FUNDAMENTALS OF TURFGRASS MANAGEMENT

FIFTH EDITION

NICK E. CHRISTIANS · AARON J. PATTON · QUINCY D. LAW

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Cover image: Kentucky bluegrass (*Poa pratensis*) leaf tip with guttation fluid. Photo by Aaron J. Patton.

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I would like to dedicate this book to my wife, Marla, who helped with editing and proofreading of the text during its preparation, and to my sons, Lance and Tim. It is also dedicated to the many academic advisers, teachers, friends, and coworkers who taught me the things that I know about the turfgrass industry.

—Nick E. Christians

I would like to dedicate this book in memory of David Marron. David was my high school librarian who gifted me my very first turfgrass book when I was a junior in high school. He passed away shortly thereafter, but I will forever appreciate his friendship, kindness, and support of my academic interests.

—Aaron J. Patton

For my parents, whose boundless love, support, and guidance made this possible. My mother, Leslie, is a school teacher who demonstrates that teaching and learning extend beyond the classroom. My father, Randy, is an agronomist who cultivated my love for the land. All of my accomplishments have been attained from standing upon their shoulders.

—Quincy D. Law

Contents

Preface

When I (Dr. Nick Christians) graduated from the Colorado State University School of Forestry in 1972, I quickly found that employment opportunities were very limited in my chosen field. Fortunately, I had taken courses in agronomy and horticulture, including turfgrass management. I had also worked part time in the sod industry for two years and had developed an interest in the turfgrass profession. The turf industry was booming in the early 1970s, and I found a job as an assistant golf course superintendent under certified superintendent Tom Rogers at Flatirons Country Club in Boulder, Colorado.

I quickly found that the real world of broken irrigation heads, tight budgets, and constantly changing greens committees was much different from the academic world of quick, easy answers. I also found how little four years of college had taught me that I would need to know. The next year I became the superintendent of Pueblo West Golf Course in Pueblo, Colorado. This further opened my eyes to the reality of personnel management and the political realities of the business world.

Later, I had the chance to go to graduate school and then to establish a teaching and research program at Iowa State University. I decided that my teaching would reflect the realities that I had experienced in the industry and that my students would get as much real-world exposure as they could through my teaching, through internships, and from other practical experience.

This is the same philosophy infused into this text. While no academic course or textbook will ever take the place of hands-on experience, there are perspectives that practical experience—and only practical experience—can bring to a book. When I began my career on the golf course, I found many things that I wished I had been taught and that I later had to learn on my own. Where possible, I have tried to incorporate those things into my teaching and writing.

One of the most important of these was mathematics. Calculation of application rates of fertilizers and pesticides, irrigation calculations, topdressing problems, and other mathematically related subjects are an important part of every turfgrass manager's job. While some mathematical subjects are covered in this book, those who would like a more in-depth coverage of the subject are directed to *The Mathematics of Turfgrass Maintenance*, 4th ed., by N. E. Christians and M. L. Agnew (John Wiley & Sons, Hoboken, NJ, 2008).

The primary objective of this book is to introduce the principles of turfgrass management. It begins at a level suitable for those just entering the field, but also contains beneficial information for experienced turfgrass managers. The goal is to present the information in a straightforward way that readers can easily understand. There is an emphasis on explaining why certain management practices are needed. Hopefully, the text will help readers with a fundamental understanding of turfgrass management so that they can adapt and apply what they have learned to the varied situations in the field.

This fifth edition contains extensive updates and significant revision. Two new authors (Dr. Aaron J. Patton and Quincy D. Law, M.S.) add their field and research experience to enhance this new edition. Their additions and updates to each chapter provide valuable insights. The text is updated throughout to reflect the latest research-based information and trends in the turfgrass industry.

—Nick E. Christians

Specific changes to this edition include the following:

- Two new chapters (Chapter 1: Benefits of Turf and Its Management and Chapter 12: Light Requirements and Shade Management)
- Multiple new and revised figures throughout the book
- Increased discussion and description of cool-season and warm-season turfgrasses
- Extra information on establishment methods and costs
- Updated information on soil testing and turf nutrition
- Expanded content on cultivation and sand topdressing
- Enhanced weed management information
- Added information on professional lawn care programs
- New information on fertilizers, herbicides, insecticides, fungicides, and plant growth regulators

Acknowledgments

There were a number of individuals who helped edit parts of the text and provided advice during its preparation and revision. They include Dr. Mike Agnew, Mr. B. J. Bilas, Dr. Prasanta Bohmick, Dr. Douglas Brede, Dr. Leah Brilman, Dr. Joe DiPoala, Dr. Mark Gleason, Mr. Matt Heiss, Dr. Clinton Hodges, Mr. Daryle Johnson, Dr. Young Joo, Dr. Kevin Kenworthy, Mr. Mark Kuiper, Dr. Donald Lewis, Mr. Mike Loan, Dr. David Martin, Dr. Lee Miller, Dr. David Minner, Dr. Justin Moss, Dr. Mike Richardson, Dr. Doug Richmond, Dr. Trey Rogers, Dr. Clark Throssell, Dr. Bryan Unruh, and Dr. Donald White.

I also thank my wife, Marla Christians. I would also like to give special acknowledgment to Jennifer Craig, the artist who drew many of the grass pictures in Chapters 2, 3, and 4 and the soil profile pictures in Chapter 20, and to Jane M. Lenahan, who produced many of the other drawings in the text.

— Dr. Nick E. Christians

In the beginning God created the heavens and the earth. Then, he said "Let the earth bring forth grass" (NKJV). I am grateful that my Lord filled me with a passion for the turfgrass He created. He blessed me with a wonderful wife, Ella, and four great children: Elijah, Jacob, Samuel, and Kathryn. I thank them for their encouragement and support during the revision of this text.

— Dr. Aaron J. Patton

Writing a textbook with my two biggest mentors in turf has truly been an honor. I am grateful to have worked so closely with Nick Christians and Aaron Patton and am a better turfgrass scientist for doing so. Thank you for the opportunity.

— Quincy D. Law, M.S.

CHAPTER 1

BENEFITS OF TURF AND ITS MANAGEMENT

It is not difficult to find beauty in the natural world, especially when considering that much of the splendor arises from living organisms. Though turf is usually not the focal point of a landscape, it can cover a large portion of the managed landscape. In fact, managed turf accounts for approximately 13,840 mi^2 (35,850 km^2) in the United States (Milesi et al., 2005). Turf and its management benefit the environment, society, and economy in addition to the beauty provided. These benefits are why turf is planted and utilized in so many places in the landscape.

ENVIRONMENTAL BENEFITS

As a low-growing groundcover with an extensive, fibrous root system, turf benefits the environment by improving the air (atmosphere), water, and soil. Given the interconnectivity of an ecosystem, many of these benefits are collective. Further, managed turf is usually located in urban and suburban environments where pollution is likely to occur.

