phyllanthus **Trifoliate** White clover **Simple** Broadleaf plantain

Leaf arrangement	Leaves can be arranged opposite one another along the stem (opposite), alternate to one another along the stem (alternate), or in a whorl of several leaves that wrap around the stem (whorled). Some plants also create a rosette of basal leaves when growing in the vegetative stage. The rosette leaves may completely die and decay once the plant starts to bloom. Leaf arrangement is usually consistent between individuals.  **Alternate** Virginia creeper **Opposite** Mouseear chickweed **Worled** Catchweed bedstraw **Rosette** Prickly lettuce
Leaf shape	The shape of a given plants leaves is not always a reliable identification characteristic. Although some species have leaf shapes that are consistent between individuals others may have extremely variable leaf shapes from one individual to the next.  **Oval** Common chickweed **Heart Shape** Persian speedwell **Lance Shaped** Horseweed **Needle** Field horsetail  **Dissected** Mugwort

Leaf margin	The edge or margin of the leaf can sometimes aid in plant identification but like leaf shape, the margins can sometimes vary between individuals or between leaves on different parts of the plant.  **Entire** Common chickweed **Serrate** American burnweed **Lobed** Ground ivy
Stem	The central trunk from which all branches or leaves arise can be square, round, or round with edges. These stem shapes are usually consistent between individuals and a good identification character.  **Round** Persian speedwell **Square** Henbit

Flower	Flower shapes have two primary categories. A symmetrical flower will yield two identical sides if cut through the face in any direction. A nonsymmetrical flower will have at least one direction where cut pieces are not identical.  **Symmetrical** Common chickweed  **Nonsymmetrical** Henbit
Roots	Roots can indicate if a plant is an annual or perennial due to presence of perennial structures like rhizomes, taproots, bulbs, nutlets, and corms.  **Fibrous** Path rush  **Tap root** Poison hemlock  **Rhizome** Dallisgrass
Ligule	A thin outgrowth at the junction of leaf and leaf stalk of many grasses. The ligule is consistent between individuals of a species regardless of environment.  **Membrane** Dallisgrass  **Hairy** Southern Sandbur  **None** Barnyardgrass

Vernation	Arrangement of grass leaves in the bud. As the newest leaf unfolds, one can determine vernation as rolled or folded. Vernation is consistent between leaves on a plant and between multiple plants within a species.  **Rolled** Johnsongrass **Folded** Annual bluegrass
Auricle	An ear-shaped appendage found on grasses where the leaf connects to the stem.  **Auricles on Quackgrass**

Leaf hair	In grasses, the amount of hair on the leaf and its type and location can be a helpful identification character. Unfortunately, leaf hair is environment dependent and should be used as one of several characters for identification purposes.  **Entire Leaf Hairy** Large crabgrass **Entire Leaf Smooth** Fall panicum **Part of Leaf hairy** Yellow foxtail
Seedhead	Grasses make distinct seedheads in most cases. When seedheads are available, identification is usually easier.  **Spike** Nimblewill **Raceme** Goosegrass **Panicle** Johnsongrass

Table 4. Descriptive characteristics of the most common broadleaf weeds of turfgrass in Virginia.

Common name	Scientific name	Life cycle	Cotyledon	Broadleaf Habit	Leaf Type	Leaf Arrangement	Leaf Shape	Leaf Margin	Stem	Flower	Roots
Virginia creeper	*Parthenocissus quinquefolia*	P	Lance	Vine	Palmate	Alternate	Lance	Serrate	Round	Symmetrical	Rhizome
flexuous bittercress	*Cardamine flexuosa*	WA	Round	Upright	Pinnate	Rosette/ Alternate	Oval	Entire	Round	Symmetrical	Taproot
longstalked phyllanthus	*Phyllanthus tenellus*	SA	Oval	Upright	Pinnate	Alternate	Oval	Entire	Round	Symmetrical	Fibrous
trailing crownvetch	*Coronilla varia*	P	Spoon	Vine	Pinnate	Alternate	Oval	Entire	Square	Nonsymmetrical	Fibrous
mulberryweed	*Fatoua villosa*	SA	Round	Upright	Simple	Alternate	Heart	Serrate	Round	Symmetrical	Fibrous
common mallow	*Malva neglecta*	SA	Heart	Upright	Simple	Alternate	Heart	Serrate	Round	Symmetrical	Fibrous
bull thistle (mature)	*Cirsium vulgare*	B	Oval	Upright	Simple	Rosette/ Alternate	Dissected	Entire	Round	Symmetrical	Taproot
bull thistle (young)	*Cirsium vulgare*	B	Oval	Prostrate	Simple	Rosette/ Alternate	Lance	Entire	Round	Symmetrical	Taproot
field bindweed	*Convolvulus arvensis*	P	Round	Vine	Simple	Alternate	Lance	Entire	Round	Symmetrical	Fibrous
common pokeweed	*Phytolacca americana*	P	Lance	Upright	Simple	Alternate	Lance	Entire	Round	Symmetrical	Taproot
wild mustard	*Sinapis arvensis*	WA	Heart	Upright	Simple	Alternate	Lance	lobed	Round	Symmetrical	Taproot
horsenettle	*Solanum carolinense*	P	Lance	Upright	Simple	Alternate	Lance	Lobed	Round	Symmetrical	Rhizome
common lambsquarters	*Chenopodium album*	SA	Oblong	Upright	Simple	Alternate	Lance	Serrate	Round	Nonsymmetrical	Fibrous
Canada thistle	*Cirsium canadense*	P	Oval	Upright	Simple	Alternate	Lance	Serrate	Round	Symmetrical	Rhizome
horseweed	*Conyza canadensis*	SA	Oval	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Fibrous
American burnweed	*Erechtites hieracifolia*	SA	Spoon	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Fibrous
prickly lettuce	*Lactuca serriola*	SA	Spoon	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Fibrous
common groundsel	*Scenecio vulgaris*	WA	Lance	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Fibrous
dandelion (young)	*Taraxacum officinale*	P	Spoon	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Taproot
dandelion (mature)	*Taraxacum officinale*	P	Spoon	Upright	Simple	Rosette/ Alternate	Dissected	Entire	Round	Symmetrical	Taproot
Asiatic hawksbeard	*Youngia japonica*	SA	Heart	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round	Symmetrical	Fibrous
lawn burweed	*Soliva sessilis*	SA	Oval	Prostrate	Simple	Alternate	Dissected	Entire	Round	Symmetrical	Fibrous

Carolina geranium	*Geranium carolinianum*	B	Heart	Upright	Simple	Alternate	Dissected	lobed	Round	Symmetrical	Fibrous
mugwort	*Artemisia vulgaris*	P	Spoon	Upright	Simple	Alternate	Dissected	Serrate	Round	Nonsymmetrical	Rhizome
wild carrot	*Daucus carota*	B	Needle	Upright	Simple	Alternate	Dissected	Serrate	Round	Symmetrical	Taproot
smooth pigweed	*Amaranthus hybridus*	SA	Lance	Upright	Simple	Alternate	Oval	Entire	Round	Nonsymmetrical	Fibrous
prostrate knotweed	*Polygonum aviculare*	SA	Oblong	Prostrate	Simple	Alternate	Oval	Entire	Round	Symmetrical	Fibrous
parsley-piert	*Aphanes arvensis*	WA	Oval	Prostrate	Simple	Alternate	Oval	lobed	Round	Symmetrical	Fibrous
rough fleabane	*Erigeron strigosus*	WA	Oval	Upright	Simple	Alternate	Lance	Entire	Round W/ Edges	Symmetrical	Fibrous
perennial sowthistle	*Sonchus arvensis*	P	Oval	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round W/ Edges	Symmetrical	Taproot
spiny sowthistle	*Sonchus asper*	SA	Spoon	Upright	Simple	Rosette/ Alternate	Lance	Serrate	Round W/ Edges	Symmetrical	Fibrous
broadleaf dock	*Rumex obtusifolius*	P	Lance	Upright	Simple	Rosette/ Alternate	Heart	Lobed	Square	Symmetrical	Taproot
wild violet	*Viola sororia*	P	Oval	Prostrate	Simple	Alternate	Heart	lobed	Square	Nonsymmetrical	Rhizome
yellow woodsorrel	*Oxalis stricta*	P	Oval	Upright	Trifoliate	Alternate	Heart	entire	Round	Symmetrical	Rhizome
common lespedeza	*Lespedeza striata*	SA	Oval	Upright	Trifoliate	Alternate	Oval	Entire	Round	Nonsymmetrical	Fibrous
black medic	*Medicago lupulina*	SA	Oval	Upright	Trifoliate	Alternate	Oval	Entire	Round	Nonsymmetrical	Fibrous
white clover	*Triflolium repens*	P	Oval	Upright	Trifoliate	Alternate	Oval	Entire	Round	Nonsymmetrical	Rhizome
indian mock-strawberry	*Duchesnea indica*	P	Oval	Prostrate	Trifoliate	Alternate	Oval	Serrate	Round	Symmetrical	Stolon
poison ivy	*Toxicodendron radicans*	P	Oval	Vine	Trifoliate	Alternate	Oval	Serrate	Round	Symmetrical	Rhizome
silvery thread moss	*Bryum argenteum*	P	N/A	Prostrate	Simple	N/A	N/A	N/A	N/A	N/A	N/A
corn speedwell	*Veronica arvensis*	WA	Round	Prostrate	Simple	Opposite	Heart	lobed	Round	Symmetrical	Fibrous
Persian speedwell	*Veronica persica*	WA	Spatula	Prostrate	Simple	Opposite	Heart	lobed	Round	Symmetrical	Fibrous
hemp dogbane	*Apocynum canabinum*	P	Oval	Upright	Simple	Opposite	Lance	Entire	Round	Symmetrical	Rhizome
eclipta	*Eclipta prostrata*	SA	Spoon	Prostrate	Simple	Opposite	Lance	Entire	Round	Symmetrical	Fibrous
buckhorn plantain	*Plantago lanceolata*	P	Needle	Upright	Simple	Rosette/ Opposite	Lance	Entire	Round	Nonsymmetrical	Fibrous

dogfennel	*Eupatorium capillifolium*	P	Oval	Upright	Simple	Opposite	Dissected	Entire	Round	Nonsymmetrical	Rhizome
mouseear chickweed	*Cerastium vulgatum*	P	Spoon	Upright	Simple	Rosette/ Opposite	Oval	Entire	Round	Symmetrical	Fibrous
spotted spurge	*Chamaesyce maculata*	SA	Oval	Upright	Simple	Opposite	Oval	Entire	Round	Nonsymmetrical	Fibrous
broadleaf plantain	*Plantago major*	P	Spoon	Upright	Simple	Rosette/ Opposite	Oval	Entire	Round	Nonsymmetrical	Taproot
common purslane	*Portulaca oleracea*	SA	Oblong	Prostrate	Simple	Opposite	Oval	Entire	Round	Symmetrical	Fibrous
common chickweed	*Stellaria media*	WA	Lance	Upright	Simple	Opposite	Oval	Entire	Round	Symmetrical	Fibrous
ground ivy	*Glechoma hederacea*	P	Heart	Prostrate	Simple	Opposite	Heart	lobed	Square	Nonsymmetrical	Stolon
henbit	*Lamium amplexicaule*	WA	Round	Upright	Simple	Opposite	Heart	lobed	Square	Nonsymmetrical	Fibrous
Virginia buttonweed	*Diodia virginiana*	SA	Oblong	Upright	Simple	Opposite	Lance	Entire	Square	Symmetrical	Fibrous
carpetweed	*Mollugo verticillata*	SA	Oblong	Prostrate	Simple	Whorled	Lance	Entire	Round	Symmetrical	Fibrous
field horsetail	*Equisetum arvense*	P	Needle	Upright	Simple	Whorled	Needle	Entire	Round W/ Edges	Nonsymmetrical	Rhizome
catchweed bedstraw	*Gallium aparium*	WA or SA	Oval	Upright	Simple	Whorled	Needle	Entire	Square	Symmetrical	Fibrous

Table 5. Descriptive characteristics of the most common grass or grass-like weeds of turfgrass in Virginia.

Common name	Scientific name	Life cycle	Type	Cotyledon	Ligule	Vernation	Auricle	Max Blade Width (in)	Leaf Hair	Grass Seedhead	Roots
creeping bentgrass	*Agrostis stolonifera*	P	Grass	thin long	Membrane	Rolled	No	0.125	None	Compressed Panicle	Stolon
wild garlic	*Allium vineale*	P	Lily	fat short	None	Rolled	no	0.125	None	N/A	Bulb
field sandbur	*Cenchrus spinifex*	SA	Grass	thin long	hairy	Rolled	no	0.25	Collar	Spike	Fibrous
bermudagrass	*Cynodon dactylon*	P	Grass	thin long	hairy	Folded	no	0.125	Collar	Raceme	Stolon
annual sedge	*Cyperus compressus*	SA	Sedge	thin long	None	Triangle	no	0.125	None	N/A	Fibrous
yellow nutsedge	*Cyperus esculentus*	P	Sedge	thin long	None	Triangle	no	0.125	None	N/A	Tuber
purple nutsedge	*Cyperus rotundus*	P	Sedge	thin long	None	Triangle	no	0.125	None	N/A	Tuber
orchardgrass	*Dactylis glomerata*	P	Grass	thin long	Membrane	Folded	no	0.25	None	Compressed Panicle	Fibrous
smooth crabgrass	*Digitaria ischaemum*	SA	Grass	thin short	Membrane	Rolled	no	0.375	None	Raceme	Fibrous
large crabgrass	*Digitaria sanguinalis*	SA	Grass	fat short	Membrane	Rolled	no	0.375	Total	Raceme	Fibrous
barnyardgrass	*Echinochloa crus-galli*	SA	Grass	thin long	None	Folded	No	0.25	None	Panicle	Fibrous
goosegrass	*Eleusine indica*	SA	Grass	thin short	Membrane	Folded	no	0.25	Collar	Raceme	Fibrous
quackgrass	*Elymus repens*	P	Grass	thin long	Membrane	Rolled	Yes	0.25	None	Spike	Rhizome
tufted lovegrass	*Eragrostis pectinacea*	SA	Grass	thin long	hairy	Rolled	no	0.125	Collar	Panicle	Fibrous
path rush	*Juncus tenuis*	P	Rush	thin long	None	Rolled	no	0.1	None	N/A	Fibrous
false green kyllinga	*Kyllinga gracillima*	P	Sedge	thin long	None	Triangle	no	0.125	None	N/A	Rhizome
Italian ryegrass	*Lolium multiflorum*	WA	Grass	thin long	Membrane	Rolled	Yes	0.25	None	Spike	Fibrous
perennial ryegrass	*Lolium perenne*	P	Grass	thin long	Membrane	Folded	Yes	0.125	None	Spike	Fibrous
Japanese stiltgrass	*Microstegium vimineum*	SA	Grass	fat short	Membrane	Rolled	no	0.375	Collar	Spike	Fibrous
nimblewill	*Mulenbergia schreberi*	P	Grass	thin long	Membrane	Rolled	no	0.125	Collar	Spike	Stolon
star-of-Bethlehem	*Ornithogalum umbellatum L.*	P	Lily	thin long	None	Rolled	no	0.1	None	N/A	Bulb
fall panicum	*Panicum dichotomiflorum*	SA	Grass	thin long	hairy	Rolled	no	0.5	None	Panicle	Fibrous

dallisgrass	*Paspalum dilatatum*	P	Grass	thin long	Membrane	Rolled	no	0.5	Variable	Raceme	Rhizome
thin paspalum	*Paspalum setaceum*	P	Grass	thin long	Membrane	Rolled	no	0.5	Margin	Raceme	Rhizome
annual bluegrass	*Poa annua*	WA or P	Grass	thin long	Membrane	Folded	no	0.125	None	Panicle	Fibrous
roughstalk bluegrass	*Poa trivialis*	P	Grass	thin long	Membrane	Folded	no	0.125	None	Panicle	Stolon
tall fescue	*Schedonorus arundinaceus*	P	Grass	thin long	Membrane	Rolled	Yes	0.375	None	Compressed Panicle	Fibrous
giant foxtail	*Setaria faberi*	SA	Grass	thin long	hairy	Rolled	no	0.5	Total	Spike	Fibrous
yellow foxtail	*Setaria pumila*	SA	Grass	thin long	hairy	Rolled	no	0.25	Half	Spike	Fibrous
green foxtail	*Setaria viridis*	SA	Grass	thin long	hairy	Rolled	no	0.25	None	Spike	Fibrous
johnsongrass (mature)	*Sorghum halepense*	P	Grass	thin long	hairy	Rolled	no	0.75	None	Panicle	Rhizome
johnsongrass (young)	*Sorghum halepense*	P	Grass	thin long	Membrane	Rolled	no	0.75	None	Panicle	Rhizome

General Mechanical Controls:

The primary means of mechanical weed control in turf is hand weeding, flail mowing, directed flame or radiant heat, and string trimming. Hand weeding is often overlooked as a viable option for lawn weed control. Tools are available to allow one to remove weeds from turf without bending. A quick Internet search will provide information and vendors for such tools. Chemical sprays are often perceived as the "easiest" approach to weed control, but hundreds of weeds can be hand pulled in the time required to research and determine the appropriate chemical for the properly identified weed, purchase the chemical, mix the product in a calibrated applicator, and apply the product. The turf manager must then wait one to three weeks for the product to work. One may argue that hand pulling is actually the easier choice. Plants like dandelion, plantain, ryegrass, annual bluegrass, crabgrass, and goosegrass have few or no creeping stems and are easier to pull than creeping plants like bermudagrass (wiregrass), nimblewill, and white clover. Although hand pulling creeping perennials like bermudagrass and nutsedge does not completely eradicate the population, such efforts are still beneficial to the turfgrass and will limit population expansion of the weed. Always wait until after a rainfall or irrigation to hand pull weeds as plants will then be easier to pull. Discard plants rather than leaving them to be mown into the lawn as the pulled plants can continue to grow and produce seed before they die and/or stem fragments from some plants can take root in the lawn. Other mechanical means like flail mowing and string trimming help suppress weed expansion or may work with natural stress to kill weeds. In most cases, however, weed recovery is inevitable given enough time and optimal growing conditions.