Turf benefits the atmosphere. By absorbing atmospheric pollutants, turf is able to improve air quality. An example currently of great interest is soil carbon sequestration. Soil carbon sequestration is the use of green plants to capture atmospheric carbon dioxide via photosynthesis, which is then stored in the soil as organic carbon. Societies are searching for ways to reduce atmospheric carbon dioxide concentrations, and carbon sequestration is one such method (Follett et al., 2011). Soil carbon sequestration is a collective benefit, as it both reduces atmospheric carbon dioxide and increases soil carbon (discussed below). Grasses are also able to absorb other atmospheric pollutants, including ozone, sulfur dioxide, nitrogen dioxide, ammonia, carbon monoxide, volatile organic compounds, and lead (Stier et al., 2013). However, absorbing too much of some of these pollutants can be detrimental to turf health.

Turf benefits water. Turfgrass plants increase the hydraulic resistance of moving water, which reduces surface runoff (Ree, 1949; Gross et al., 1991). Reduced surface runoff allows for greater water infiltration and subsequent groundwater recharge. As water infiltrates and passes through the grass, thatch, and soil, it is filtered and cleansed

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by microorganisms that digest and degrade organic chemicals or pollutants (Beard and Green, 1994). A buffer strip of Kentucky bluegrass has a similar groundwater recharge rate as a mixed forb and grass prairie and results in a reduction in drainage water volume compared to the absence of a buffer area (Steinke et al., 2009). Turfgrasses also act as vegetative filter strips that reduce the amount of sediment transported to surface streams and waters (Beard and Green, 1994).

Turf benefits soil. Turfgrasses can both conserve and improve soil by reducing sediment losses and adding organic matter to the soil. The extensive fibrous root system helps to knit the soil together. This keeps the soil in place and helps to reduce erosion, dust, and mud. Turf often allows otherwise unsuitable land to be utilized by communities, such as a grassed hillside park and amphitheater (Figure 1.1). Additionally, the turnover of plant tissue adds organic matter to the soil and thus increases soil carbon, nitrogen, and general fertility. Soil organic matter also increases the water holding and cation exchange capacities of the soil. In fact, a high percentage of the world's most fertile soils developed under a native vegetation of grass (Gould, 1968). Soil carbon helps to increase soil aggregate stability, decrease runoff and erosion, and improve water infiltration (Angers and Carter, 1996) as well as decrease soil bulk density (Blevins et al., 1983).

SOCIETAL BENEFITS

Societal benefits are also known as ecosystem services, which are the benefits people obtain from ecosystems. In this case, it is the benefits people obtain from turfgrass ecosystems. Turfgrass ecosystems are unique in that they usually bridge the gap between disturbed and natural habitats.

Turf provides aesthetic value. A dense, lush turfgrass surface can grow into a nearly perfect, carpet-like groundcover that is visually pleasing. As a part of numerous

FIGURE 1.1 ***The turf on Slater Hill on the Purdue University campus allows for a steep sloping area to be used as a park and natural amphitheater.***

FIGURE 1.2 ***A concentric circle pattern around these shrubs is achieved in the turf by using turfgrass cultivars with different genetic color near Tiananmen Square in Beijing, China.***

landscapes, turf provides green color for a large portion of the year. Some turfgrasses still have ornamental value when dormant, such as the straw gold color of dormant zoysiagrass (*Zoysia* spp.). Turfgrasses with different shades of green can even be used to create a pattern in a turf sward (Figure 1.2). Though athletic fields are primarily maintained for recreation, they are often mown into intricate patterns that provide a very attractive appearance for major events (Figure 1.3). The low height of turf gives a feeling of openness that cannot be achieved with trees or shrubs, and it can act as a foreground and/or background for the focal points in a landscape.

Turf provides recreation. Golf courses, athletic fields, parks, and other areas are often managed with recreation as the specific intent. Home lawns, courtyards, and industrial areas are also used for recreational purposes. Turfgrasses provide a cushioning effect that reduces injuries to participants when compared to poorly or nonturfed soils, especially in contact sports such as football, rugby, and soccer (Gramckow, 1968). Proper turfgrass management is also relevant, as there is a substantial benefit of maintaining quality turf for reducing the hardness of sports fields (Rogers and Waddington, 1992). Turfgrasses have a greater ability to tolerate traffic and reduce surface hardness compared to weeds such as large crabgrass (*Digitaria sanguinalis*) and white clover (*Trifolium repens*) (Brosnan et al., 2014). Many of the recreational opportunities associated with turf provide physical health and fitness benefits for humans as well.

Turf improves the living environment for humans. Through photosynthesis, actively growing turf removes carbon dioxide from the air and produces oxygen in return. Approximately 25 ft^2 of turfgrass produces enough oxygen for one person for an entire day (Watschke, 1990). Turf is also able to dissipate radiant heat and provide a cooling effect via evapotranspiration, which can dissipate roughly half of the sun's heat (Watschke, 1990). The structure and density of turf help to reduce noise and glare. Turf absorbs jarring noises better than hard surfaces, and the multidirectional light reflectance between the leaf surfaces reduces glare. Turf can also reduce noxious pests

FIGURE 1.3 ***An intricate mowing pattern on a baseball field that provides aesthetic appeal without influencing the playability. (Courtesy of Joey Stevenson)***

and allergy-related pollens (Beard and Green, 1994), and it offers a less favorable habitat for unwanted nuisance insects and disease vectors (Clopton and Gold, 1993).

Turf improves the mental health of humans. Compared to an urban walk along a busy street, a nature walk through grasslands with scattered shrubs and oak trees lead to decreases in anxiety, rumination, and negative emotions (Bratman et al., 2015). Additionally, organized recreational activities improve mental health, alertness, and resiliency against stress (Street et al., 2007), which are often made possible by turf.

Turf provides a means of waste disposal and conservation. Biosolids are mainly organic, solid materials produced by wastewater treatment processes. Biosolids contain nutrients and thus can be used as a fertilizer. However, due to their origination, biosolids can be high in heavy metals, pathogens, pharmaceuticals, and anything else flushed down a toilet or rinsed down a drain. Further, sewage effluent or recycled water—the wastewater from sewage treatment facilities—is a source of irrigation water widely used for turf. Forty-five percent of golf courses in the Southwest United States use recycled water to conserve drinking water (Gelernter and Stowell, 2015). As such, turf is an ideal crop to use biosolids as a fertilizer and recycled water for irrigation because it is not a food crop and covers a large portion of the landscape where biosolids are produced and water is recycled (urban and suburban areas).

ECONOMIC BENEFITS

Turf benefits the economy. The turfgrass industry provides employment, spends money on inputs, earns income on the sale of turfgrass products and services, and pays taxes. It is through these means that the turfgrass industry directly benefits the economy.

The United States turfgrass industry generated an estimated $57.9 billion in revenue and provided 822,849 jobs in 2002 (Haydu et al., 2006). These figures include sod farms, lawn care services, lawn and garden retail stores, lawn equipment manufacturing, and golf courses. Sports turf, which was not included in the study, benefits the economy in many of the same ways. There are other economic benefits, including increased home values. Behe et al. (2005) found that perceived home value increased by 5 to 11% for homes with a good landscape.