Some mat-forming plants like moss can be removed by raking or vertical mowing. It is always important to remove thick mats of biological material prior to seeding new turfgrass in the area. Some species of weeds may invade turf soon after establishment but will not persist more than two to three years as they cannot compete in the presence of regular mowing. Thus, mowing acts as a mechanical control in a select few situations.

Solarization and shading are nonchemical approaches to weed control in many situations. Unfortunately, these methods also kill desirable turfgrass. Solarization kills plants by covering them with a clear material and allowing solar radiation to heat the area to a temperature above that which supports plant life. Shading removes plants ability to capture energy and eventually leads to death. Both techniques take one to two months to kill plants and then the area must be seeded or sodded back to desirable turfgrass.

By understanding the life cycle of target weeds, one may learn that plants will completely die with summer heat or winter frost. If these natural events will kill the weed within a few weeks, costly chemicals are not needed. As mentioned earlier, large amounts of biological

material left behind after these weeds die should be removed to allow turfgrass to fill the voids.

Precautions When Using Herbicides:

When choosing weed control products, know that most herbicides are relatively safe but still should be handled with respect and stored in a secure manner. When on the job site, applicators often forget the pesticides must always be kept out of the reach of children. If you mix a product and then leave the mixing site to spray the product, you must store the pesticide securely before you leave. This is particularly true of lawn care operators in residential neighborhoods. Still, most herbicides are far less toxic than insecticides or fungicides and have an LD_{50} value greater than 2000 to 5,000 mg/kg. Those values are often less than that of table salt (3,000). In fact, only a few herbicides are as toxic as caffeine (192) and aspirin (200) and these include paraquat (150) and diquat (231). Always follow label instructions on any pesticide product and you will be using the product in a safe manner.

Although herbicides exhibit relatively little danger to humans, pets, and wildlife, they can cause serious injury to desirable ornamental plants and should be kept away from hardscapes, unless registered for such use, as they can move into streams and rivers through man-made drainage systems. Don't spray products when wind speeds are greater than 5 mph if possible and use shields to protect spray from effects of wind. Similarly, many granular spreaders have deflector shields to minimize product delivery onto hardscapes. If granules are strewn onto sidewalks or pavement, sweep them up and/ or blow them back onto the lawn. Never discard granules or liquids into any drain.

Don't apply any herbicide to areas that are saturated with water from frequent rains or irrigation. If soils are saturated and another rainfall occurs soon after herbicide application, the product will be highly prone to move in surface runoff water and can injure plants away from the target site and/ or move into storm water drains. Some herbicides can be tracked with shoes or tires to nontarget areas. Prevent traffic on treated areas until after rainfall or irrigation. Most herbicides are rain fast within 4 to 8 hours and can be irrigated to wash excess residue from leaves and prevent product from being dislodged by foot or vehicle traffic.

Always read and follow the label on the herbicide product. The label is federal law and to apply the product in any way other than that specified on the label is a federal crime. These rules apply to handling, mixing, transporting, storing and applying the pesticide. For more information on safe use of pesticides, refer to Chapter 1 in the Virginia Pest Management Guide.

Applying Herbicides Correctly:

Granular and sprayable herbicides are available for use in turf. Granular products can be strewn manually, scattered using specialized product containers, or applied using drop or rotary spreaders. There are two ways to calibrate the application of granular products. One is to measure the amount of product and apply all of that product uniformly to a given area of turf. The other is to calibrate the delivery rate of a machine and operate the machine until all desired area is covered. Product bags often indicate the amount of area covered by one bag (e.g., "covers 5000 sq ft"). The product in these bags is typically well blended so one can simply use half the bag's contents to cover half the indicated area. The scientific way to partition product is by weight but this is impractical in some cases. Partitioning the product by volume is an effective alternative. It is important that any measuring devices, such as cups, tin cans, etc. are filled in a consistent manner each time for volume measurements to be accurate.

Once you have a means of measuring product, you must determine the square footage of the area to be treated. Divide irregularly shaped areas into several rectangles or squares and determine the area of each. Simply multiply the length by the width of a given area to determine the area in square feet. For example an area 15 feet by 25 feet contains 375 square feet. Repeat this process until the entire turf has been measured and simply total the sum of all small areas into one number, which represents the square footage of your turf. Let's say that your area requires 75% of a bag of product. Place the product into the spreader, set the spreader on a low level, cover the entire turf, then check the amount of product used. After this procedure you can calculate the number of times you will need to cover the turf before the product is completely spread. If more than four times are needed, it is best to adjust the spreader to a slightly higher level and repeat the process. It is generally recommended that you evenly apply the product to the turf in two to four passes. By running your spreader over the entire area two to four times, you ensure that your application is uniform and does not have any pattern associated with your walking/driving direction. Change your walking/driving pattern each time you cover the turf with the spreader in order to further improve product distribution. A more professional approach is to equip the spreader with a catch device, estimate the width of spread and operate the spreader along a linear track of a known distance. Multiply the distance traveled by the estimated width of spread to determine the area that would have been covered in the calibration pass. Use this area and the weight of product in the catching device to calculate the product rate per unit area.

To apply sprayable products, most professional units are ground-driven, variable output. If the onboard user interface is calibrated properly, the applicator simply enters the desired output of spray per unit area and the machine will vary output based on speed of travel to ensure the correct rate is sprayed. The applicator only needs to calculate the correct

amount of herbicide to add to a spray tank with a given amount of water. On older equipment, one must catch water from each nozzle on the boom for a given amount of time (e.g., 15 seconds) and convert that amount to gallons per minute. The following equation is then used to calculate spray rate per unit area: GPA = (GPM X 5940)/(NSI X MPH) where GPA is gallons of spray per acre, GPM is gallons of spray per minute from one nozzle, NSI is nozzle spacing in inches, MPH is speed in miles per hour, and 5940 is a constant. For this calibration approach to work, the applicator speed must be held constant. In lawn care, the primary equipment is the pump sprayer and the hose-end sprayer. Regardless of the spray equipment, the techniques for application are similar. To calibrate a pump sprayer, fill the sprayer with a known amount of clean water, mark off an area of 1000 square feet (e.g., 20 ft by 50 ft) and cover the area completely while spraying the clean water. Now check to see how much water was used in the test spray. This amount is your spray rate and should be near 0.5 to 1.0 gallons per thousand square feet. Knowing your spray rate will allow you to calculate the amount of concentrate product for each gallon of water and also know how much area it should treat. For high-output ChemLawn-type spray guns, set the desired pressure and choose the desired nozzle. Spray 1000 square feet or similar known area and determine the amount of time needed for the applicator to uniformly cover the area. With pressure and nozzles at the same setting, spray water into a large bucket for 10 to 30 seconds to determine the rate of output per unit time. Once you know rate of spray output and area covered per unit time, the rate of spray output per unit area can easily be calculated. Most spray guns are operated at 2 to 4 gallons of spray per 1000 square feet.

Figure 1. Common summer annual grass weeds of Virginia turfgrass.



Smooth crabgrass (*Digitaria ischaemum*)



Goosegrass (*Eleusine indica*)

I. Preemergence Control of Crabgrass, Goosegrass, and Other Summer Annual Grass Weeds

Preemergence herbicides (Table 6) work by creating a barrier of herbicide on the soil surface through which seedling weeds must grow when they germinate. Germinating

seedlings have shallow roots and are sensitive to effects of these herbicides while emerged plants are generally not susceptible. The following are important factors that determine effectiveness of these herbicides.

RATE - product rate is always important when using herbicides. As rate of preemergence herbicides decrease, the duration of effective weed prevention decreases. At full professional rates, most products prevent weed emergence for about 2 months. Only in special environmental conditions do these products exceed 2 months of activity. If excessive rates are applied, desirable turf may be injured or herbicide will persist for several months and may prevent turfgrass seedling establishment for renovation. In some cases, it is desirable to reduce the preemergence herbicide rate initially and apply another reduced-rate treatment one to two months later. This approach works with root inhibitors like prodiamine, pendimethalin, and dithiopyr but does not work with shoot inhibitors like oxadiazon.

TIMING - much debate has been waged related to timing of preemergence crabgrass herbicides. Most extension recommendations suggest applying the products just before crabgrass (Figure 1) emergence. Crabgrass emerges when soil temperatures are above 55 F for several days or growing degree days at base 55 F reach a cumulative 70 to 100 units. Biological indicators of crabgrass emergence include Forsythia bush and Daffodil. Crabgrass emerges when approximately half of Forsythia blooms have fallen and after most Daffodil blooms have faded. So herbicides should be applied during full Forsythia and Daffodil bloom. But what about applying product earlier in the fall? Fall application is an acceptable approach to spring crabgrass control but is NOT as effective as spring application. Many believe herbicides do not degrade in winter. In short, herbicide will still degrade but at a much slower rate than in summer. If you have a warmer wet winter, you will lose over half of your herbicide between fall application and spring. If you have a cold dry winter, you may lose less than half of your herbicide in the same time period. Field dissipation studies have shown that half of applied pendimethalin degrades in about 44 days during summer temperatures. The time required to lose half of applied pendimethalin in winter (average 50 F) is 101 days. So it is not unreasonable to expect half of applied pendimethalin to be lost over the 150 to 180 days of fall/winter if one applied in October and crabgrass emerges in March or April. Advantages to fall application include control of some winter weeds but the disadvantage is that crabgrass control will not last as long into the summer when compared with a spring application.

'WATER- IN' THE PRODUCT - Preemergence herbicides must be "incorporated" onto the soil surface via irrigation or rainfall before the products will have any activity on target weeds. A light rain or irrigation is sufficient. Crabgrass herbicides are highly susceptible to photodegredation (i.e. destroyed by light) between application and incorporation so it is important to have them watered in within a few days of treatment. It is reasonable to

expect as much as half of applied product to degrade in sunlight if no rainfall or irrigation is supplied within 2 weeks of application.

UNIFORM APPLICATION - since these products work by creating a barrier, they are only as effective as the uniformity of that barrier. Sprayable products allow for more uniform application than granules but both types can be applied uniformly by setting the applicator to half or quarter rates and covering the entire area 2 or 4 times.

Table 6. Herbicides that prevent emergence of crabgrass and other annual grasses.

Active Ingredient(s)	Special Notes
Benefin + Trifluralin	
Benefin + Oryzalin	Only apply to mature tall fescue or warm-season grasses. Excessive rates will injure turf.
Bensulide	Used on golf putting greens and other areas
Bensulide + Oxadiazon	Used on golf putting greens, excessive rates will injure turf.
Dithiopyr	Controls emerged crabgrass up to the tillering growth stage.
Dithiopyr + Oxadiazon	Excessive rates will injure turf.
Oryzalin	Only apply to mature tall fescue or warm-season grasses. Excessive rates will injure turf.
Oxadiazon	Among the most effective on goosegrass. Excessive rates will injure turf.
Pendimethalin	
Pendimethalin + Oxadiazon	Excessive rates will injure turf. Improved goosegrass control.
Prodiamine	
Prodiamine + Oxadiazon	Excessive rates will injure turf. Improved goosegrass control.
Prodiamine + Sulfentrazone	Also controls sedges if applied as a second treatment after May 15. Excessive rates will injure turf.

II. Postemergence Control of Crabgrass, Goosegrass, and Other Summer Annual Grass Weeds

There are only five active ingredients that can selectively control mature crabgrass and other annual grass weeds in ornamental turfgrass (Table 7). These include fenoxaprop, quinclorac, mesotrione, topramezone, and MSMA. Organic arsenicals like MSMA can only be used in golf and sod turf and under certain EPA restrictions. These products should be applied to actively growing crabgrass and annual grassy weeds. Younger plants are easier to control than older plants. It is important to accurately identify the grass weed being targeted. For example, quinclorac is the most common active ingredient for postemergence crabgrass control and it does not control goosegrass or bermudagrass. Mesotrione and topramezone effectively control nimblewill but quinclorac and fenoxaprop do not. Fenoxaprop and topramezone control goosegrass but quinclorac and mesotrione typically do not. The following are the most important rules to follow when targeting annual grass weeds with postemergence herbicides:

IDENTIFY THE TURFGRASS - some herbicides are safe to use on one species of turfgrass but will severely injure or kill another species of turfgrass. These differences often occur between warm-season and cool-season turfgrasses but are not limited to this trend. One must identify all species of turfgrass in the turf and confirm that the product used is safe on these species.

IDENTIFY THE GRASSY WEED - many grass weeds look alike and herbicides are often specific to the ones they control.

AVOID STRESS - drought, heat, frost, or any other stressful situation that reduces the growth rate of target grass weeds will severely reduce effectiveness of selective grass killers.

USE ADJUVANT - most products are prepackaged with appropriate adjuvants but some selective grass herbicides may need other additives, such as surfactants, to make them work. Read and follow the herbicide label. Quinclorac and topramezone typically require a methylated seed oil adjuvant for best activity. Fenoxaprop and mesotrione typically require a nonionic surfactant.

MIX CAUTIOUSLY - grass herbicides like fenoxaprop have serious problems when mixed with some other herbicides like 2.4-D, MCPP, and sulfonylureas. Don't mix these with broadleaf herbicides, insecticides, or other products unless the mixture is known to be effective.

REPEAT TREATMENT - typically products need to be applied at 2 to 4 week intervals for complete control. Mesotrione requires a repeat treatment at 3-week intervals on any mature weeds. Topramezone also benefits from a repeat treatment at 3-week intervals. Quinclorac can sometimes require a repeat treatment when crabgrass is between 4 and 8 tillers during the initial application.

WATCH THE RATE - Selective grass herbicides have a high possibility of injuring desirable turfgrass. Sprayers must be accurately calibrated and it is important not to apply excess product or severe turfgrass injury may result.

Table 7. Herbicides that control emerged crabgrass and other annual grasses in Turf.

Active Ingredient(s)	Special Notes
Fenoxaprop	Only kills grasses. Some turfgrass injury is to be expected. Avoid applying during stressful periods. Don't mix with 2,4-D, MCPP, and some other products. Use of 0.25% v/v nonionic surfactant may improve control.
Quinclorac	Kills crabgrass, foxtail, barnyardgrass and others but not goosegrass or perennial grasses. Can be used in most turfgrass species. Do not use in centipedegrass. Also kills clover, dandelion, and some other broadleaf weeds. Requires MSO at 0.5 to 1.0% v/v.
Mesotrione	Must be applied twice at 3-week intervals for effective control of mature weeds. Also controls perennial grasses, sedges, and broadleaf weeds. For use in most cool-season grasses and centipedegrass. Add 0.25% v/v nonionic surfactant to improve control.
Topramezone	Kills broadleaf weeds and grasses. Excellent goosegrass and bermudagrass control. Not for use in warm-season turf except centipedegrass. Requires methylated seed oil adjuvant at 0.5% v/v.

III. Control of Annual Bluegrass and Winter Broadleaf Weeds

Figure 2. Annual bluegrass (*Poa annua*).



Annual bluegrass (Figure 2) and other winter weeds germinate when air temperatures fall below 75 F for extended periods as Fall is approaching. Controlling these weeds with preemergence herbicides is similar to controlling crabgrass with preemergence herbicides, except products are applied in late summer or early fall instead of early spring. Refer to the section on "Preemergence Control of Crabgrass, Goosegrass and Other Summer Annual Grass Weeds" for specific products. Annual bluegrass germinates around the same time we seed desirable cool-season turfgrass for turf renovation or establishment. Avoid applying preemergence herbicides for annual bluegrass control before any lawn seeding. Seeding must be delayed for 2 to 4 months following herbicide application. Herbicides may typically be applied after the second mowing on new turfgrass with some exceptions. Read and follow herbicide label. Also, avoid fertilizing the lawn with phosphorus fertilizer in early fall as it promotes survival of germinating annual bluegrass seedl ings. In warm-season turf, use trifloxysulfuron, foramsulfuron, or flazasulfuron for selective postemergence annual bluegrass control. Indaziflam is highly effective for preemergence control of annual bluegrass in warm-season turf and can extend residual control for several months. During winter dormancy, glyphosate can be combined with oxadiazon or flumioxazin for postemergence and residual control of annual bluegrass. In cool-season fairways, amicarbazone, bispyribac sodium, and ethofumesate can selectively control annual bluegrass in some cases.

V. Postemergence Control of Broadleaf Weeds

Broadleaf weeds can be controlled anytime weeds are actively growing. Annual broadleaf weeds are best controlled when weeds are young. Perennial broadleaf weeds are best treated in the fall when weeds are moving energy reserves to roots in preparation for winter dormancy. The following points are important when controlling broadleaf weeds in turf using the herbicides in table 8:

IDENTIFY THE LAWN GRASS - some herbicides are safe to use on one species of turfgrass but will severely injure or kill another species of turfgrass. These differences often occur between warm-season and cool-season turfgrasses but are not limited to this trend. One must identify all species of turfgrass in the lawn and confirm that the product used is safe on these species.

IDENTIFY THE WEEDS - some broadleaf weeds die in summer or winter and may not need treatment. Others may require special active ingredients to insure complete control.

ACTIVELY GROWING WEEDS - avoid stressful periods (drought, heat, cold, etc) so that weeds are growing when treated.

GET THE HERBICIDE IN - most broadleaf herbicides enter through foliage and require good coverage with foliar sprays or the presence of dew on foliage to dissolve granules and allow herbicide to enter the plant.

REDUCE DRIFT - broadleaf herbicides can harm desirable ornamental shrubs and flowers so don't apply them in windy conditions and take steps to avoid drift onto nontarget sites.

HARD-TO-KILL - Some perennial broadleaves like ground ivy, wild violet, common lespedeza, woodsorrel, and Virginia buttonweed are difficult to kill. Use products that contain triclopyr, fluroxypyr, or penoxsulam and expect to treat these weeds repeatedly, regardless of the product used.

Table 8. Herbicides that selectively control broadleaf weeds in lawn grasses.

Active Ingredient(s)	Special Notes
2,4-D + MCPP	Both granular and spray products available. Must have dew on turf for granular application.
2,4-D + Dicamba + MCPP	Both granular and spray products available. Must have dew on turf for granular application.
2,4-D + Dicamba + MCPP + Carfentrazone	Spray products only. Provides symptoms within 48 hours.
2,4-D + Dicamba + Fluroxypyr	Spray products only. Improved control of hard-to-kill broadleaf weeds. Safer on bermudagrass and fine fescues compared to triclopyr products.
2,4-D + Dicamba + MCPP + Sulfentrazone	Both granular and spray products available. Also controls sedges.
2,4-D + Dicamba + MCPP + Dithiopyr	Granular products only. Also provides residual control of crabgrass and annual bluegrass.
2,4-D + Dicamba + MCPP + Isoxaben	Spray products only. Also provides residual broadleaf control.
2,4-D + Dicamba + Quinclorac	Spray products only. Also controls crabgrass.
2,4-D + Dicamba + Quinclorac + Sulfentrazone	Spray products only. Also controls sedges.
2,4-DP + 2, 4-D + MCPP	Both granular and spray products available. Must have dew on turf for granular application.
Dicamba + MCPP + MCPA + Carfentrazone	Spray products only. Provides symptoms within 48 hours.
Triclopyr	Spray products only. Kills brush, aids in control of perennial weedy grasses.
Triclopyr + 2.4-D + Dicamba	Spray products only. Improved control of hard-to-kill broadleaf weeds.
Triclopyr + dicamba + MCPA	Spray products only. Improved control of hard-to-kill broadleaf weeds.
Penoxsulam	Granular products only. Aids in control of hard-to-kill broadleaf weeds; use in conjunction with other broadleaf herbicide for broad-spectrum control.
Penoxsulam + Dicamba	Granular products only. Improved control of hard-to-kill broadleaf weeds.
Penoxsulam + 2.4-D + Dicamba	Granular products only. Improved control of hard-to-kill broadleaf weeds.

VI. Postemergence Control of Perennial Grass Weeds

The most common perennial grass weeds in Virginia are bermudagrass (wiregrass), dallisgrass, nimblewill, orchardgrass, quackgrass and roughstalk bluegrass (Figure 3). In most cases, the only control is to hand weed the grass or spot treat with a nonselective herbicide that contains glyphosate. In recent years, research studies have led to selective control measures for bermudagrass in cool-season lawns. Products that contain fenoxaprop, fluazifop, mesotrione, or topramezone can be used as recommended to control bermudagrass. More effective control can be achieved by mixing these products with triclopyr (Turflon Ester contains 61.6% triclopyr and is mixed to apply 0.73 fl oz per gallon to treat 1000 sq ft.). Triclopyr should not be applied during summer on Kentucky bluegrass or hard fescue. Selective bermudagrass control requires 4 to 8 treatments per year depending on rate. Start treating when targeted bermudagrass starts to produce shoots and leaves in late spring and treat at 3 week intervals for 2 to 4 applications. Avoid treating in July and early August. Resume treatments in Mid to late August and apply an additional 2 to 4 treatments at 3-week intervals until frost. If the product label does not allow this many treatments, supplement with another product and apply in sequence or hand weed bermudagrass during mid summer and limit treatments to spring and fall. Turfgrasses will be temporarily injured when targeting bermudagrass with these herbicides. Delay treatment if turfgrass has not completely recovered prior to the next normally-scheduled

Figure 3. Common perennial grass weeds.



Bermudagrass (*Cynodon dactylon*)



Dallisgrass (*Paspalum dilatatum*)



Nimblewill (*Muhlenbergia schreberi*)

treatment. If turfgrass injury is a concern, treat only in spring and fall and discontinue treatments during mid-summer. Do not exceed maximum use rates or number of applications specified on product labels. Beware that by injuring desirable turfgrass, these treatments may increase the severity of brown patch and pythium diseases.



Orchardgrass (*Dactylis glomerata*)

VII. Postemergence Control of Sedges

Yellow nutsedge (Table 9) is the most common sedge problem in Virginia. Sedges typically emerge in early summer and are present from June until frost. Most sedges are perennials and enter dormancy during winter. Sedges are typically not controlled by selective grass killers or preemergence herbicides that are used to prevent crabgrass. Sedges thrive in wet or hot summers and often require more than one herbicide treatment for season-long control. Yellow nutsedge continually produces small nutlets underground that will sprout sometime, maybe years, in the future. It is important to hand pull small populations of sedge plants to reduce production of these nutlets. Hand pulling does not remove nutlets that are already produced but helps reduce population expansion by preventing mature plants from making more nutlets. Herbicides will kill some, but not all, nutlets attached to parent plants. In short, sedge problems will typically not be solved in one or two seasons and requires constant vigilance.

Table 9. Herbicides that selectively control sedges in lawn grasses.

Active Ingredient(s)	Special Notes
Bentazon	Requires good coverage and repeat treatment after 2 weeks.
Halosulfuron	Avoid stress, add surfactant, repeat treatment after 4 weeks if needed.
Sulfentrazone	Fast acting. Provides some soil residual to reduce new sedge sprouts.
Sulfentrazone + 2,4-D + Dicamba + MCPP	Both granular and spray products available. Also controls broadleaf weeds.
Sulfentrazone + Prodiamine	Also provides residual control of crabgrass, goosegrass, and other annual grasses.
Sulfentrazone + 2,4-D + Dicamba + Quinclorac	Also controls broadleaves and crabgrass.

Figure 4. Common sedges found in Virginia turfgrass.



Yellow nutsedge (*Cyperus esculentus*)



False green kyllinga (*Kyllinga gracillima*)

VIII. Weed Control at Seeding

Seedling emergence is the most delicate stage of the turfgrass life cycle. Only a few herbicides can be applied to young turfgrass or be used for residual weed control while turfgrass is germinating. When planning to seed new turfgrass, the following points should be considered:

KILL THE OLD - use a nonselective herbicide, such as glyphosate, to kill existing vegetation where a complete lawn renovation is desired. Glyphosate should be applied at least a week in advance of seeding but longer is better. If bermudagrass or other hard-to-kill perennials are present allow 4 weeks or more for repeat treatment of escaped plants.

SOIL TEST - if renovating the lawn, take the opportunity to conduct a soil test and add/incorporate appropriate soil amendments before seeding the new lawn grass.

SEED-TO-SOIL CONTACT - do seeding preparations such as vertical mowing, raking, or tilling prior to applying siduron for crabgrass prevention during seedling establishment.

KNOW HERBICIDE HISTORY - Most herbicides require a 30 day wait before turfgrass seeding is allowed. Turfgrass seeding may be restricted for 60 to 120 days following treatment with preemergence crabgrass preventers. Check herbicide labels for seeding restrictions when planning to seed.

SEED IN FALL - By seeding in fall, you avoid summer annual weeds like crabgrass from choking out your desirable turfgrass seedlings.

CONTROL WEEDY GRASSES IN SPRING - If seeding in spring, make sure you seed as early as possible and use siduron, mesotrione, or quinclorac for preemergence and early postemergence weed control.

CONTROL BROADLEAF WEEDS - carfentrazone is an active ingredient often added to broadleaf herbicides to provide rapid symptoms on weeds. Unfortunately, most broadleaf herbicides can't be applied to young turfgrass seedlings but carfentrazone can be applied to seedling turf.

Chapter 11. Turfgrass Disease Management

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Overview:
All turfgrasses are susceptible to a wide array of diseases, though the detail required for disease management strategies varies greatly, depending on use, budget, and expectations. While the total number of potential turf diseases may be high, there are only a handful that commonly attack most grasses grown in Virginia.

In order to gain a healthy understanding of the nature of diseases, it is important to understand some of the most common concepts. Below are definitions for some of the critical terminology used for diagnosing a disease, as stated in the Compendium of Turfgrass Diseases (3rd Edition, APS Press).

- Disease: abnormal functioning of an organism
- Abiotic: non-living; pertaining to nonliving agents that cause diseases or to the diseases caused by such agents
- Biotic: living; pertaining diseases caused by living organisms
- Disease complex: disease resulting from combined or sequential actions of two or more biotic or abiotic agents
- Disease cycle: the succession of all events and interactions among a host, a parasite, and the environment in the process of disease, from initial infection of the host by a causal agent, through pathogenesis, to overseasoning, until another infection occurs
- Pathogen: a disease-producing organism or agent
- Sign: an indication of disease from direct observation of a pathogen or its parts on a host plant
- Inoculum: pathogen or its parts, capable of causing infection when transferred to a favorable location
- Spore: a reproductive structure of fungi and some other organisms, containing one or more cells
- Hyphae: tubular filament of a fungal thallus or mycelium, the basic structural unit of a fungus
- Mycelium: mass of hyphae constituting the body (thallus) of a fungus
- Fruiting body: any of various complex, spore-bearing fungal structures

- Symptom: an indication of disease from the reaction of a host
- Lesion: a localized diseased area or wound
- Patch: in grasses, a distinctly delimited, somewhat circular area in which most or all plants are affected by disease

While both living and non-living agents may cause diseases, we typically focus on diseases caused by a living infectious organism, or pathogen. In order for a biotic disease to occur, there must be the presence of a susceptible host, a pathogen capable of causing disease, and favorable environmental conditions. The overlap of these three factors dictates the likelihood of disease development, and is often referred to as the disease triangle. A fourth dimension that pertains to disease development is time. Most pathogens require a certain period of time of favorable environmental conditions to be able to infect its host and begin the disease process.

As discussed in previous chapters, Virginia is located in the transition zone, where both cool-season and warm-season grasses are grown. Many of the most common diseases in Virginia occur at times of the year outside of each grass' peak growing season. Cool-season grasses are typically most susceptible to diseases in the summer, while turf growth is minimal but pathogen activity is high. The optimal growth of warm-season grasses is during the summertime, and they are typically able to outcompete pathogens. However, these grasses are more susceptible to attack from pathogens during spring green-up and as they approach dormancy in the fall.

The single most important factor for successful management of turf diseases is maintaining a healthy stand of turfgrass. Many of the sample principles discussed in the previous chapter (Weed Management in Turfgrasses) hold true for reduced disease pressure. While maintaining a healthy stand of turf will not eliminate disease, it may prevent disastrous consequences resulting in the need for re-establishment.

An integrated approach to manage turfgrass diseases:

Managing turfgrass to reduce diseases is a dynamic process and requires constant monitoring, scheduling, and rescheduling. Diseases cannot be completely controlled with cultural strategies, but the rate of development, incidence, and severity can be dramatically decreased. Turfgrass pathogens can be damaging to a plant regardless of its health, but are most destructive when plants are under stress. Fungi are generally opportunistic and cause the most damage when plants under stress are less able to defend themselves from penetration and colonization by the fungus. Stress can be brought on by a number of environmental factors, such as soil pH, soil moisture, excess thatch accumulation, soil compaction, and temperature or nutritional extremes. Cultural strategies can be used to reduce these stresses and promote an

environment less conducive for disease development. These strategies should be regular components of a maintenance program, especially in situations where a particular disease occurs on the same field from year to year. The following discussion relates to reducing disease severity through some of the most common cultural practices.

Plant nutrition in disease management. Under conditions of nutritional extremes (either too much or too little) plants often become more vulnerable to outbreaks of disease. Macronutrients such as calcium, nitrogen, potassium, and phosphorous are known to play a role in disease development. Nitrogen typically plays the largest role in disease development. Determining the proper balance of nitrogen fertilization can be particularly tricky because excessive amounts may contribute to the development of some diseases while inadequate amounts may promote other diseases. Available nitrogen causes rapid growth in plants and increased tolerance to damage from some pathogens, however, the succulent tissues of rapidly growing plants are easily penetrated by other pathogens. When the availability of nitrogen is low, higher incidence of red thread, pink patch, dollar spot, anthracnose, and rust may be expected. When nitrogen levels are excessive, the severity of brown patch, *Pythium* blight, gray leaf spot, and Microdochium patch (pink snow mold) may increase. Additionally, plants that are deficient in calcium are more vulnerable to development of *Pythium* blight, red thread, summer patch, and necrotic ring spot.

It is difficult to recommend a proper fertilization schedule due to the variation in needs from site to site and throughout the course of the season, but suggested programs are detailed in Chapter 5 (Nutrient Management). The dynamic process of nutrient utilization by the plant will require modification of the schedule for fertilization throughout the season. The following strategies should be helpful for scheduling fertilization applications. The use of slow-release fertilizers can help keep the amount of readily available nitrogen and potassium available to the plant at one time at acceptable levels and reduces the leaching of nutrients from the soil. When using readily available forms of nitrogen, applying low rates at more frequent intervals (known as "spoon feeding") will reduce the chance of excessive nutrients. Due to the high potential for nutrient leaching in sand-based soils, these systems usually require more careful monitoring of nutrient balance to maintain turf health and vigorous growth. Overall, balancing the nutrient needs of the turfgrass plant while trying to avoid over-fertilization will help to reduce the severity of diseases might occur.

Mowing height and clipping removal. Stands of turfgrass maintained at lower mowing heights are generally more susceptible to development of diseases. This is primarily due to increased stress on the plant. The severity of summer patch, necrotic ring spot, melting-out, and *Bipolaris* leaf spot on Kentucky bluegrass are increased as mowing height is decreased below 1 1/2 inches. While diseased leaves can be a source of inoculum, unless the disease severity is wildly

out of control, the benefits of mulching clippings outweigh the impact any effect not removing diseased clippings would have in an area. Raising the mowing height when possible (except during gray leaf spot outbreaks) will help to reduce the stress on the plant and therefore, will reduce the severity of most turfgrass diseases. The optimal mowing heights for each grass grown in Virginia is discussed in greater detail in Chapter 6 (Mowing Principles and Practices).

Leaf wetness. Leaf wetness is a requirement by fungi for spore germination, mycelial growth, penetration, and infection of host cells. Minimizing the duration of leaf wetness is essential to reduce the number of infections per leaf for most diseases. Most pathogenic fungi require a period of 6 to 12 hours depending on temperature and other environmental factors to penetrate epidermal cells of turfgrass plants. Extended periods of light rain, dense fog, or high humidity are unavoidable and contribute to the development of disease. Strategies that reduce leaf wetness duration can reduce disease severity. Accumulation of dew on leaves occurs between dusk and dawn, and often remains on the leaf blade until late morning. This period of time is long enough for most pathogens to penetrate the leaf surface. Dragging a pole or garden hose across the playing surface when it is wet can whisk the excess water from the leaves, thus decreasing the chances of infection. This can be done early in the morning to decrease the period of leaf wetness by several hours. Scheduling irrigation to be completed just before sunrise dilutes nutrient-rich guttation water that is formed throughout the night, and is another means for decreased leaf wetness periods. A general "rule-of-thumb" for scheduling irrigation to reduce disease development is to never irrigate between 6pm and 10pm or between mid-morning and noon. Light syringing in the afternoon can serve to cool the playing field, but it can also increase disease development if leaves do not have adequate time to dry. If afternoon syringing is necessary, the best time to do so is mid-afternoon, after the leaves have had a chance to dry and will have time to dry before evening dew is present.

Managing thatch to reduce disease. Thatch is an accumulation of slow-decaying organic matter, comprised primarily of roots, stems, stolons, rhizomes, and leaves of living turfgrasses. Bunch-type grasses, such as fescues and ryegrasses, are not prone to excessive accumulation. A diverse microbial population is responsible for thatch degradation in the soil. At times of rapid growth, the microbes that decompose thatch cannot keep up, resulting in an excessive accumulation of thatch. This can indirectly contribute to disease development. A stand of turfgrass with a thick layer of thatch is generally more vulnerable to stress from temperature and moisture extremes because the crowns of many plants are located within the thatch layer, and not in soil that moderates the effects of temperature and moisture. The sponge-like thatch layer also serves as a reservoir for fungal pathogens when environmental conditions are not conducive for disease development. While it is beneficial to have a moderate amount of thatch to improve wear tolerance, accumulation greater than 3/4" can contribute to a number of diseases. Regular topdressing and core cultivation will prevent the accumulation of excessive

thatch in prone grasses, such as bermudagrass, Kentucky bluegrass, and creeping bentgrass. If thatch thicknesses exceed the recommend depth, aggressive management using vertical mowing and core cultivation will be required to reduce the thatch to an acceptable depth. Management of thatch will help to reduce the amount of fungal inoculum present and increase the plant's health, resulting in a reduction of many important diseases.

Table 1. Characteristics of the most common diseases of turfgrasses in Virginia.

Brown patch
Common on cool-season grasses during warm to hot, wet weather. Most common disease of tall fescue. Brown patch on lawn grasses (left) may range from a few inches to two feet in diameter. A gray "smoke ring" may be present along the perimeter of patches, especially on closer-cut grasses (middle). Upon closer examination of individual leaves (right), characteristic lesions are typically a dull tan and brittle, with a dark margin separating necrotic and green tissue. 