NET BENEFITS

The use of irrigation, fertilizers, pesticides, and frequent mowing for maintaining turf is often viewed negatively. Though these practices can have a detrimental impact on the environment, they can also enhance the benefits of turf and its management. For example, phosphorus (P) is often the limiting nutrient for algal growth in aquatic ecosystems, so P fertilization is often banned or not recommended for turf. However, P is often necessary for proper turfgrass establishment. Once established, the turf will help reduce soil erosion, which will keep the soil and P in place. Thus, it is important to consider the **net benefit** of the turf and its management. A single P fertilization event at the time of establishment will likely have much less of a negative impact than the continuous erosion of a P-laden soil.

In addition to the net benefit, the context of the benefits should be considered. As in, to what is the turf being compared? The benefits of turf are more pronounced when compared to impervious asphalt or concrete versus comparing turf and a tallgrass prairie or hardwood forest. Further, the level of maintenance for the turf can have a major impact on both the context and net effect of each benefit.

The focus of the remainder of this textbook is on the proper management of turf. Learning the fundamentals of turfgrass management will help to improve the quality and sustainability of managed turf. Properly managed turf provides the greatest environmental, societal, and economic benefits.

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PART I

GRASSES

CHAPTER 2

INTRODUCTION TO THE GRASSES

A basic part of turfgrass management is to develop a clear understanding of the grasses and how they are used. The objective of this chapter is to introduce the reader to the grasses and some of their unique characteristics. It includes information on growth, identification, and regional adaptation, and it introduces some of the terminology that is necessary to understand this diverse group of species.

The grasses belong to a larger group of plants called the monocotyledons, or simply "monocots." The monocots are flowering plants that have one seed leaf (or cotyledon) in their seed. They usually have parallel veins in their leaves, stems with vascular bundles, and flower parts in multiples of three. Plants in the sedge, rush, and lily families are also monocots and may be mistaken for grasses because of their grasslike appearance. The grasses are distinguished from these by their two-ranked leaf arrangement (Figure 2.1). Each successive leaf of a grass plant is attached at a 180-degree angle from the previous leaf. The leaves of sedges are three-ranked (120-degree angle), and the leaves of rushes are round in cross section (Pohl, 1968). Leaf arrangement in lilies is variable and can be alternate, opposite, whorled, or originating only from the base.

There are also several dicotyledonous plants, or "dicots," found in the landscape. They include many weed plants, such as dandelion, white clover, and ground ivy, as well as many trees and shrubs. They differ from the monocots in that they have two cotyledons in their seeds, a netlike vein arrangement in their leaves, and flower parts in multiples of four or five. As discussed later in Chapter 13, "Turf Weed Management," the varying response of monocots and dicots to certain herbicides forms the basis for selective control of many dicot weed species in turf.

The grasses are an incredibly diverse group of more than 10,000 individual species (Watson and Dallwitz, 1992). They range from the small, fine-textured plants that attain a mature height of 1 in. (2.5 cm) (Hitchcock and Chase, 1950) to the giant bamboos, which may reach a height of 100 ft. (30 m) and have a stem diameter of up to 1 ft. (30 cm) (Pohl, 1968). Only a very small number of the grasses are suited for use as turf. They are generally the more low-growing members of the group, which are able to form a high density under the continuous defoliation caused by mowing. By definition, a **turfgrass** is a gramineous (grass), root-bearing plant that covers the land surface and tolerates traffic

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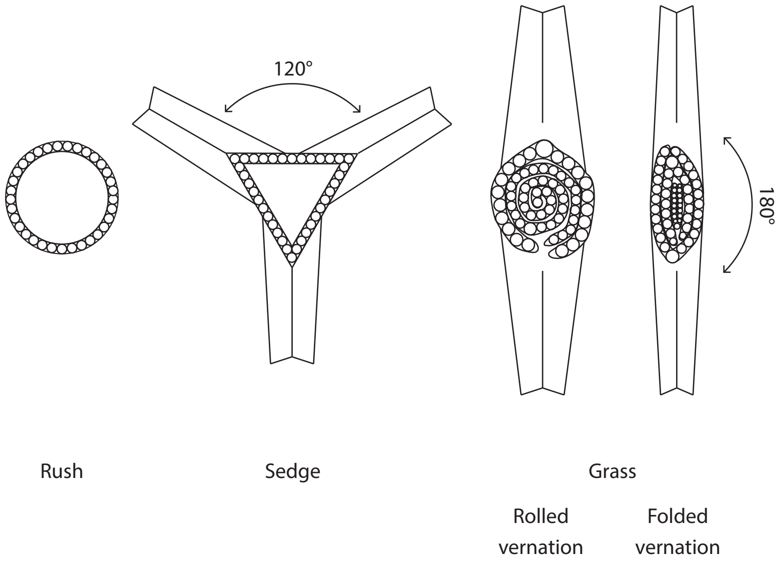

FIGURE 2.1 ***Rushes are round in cross section; sedges are triangular in cross section with a three-ranked leaf arrangement; and grasses are rolled or folded in cross section with a two-ranked leaf arrangement. (Drawing by A. Patton.)***

and defoliation. Approximately 50 grass species in the world fit this criterion. It is this small, select group of turfgrasses that this book will cover.

PHOTOSYNTHESIS AND RESPIRATION

Plants are able to harvest light energy and convert it to chemical energy through a process known as **photosynthesis** (Equation 2.1). **Photo** means "light," and **synthesis** means "putting together." Photosynthesis is the process by which plants form the energy they need to function, which is in the form of **carbohydrates**. **Chlorophyll**, the pigments that give plants their green color, absorbs the light energy that is used to synthesize energy-rich carbohydrates ($C_6H_{12}O_6$) using carbon dioxide (CO_2) from the atmosphere and water (H_2O) from the soil. These carbohydrates are very important food sources for human beings: Breakfast cereals and bread are just two examples of foods containing plant-derived carbohydrates. Oxygen (O_2) is a byproduct of photosynthesis that is released into the atmosphere.

Photosynthesis

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 \tag{2.1}$$

Carbohydrates are also very important to the plant. They are consumed during the process known as **respiration** (Equation 2.2), which utilizes the energy stored as carbohydrates for plant growth and development. As a result, CO_2 and H_2O are released during respiration.

Plant respiration

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy} \tag{2.2}$$

The available carbohydrate content can be critical to plant survival. Under favorable conditions, the plant is able to produce the carbohydrates it needs and store the excess. However, under conditions where carbohydrate consumption exceeds that of production, the plant relies on stored reserves to support respiration and growth. Equation 2.3 provides a simple description of the interrelationship between photosynthesis, respiration, plant growth, and stored reserves (Volenec, 2016).

Interrelationship of photosynthesis, respiration, plant growth, and stored reserves

$$\text{Photosynthesis} - \text{Respiration} = \text{Plant Growth} + \text{Stored Reserves} \tag{2.3}$$

The consumption of stored carbohydrates can only occur for a short period of time, as plants will eventually die if carbohydrate supplies are exhausted. Carbohydrate status is an important factor in the grass plant's ability to emerge from dormancy or recover from damage. Both environmental conditions and management practices can affect the plant's carbohydrate production and storage. For example, high temperatures increase plant respiration and decrease photosynthesis in cool-season grasses, resulting in the consumption of stored carbohydrates.