Dollar spot

Affects both warm- and cool-season grasses during warm, humid days and cool nights, especially during heavy dew. White mycelium (left) is often visible in the morning during active epidemics. Individual infection centers may be small, silver dollar sized spots on closely mowed turf (middle), or up to six inches and less defined at higher mowing heights (right).



Spring dead spot

Appears of dead patches of turf in the spring, but may persist well into summer months. Common on bermudagrass recreational fields, especially in high traffic areas (left). Patches are sunken through the thatch layer, often times an inch or more below the normal playing surface (middle). Infected stolons are generally black and rotten (right).



Pythium blight

Most severe on cool-season grasses during hot, wet weather, but may also affect warm-season grasses later in the fall when the turf is not growing as actively but remains wet. Pythium blight may start as small, water-soaked spots, often with foliar mycelium growing in the morning (left), but can rapidly destroy large stands of turf, leaving a matted layer of decaying leaves (middle). Spores of the pathogen can easily be spread via moving water or tracked on shoes or equipment (right).



Large patch

Most common on intensively managed zoysiagrass, but may be problematic on other warm-season grasses. Typically occurs in spring and fall, as warm-season grasses break or approach dormancy. Lesions may appear on stolons (left) or at the base of leaf sheaths, allowing shoots to easily be pulled away. Large patch on zoysiagrass is slow to recover in relation to surrounding healthy turf (middle). Large patch may appear on bermudagrass the same time as spring dead spot, but is typically less severe and quickly recovers (right).



Gray leaf spot

Occurs during prolonged wet weather, most commonly during late summer. Tiny pinpoint lesions may be present on leaf blades, but a more common characteristic of perennial ryegrass is a twisted fishhook shape (left). New infections can occur in as little as 9 hours, so entire stands can quickly be destroyed under favorable conditions (middle). Very host specific, GLS is only problematic on perennial ryegrass, tall fescue, and St. Augustinegrass. The light green unaffected patch is roughstalk bluegrass, surrounded by susceptible perennial ryegrass (right).



Anthracnose

Most common during heat and/or drought stress on annual bluegrass putting greens, though may occur throughout the growing season. Individual infection centers may start as small, discolored spots that range from yellow to orange to brown. As the disease progresses, the overall appearance is a general decline (left). Severe outbreaks will cause a basal rot (middle) that kills the entire plant, but often times only some leaves will be blighted. Blighted foliage typically have small spines or setae on dark fruiting bodies (right).



Leaf spot/melting out

This group of diseases may occur at different times throughout the year and affect both warm- and cool-season grasses. Irregular thinning of cool-season grasses is common in the spring (left). The leaf spot stage (middle) is most common during rainy weather in late spring, while the more damaging melting-out occurs during the summer. Leaf spot is most common on bermudagrass in early fall, during prolonged wet and overcast days (right).



Fairy ring

Common throughout the growing season on all turfgrasses. Three types of fairy ring occur: Type 1 fairy rings appear as a zone of dead grass, often with a dark green band around the perimeter (left). Type 2 fairy rings appear in rings of stimulated, healthy green grass (middle). In some instances, mushrooms or puffballs (right) may form in circles with no apparent affect on the turf (Type 3).



Red thread
Most common in spring or fall during cool, wet weather conditions. Red thread is most severe in nitrogen-deficient turf. Perennial ryegrass and fine-leaf fescues are most susceptible. Red tendrils of the pathogen appear on leaf tips (

Management of Common Diseases in Virginia:

Brown Patch (Rhizoctonia blight). This disease is the most common disease of tall fescue lawns in Virginia, but also occurs commonly on perennial ryegrass and creeping bentgrass. Brown patch is caused by the fungus, *Rhizoctonia solani*, and is most active during warm to hot, wet weather. It is of particular importance on cool-season turfgrasses that receive heavy spring nitrogen fertilization. Rapidly growing turf from over-fertilization will increase the severity of disease. Best management practices to reduce the likelihood and severity of brown patch include applying low to moderate nitrogen rates during active growth, well-timed irrigation to reduce leaf wetness periods, and improving surface drainage. Moderate outbreaks of brown patch may be unsightly for several weeks, but typically do not cause extensive long-term damage. However, large stands of turf may be killed during prolonged severe epidemics. Numerous fungicides are available for suppression of the disease. Strobilurin fungicides, such as azoxystrobin (active ingredient), are particularly strong at controlling brown patch. Fungicide resistance by the causal organism is highly unlikely, though label recommendations for resistance management should always be followed.

Dollar Spot. More money is spent on fungicides for control of dollar spot than any other disease. This disease generally occurs from late spring through early fall. Dollar spot is caused by *Sclerotinia homoeocarpa*, and can occur on most turfgrasses, beginning in the spring during the first warm, moist periods of the season and may continue into late fall. The cotton-like web of the fungus (mycelium) is clearly visible early in the morning when dew is present. Leaves of higher-cut grasses will have characteristic hour-glass shaped lesions that may cause a girdling effect. Straw-colored patches may range from 1-3 inches to several feet. This disease is often an indicator of low nitrogen fertility, but do not excessively apply nitrogen because it can increase the likelihood of other diseases and negatively affect the root to shoot ratio. It is

important to note that applications of nitrogen will not cure the disease, but allows the plant to "out grow" the disease. Limited infections do not usually cause massive turf loss, but the plant can be weakened such that it is subject to environmental stress later in the summer. Plants that have been stressed by drought become more susceptible to this disease. Dollar spot severity can be significantly reduced by shortening leaf wetness periods. As discussed before, this can be accomplished by completing irrigation just before sunrise or by running a hose over the field while the dew is still present. There are a number of products labeled for the control of dollar spot, with several SDHI or DMI chemistries having the longest residual. In addition to synthetic chemistries, some bio-fungicides are available for suppression of dollar spot during low disease pressure situations, but can not act as a stand-alone fungicide during periods of heavy disease pressure.

Spring Dead Spot (SDS). This is the most common and destructive disease of bermudagrass, and is caused by three species of *Ophiosphaerella*. Two of the species are prolific in Virginia (*O. korrae* and *O. herpotrica*), and play an important role in successful management of SDS. It has also been found on zoysiagrass in Virginia, though less common. As the name implies, the symptoms appear in the spring as bermudagrass emerges from winter dormancy. However, the disease is caused by a soil - borne fungus that attacks the turf's root system in the fall, with no evidence of damage until spring. For this reason, curative fungicide applications in the spring are ineffective. Cultural and chemical management of this disease requires a long-term commitment, as acceptable suppression in a single year is unlikely. Raising the mowing height and ensuring adequate potassium nutrition should aid in reducing disease pressure. Avoiding high nitrogen applications in late summer and early fall can also reduce disease severity. The use of nitrogen throughout the season can impact SDS epidemics, but the source is dependent on causal agent. SDS caused by *O. korrae* can be reduced over time with calcium nitrate, while *O. herpotrica* is reduced with ammonium sulfate N sources. Current research at Virginia Tech is addressing geographic distribution of each species listed above. Core cultivation is recommended when thatch accumulation exceeds one-half inch, as the disease tends to be more severe.

Large Patch. Large patch is caused by the same fungal pathogen, *Rhizoctonia solani*, as brown patch. However, occurrence of large patch is during the spring and fall on warm season grasses as they break or approach dormancy. Zoysiagrass is most frequently affected by large patch, but it may also develop on bermudagrass or St. Augustinegrass in Virginia. Cultural practices mentioned above for suppressing brown patch will also aid in large patch management. Avoid heavy doses of readily available nitrogen in the spring or fall. Improve low-lying areas with poor surface drainage by diverting water away or by installing subsurface drainage. Curative fungicide applications may stop the growth and development of disease, but recovery will be slow in affected areas, especially on zoysiagrass. In areas with a history of large patch,

management decisions to address the cause should be made where appropriate. Preventative fungicide applications should be made in the fall when canopy temperatures are consistently between 65-75°F.

Pythium Blight. This disease can cause destruction on most warm- and cool season turfgrasses. Pythium blight typically occurs on cool-season turf in the summer, when relative humidity is high and nighttime temperatures do not drop below 68 degrees. Warm-season grasses may be impacted in early fall during extended periods of rainfall, especially when temperatures are still relatively warm. In the early morning while dew is still present, the leaves of diseased plants may become covered with white, strands of mycelial growth of the pathogen. By mid-morning, the white mycelium typically fades to a smoky gray, and becomes less visible as the day progresses. The disease is spread by mowers and equipment, shoes, or water flow. In many cases, the pattern in which the disease was tracked is quite obvious because of the damage. At early stages of disease development, this can easily be mistaken for dollar spot. Control options for the diseases are drastically different, so it is important to accurately determine which disease is present. Studies at Virginia Tech have shown that Pythium blight can be effectively suppressed with several fungicides and phosphite products.

Gray Leaf Spot. While most leaf spot diseases are considered more of a nuisance than a problem, gray leaf spot can be very destructive over a short period of time. Perennial ryegrass and tall fescue are particularly susceptible to gray leaf spot, caused by *Pyricularia grisea* . This disease is most severe when night temperatures exceed 70°F. On perennial ryegrass, numerous, tiny pin-point lesions may be seen on the leaves. The gray spots on perennial ryegrass leaves are sometimes round to oval and are often surrounded by a brown or yellow border. Affected leaves often are twisted and curl into the shape of a fishhook. As this disease is most impacted by excessive moisture, strategies to reduce leaf wetness are the most important best management practices. Due to the nature of this pathogen, there is a high risk of developing resistance to several classes of fungicides, such as QoI, benzimidazoles (thiophanate-methyl), and DMI . While rotating classes of fungicides will not completely prevent resistance, it will reduce the rate in which resistance develops.

Leaf Spot & Melting Out. There are a number of leaf spot diseases that occur on various turfgrasses. In fact, every species of grass is affected by at least one leaf spot disease. Disease development of this group occurs most frequently during rainy periods or when dense fogs are present for long periods of time. The diseases in this group that are most common in the Transition Zone include Melting out of Kentucky bluegrass (*Drechslera poae*), *Bipolaris* leaf spot (*Bipolaris sorokiniana*), Net blotch (*Drechslera dictyoides*), Zonate eyespot (*Drechslera gigantean*), and leaf blotch of bermudagrass (*Bipolaris cynodontis*). As the name implies, the symptoms of most leaf spot diseases are dark, water-soaked lesions that appear first on the

leaves. If the fungus only attacks the leaves, it is more of a nuisance than a serious pest. However, pay attention that the disease does not progress into a stem blight that ultimately attacks the growing points. This phase of the disease is often called "melting out". Note again that leaf spot diseases are typically considered "nuisance" diseases – something to notice and pay attention to, but rarely to treat. However, if their infections are severe, they can possibly lead to turf damage later in the summer when environmental conditions are more stressful. With each leaf spot disease, there are no visible signs of the fungus that can be seen with the naked eye. For proper diagnosis of a leaf spot disease, microscopic identification of the fungal species by a plant diagnostic lab is recommended. Most leaf spot diseases are more severe when high amounts of nitrogen are available for plants. Heavy applications of readily available nitrogen should be avoided from late spring through the summer. If applications of nitrogen are needed during this time of year, "spoon feeding" with water soluble forms more frequently will limit the severity more so than less frequent applications at higher nitrogen rates.

Fairy Ring. Fairy rings may be present in any turfgrass stand, and are not impacted by the species. This is because the cause of fairy rings has no direct activity on the plants, unlike with most other diseases. Fairy rings are caused by a group of basidiomycete fungi, which sometimes develop mushrooms or puffballs. Fungi that cause fairy rings survive by feeding on organic matter, which releases nutrients to the turf. There are three types of fairy rings that may be present in turfgrass stands. Type 1 is not the most common, but does represent the most destructive fairy rings. Type 1 fairy rings have a zone of dead grass, but may have an outer ring of stimulated growth. Initial stages of Type 1 rings are circular rings that appear drought stressed or fertilizer burned. Many notice circles of stimulated growth in turfgrass, with no other symptoms. This is a Type 2 fairy ring. Type 2 fairy rings can often be masked with light nitrogen or iron applications. Type 3 fairy rings do not have a noticeable zone of stimulated growth, but rather have a circle of fungal fruiting bodies (mushrooms or puffballs). Chemical applications are typically ineffective, since the fungus does not have any direct contact with the plants. Mycelium grows throughout the upper soil and thatch layers, making direct contact with active ingredients less likely.

Red Thread. The disease is most common from late winter through spring, but may occur at any time during the year during periods of prolonged leaf wetness. Red thread is easy to diagnose by the presence of thin, coral-pink to red thread-like structures at the terminal portions of leaves. Red thread can be found in patches, ranging from a few inches to several feet in diameter. When conditions remain favorable for long periods of time, the entire patch may appear red, due to the growth of the pathogen over the entire leaf blades. It is important to note that red thread affects only above ground portions of the plant, typically resulting in a full recovery by the plant as the pathogen becomes inactive. The disease is most severe on turf managed under low nitrogen fertilization. The application of readily available forms of nitrogen

can limit the damage caused by these diseases, while also allowing for more rapid recovery. Fungicides are typically not warranted for managing the disease since it does not attack the terminal parts of the plant, but several are available if symptoms are unacceptable.

Pest Management Guide (PMG)

For the latest information on chemicals control options, please consult the Virginia Cooperative Extension PMG web site: Horticultural and Forest Crops:

http://pubs.ext.vt.edu/456/456-017/456-017.html

(From the homepage, go to the attachments column on the right-hand side and select: "Turf (full section) (PDF)" or "Turf: Diseases (PDF)".

When applying any pesticide, always read and follow all label instructions.

Chapter 12. Principles in Sprayer and Spreader Calibration

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Source and Application Method Considerations

After determination of the source and form of nutrients that best fit the situation, it is necessary to have an accurate assessment (size, surrounds, plant materials etc.) of the area planned for fertilization. Square footage of areas can generally be calculated by assessing site characteristics for typical shapes and using some basic geometric formulas for the different shapes detailed in Figure 1 to calculate square footage. For instance, using the formula for the circle below, one could calculate the square footage of an area of a circular courtyard having a diameter of 25 ft as having a total square footage of $3.14 \times (12.5)^2 = 490.6$ sq ft.

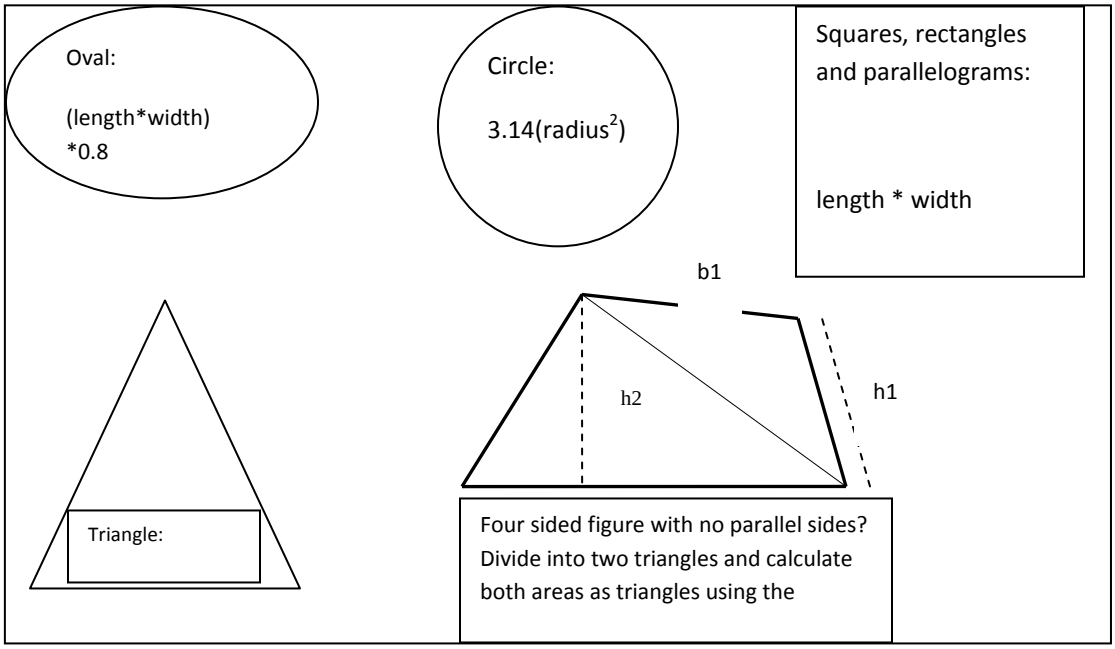


Figure 1. Mathematical formulas for calculating the square footage of various shapes found in turf and landscape management situations.

The next step to consider is the basic calculation of how much product is needed to deliver the desired amount of nutrient. The three numbers that comprise the fertilizer

grade on the label represent the percentages of nitrogen (N), phosphate (P_2O_5), and potash (K_20) by weight, and the label will list any other nutrient contained within the fertilizer on a percentage by weight basis as well. Fertilizers are available in either dry or liquid formulations. First consider dry formulations and their standard delivery methods. For dry formulations, the percentage of each nutrient by weight will be indicated in the guaranteed analysis section. To determine the amount needed for a given area, use the following basic formula (and note that N is generally used since it is usually the most limiting nutrient).

$$\text{Pounds fertilizer per area} = \frac{\text{lbs N needed per area}}{\text{N from fertilizer formula as a decimal (i.e. the number divided by 100)}}$$

Example: Using a 16-4-8 fertilizer to supply 1 pound of N per 1000 square feet gives:

$$\text{Pounds fertilizer per area} = \frac{\text{1.0 lb N per 1000 sq ft}}{0.16}$$

$$= \text{6.25 lbs of fertilizer per 1000 sq ft}$$

Since the numbers on the fertilizer grade represent their percentage by weight, then the amounts of P_2O_5 and K_2O that would be delivered to the area would be 6.25 x 0.04 = 0.25 lbs of P_2O_5 (phosphate) per 1000 sq ft; 6.25 x 0.08 = 0.5 lbs of K_2O (potash) per

1000 sq ft. Notice that the proportion of the nutrients remains constant. A 16-4-8 product has a 4-1-2 proportion of N-P_2O_5-K_2O.

Product requirements for larger or smaller areas can simply be made by using standard proportions. For instance, the basic algebraic steps of "cross multiply, divide, and solve for the unknown' are a popular way of performing fertilizer calculations. For example, for the proportion of 1/2 = Y/4; cross multiplying results in (4 x 1) = (2 x Y) or 4 = 2Y; dividing each side by 2 results in Y = 2. Apply this same proportion concept to fertilizer calculations with the only requirement being that the units in the numerators (top number in the proportion) and the denominators (bottom number of the proportion) must match. Assume the goal is to deliver 1 lb N per 1000 sq ft to 10,000 sq ft of area with the 16-4-8 fertilizer previously considered. The previous calculation determined that 6.25 lbs of 16-4-8 total are needed to deliver a desired level of 1 lb N per 1000 sq ft to the 10,000 sq ft area. Carefully keeping the proportion rules for similar units in numerators and denominators in place, the basic proportion is:

$$\frac{6.25 \text{ lbs } 16\text{-}4\text{-}8}{1000 \text{ sq ft}} \times \frac{? \text{ lbs } 16\text{-}4\text{-}8}{10{,}000 \text{ sq ft}} \rightarrow 62{,}500 :: ?1000 \rightarrow ? = 62.5 \text{ lbs of } 16\text{-}4\text{-}8$$

Drop spreader calibration

Drop spreaders (Figure 2) allow granules to drop out of a hopper by gravity and provide the most accurate distribution as the material falls directly below its release point. Wind is of minimal concern with distribution uniformity, but applications take longer since only limited areas are being covered in a single pass. Drop spreaders are preferred when applying very fine material, a mix of nutrients of differing sizes, and are ideal to use around impervious surfaces as a means of ensuring product is kept off the hardscapes. To calibrate the spreader, you will need to collect and weigh the amount of product actually dropped in a known area at a given spreader setting. It is strongly recommended to apply material at ½ the desired rate in perpendicular directions to



Figure 2. A typical 3 ft wide drop (gravity-fed) spreader.

reduce the possibility of skips and to avoid fertilizer application disasters such as shown in Figure 3.



Figure 3. Striping is evidence of either a poorly calibrated drop spreader or an inexperienced operator that did not properly apply the fertilizer.

Steps in Drop Spreader Calibration

1) Determine a known area for the calibration: Measure the width of your spreader (ft) and the distance (Figure 4) you will walk during the calibration process. For this example assume a 2 ft wide spreader (drop width, not overall width of spreader) and plan on walking a 50 ft length for a calibration area of 2 ft x 50 ft = 100 sq ft.



Figure 4. Set a known distance for calibration.

2) Prepare a collection device: A huge time saver in calibrating a drop spreader is to hang a 'catch pan' from the base of the spreader frame to collect all product that falls through the hopper. A catch pan

made by cutting an appropriate length of 4 inch diameter PVC pipe and fitted with two end caps is shown in Figure 5. An alternative method to collect product is to drop the material on a piece of plastic or a clean, hard surface that can be swept to collect the product after it is dropped. (Note: for lengths greater than 10 ft, you will want to use a catch pan rather than dropping on plastic or a hard surface and collecting.)



Figure 5. A homemade catch pan made from a piece of PVC pipe.

3) Ensure normal spreader operation: Place enough of your dry product in the spreader to completely cover the base AND make sure the particle size is small enough to readily flow through the spreader. Specialty turf fertilizers generally work well, but many agricultural grade materials (for example, 10-10-10) are usually too large to flow through a drop spreader.

4) Make the calibration "run": Select a low to medium setting on the spreader (Figure 6). Begin walking a few paces behind the calibration starting point in order to establish a consistent speed. Open the spreader as you reach the starting point and walk the desired, known length. Collect the product in the catch pan, sweep it up off the hard surface, or collect it off the plastic, and place in a container of a known weight.



Figure 6. Adjusting the setting on the spreader will increase or decrease the size of the openings at the base of the spreader.

5) Weigh the product (Figure 7) and calculate the amount of product (total weight minus weight of the container) being delivered per unit area. If the amount delivered does not match the amount you are trying to apply, adjust the spreader setting and repeat the calibration steps until you collect the desired amount. Note: one of the biggest limitations when using a small area for calibration is the accuracy of the scales. Accurate calibrations are possible in small areas with very precise scales as

pictured in Figure 7, but if one desires to use standard scales from around the house, the calibration area (and therefore the amount of product collected) will have to be much larger.



Figure 7. Scales that measure in units of ounces or grams allow for accurate spreader calibration on relatively small areas.

Example: The fertilizer selected for application is a 6-2-0 organic material (containing 6% N, 2% P_2O_5, and 0% K_2O by weight). The desired level of application for this slowly available N source is 1.5 lbs of N/1000 sq ft, so the formula is 1.5 ÷ 0.06 = 25 lbs of 6-2-0 fertilizer required per 1000 sq ft. The spreader is 2 feet wide (and is equipped with a catch pan) and a length of 25 ft has been measured, resulting in a 50 sq ft calibration area (25 ft in length x 2 ft drop spreader width = 50 sq ft of area covered in a single pass). The set-up for the proportion is:

$$\frac{25 \text{ lbs. of 6-2-0}}{1000 \text{ sq ft}} \quad X \quad \frac{? \text{ lbs of 6-2-0}}{50 \text{ sq ft.}} \quad \rightarrow \quad 1250 = 1000? \quad \rightarrow \quad ? = 1.25 \text{ lbs of 6-2-0}$$

Continue to adjust the setting on the spreader until 1.25 lbs of 6-2-0 is collected (or, if desired to work in ounces or grams the calculations will be 1.25 lbs x 16 oz per lb = 20 ounces of the product, or 1.25 lbs x 454 grams per lb = 567.5 grams) during the calibration run.

To avoid skips in application, it is recommended to calibrate for a ½ rate, and make two perpendicular passes over the treatment area in order to improve application uniformity. Therefore the calibration for a ½ rate application that will be made in two directions would be 1.25 ÷ 2 = approximately 0.63 lb of 6-2-0.

Broadcast (rotary) spreader calibration.

Broadcast spreaders (Figure 8) deliver product by dropping a dry granule onto a spinning impeller. The spread pattern of a broadcast spreader is not as precise as a drop spreader but it is usually the preferred means to rapidly deliver fertilizer to a large area. A consistent walking speed is important to optimize uniform delivery and wind is much more of a concern for distribution uniformity, especially with light weight materials. The potential for materials landing on hardscapes is much greater with broadcast spreaders due to the wide throw of the materials in the spread pattern. Particular care needs to be taken when using these spreaders near sidewalks, streets etc. to ensure product does not land on hardscape, and potentially end up in a nearby water source. Many of these spreaders have deflector attachments that should be employed around hardscapes to minimize the potential for fertilizer ending up on the hard surfaces; however, even when deflectors are used, the site should be inspected after application and product swept up or blown back into the turf. Spreading mixed materials of different sizes can be a problem since larger, heavier, particles are thrown farther than smaller particles, thus reducing even distribution of nutrients. As with drop spreaders, application uniformity can often be improved by applying ½ rates in two directions (detailed below).



Figure 8. A broadcast spreader can hold relatively large volumes of fertilizer and is a useful tool to rapidly apply granular fertilizers to large areas.

<u>The Steps in Broadcast (Rotary) Spreader Calibration</u>

1) Ensure the spreader is operating normally: Place enough product in the spreader to completely cover the base of the spreader.

2) Determine uniformity and the effective spreader width (ESW): Product can be propelled 15 feet or more in a semi-circle around the spreader, with the amount delivered decreasing with distance from



Figure 9. Fertilizer catch pans are being placed at regular intervals in order to determine the effective swath width fertilizer distribution.

the spreader. It is important to know how the spreader distributes product. Use catch pans (inexpensive aluminum baking pans as pictured in Figure 9) spaced uniformly every two to three feet from the center of the spreader, and perpendicular to its line of motion. Depending on the size of the spreader, anticipate product spread distance to range from 12 to 20 feet. Begin walking a few paces behind the calibration starting point in order to establish a consistent walking speed prior to opening the hopper (Figure 10). Open the spreader in time to distribute product across the catch pans and close it as soon as you pass the line of pans.

3) Collect results: Collect the fertilizer that is captured in each pan and place the product in small clear cups or tubes to make a visual evaluation of the spreader pattern (Figure 11). Be sure to keep the samples in the same order - by distance from the spreader – as the pans. The desired distribution for a standard application should be essentially a "bell-shape" pattern, with the largest amount of product in the middle catch pan, and uniform amounts extending away from the center.



Figure 10. Establish a consistent walking speed prior to fertilizer delivery in the calibration run.

4) Evaluate spread pattern and determine ESW: By visually evaluating the fertilizer collected from the catch pans the ESW can be determined as being that distance where the fertilizer product is approximately 50%.of the total collected from the center catch pan. Using the example in Figure 11, that point occurs at approximately 6 ft, so in this example, the ESW is 6 ft on either side of center, for a total ESW of 12 ft. The application strategy will be to overlap distribution by 6 feet in order to uniformly achieve 100% coverage. If the distribution is not uniform, the spreader might need an adjustment or repair, or the non-uniform distribution will have to be accounted for in the delivery of the product. Note that

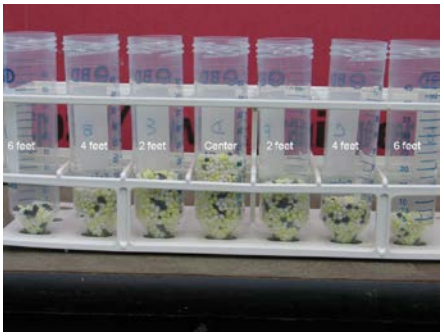


Figure 11. The collection of fertilizer from catch pans on 2 feet spacing from the center demonstrate an effective spreader width of 12 feet in this example.

some professional spreaders intentionally have adjustments and/or shields to deflect granular products from being discharged in a certain direction (e.g. in order to restrict fertilizer from being thrown onto a hardscape).

5) Calibrating weight delivered: Now that the ESW and the overlap width of spread are known, the spreader will be calibrated to determine an appropriate setting to deliver a desired amount of material. The use of a 'collection bag' (Figure 12, an attachment that encloses the impeller and captures the product as it is being delivered) greatly speeds the calibration process, and prevents product from repeatedly being delivered to an area during the calibration run. Consider the goal in this example is to deliver a total of 1 lb N/1000 sq ft using urea (45-0-0). If possible, perform the calibration using a calibration run length that results in 1000 sq ft of coverage. If the ESW is 12 feet, then the desired calibration length is 83.3 ft (1000 sq ft ÷ 12 ft ESW = 83.3 ft length). If 45-0-0 (urea) is the fertilizer of choice, the formula for how much product is needed is (1 x 100) ÷ 45 = 2.2 lbs urea needed per 1000 sq ft to deliver 1 lb N per 1000 sq ft. Set the spreader setting to a low to medium range, establish a comfortable, repeatable walking speed that is initiated several feet before the beginning of your calibration course, and collect fertilizer in the collection bag over the 83 ft distance. Weigh the material collected and adjust the spreader setting up or down depending on the amount collected. Repeat the process until approximately 2.2 lbs urea are collected. Just as for drop spreaders, the uniformity in distribution can be improved by applying the fertilizer in two directions. If this strategy is employed, then the calibration run would collect 1.1 lbs urea (one-half the full rate).



Figure 12. This rotary spreader is equipped with a 'collection bag' to capture all the granular product that is applied during calibration.

In the absence of a 'collection bag' it is possible to simply weight out a known amount of fertilizer to place in the hopper, apply product to a length of at least 25 feet, and then determine how much fertilizer remains in the hopper in order to determine the level of nutrient applied. For instance, 2 pounds of urea is placed in the fertilizer hopper with a previously determined ESW of 12 feet and a calibration run length of 25 ft. The total area covered in a single pass is 12 ft x 25 ft = 300 sq ft. It was previously determined

that 2.2 lbs urea per 1000 sq ft was required to deliver 1 lb N per 1000 sq feet. The proportion would be:

$$\frac{2.2 \text{ lbs } 45\text{-}0\text{-}0}{1000 \text{ sq ft}} \text{ X } \frac{? \text{ lbs } 45\text{-}0\text{-}0}{300 \text{ sq ft}} \rightarrow 660 :: ?1000 \rightarrow \begin{array}{l} ? = 0.66 \text{ lb} \\ \text{of } 45\text{-}0\text{-}0 \end{array}$$

Choose a low spreader setting, apply the fertilizer over the 25 ft calibration run length, and collect and weigh the remaining fertilizer in the hopper. If 2 lbs of urea was placed in the hopper before the application, then the desired amount remaining in the hopper is 2 lbs – 0.66 lbs = 1.34 lbs urea. Repeat the process until you determine the appropriate spreader setting. The obvious disadvantage of this method is the application of product during the calibration area.

Another method is to apply the dry product to a clean paved area where the product can be collected by sweeping after delivery. Again, determine a suitable length based on the ESW (of course, having to sweep up product over an 83.3 feet length is quite labor intensive, therefore, a shorter length is typical, but some precision in calibration is likely sacrificed). Apply the product, collect it with a broom and dust pan, and weigh to determine a rate of product per unit area covered in the calibration run. Since all the product is collected, it is not necessary to start with a known quantity. As before, keep adjusting the spreader settings until the appropriate amount of product is delivered per unit area.

Finally, a fourth method of delivery that actually does not involve calibration is what is sometimes referred to as the 'exercise method'. For this method, divide the lawn up into logical areas of known square footage. Next, weigh precise amounts of fertilizer to cover that known area. For instance, if an area measures 5000 sq ft and the goal is to deliver 2.2 lbs of urea per 1000 sq ft (i.e., 1 lb of N per 1000 sq ft), then 11 lbs of urea are needed for the lawn based on the following proportion:

$$\frac{2.2 \text{ lbs } 45\text{-}0\text{-}0}{1000 \text{ sq ft}} \text{ X } \frac{? \text{ lbs } 45\text{-}0\text{-}0}{5000 \text{ sq ft}} \rightarrow 11{,}000 :: ?1000 \rightarrow \begin{array}{l} ? = 11 \text{ lbs} \\ \text{of } 45\text{-}0\text{-}0 \end{array}$$

Weigh 11 lbs of urea and place it in the spreader. Select a very low spreader setting and cover the lawn in multiple directions until the spreader hopper is emptied. No calibration is required, but the only way to ensure uniform spread is to get plenty of 'exercise' covering the lawn in multiple directions, delivering small amounts of product. This method is very suitable for someone infrequently fertilizing small lawn areas, but obviously is not an efficient use of time for professional applicators that are potentially fertilizing several acres per day.

Spread Patterns

The spread pattern with a rotary spreader will never be completely uniform because of the variability in spread due to wind, speed, equipment operation, and for some fertilizers, the different sizes and weights of particles. To manage the non-uniformity of spread, most textbooks suggest calibrating the spreader to deliver ½ the desired rate of product and apply the product in two passes at right angles to each other, while other published information suggests that similar (if not better) delivery results can be obtained by applying granular products at ½ application rates in a parallel delivery pattern (Figure 13).

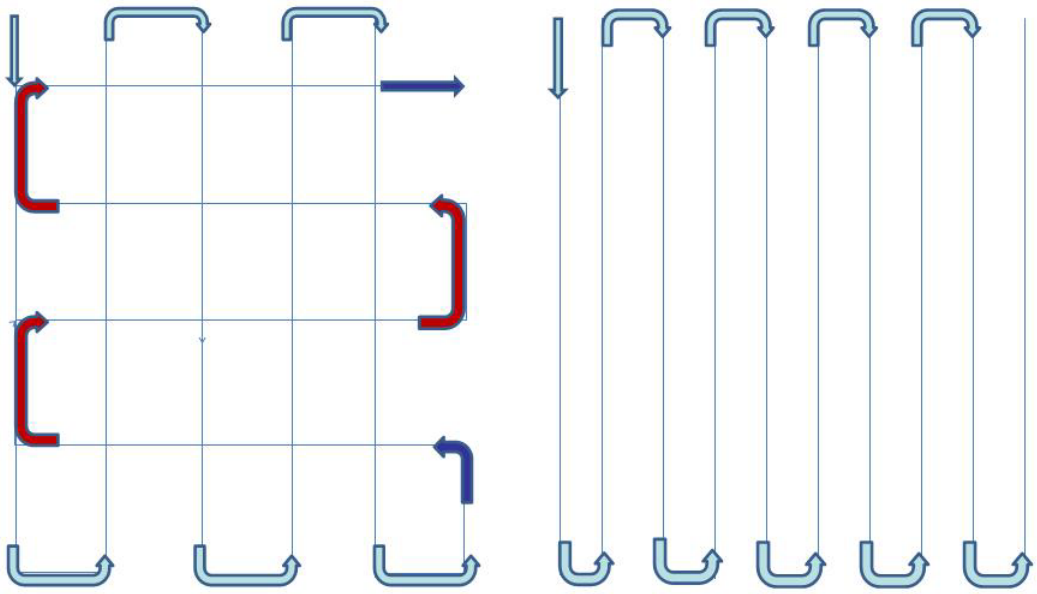


Figure 13. Standard right-angle application method (left) and the overlap delivery method (right).