Mowing is an example of a management practice that can affect carbohydrate supply, as the practice removes photosynthetically active tissues. With a higher mowing height, more leaf area is available to undergo photosynthesis, and a greater amount of photosynthesis leads to greater carbohydrate production. The more photosynthesis, the more carbohydrates produced. Low mowing heights reduce the plant's ability to produce and store carbohydrates and can also reduce its ability to tolerate stress.

Fertility can also impact carbohydrate status. High nitrogen (N) applications, particularly at times when the plant is growing rapidly, can result in excess use of carbohydrates for tissue production, thereby reducing carbohydrate storage. A proper management strategy to ensure sufficient energy storage depends on a thorough knowledge of plant growth and development. Both fertilization and mowing are discussed in detail later in the book (Chapters 8 and 9).

PHOTOSYNTHETIC PATHWAYS

Though the general process of photosynthesis is similar for all green plants, there are three unique pathways. These are known as the C_3, C_4, and crassulacean acid metabolism (CAM) pathways. The three pathways have distinct anatomical and physiological characteristics that result in different plant growth patterns, requirements, and stress tolerances. The C_3 and C_4 pathways initiate their carbohydrate production with different carbon compounds, and the pathways are named after the number of carbon atoms in said compounds (i.e., C_3 and C_4 plants produce three and four carbon compounds, respectively). Turfgrasses are either C_3 or C_4 plants, which are known as **cool-season** and **warm-season** grasses, respectively. Certain turfgrass weeds, such as common purslane (*Portulaca oleracea*), are CAM plants.

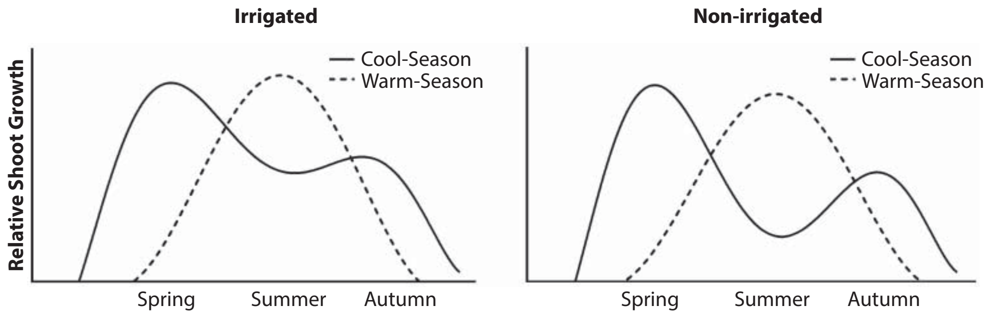

FIGURE 2.2 ***Seasonal shoot growth patterns of cool- and warm-season grasses under irrigated and nonirrigated conditions. (Drawing by A. Patton.)***

The photosynthetic pathways have important implications in terms of turfgrass management. As the name indicates, cool-season grasses are best adapted to the cooler times of year. They thrive in temperatures from 65 to 75°F (18 to 24°C); conversely, warm-season species are best adapted to temperatures between 80 and 95°F (27 to 35°C) (Beard, 1973). These temperature preferences lead to different growth patterns for cool- and warm-season grasses throughout the year, which is illustrated in Figure 2.2. The cool-season species emerge from dormancy and grow rapidly in the spring. They can be intolerant of summer stress periods, and growth is slowed in midsummer, especially when not irrigated. Their growth increases in the fall, though not to the same rapidity as spring. Cool-season grasses maintain their green color well into the fall and may retain some green color through winter.

Warm-season species emerge from dormancy slower and do not reach their maximum growth rate until midsummer. Their growth rate slows in the fall, and they go into dormancy when soil temperatures fall below 50°F (10°C) (Beard, 1973). Warm-season grasses lose their chlorophyll as they go dormant following frost or sustained temperatures <50°F (10°C), and they remain brown until spring.

The C_4 photosynthetic system has several advantages over the C_3 system. First, C_4 photosynthesis is more efficient than C_3 photosynthesis at higher temperatures; C_3 plants are hindered by a metabolism process known as **photorespiration**. Photorespiration occurs because the enzyme that initially catalyzes CO_2 fixation in C_3 plants, RuBisCO, is also able to catalyze the fixation of O_2. When O_2 is fixed instead of CO_2, carbohydrates are produced at a reduced rate and higher metabolic cost. Thus, photorespiration reduces the photosynthetic efficiency of C_3 plants at high temperatures.

To prevent photorespiration, C_4 plants catalyze CO_2 fixation with a different enzyme [phosphoenolpyruvate (PEP) carboxylase] and attach CO_2 to a different compound (PEP), resulting in the four-carbon compound after which the pathway is named. Additionally, C_4 plants spatially isolate RuBisCO from O_2 via leaf anatomy and by concentrating CO_2 around the enzyme. The additional steps associated with C_4 photosynthesis come at a higher energy cost per carbohydrate produced when directly compared to C_3 photosynthesis, but avoiding photorespiration losses can make up for the higher energy cost. Temperature has a major influence on photorespiration, as high temperatures reduce the solubility of CO_2 and diminish the ability of RuBisCO to differentiate between CO_2 and O_2. Accordingly, the differences in photosynthetic efficiency between the C_3 and C_4 pathways are more apparent at high temperatures.

Compared to the C_3 pathway, the C_4 pathway has an increased nitrogen use efficiency (NUE) and water use efficiency (WUE). By allocating a smaller amount of N to RuBisCO, C_4 plants are able to produce more biomass per unit N and thus have a higher NUE. Additionally, C_4 plants have a higher photosynthetic rate per unit leaf area and a lower stomatal conductance versus C_3 plants, which corresponds to the increased WUE. Another advantage of C_4 plants is that they have a much higher light saturation point than C_3 plants. This allows C_4 plants to capture a greater amount of light energy in full-sun conditions, and it allows them to survive a higher amount of light stress.

By contrast, C_3 plants are better suited to grow in colder environments than C_4 plants due to the sensitivity of PEP carboxylase to low temperatures. Additionally, C_3 plants have a higher photosynthetic rate than C_4 in low-light conditions. This is because C_3 plants have a lower light compensation point (LCP), which is the light level at which photosynthesis and respiration reach equilibrium and the net carbon gain is zero. A more extensive discussion on light requirements is given later in the book (Chapter 12).

There are other practical differences between cool- and warm-season grasses that play a role in their management. One of these is rooting. Although rooting depth is affected by several factors, such as environment, mowing height, fertility level, and soil-related factors, warm-season grasses will usually have a deeper root system than cool-season grasses. Most of the root mass of cool-season grasses is in the upper 12 to 18 in. (30 to 45 cm) of the soil, although individual roots may extend to several feet. The root mass of warm-season grasses can reach 3 ft. (0.9 m) or more into the soil, but again, individual roots may grow to a considerable depth. This is one reason that warm-season grasses are better adapted to drought and require less irrigation than cool-season grasses managed under the same conditions. The many practical differences in the management of cool- and warm-season grasses will be a recurring theme through subsequent chapters on fertilization, mowing, and pest management.