Final thoughts on spreader calibration

Several national lawn product retailers sell spreaders specifically designed for their products. Part of the advantage of using these specialty products is the "cookbook" nature

of the application instructions. However, it is still wise to use their recommended settings only as guides for beginning your own calibration steps rather than taking the suggested spreader settings and application levels as guarantees. Not all spreaders deliver product alike, and over time (and with use) spreader performance is likely to change. Record all information involved in calibration steps (amount and type of product, spreader settings, etc.) for future reference. This will make future calibrations that much quicker and easier.

Liquid fertilizers and sprayer calibration

Many specialty products are marketed as liquid formulations that quickly go into solution or are easily suspended in water. Many micronutrient formulations are sold as chelates, organic forms of the nutrient that are in a liquid formulation. Also, several common granular forms of fertilizers are highly water soluble and can be quickly dissolved in water to make their own 'spray solution', while others are quite insoluble and unsuitable for liquid feeding. . Before adding different fertilizers and/or pesticides to a tank, check the label very carefully for specific comments regarding tank mixing and/or conduct a test of the compatibility of the two products by adding small, proportional amounts of the products that simulate what will be added to the spray tank. If the product blends into a uniform solution, mixing in the tank should be fine. If the combination becomes a sludge-like consistency, tank-mixing should be avoided.

Sprayer components

All spray systems will have a tank, a pump, a boom, nozzles, and sprayer tips. The system will logically be mobile, whether it is by way of someone walking or a motorized vehicle. While it is beyond the scope of this book to provide exhaustive detail on all these components (the reader is recommended to review Grisso et al., 2009, *Fine Tuning a Sprayer with "Ounce" Calibration Method* detailed at the end of this chapter), there are some basic details about the sprayer components where general details will suffice in obtaining accurate calibration. The pump is used to create pressure (whether the pump is powered by hand or an engine) and it is important that the pressure is optimal for the



Figure 14. Evaluating nozzle and tip performance prior to calibration is easily accomplished by spraying water on a road or driveway to evaluate boom nozzle height and overlap.

system and the product, and that it is consistent and repeatable. Most products will have recommended pressure and spray volume recommendations on their labels.

Next, choose an appropriate nozzle and tips for the system and the application. Again, this information is usually provided on the product label or as a recommendation provided by the sprayer system and/or the nozzle and tip supplier. True foliar feeding of nutrients that are intended to primarily enter a plant through the leaves is accomplished with spray volumes of 45 gallons per acre or less. In other situations where a liquid fertilizer might be mixed with an insecticide intended to enter the soil in order to control a ground-borne pest, the recommended volume of liquid delivery might be 100 to 200 gpa. Other factors to consider when selecting and optimizing the use of nozzles and tips for multi-nozzle booms (often used in golf turf management) are their appropriate spacing and height off the ground. Some tips require up to 33% overlap of the spray pattern to ensure 100% coverage. The manufacturers of the nozzles and tips provide helpful charts for these criteria, with much of the information being available on the world wide web.



Figure 15. The basic equipment needed for sprayer calibration.

Routinely check the system and its components to ensure proper working condition. Check that hoses and fittings are securely attached, nozzles and tips are not clogged, and that spray pressure generated by the pump is constant. A great place to run a preliminary inspection of the system is to conduct a sprayer test by applying water on a driveway or parking lot that makes it easy to evaluate that boom height, nozzle selection, and nozzle spacing are all appropriate to provide uniform application (Figure 14). After this initial check, gather all the equipment you will need for the calibration: a stopwatch, a measuring tape or wheel, flags to mark your course, and containers to collect and measure the liquid discharge (Figure 15).

The 'Ounce' Calibration Method

This method of calibration is very popular because it eliminates a lot of the math in the calibration calculations. Since a gallon equals 128 ounces, if a sprayer is calibrated on an area of 1/128th of an acre (1/128th of an acre equals 43,560 sq ft ÷ 128 = 340 square feet), then the ounces collected during calibration equates to gallons per acre.

Begin by measuring the nozzle spacing on the boom (Figure 16) as this determines the course length required to cover 1/128th of an acre. For example, with a 20 inch nozzle spacing as depicted in Figure 16 (20 inches equals 1.67 ft) the calculation will be 340 sq ft ÷ 1.67 feet nozzle spacing = approximately 204 linear feet (see Table 1 for course lengths based on standard nozzle spacing). When calibrating a single nozzle as for a hose-end or backpack sprayer, determine the spray width (in feet) for the single nozzle and divide this into 340 sq feet to determine the course length for calibration.



Figure 16. Nozzles must be equally spaced on the boom according to manufacturer recommendations.

Table 1. Course Lengths Required to Calibrate 1/128th of an Acre (i.e. 340 sq ft) Based on Boom Nozzle Spacing in Inches

Boom Nozzle spacing (in.)	Course length (ft)
12	340
16	255
20	204
24	170
28	146
32	127
36	113
40	102

If the boom has 20 in. nozzle spacings then table 10.1 indicates that a course length of 204 ft is required to cover 1/128th of an acre. Fill the tank at least half way with water, determine an optimum speed for the terrain and product delivery (usually 3 to 4 mph), set the power take off (PTO) at an appropriate rate of rpm's for the pump to deliver the desired pressure and volume of spray solution, and operate the sprayer system as if product is being applied. Be sure that the test course terrain is comparable to the area that you will be treating so that your calibration run equates well with the actual area to cover. Time how long it takes to travel the 204 ft for this particular spray system set-up.



Figure 17. Capture the discharge from a nozzle for the same time duration it took to drive the test course.

Then, operate the sprayer in a stationary position, capturing the discharge from a single nozzle for the time period it took to drive the 204 ft test course in this example (Figure 17). Using a measuring cup marked in ounces, what is collected in ounces simply equals gallons per acre (gpa). In the example presented, the 40 ounces of discharge collected for the known time period equates to a sprayer calibrated to deliver 40 gpa. Catch the output from at least 3 nozzles for the required duration to ensure that all nozzles are performing comparably. If a nozzle does not deliver an output that is within ± 5% of the average nozzle output, check the filter and tip to see if they are clogged and/or damaged. Replace any suspect nozzle and/or tip.

Example of of how much product to add

The label of a popular 15-0-0 liquid fertilizer that is also 4% sulfur and 6% iron by weight recommends an application range of 2 to 8 fl oz per 1000 sq ft. If 4 oz per 1000 sq ft is selected, how much is added to the sprayer system that was just calibrated in the preceding example?

If relatively large areas are to be treated it is logical to prepare full tanks of spray solution. Assume the system has a 100 gallon tank. As calibrated at 40 gpa, then a full tank can cover 100 gal ÷ 40 gpa = 2.5 acres. How many square feet are in 2.5 acres? One acre is 43,560 sq ft so 2.5 x 43,5460 = 108,900 sq feet. Using a basic proportion the setup is:

4 fluid oz product / 1000 sq ft	X	? fluid oz product / 108,900 sq ft	→	435,600= ?1000	→	? = approx. 436 fluid oz of product

436 fluid oz ÷ 128 fl oz per gallon = approximately 3.4 gallons of the 15-0-0 liquid fertilizer to be added to a full tank of a sprayer calibrated to deliver 40 gpa. To prepare a full tank, fill the tank partially with water, add the fertilizer, and then add the remaining water to bring the tank to the 100 gallon level.

What if the goal was to only cover 20,000 sq ft of area? It was just calculated that a full sprayer holding 100 gallons will cover 108,900 sq feet. There would be no point in mixing a full tank but instead, just enough to cover 20,000 sq ft. A simple proportion would be:

$$\frac{100 \text{ gallons}}{108{,}9000 \text{ sq ft}} \times \frac{? \text{ gallons}}{20{,}000 \text{ sq ft}} \rightarrow 2{,}000{,}000 = ?108{,}900 \rightarrow ? = \text{approx. } 18.4 \text{ gallons water}$$

How much fertilizer is needed to treat the 20,000 sq ft area using a 4 fluid oz per 1000 sq ft rate?

$$\frac{4 \text{ fluid oz product}}{1000 \text{ sq ft}} \times \frac{? \text{ fluid oz product}}{20{,}000 \text{ sq ft}} \rightarrow 80{,}000 = ?1000 \rightarrow ? = 80 \text{ fluid oz product}$$

Add a few gallons of water to the tank, add the 80 fl oz of fertilizer, and then fill the tank to a final volume that is approximately 18.4 gallons.

How about adding dry products or powders? Many commercially available powdered fertilizers are highly water soluble and even some bulk fertilizers materials may be sufficiently soluble to deliver in liquid form. For instance, up to 6.5 lbs of urea (45-0-0) is soluble in a gallon of water. Note that rapid mixing and even heat may be needed to speed dissolution of some materials unless dilute solutions are desired). Consider an example where the goal is to use the calibrated sprayer above to provide a nitrogen (N) level of 0.25 lb per 1000 sq feet (using urea, 45-0-0) to 20,000 sq ft of turf.

It will take 0.25 lbs N ÷ 0.45 = 0.56 lbs urea per 1000 sq feet to deliver the desired level of N. The area to be covered is 20,000 sq feet.

0.56 lb 45-0-0 / 1000 sq ft	X	? lb 45-0-0 / 20,000 sq ft	→	11,200= ?1000	→	? = 11.2 lbs 45-0-0

It was previously determined (see above) that a sprayer calibrated to deliver 40 gpa would need approximately 18.4 gallons of total spray volume to treat 20,000 sq ft. Fill the tank with approximately 9 gallons of water, add the 11.2 lbs of urea (stirring or agitating to ensure the product fully dissolves), and bring the final tank volume to approximately 18.4 gallons. The sprayer is calibrated to deliver 0.25 lb N per 1000 square feet.

Other considerations with sprayable fertilizers

Because of the high volumes applied and relatively dilute concentration of nutrients, liquid fertilizer applications are often very uniform and precise. However, you should pay very close attention to the label recommendations regarding spray volume, nozzles and tips, and the requirement for sprayer agitation. Also, be sure to record your own observations regarding sprayer performance and plant response for future reference. Watering in of many liquid fertilizers may be recommended after application to reduce leaf burn potential, or to improve uptake efficiency. Be very careful regarding the compatibility of tank mixtures of fertilizers, pesticides, and other spray additives as they can cause undesired changes in physical and/or chemical properties of the materials.

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Chapter 13. Best Management Practices (BMPs) in Turfgrass Management that Protect Water Quality

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Figure 1. The difference in water clarity and sediments coming off a grassed slope (top) versus a mulched ground cover planting bed (near) is very evident during a rainstorm event.

Turfgrasses are the only plants that can regularly tolerate intensive traffic AND mowing at cutting heights ranging from 0.1 to 4 inches. The ability of turfgrasses to tolerate traffic and regular clipping results in turfgrasses having great value in three distinct areas of use. **Recreational** turf spans the use of turfgrasses for a myriad of sports for athletes of all ages, skills, and sizes. These turfed areas range from the most renowned stadiums and golf courses in the world to your local park and recreation department fields. Don't forget that your lawn is likely a recreational area for your family as well. The second use of turf is as an **ornamental** component of landscapes. While turf is not as showy as annuals, perennials and flowering trees and shrubs, a well maintained, dense and uniform green lawn offers great value to your property and provides enjoyment and a sense of pride in the property. The third use of turfgrass is the one that gets the least attention but it is probably the most important: the **functional** use of turfgrass**.** Turfgrasses are one of the most prevalent plant systems found in urban areas of the Chesapeake Bay watershed and because turfgrass is so prevalent if it is properly maintained it can be an important plant in protecting water quality (Figure 1). The key phrase is "properly maintained" and this publication and the certification program are devoted to the strategies that promote a healthy, dense environmentally friendly turf. The fibrous root system of a turfgrass is tremendously effective in soil stabilization (aka erosion

control) and this might be the most important function of turfgrasses overall. Sod can provide instant soil stabilization and depending on how it is harvested, rapid use of the turf. The fibrous root system also serves as a highly efficient filter of chemicals in the water flowing through the soil. Turfgrasses are also known for being extremely effective in moderating temperatures (Figure 2), noise abatement, and carbon sequestration. Most of these very desirable features of the functional use of turfgrasses are overlooked when it comes to comparing the uses of turfgrass for recreational and ornamental purposes, but turfgrasses truly can be an important part of pro-environment management strategies.



Figure 2. The evapotranspirative cooling potential of turfgrass is shown in this picture (right) when compared to the surface temperatures of a synthetic rubber infill field (left) and an asphalt-paved parking lot (center). Photo courtesy of Erik Ervin.

This chapter outlines the major sources of water quality impairment that can apply to turfgrass management systems and considers a variety of BMPs in turfgrass management that can help protect water quality, that range widely in complexity, cost, and implementation. However, most of these BMPs are simple, commonsense management strategies that don't require specialized education or equipment. This chapter is not all-inclusive in BMPs but will build upon and summarize the principles presented in this

training manual and prepare you for the testing component on Water Quality, Nonpoint Source Pollution and BMPs for Water Quality Protection of the Virginia Certified Turfgrass Professional program.

Water Quality and Nonpoint Source Pollution

Protecting water quality is a vital part of our social well being, but in areas with adequate year-round precipitation, water is sometimes taken for granted. Water provides us with specific services, but a water source's quality can become impaired to the point it is unable to provide that service. We rely on water for drinking water supplies, supporting aquatic life, production of edible and marketable fish and shellfish, as well as wildlife and recreational uses including, swimming, boating, fishing and shellfish harvesting. Water quality standards were developed to protect our water sources.

Although there are many ways water quality can become impaired, one of the more common impairments is from nonpoint source pollution, especially from excess nutrients and sediments. Nonpoint source pollution occurs when rain runs off agricultural, suburban and urban landscapes and into our waterways. The runoff containing pollutants is referred to as a nonpoint source because it does not come from a single source like a wastewater treatment or industrial discharge pipe.

Excess sediment, nitrogen (N), and phosphorus (P) are three main pollutants that can impair our waters. Specifically, eroded soils (sediments) can collect in bodies of water and cause flooding issues and clouding of water during and shortly after heavy rain events. If suspended sediments stay in surface waters for extended periods of time they can also be detrimental to sub-aquatic vegetation by blocking sunlight. Small amounts of N and P are normally found in water and they help support desirable growth and development of aquatic plants and animals. However, excessive concentrations of N and P pose a water quality threat to both surface and ground waters, negatively impacting the health of plant and animal life living in and supported by those water sources (Moss et al., 2011; Pearl et al., 2001; Ruuhijarvi et al., 2001; Schmidt et al., 2012). The most common malady of these contaminated waters is **eutrophication** (Figure 3), defined as the process of changing the nutritional status of a given water body by increasing nutrient resources (Richardson and Jorgensen, 1996). When eutrophication occurs, harmful phytoplankton, known as cyanobacteria, proliferate and degrade water quality through rapid oxygen consumption (O'Niel et al., 2012).

Phosphorus plays a significant role in the eutrophication of freshwater bodies and is the primary nutrient contributing to freshwater algal blooms (O'Niel et al., 2012; Sharpley et al., 1994). While N is also involved in the eutrophication of freshwater sources, P is the



Figure 3. A pond with a serious eutrophication problem due to excessive nutrient loading.

primary nutrient of concern in freshwater situations because many cyanobacteria capable of blooming in freshwater are also capable of fixing nitrogen (O'Niel et al., 2012). Multiple genera within the diverse phyla comprising phytoplankton are capable of forming blooms, but cyanobacteria are the most problematic and widespread (Pearl et al., 2001). When excessive P levels occur and cyanobacteria are allowed proliferate, oxygen is depleted, pH changes, water clarity decreases, and adverse food chain effects occur (Sharpley et al., 1994).

Nitrogen is the primary nutrient driving damaging algal blooms in estuaries because production of biomass that sinks into bottom waters and leads to low-oxygen situations is more likely to be controlled by N than by P (Howarth and Marino, 2006). N is also a nutrient of concern in freshwater situations due to its potential to persist in ground water sources potentially used for human consumption (Goolsby and Battaglin, 2001). It is estimated two-thirds of Unites States coastal waters are moderately to severely degraded due to N pollution (Bricker et al., 1999). P has been identified to play a role in the eutrophication of estuaries as well (Malone et al., 1996), so it is important for N-control strategies go hand in hand with P-control (Howarth and Marino, 2006). However, significantly reducing N and P contamination is often difficult because water quality damage can be done by both P and N at relatively low concentrations (Sharpley et al., 1994).

Pathways of Nutrient Loss

Because turfgrasses are so prevalent in the Chesapeake Bay watershed, if they are not managed properly they can have a major impact on water quality. Improperly managed turfgrasses can be subject to excessive or poorly timed fertilizer applications and can also be seen as weak (less dense) stands of turfgrass. Improperly managed turfgrasses increase the chance that nutrients can be lost to the environment through several different pathways.

Nitrogen is considered to be very mobile because of its chemical properties and how it reacts in soil environments. Nitrogen can be lost to the environment through leaching, volatilization, denitrification, runoff and erosion. Nitrogen is found in three main forms:

Organic-nitrogen, nitrate-nitrogen (NO_3^-) and ammonium-nitrogen (NH_4^+). These forms aren't inherently bad, they simply must be managed appropriately in order to reduce their potential for moving off site. For instance, the two plant-available forms of N are the previously mentioned ammonium (NH_4^+) and nitrate (NO_3^-) forms.