Other practical differences between cool- and warm-season grasses influence what weed species might be problematic in certain areas because of changes in light adaptation. The improved growth of C_3 plants in moderate shade compared to C_4 plants helps to explain why warm-season grasses, such as crabgrass and bermudagrass, do not grow in areas too heavily shaded but why cool-season grasses are better able to grow in shady areas.

Another practical application to understanding the difference between the cool- and warm-season plants is that it helps explain why C_4 plants (e.g. crabgrass) are so competitive with C_3 plants (e.g. Kentucky bluegrass) during hot, dry conditions of midsummer. Warm-season weeds are competitive in cool-season lawns in summer and, conversely, cool-season weeds are competitive in warm-season lawns in autumn, winter, and spring.

SPECIES ADAPTATION

The cool-season grasses are best adapted to the cooler regions of the northern and far southern latitudes, and the warm-season grasses are best adapted to the warmer regions closer to the equator. Species adaptation is more complex than that, however, and the United States is generally recognized to have many separate climatic zones

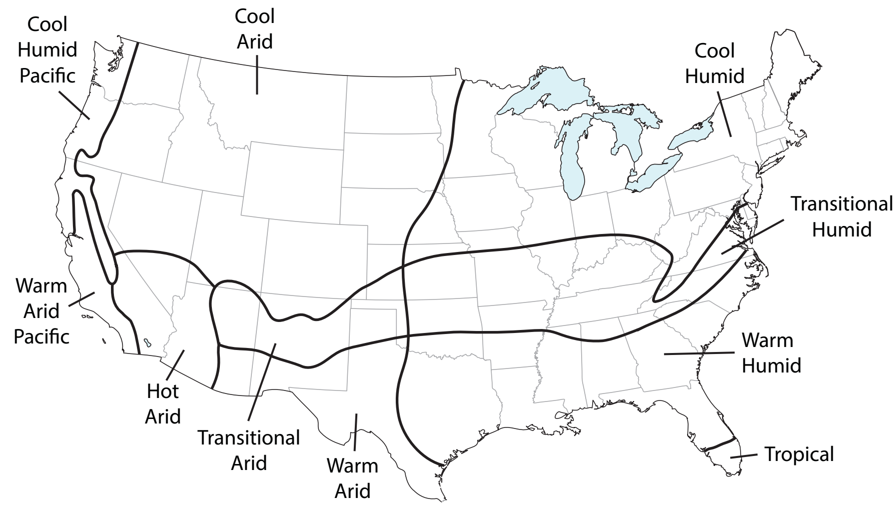

FIGURE 2.3 ***Climatic zones of turfgrass adaptation for the United States. (Drawing by A. Patton.)***

of grass adaptation (Figure 2.3). Climatic zones include the **cool humid** zone, which encompasses the Northeast, much of the Midwest, and much of the Pacific Northwest; the **warm humid** zone, which includes the Southeast and extends into eastern Texas; the **warm arid** zone, which includes western Texas and southern California; the **hot arid** zone, including the desert areas of California, Nevada, and Arizona; a small section of **tropical** climate in southern Florida; and the **cool arid** zone, which includes much of the drier areas in the Midwest and West. There is also a region known in the turf industry as the **transition zone**, which extends through the central part of the country and cuts through parts of each of the other four primary climatic zones. This is the most difficult region in which to manage grasses. In the transition zone, it is cool enough in the winter to make it difficult to maintain perennial stands of many warm-season grasses without the threat of winterkill, yet it is warm enough in the summer to make it difficult to maintain high-quality, cool-season grasses. Most cool- and warm-season grasses are not well adapted to the transition zone.

Cool-season grasses are best adapted to the cool humid zone, which include the bluegrasses, fescues, ryegrasses, and bentgrasses. Buffalograss and zoysiagrass, both of which are warm-season grasses, are also found in the western and southern parts of this region, respectively, even though the growing period for warm-season species is relatively short in these areas.

Bermudagrass is the most widely used species in the warm humid zone. It can be found throughout the region, although it is sometimes subject to winter damage in the northern parts of the zone. Zoysiagrass is widely used in the transition zone, whereas carpetgrass, centipedegrass, bahiagrass, seashore paspalum, and St. Augustinegrass are more common in the warm humid climate in the Gulf Coast region. Creeping bentgrass is often used on golf course greens in the warm humid and warm arid zones, although it is out of its region of adaptation and can be very difficult to manage because of the high temperatures in the summer, especially where humidity and diseases are more problematic. Perennial ryegrass, rough bluegrass, and some of the other cool-season grasses are commonly used for **overseeding** (see Chapter 20) to provide a winter cover in dormant bermudagrass. Annual bluegrass, a cool-season weed, can also be found throughout all of the regions on golf courses and other closely mown turf areas.

The warm-season grasses are best adapted to the warm arid zone because of its high summer temperatures. Bermudagrass is most commonly used in this area, although any of the warm-season species can be used if supplemental irrigation is available. Buffalograss is becoming increasingly important in the more arid parts of this region. As in the warm humid region, cool-season grasses are used for winter overseeding, and creeping bentgrass is sometimes used on golf course putting greens, particularly at higher elevations. Annual bluegrass is also common on closely mown areas. Growth of turfgrasses in the hot arid portion of the United States is dependent on supplemental irrigation.

Any of the cool-season grasses can be used in the cool arid zone if irrigation is available. However, buffalograss use is increasing in the warmer parts of the region, such as Kansas, Nebraska, and Colorado, on nonirrigated sites. In the cooler arid regions, less commonly used cool-season species, such as the wheatgrasses and Canada bluegrass, can be found on nonirrigated sites.

Most of the warm-season grasses grow well in southern Florida's tropical climate with the exception of buffalograss, which does not perform well in humid areas, and centipedegrass, which performs better in northern Florida. *Zoysia matrella* cultivars often perform better in this climate than most *Zoysia japonica* cultivars.

The grasses used in the transition zone vary widely. Tall fescue has become one of the most popular lawn species throughout the central and northern parts of the region. Kentucky bluegrass and perennial ryegrass are also widely used in northern sections. Creeping bentgrass is used on golf course putting greens. Bermudagrass is more common to the southern part of the region. Zoysiagrass is best adapted to this region and can be found on lawns, golf course fairways and tees, and some sports field areas.

While temperature and rainfall are key to understanding the climatic zones where turfgrasses can be grown, light is also important. Many warm humid regions of the world such as Eastern China, Japan, and Korea have difficulty growing some turfgrasses due to the lower solar radiation and subsequently lower photosynthetically active radiation (PAR) in that region compared to areas in the Southeastern United States with a similar climate. Bermudagrass is a great example of a high-light-requirement turfgrass that does well in the Southeastern United States but performs poorly in many Asian countries. Zoysiagrass, on the other hand, has a lower light requirement than bermudagrass, and it performs well in the low-light, warm humid regions of Asia. More about the light requirements of turfgrass is discussed in Chapter 12.