Both ammonium and nitrate forms of N are subject to changing form by naturally occurring chemical reactions under specific soil conditions. These reactions can make nitrogen more available to plants in some conditions, but also more susceptible to loss under others. Nitrate nitrogen because of its negative charge (NO_3^-), and the weakly net negative charge of soils, has no attraction to soil particles and is subject to leaching below the rootzone if enough water is passing down through the soil profile. The greatest risk of nitrate leaching is when plants are not actively growing and/or when the turfgrass is being grown on a high sand content soil, either modified or naturally occurring. Nitrogen can be leached from soils particularly in winter when there is excess precipitation compared to plant needs and there is nitrate-nitrogen present in the soil that was unused from the warmer growing season.

Both volatilization and denitrification require a specific form of nitrogen to be present in specific environmental conditions. Volatilization is more likely to occur when ammonium nitrogen (NH_4^+) is applied when air temperatures are hot and the soil is dry. Under these conditions a chemical reaction can occur whereby a proton (H^+) is removed from the ammonium molecule, resulting in ammonia (NH_3) gas which is released into the atmosphere. Alkaline (high pH) surface soil conditions will increase volatilization. Denitrification occurs generally in warm soils when nitrate-nitrogen (NO_3^-) is present. Soil bacteria will reduce (remove oxygen) nitrate-nitrogen (NO_3^-) into gaseous forms of nitrous oxide (N_2O) or N_2 gas that are released to the atmosphere.

Nitrogen loss through runoff and erosion also occur in very specific situations. When water-soluble (i.e. readily available to the plant) nitrogen in the forms of NO_3^- or NH_4^+ is applied and is not incorporated (with either light irrigation or rainfall) it can be subject to runoff. Runoff from landscaped areas can occur during large rain events or during smaller events where impervious surfaces direct flow across a landscape. Nitrogen loss through soil erosion occurs when runoff passes over bare or poorly stabilized soil and soil-attached nitrogen, usually found as organic nitrogen, can also be transported to nearby waterways.

Phosphorus is generally considered to be a very immobile nutrient because soluble phosphorus, regardless of its form, readily forms insoluble compounds with aluminum, iron or calcium in the soil. Phosphorus loss by runoff and leaching is generally considered to be minimal. However, loss to the environment can still occur through erosion, runoff and leaching. In some lawn situations that have received complete fertilizers (N-P-K) for many years out of 'habit' or 'tradition', there can be such high concentrations of phosphorus in

the soil that it can leach even though it is considered to be a chemically immobile nutrient. Simply put, these soils require a soil test and it is very likely that the test results will indicate no need for supplemental P for many years.

Phosphorus loss that accompanies soil erosion is the most likely way P is transported to water sources. Soil erosion from bare or poorly stabilized soils can transport sediments and tightly bound phosphorus directly to waterways. and mainly occurs on soils that have extremely high phosphorus concentrations. Nitrogen and Phosphorus, because of their unique loss pathways, are managed differently when they are applied to the landscape. In general, nitrogen is highly mobile and very dynamic in changes in its form in the soil. To minimize N loss, the timing, placement and application rate should be closely managed. Phosphorus on the other hand is typically seen as immobile and found as an insoluble compound in soil. To minimize its loss placement should be closely managed. Only apply phosphorus when needed according to a soil test and be sure to correct any bare or poorly stabilized soil issues as they occur.

Understanding the pathways through which nutrients are lost to the environment is an important part of properly maintaining turfgrass, but there are other practices that can be implemented that can further reduce the amount of nutrients lost to the environment.

Practical use of Stormwater Best Management Practices



Figure 4. A standard lawn maintenance practice such as core aeration can be an effective way to reduce the amount of water moving across the surface of a turfed area.

A stormwater best management practice (BMP) is any action or structure that controls, conveys or treats stormwater as it moves across the landscape. A BMP can be as simple as increasing the infiltration rate of a soil so that less stormwater runs off the landscape (like core-aerating as shown in Figure 4 or adding a soil amendment) or as complex as constructing a wetland that is specifically designed to control the flow of stormwater and remove nutrients before they enter natural waterways. There are two main types of BMPs, structural and non-structural. Examples of structural BMPs are rain gardens and large stormwater detention ponds.

These practices require some level of designing and construction. Examples of non-structural BMPs are street sweeping and urban nutrient management. These practices can be easily retrofitted onto existing urban areas and although they do not reduce the amount of nutrients leaving an area as much as structural BMPs do, the potential of these non-structural BMP's to be applied to large areas can increase their effectiveness. Implementing and reporting BMPs to local governments helps Virginia meet its Chesapeake Bay nutrient reduction goals and can even help alleviate the severity and coverage of future stormwater fees and regulations that could be assessed. Contact a local watershed organization, engineering firm or local government stormwater department to find more information about designing, constructing and reporting structural and non-structural BMPs. There is one BMP that should be reported for every acre of urban landscape that is fertilized by a turfgrass professional, and that is urban nutrient management. If turfgrass is fertilized following the fertility recommendations briefly discussed in this chapter and in more detail in chapter 5, the area is eligible to be reported as urban nutrient management.

There are several ways to report this acreage depending on the area being managed. Golf courses, Virginia state-owned land and localities with a DEQ Municipal Separate Storm Sewer System Permit (usually urbanized areas with greater than 50,000 people) are required to have a nutrient management plan (NMP) written for their fertilized areas. A plan written by a Virginia DCR-certified plan writer provides a road map to a responsible fertility program that is based on soil test data. Contact Virginia DCR for more information about writing NMPs, for a list of certified planners and for information about becoming a certified nutrient management planner.

Another way acreage can be reported is through the Virginia Department of Agriculture and Consumer Services' (VDACS) Certified Fertilizer Applicator (CFA) program. The CFA training focuses on practices that keep excess fertilizer out of our surface and ground waters, which helps prevent eutrophication. CFA training is required for all contractor-applicators, state agencies, localities, or other governmental entities engaged in the commercial application of fertilizers to nonagricultural lands. Although, only contractor-applicators applying fertilizer to more than 100 acres, state agencies, localities, and other governmental entities are required to report their fertilized acreage to VDACS, reporting fertilized acreage provides the tangible data Virginia needs to receive credit for the urban nutrient management BMP and all CFA's are encouraged to report. If you are a CFA you should also enroll in DCR's Water Quality Agreement Program (WQA) to receive recognition for completing the training and implementing practices that are a major part of protecting Virginia's natural resources through proper fertilization of urban landscapes. DCR distributes information about their program across Virginia, lists participating companies on its website and provides companies with promotional logos to use as advertisement. Completing the CFA training and participating in DCR's WQA program

shows current and potential customers that you understand fertilizer plays an important role in the health of our environment and that you are taking the necessary steps to ensure only the amount of fertilizer that is needed to produce a healthy landscape is used and it is applied in a manner that limits the potential loss of nutrients to ground and surface waters.

Choose the BEST Turfgrass for YOUR Situation

One of the most important steps in optimizing the environmental benefits of turfgrasses are to select the best turfgrass for the situation. In transition zone states, there are several cool- and warm-season grasses that can be used, each with their own strengths and weaknesses. In making your selection of a 'best' turfgrass for your needs, consider factors such as location, the soil, the use of the turfgrass, how much sun/shade the site receives, the level of maintenance and inputs required for proper management, your budget, and the surrounding environment. These factors have been thoroughly discussed in previous chapters of this training manual, with chapters 1 and 2 providing the most complete information on deciding with turfgrass is best adapted for your situation. As you prepare for certification, be sure to review the adaptation and uses of turfgrasses and how these can vary depending on the characteristics previously listed.



Figure 5. Take 10 to 15 samples of 3 to 4 inch soil depths in order to accurately assess the plant available nutrient status of a soil.

Turfgrass Nutrition, Fertilizer Selection and Application.

Don't guess, soil test. There is no money better spent than for a soil test. Take 10-15 samples from a targeted area to a 4 to 6" depth (Figure 5), mix the samples in a plastic bucket, and collect approximately ½ pint for your analysis. Virginia Tech offers soil testing services (resources are readily available at all Virginia cooperative extension offices) and there is a variety of soil testing options available through private labs as well. Remember that the value of your soil test results is only as good as the sample that you submit. Avoid areas that might confound your data (previous fertilizer spills, pet 'relief' areas, spots where ashes from fireplaces are dumped etc.). Sample and test persistent problem areas separately in order to target possible causes of declining plant growth. Heavy textured soils (those high in silt and clay) will only need testing every 3-4

years. Sand-based systems should be tested on an annual basis at least. A suitable pH (usually one from 6.3 to 6.8) is key to having the required nutrients in plant available form and excesses or deficiencies in nutrients will slowly but surely lead to a reduction in turf health. As far as water quality is concerned there is one nutrient of critical importance that is reported on your soil test: Phosphorus (P). If your grass needs P it would be environmentally irresponsible to NOT apply the P, but the only way to know if P is needed is on the basis of a soil test. Conversely, if there is adequate P present according to soil tests, then applying additional P makes neither environmental nor economic sense. Excessive P increases the chances of the nutrient entering our water resources where only a few parts per billion of P can cause eutrophication a bloom of algae and cyanobacteria that is so prolific in size and numbers that it robs the water of oxygen and can result in the death of aquatic plant and animal life.

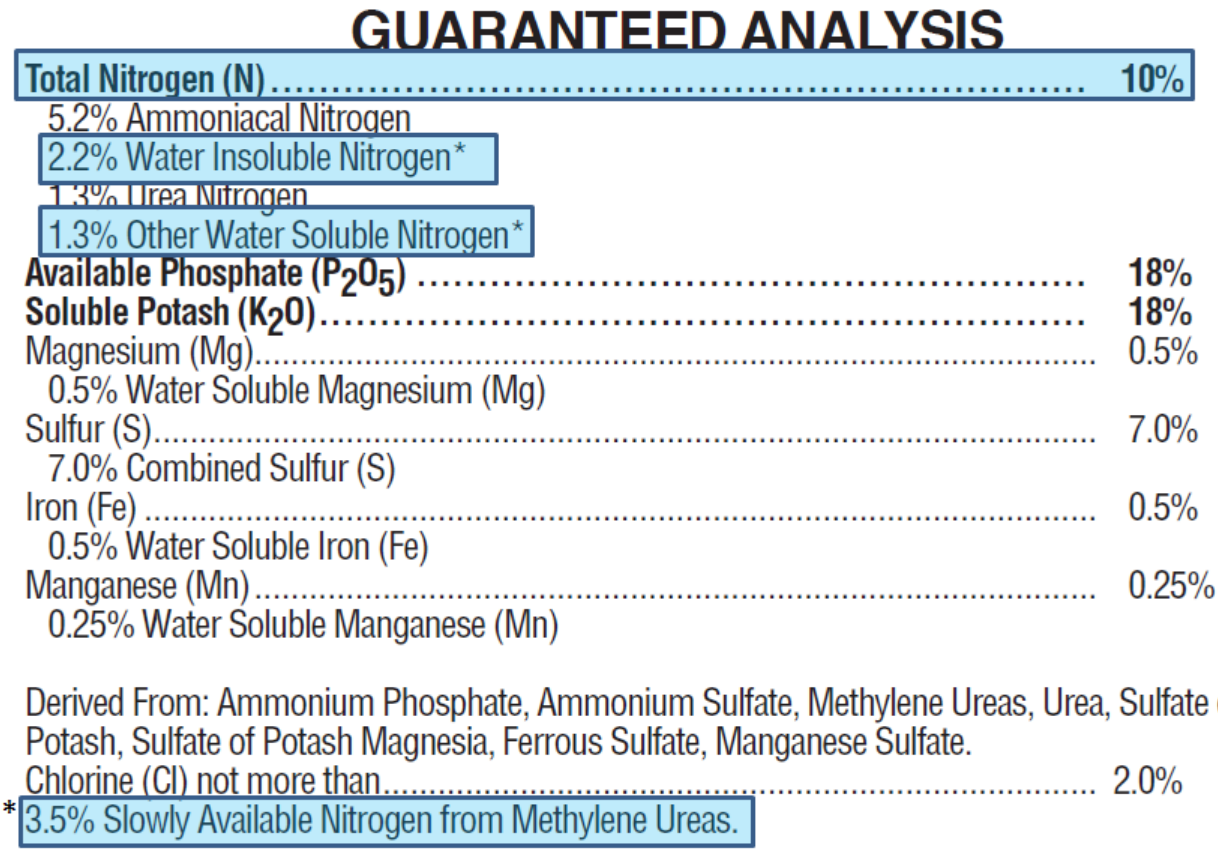
A soil test conducted in the eastern United States will likely not give you a level for nitrogen (N) because the forms of N change so rapidly in the soil in this environment that it renders the data pretty much meaningless. Soil test reports will typically provide a N recommendation based on the turfgrass and its intended use. A shady home lawn certainly has different input requirements than a high traffic sports field or a golf putting green. Each situation has a time and place where fertilizer applications are required in order to maintain a healthy turf.

For N fertility programming follow the recommendations in the Virginia DCR Standards and Criteria and Chapters 5 and 8 in this manual and match them to the grass, its use, and your situational needs for growth rate, recuperative potential, density, color etc. The specifics in fertility programming are presented in chapter 5, but the rule of thumb is that WSN levels should not exceed more than 0.7 lbs of available N per 1000 sq ft per active growing month for cool season and warm season turfgrasses. If water insoluble nitrogen (WIN) or slowly available N sources are used levels should not exceed 0.9 lbs of N per 1000 sq ft per active growing month for cool season turfgrass and 1.0 lb of N per 1000 sq ft per active growing month for warm-season turfgrasses. Note the use of the term 'active growing month' in these recommendations. In the mid-Atlantic, this generally means periods of late summer through mid-fall (the primary fertility time for these grasses) and warmer periods of spring (the secondary time for fertilizer applications) for cool-season grasses. For warm-season grasses, the optimal fertilization window is mid-spring through mid-summer. A practical way to think about timing of applications and whether or not your N application is going to have the intended response is to consider its mowing requirement: your grass is growing when it needs mowing. If there is no need to mow then there is little to no reason to provide N.

Incorporate slow release N sources into your fertility programs where they fit. The Virginia DCR Standards and Criteria defines a slow or controlled release fertilizer as a product that

contains a plant nutrient in a form that delays its availability after application compared to a soluble fertilizer product. A slow or controlled release fertilizer must contain at least 15% slowly available forms of N. See the example below for how to determine a fertilizer product's percent slowly available forms of N.

In the pictured label (Figure 6), the total N is listed as 10%. Below the total N is a list of the different forms of N found in the product and their percentages that add up to 10%. To determine what percentage of this product is slow release use the list of different forms of N to determine what percentage of total N is slowly available, be sure to pay attention to


GUARANTEED ANALYSIS

Total Nitrogen (N) 10%
5.2% Ammoniacal Nitrogen
2.2% Water Insoluble Nitrogen*
1.3% Urea Nitrogen
1.3% Other Water Soluble Nitrogen*
Available Phosphate (P_2O_5) 18%
Soluble Potash (K_2O) 18%
Magnesium (Mg) 0.5%
0.5% Water Soluble Magnesium (Mg)
Sulfur (S) 7.0%
7.0% Combined Sulfur (S)
Iron (Fe) 0.5%
0.5% Water Soluble Iron (Fe)
Manganese (Mn) 0.25%
0.25% Water Soluble Manganese (Mn)

Derived From: Ammonium Phosphate, Ammonium Sulfate, Methylene Ureas, Urea, Sulfate
Potash, Sulfate of Potash Magnesia, Ferrous Sulfate, Manganese Sulfate.
Chlorine (Cl) not more than 2.0%
* 3.5% Slowly Available Nitrogen from Methylene Ureas.

Figure 6. Designations of 'water insoluble nitrogen and 'slowly available nitrogen (SAN) from methylene ureas' in this product's guaranteed analysis indicate the N in this fertilizer is 35% slowly available N (3.5% SAN/10% total N = 35%) .

keywords such as WIN, other water soluble N, slowly available N as well as asterisks (*) and other notations (Figure 6).

The product has 2.2% WIN with an asterisk and 1.3% other water soluble N also with an asterisk. At the bottom of the label we see the asterisk note stating 3.5% slowly available N from methylene ureas. 3.5% of this product's total N is slowly available N, but further calculation is needed to determine the product's percent slowly available N (the slowly

available N was totaled on this label, but that is not always the case, it may have to be done separately). Taking the percent slowly available N (3.5%) and dividing that by the product's total N (10%), then multiplying the answer by 100 gives us the percent slowly available N for the product (35%). This calculation informs you that 35% of the N in this product is contained in a N form that delays its availability and 65% of the N in this product is water soluble.

As detailed in chapter 5, slowly available nitrogen sources can be applied at slightly higher N levels per application and they will provide steady and sustained color and growth responses and have less potential for N leaching. There is certainly nothing wrong with utilizing soluble N sources in turfgrass fertility programs as there are many times it is desired to have a quick boost in turfgrass color and growth. Intensively managed turfgrasses such as those grown on sand-based golf greens are often fertilized by spoonfeeding N on a much more regular basis in amounts ranging from 0.05 to 0.15 lb N per 1000 square feet. This level of management allows the superintendent to maintain control of their rates of turfgrass growth and their expertise and specialized equipment for delivering these very small rates (these treatments are often delivered as sprays)is the ideal way for managing such an intensively grown turf. However, for turf that receives much less attention, the steady and sustained N release from a slow release source can meet the typical needs for the situation and these sources reduce the extreme peaks and valleys in growth and color responses and greatly limits the potential for N leaching.



Figure 7. Collection pans are being used to calibrate the fertilizer delivery rate of this broadcast spreader.



Figure 8. Sweep or blow all fertilizers or pesticides back into the lawn in order to protect water quality. It is both environmentally and economically responsible.

Another critical part of successful fertilizer applications is in equipment calibration (Figure 7). Choose the best delivery method for your situation and capabilities (rotary or drop spreaders? backpack or multi-nozzle engine-powered sprayers?) and ensure the equipment is properly calibrated for the application. Calibration settings are never going to be permanent because of wear and tear on both the equipment AND the applicator! However, it only makes sense to record notes about calibration settings and use those when making periodic calibration checks on sprayers and spreaders. Utilize deflector shields on spreaders and 'sprayer skirts' on mechanized sprayers to minimize the potential of product being delivered to non-target areas. Proper calibration leads directly to improved turfgrass performance, environmental protection, and economic savings.

Fill spreaders and sprayers in designated areas for such purpose and have a response plan in place in case spills occur. The three "C's" for when a spill occurs applies in all situations: Control, Contain, and Clean. Safety Data Sheets for chemicals should always be close at hand in order to correctly address the procedures to follow in case of any spills etc. And be sure to store your chemicals, fertilizers, fuels and solvents properly and have appropriate containment systems in place that can negate potential environmental impact if spills etc. occur.



Figure 9. Grass clippings are essentially slow release fertilizer and when they are left on streets, they typically end up in stormwater drains after a rainfall event.

One of the simplest means of protecting water quality is to keep chemicals and clippings off

of hardscapes (Figures 8 and 9). This is most routinely considered when it comes to applying any type of granular fertilizer or pesticide. Sweep, blow, or brush the material back into the turfgrass. Similarly, keep clippings off of hardscapes. Grass clippings are nothing more than slow release fertilizer that can ultimately be transformed back into nutrient forms that can impair water sources. Consider where mower decks are cleaned and how that might affect water quality. If clippings are simply washed down into a drain, there is a strong likelihood for most situations that those clippings are entering the stormwater. If you don't have a containment system that collects clippings, solvents etc., then it makes sense to wash or blow clippings off of mower decks and cutting blades in grassy areas away from stormwater drains and any surrounding water sources. Collect the clippings on rinse pads and recycle or compost them rather than washing them into the storm drain.

Consider locations with moderate to extreme slope and the turf's proximity to water sources when making decisions about fertilizer sources and application strategies. Refrain from managing turfgrasses to the edge of water sources. Turfgrasses can make exceptional buffers and simply raising the cutting height of the grass an inch or so over a 15-20 foot swath adjacent to the water source can greatly reduce the potential for negative water quality impacts. Florida's turfgrass industry professionals and regulatory officials refer to this as the 'Ring of Responsibility' and it is a great management concept in protecting water quality.

Manage the soil

A healthy soil leads to a healthy turf. As indicated in the previous section, soil testing to confirm that a soil has an appropriate pH and levels of required nutrients is a great first step to improving soil health. There are billions of other microorganisms living in the soil that also respond positively to a healthy soil, with most of these microbes responsible for breaking down organic matter and returning the elements in the organic matter into nutrients for grasses and other higher plants. One of the biggest limiting factors in trafficked soil is compaction. Since turfgrasses have the unique capability of being regularly and intensively trafficked, relieving soil compaction is a great way to promote and/or maintain a healthy soil. It is not just the physical limitations of compaction that are a concern, but a lack of oxygen to drive plant and microbial respiration processes. Probe a moist soil with a screwdriver in order to 'test' its level of compaction. If you can not push the screwdriver into the soil at least 3 inches deep, the soil will likely benefit from hollow-tine (core) aeration. Consider how aerating a soil can also improve the retention of water and any sediment, pesticides and/or nutrients that might be carried by the water. A soil that is receptive to water keeps many of these potential water quality concerns at bay, so do not forget the value of aerating soils in water quality protection.

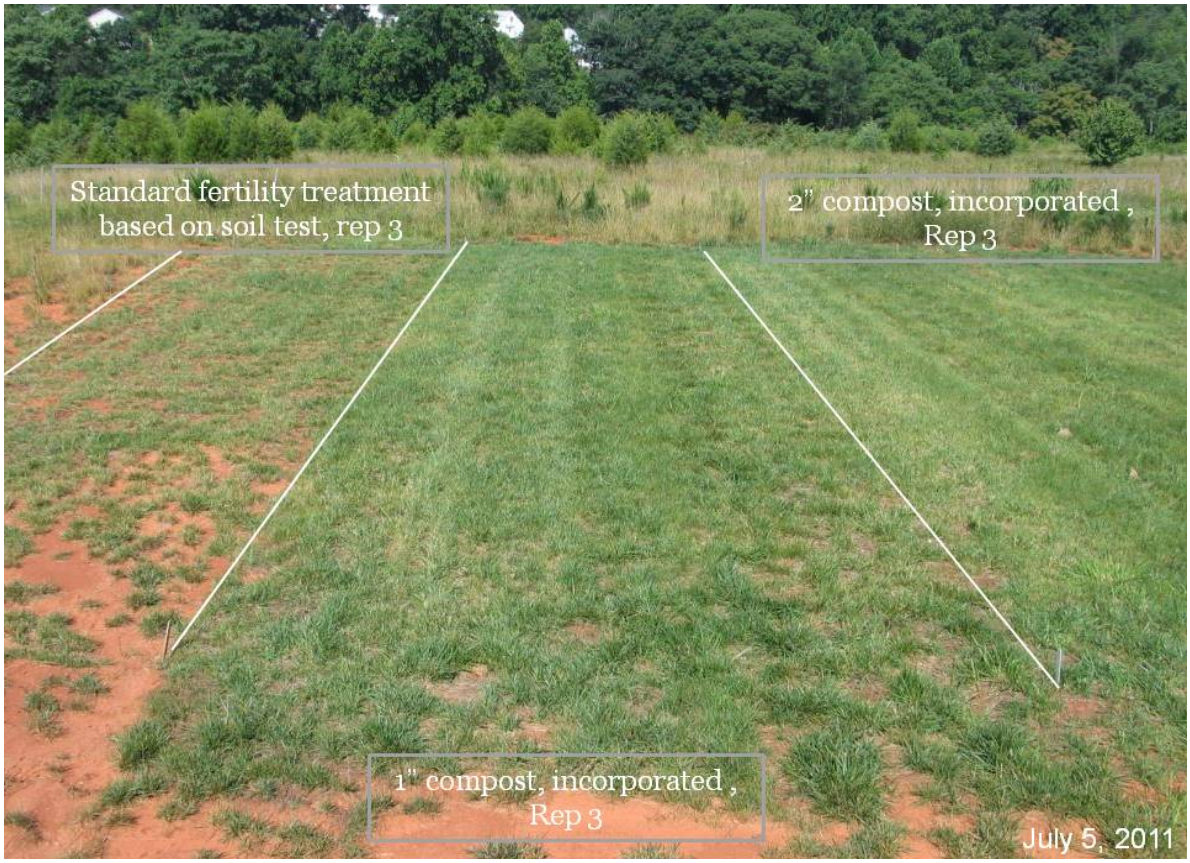


Figure 10. The improved density of a tall fescue stand from pre-plant incorporation of compost at 1" (center) or 2" (right) depths as compared to the control plot that received no compost (left).

Another strategy in improving soil health is to utilize compost as a soil supplement (Figure 10). Completely stabilized, high quality compost applied at depths of 0.25 inch one to two times per year is a great way to improve soil organic matter levels and enhance soil structure. Combining compost applications with scheduled core aeration events increases the rate of achieving the desired benefits from adding the compost. Committing to a compost topdressing (or soil incorporation program at establishment) will typically reduce the need for fertilization, supplemental irrigation, and disease and insect pressures. Be sure that you are using a high quality compost material in order to gain these benefits.

Pest Management

Consider that it is unreasonable (and often unattainable) to expect to maintain completely pest-free turfgrass systems. Such approaches typically require extensive uses of pesticides, and while pesticides are a very valuable tool in pest management, they are not intended to be a replacement for sound cultural and fertility management programs. A healthy, dense turf is very resistant to most pest attacks and can withstand most pest attacks when they

occur. This is where the concept of **Integrated Pest Management (IPM)** applies. IPM means you understand the pest and make informed decisions on strategies to manage or treat it, knowing full well that appropriate implementation of all of the standard management strategies (mowing, fertilization, cultivation etc.) play a big role in how detrimental a pest might be. You keep records while practicing IPM to use in the future, you scout for the pest, and you take notes on its occurrence and its severity as part of the decision making process in whether or not to apply a pesticide. Successful IPM approaches have value both to the environment AND economically.

IPM does not mean pesticides are never applied because in some instances a preventive application of a pesticide might be more environmentally friendly than a curative treatment. If you have a history of intensive annual grass pressure, it is possible (and even likely) that a preemergent herbicide can be more environmentally responsible than postemergent herbicide treatments to remove the pest. Some pests warrant chemical treatment because they can lead to catastrophic turfgrass loss that not only reduces the aesthetics of a turfgrass stand but also its desirable playability characteristics for golf or other sports. Some pests can even result in human/animal injury when not controlled. Consider examples such as Pythium blight that can kill large patches of turf within hours during abnormally wet conditions, fire ants whose sting is harmful to both humans and pets, or spine-bearing weeds like horsenettle or sandbur that would be a very painful turfgrass surface on which to walk, play, roll, or sit upon).

When you anticipate that you might have a pest problem, identification of the pest is an important first step and is key to developing a plan of treatment. For instance, many insects that you might find present in a lawn could turn out to be beneficial to the environment, possibly even serving as predators to insects that do cause problems. If you apply a broad-spectrum insecticide, you could inadvertently be removing a natural control mechanism from Mother Nature. If you can collect the pest or areas of damaged turf (and pictures of the area with your smart phone can help in identification as well) it is likely that your local extension office can aid you in pest identification. If the local extension office can't identify the pest, they can forward it on to experts at the state land grant university for identification. For instance, Virginia Cooperative Extension offers standard free services in weed, insect, and disease identification through various diagnostic clinics. Check the Virginia Cooperative Extension website (www.ext.vt.edu) for more information on how to contact these clinics and the proper ways to submit grass and pest samples.



Figure 11. White grubs are one of the insect pests for which an insecticide treatment is often based on a threshold number of pests per square foot depending on the grass and its growth rate at that time.

After identifying the pest a decision then has to be made whether or not to treat that pest. Is it present in sufficient numbers to cause damage? This type of information might not be readily apparent to you and it is another reason to establish a relationship with the professionals at your extension office. Points to consider might include the level of damage or numbers of the pest that are visible AND the current growth rate of the turfgrass. For instance, many insect pests have targeted 'threshold numbers' (numbers of the pest per unit area) that can help when making a decision about whether or not to apply an insecticide (Figure 11). Even then, the timing of their occurrence, the type of grass they are attacking (warm-season or cool-season), and the overall health of that grass should be considered as treatment still might not be necessary. As an example consider that the typical time to treat grubs with an insecticide in the mid-Atlantic is usually mid-late summer when the grubs are very small. Under what is often the driest, hottest time of the year, a cool-season grass could experience major damage from grubs feeding on their root system, whereas a warm season grass is much more tolerant of the grub activity since the grass is much better adapted to those environmental conditions.

When a decision is made to apply a pesticide, there is one basic rule to follow for all registered pesticides, whether they are synthetic or naturally occurring products: the label IS the law (Figure 12). Following it according to the pest to be treated, the rate to be applied, the reentry interval after the application etc. is all necessary to meet the label requirements. When selecting a pesticide, educate yourself on what pesticide will control the pest with the least environmental impact and pay particular attention to the surrounding environment and pending weather conditions. Most university cooperative extension services provide publications with titles such as "pest management guidelines" available either on the web or at county offices. Your local extension agent can be a great help in choosing an appropriate pesticide, and your local product sales representatives will be well versed in a variety of treatment options.

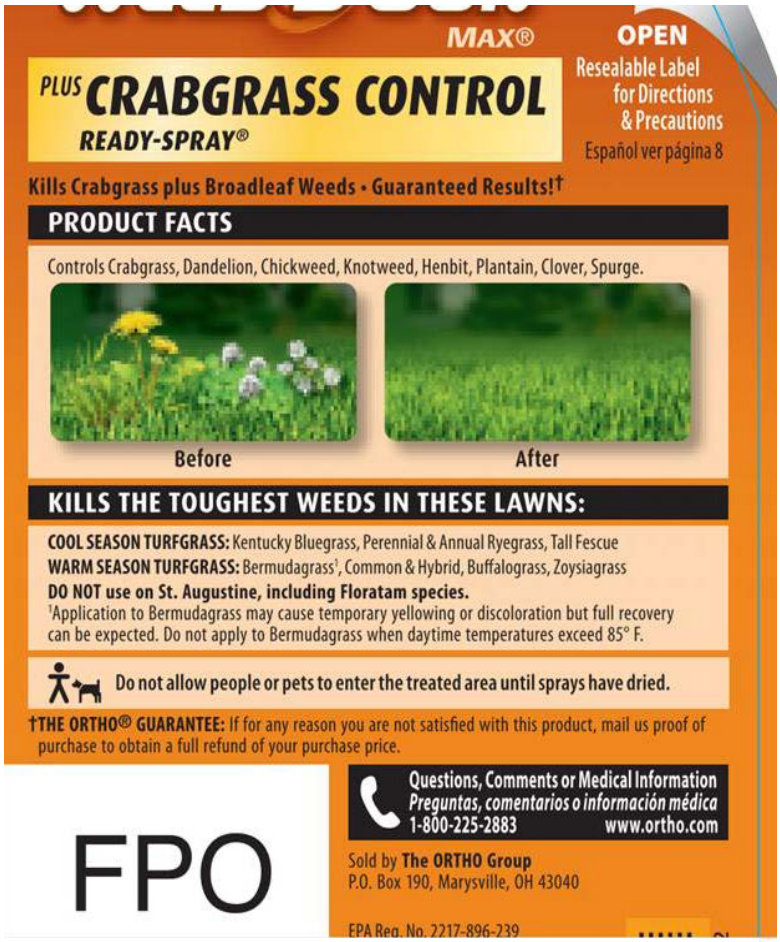


Figure 12. The label instructs the user on how to safely and properly apply the pesticide. The label is the law!

Consider current or pending weather conditions. Is the wind strong enough to cause spray drift onto non-target areas? If the wind is blowing and you must treat, can you adjust your sprayer by reducing spray pressure or increasing spray volume? Or is it possible to have a granular formulation of the pesticide available as an alternative delivery method to a spray. Consider if a forecast rain event is desirable or undesirable for optimizing the efficacy of the pesticide. For instance, rainfall totaling 0.25" or less can be a very desirable event for an application of a preemergent herbicide, but a terrible thing to immediately follow behind a postemergent herbicide treatment that needs to remain on the weed leaves for a few hours in order to optimize uptake.

Cultural Programs

Mowing. It might seem strange to consider mowing as a BMP in turfgrass management but it is THE characteristic of turfgrass management that makes turfgrasses so unique, and it is the practice that is most frequently mismanaged. Different turfgrasses have different optimal cutting heights based on the species, the time of year, and their use. However, a general misperception is that 'close mowing' will reduce cutting requirement. At some point, this misperception will be proven true (i.e. the grass will die!), but when maintained at proper mowing heights, turfgrass systems do not require a lot of additional inputs to perform positively for the environment. A healthy, dense stand of turf controls far more weeds than any preemergent herbicide ever will and combats insect and disease pressure quite well on its own too. Another BMP when mowing is to use mulching decks (Figure 13) and/or blades whenever possible and return clippings back into the turf. As stated earlier,



Figure 13. A mulching deck chops clippings into very small pieces that are broken down much more rapidly by soil microbes. Returning clippings can account for up to 1/3 of seasonal nitrogen needs.

clippings are nothing more than slow release fertilizer for your turfgrass and research has shown they can deliver up to 1/3 of your seasonal N requirement for the turfgrass.

Irrigation. Appropriate irrigation is also a BMP in sustainable turfgrass management. Excess irrigation is a waste of one of our most valuable resources AND too much water leads to an unhealthy turf and increases the chances of fertilizers, chemicals, and sediment being transported in the runoff, and likely ending up in our water resources. In general grasses evolved in drier climates and when an appropriate species suitable for the use and maintenance of a particular location is selected, supplemental irrigation is most often not required for survival of the grass. Under extreme drought conditions, most turfgrasses will enter dormancy and remain in a very reduced state of growth and development until the drought is relieved by a rain event. The key to successful management without supplemental irrigation during a drought is to quit mowing the turfgrass and limit traffic on the turf. In almost every instance in the mid-Atlantic climate, the turfgrass will eventually receive a rainfall event adequate in amount to quickly restore turfgrass growth and development (Figure 14).



Figure 14. The rapid recovery of a drought stricken cool-season lawn is evidenced following a 0.5 inch rainfall event.

The irrigation industry is constantly striving for improvements in the overall application and management of water. High performance turf requires supplemental irrigation to meet the conditioning and playability requirements for these situations. Recent enhancements in nozzles, rain-out sensors, and in-ground moisture sensors will eventually become more commonplace on all irrigation systems and not just those of high end golf courses and

sports fields. Until that happens, there is one very important rule of thumb in turfgrass irrigation strategy in this climate: irrigate deeply and frequently. This promotes the deepest root system possible, and a deep root system is an important part of maintaining a healthy, dense turf.

Summary

The old saying of "an ounce of prevention is worth a pound of cure" certainly applies to water quality protection strategies. As detailed in this chapter, there are a variety of sound management strategies that can be employed to protect water quality, and most of them will actually save you money and very likely improve the health of your turfgrass while protecting the environment. Implement as many of these strategies as you can to make your managed turfgrass an environmental benefit rather than an environmental concern.

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