LATIN NAMES

Chapters 3, 4, and 5 include detailed information on a wide variety of cool- and warm-season grasses. Each grass is identified with a **common** name and a **Latin**, or scientific, name. The common name is the currently accepted name for each grass in the United States. It is not necessarily a name that will be recognized by readers from other countries, although the names of the turfgrasses in the United States are often used around the world in the professional turfgrass industry.

The Latin, or scientific, name is a universal name that is used for these grasses in every country. This naming system is also known as the **binomial** system, meaning "two names." The binomial system was developed by the world's scientists to provide uniformity and thereby enhance communication (Wilson et al., 1964). It is used to name every living thing, from human beings to microorganisms.

The Latin system of naming is the opposite of English. In English, we always put our specific name first and our general name last. In Latin, the general, or **genus**, name always comes first, and the specific, or **species**, name always comes last. The initial letter of the genus name is always capitalized, and the species name is all lowercase. The names are *italicized* or underlined to show that they are written in a foreign language. For example, the Latin name for the species that is known in the United States as Kentucky bluegrass is *Poa pratensis*. It is known by that name worldwide, although it has a variety of common names, such as Kentucky bluegrass and smooth meadowgrass. The genus name, *Poa*, applies to more than 500 different grasses, whereas there is just one *Poa pratensis*. *Poa* is translated from Greek as grass or fodder (food for livestock) and *pratensis* is translated from Latin as growing in fields or meadows (Zimdahl, 1989). A knowledge of Latin names is useful because it can prevent confusion when reading articles written by those from other parts of the world. Thus, these names are important in accurately communicating information internationally.

In some sources, an additional letter, name, or abbreviated name is included at the end of the Latin name. *Poa pratensis*, for instance, may be listed as *Poa pratensis* L. The additional letter represents the **authority**: the person who first named this species. In this case, the L. stands for Linnaeus, the person who first proposed the binomial system. Additional authorities, such as Munro, Flugge, Gaud., and Steud., will be found following the names of the various grasses. A period following the authority's name, such as *Zoysia japonica* Steud., indicates that the authority's name is abbreviated (Steud. = Steudel).

MORPHOLOGY

Morphology is the study of form and structure. An understanding of morphology can be useful in the identification process and can help in the development of effective management strategies.

The aboveground parts of the plant are known collectively as the **shoot**. The shoot includes the **stem** (or **culm**), the leaves, and the **inflorescence**. A grass leaf is composed of two distinct parts. The upper part is called the **leaf blade** (or lamina), and the lower part is called the **leaf sheath** (Figure 2.4) (Gould and Shaw, 1969; Pohl, 1968).

At intervals along the stem are enlarged areas called **nodes** (Figure 2.5). You can easily feel these nodes by running your fingers along the stem. The node is the point at which the vascular system of the leaf is attached to the stem. The node is also the point at which the **buds** are attached. Buds are very important reproductive structures that are capable of regenerating new, independent plants. The region between the nodes is called the **internode** (Figure 2.5). Internodes may range from a few cells in length for those on the crown to an inch or more in length for nodes on stolons, rhizomes, or seedheads (Langer, 1972).

At the base of the turfgrass plant, near the soil surface, is a region of nodes with tightly compacted/contracted internodes known as the **crown** (or apical dome) (Figure 2.6).

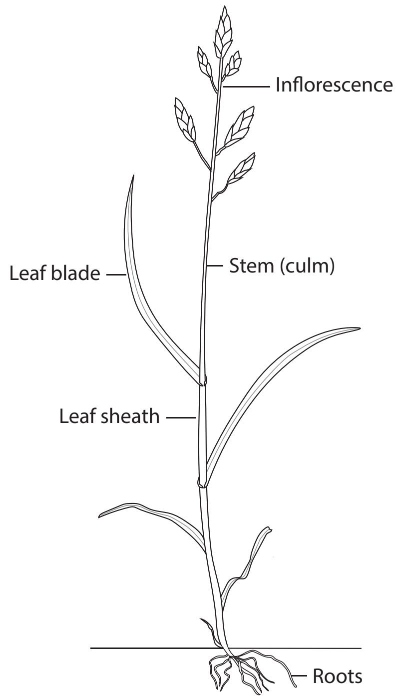

FIGURE 2.4 ***Parts of a typical grass plant, including the leaf blade and leaf sheath. (Drawing by A. Patton.)***

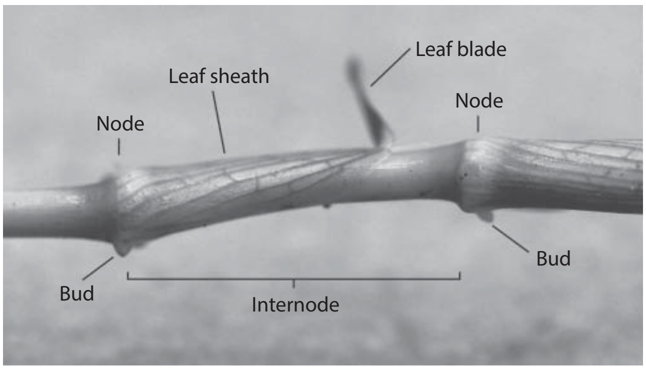

FIGURE 2.5 ***Nodes, buds, and internode of a grass plant (stolon shown) with attached leaf.***

The crown is the center of activity for the plant, and as long as it remains alive, the plant is alive. Attached to the crown or node and growing into the soil are **roots**. Roots absorb water, take up nutrients, anchor the plant, and provide sod strength.

There is a bud attached to each of the compacted nodes in the crown. Leaf buds produce new leaves, but plant crowns also contain axillary buds that can produce a new plant that can eventually develop independently of the original crown. These new plants,

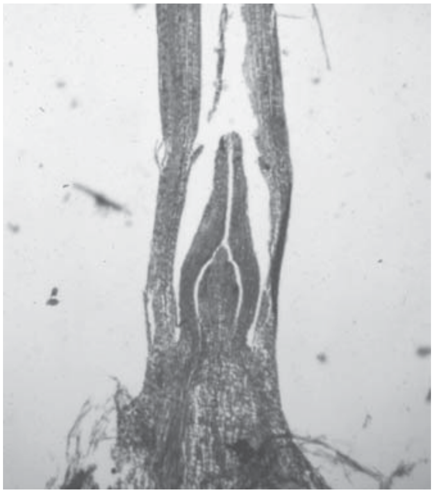

FIGURE 2.6 ***Microscopic view of a Kentucky bluegrass crown.***

or **daughter** plants, are genetic clones of the original **mother** plant that arise from tillers, rhizomes, or stolons. This is a very important means of reproduction and is one of the features of grasses that allow us to use them as highly maintained turf.

A **meristem** (or growing point) is a plant tissue containing undifferentiated cells where growth can occur. The meristems of most plants are **apical**, meaning that they are located at the tip. This can easily be observed on species such as spruce and oak trees, where new growth is added to the end of the stem each season. Though turfgrass roots, stolons, and rhizomes grow apically, the meristematic region of turfgrass leaves is unique compared to that of most other plant species. As new leaves originate from the growing point at the crown, the leaf elongates upward, beyond the growing point. Multiple overlapping leaves are formed as the grass plant grows. The newest leaves are on the inside, protected by older leaves on the outside, and all leaves protect the growing point.

At the juncture of the leaf blade and the leaf sheath is a region called the **intercalary meristem**. The intercalary meristem is the region of cell division where leaf blade growth (extension) occurs, and it is the primary reason that turfgrasses can be mown. After a leaf blade is mown, it will continue to grow, but it cannot form a new leaf tip. This is because the growth originates from below the leaf tip. If the meristem of the grass were at the leaf tip, mowing would remove the region of cell division, and regrowth following continued mowing would not be possible. Grasses can also be mown because they contain many buds. As defoliation occurs and older leaves senesce and plants die, new leaves and plants are continuously formed by the buds, thereby allowing growth to continue.

When a new leaf emerges from the bud, apical growth occurs until the leaf is differentiated into a blade and sheath and emerges from the enclosing (exterior) sheath. Once differentiated, subapical leaf growth occurs from the intercalary meristem at the base of the leaf blade. If either the roots or aboveground tissues are removed from the plant, new roots or leaves can be formed from the crown region. Although this is a considerable stress to the plant, life is able to continue. If the crown is killed, however, the plant is dead.

There are several practical examples in nature where this becomes important. There are insect pests called white grubs that will sever the root system but do not feed on the crown itself. There are also insect and disease pests that attack the foliage but leave the crown intact. These pests can cause damage, but the turf can survive their attack because the crown remains alive. The most lethal damage results from those pests that attack the crown. A good example is *Pythium* blight, a disease that kills the crown and generally results in a need for reestablishment. Some insects, for example, billbugs, also attack the crown directly and kill the plant.

GROWTH HABIT

The way in which the axillary buds develop new plants from the crown determines the **growth habit** of the plant. When the **axillary bud** begins to develop a new shoot that emerges up within the sheath tissue of the mother plant, the newly formed daughter plant is called a **tiller** (Figure 2.7). Plants that develop exclusively by tillers have a **bunch-type** growth habit. After a season's growth of a bunch-type grass, several tillers will develop in a tight group or clump around the original crown. Each of these tillers is a separate plant with its own crown, which can be carefully separated from the mother plant. These separated tillers continue to grow independently and can then form their own tillers.

On some grasses, the developing axillary bud may also emerge laterally and penetrate through the sheath of the mother plant. The result is a lateral stem that serves as a reproductive structure that can develop in two ways. First, it can grow laterally along the surface of the ground through internode elongation, forming aboveground stems called **stolons** (Figure 2.8). Stolons have nodes at various intervals, each of which has a bud that is a separate reproductive structure. These buds can develop new roots and new shoots that are clones of the mother plant. Stolon pieces can be used to establish grasses, such as bermudagrass, without the use of seed.

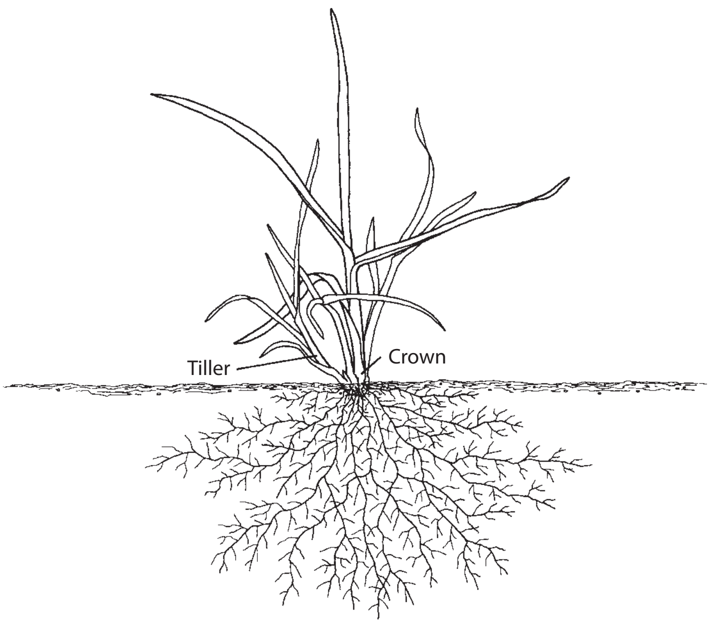

FIGURE 2.7 ***Bunch-type grass with tillers. (Drawing by J. M. Lenahan.)***

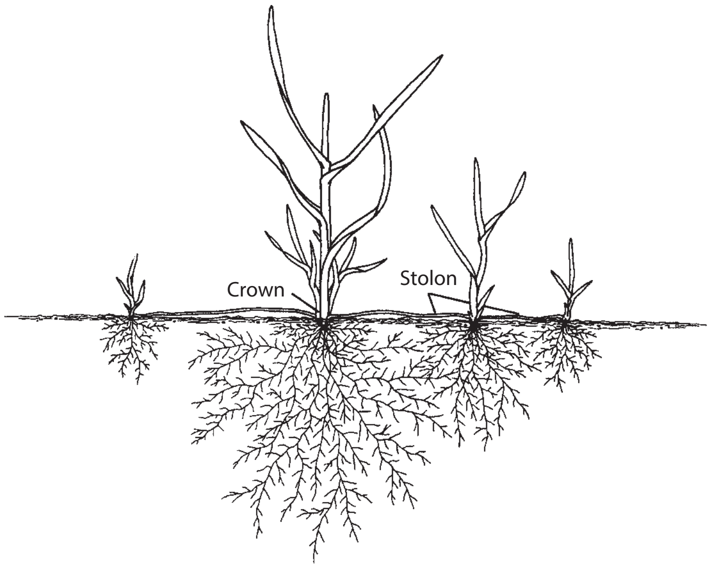

FIGURE 2.8 ***Spreading grass with stolons. (Drawing by J. M. Lenahan.)***

The second way that lateral stems serve as reproductive structures is by growth belowground. These underground stems with elongated internodes are called **rhizomes** (Figure 2.9). Rhizomes lack chlorophyll and have the appearance of large, white roots. They are not roots but are true stems, just like the aboveground stems. Roots do not have nodes. As with stolons, the nodes on the rhizomes are reproductive structures.

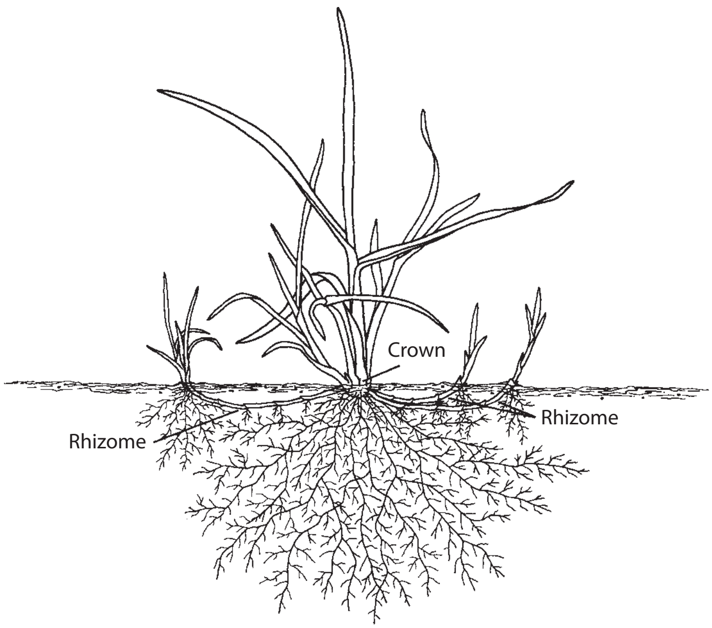

FIGURE 2.9 ***Spreading grass with rhizomes. (Drawing by J. M. Lenahan.)***

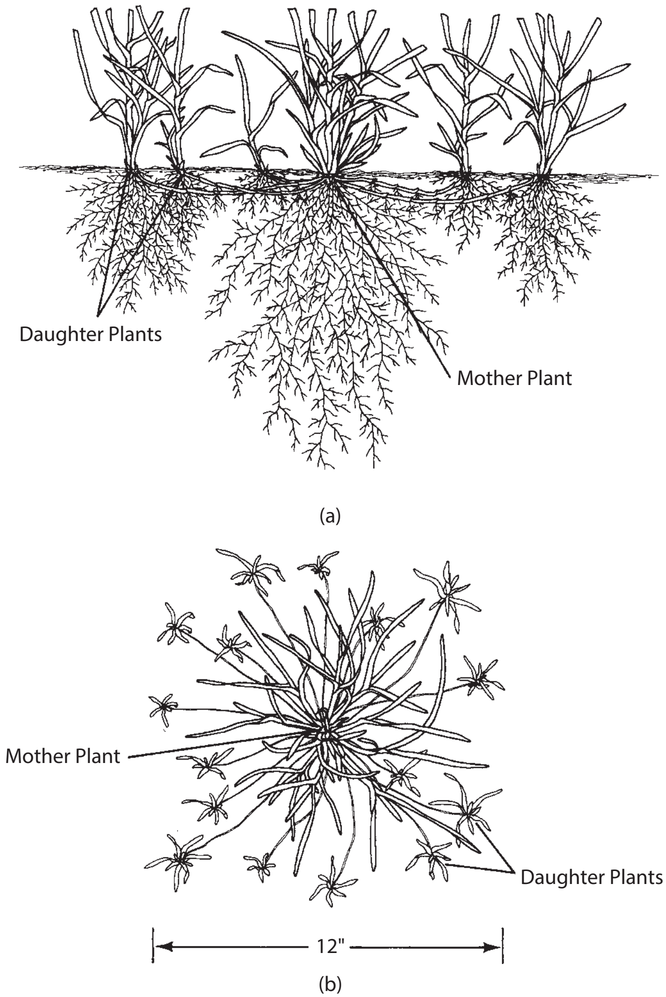

FIGURE 2.10 ***Kentucky bluegrass plant from (a) side view and (b) top view. (Drawing by J. M. Lenahan.)***

Whether a bud will form a tiller, a stolon, or a rhizome is determined by the genetic makeup of the plant. All turfgrasses produce tillers. Some turfgrasses, such as perennial ryegrass, produce only tillers. There are grasses that produce stolons but no rhizomes, such as creeping bentgrass and St. Augustinegrass. Others, such as Kentucky bluegrass and quackgrass, produce rhizomes but no stolons (Figure 2.10). Then there are grasses such as bermudagrass and zoysiagrass that produce both stolons and rhizomes.

Grasses with lateral stems have a big advantage over bunch-type grasses in that they are able to spread. If damage occurs in the turf, such as a divot on a golf course fairway or cleat damage to a sports field, lateral stems will quickly fill in the damaged area. Bunchgrasses are very slow to repair damage of this type, and overseeding may be necessary on damaged areas established with bunch-type grasses. Stolons or rhizomes are also necessary if the grass is to be used in the sod industry. Bunchgrasses will not produce a sod that can hold together for transplanting. One major disadvantage of stoloniferous and rhizomatous grasses is the extra labor costs associated with their management alongside landscape beds, gardens, and paths (cart paths, sidewalks, etc.).

While many grasses have a fixed growth habit, some species have a span of growth habits. For example, tall fescue is a bunch-type grass but it can produce short rhizomes. Some cultivars are bred to enhance rhizome production and are sold as rhizomatous tall fescues (RTFs). While these tall fescues may produce a rhizome, the rhizome is short and does not improve establishment rate or fill-in voids quicker than do conventional bunch-type tall fescue cultivars (St. John et al., 2009).

Perennial ryegrass is another bunch-type grass species that can produce lateral stems, in this case stolons or "pseudostolons." Recently, cultivars of "spreading" or "regenerating" perennial ryegrass have come on the market, including SR4600, Natural Knit®, and RPR®. While these perennial ryegrass cultivars would be slower to fill-in divots from stolons than other stoloniferous grasses such as creeping bentgrass, they can reduce divot recovery time compared to traditional, bunch-type cultivars (Golembiewski, 2016).

LEAVES

An understanding of how turfgrass leaves grow is key for turfgrass managers and useful in diagnosing potential problems.

Turfgrass leaves form when rapid cell division occurs within the outermost cell layers on the crown (Langer, 1972). Cell division is first from the apical meristem originating at the grass's crown, but leaf expansion occurs mostly from the intercalary meristem as the leaf continues to grow. Leaf blades continue to expand after emergence from the sheath, and the ligule develops at this point. Both leaf blade and sheath growth cease once the ligule is fully developed (Langer, 1972). Since leaves originate from the outermost cell layers of the crown, the outermost leaves are always the oldest (Figure 2.11). New leaf blades emerge from the folded or rolled sheaths of the older leaves. As the newest leaf blade is emerging, the next youngest leaf is elongating rapidly, and the next older leaf has likely just ceased growing (Langer, 1972).

Although most turfgrasses are perennial, leaves themselves live a short time. Temperature, light, moisture, N fertilization, carbohydrate assimilation, and other factors influence the age of the leaves and the rate at which new leaves appear (Langer, 1972), but leaves generally only live 30 to 60 days. Leaf death (senescence) begins at the leaf blade tip and spreads downward toward the base of the leaf sheath. Leaf age influences the plant's energy production and nutrient mobilization. Photosynthetic rates are highest in new leaves, and photosynthesis declines as leaves age (Langer, 1972; Ludlow and Wilson, 1971). As leaves age, they transport carbohydrates to new leaves to assist in their growth and development (Langer, 1972). Further, the plant responds to mowing (removal of existing leaf blades) by transporting N from roots and remaining leaf sheath tissue to new leaves (Ourry et al., 1988; Volenec et al., 1996).

Understanding the arrangement of leaves on the plant by age (outermost leaves are oldest, innermost leaves are youngest) and that leaves have a finite life span is helpful in diagnosing turf health. Under stressful periods, such as dry summer months for a cool-season grass, these grasses may have several visible senescing leaves and few healthy young leaves, as these environmental conditions hasten leaf death. Under favorable growing conditions, turfgrass plants will generally have more healthy leaves than