# Urban, Suburban, and Rural Amenities of Grass 8

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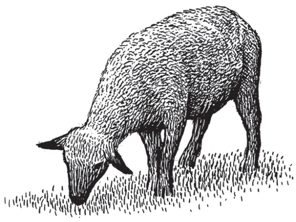
*"People are recognizing that a beautiful lawn helps to make a house a home. It adds to the beauty of the landscaping, brings satisfying relaxation and comfort to the family, and increases the material value of the home. Without grass, parks lose their appeal, and cemeteries become drab, indeed."—Burton and Sturkie, in Stefferud,* Grass: The 1948 Yearbook of Agriculture, *p. 311*

Selected grass species have been used for centuries as so-called amenity grasses to stabilize soils, beautify landscapes, and provide arenas for sports and recreational activities. These grasses evolved with their growing points located at or near the soil surface under the selection pressure of grazing animals. Continued natural selection, along with purposeful breeding, has provided many diminutive grass species and cultivars that, when properly managed, can form excellent turfs. Their use as lawns around residences and hospitals, in parks and recreational facilities, and on school and industrial grounds can enhance the aesthetic value of these sites while reducing dust, mud, heat, noise, and glare. In sports turfs, amenity grasses provide a variety of surfaces on which specific activities can be performed with relative safety and precision. And on golf courses, the greens, tees, fairways, and roughs are formed from amenity grasses maintained to provide the desired playing conditions for the different aspects of the game.

The capacity of professional turf managers to develop and maintain turfs of exceptional quality, despite the array of biotic and abiotic stresses to which these turfs are often subjected, reflects the progress made—especially during the past century—in the science and technology of amenity grass (turfgrass) management. It reflects as well the enormous array of educational opportunities available from academic institutions, concentrated principally within the United States, to those within or entering the profession.

## HISTORY OF AMENITY GRASS USE

In ancient times, men grazed livestock close to their dwellings to protect the animals from wild beasts. The closely cropped grass provided an unobstructed view of any dangers lurking in—or emerging from—nearby forests. The grass also framed the dwelling



and created a favorable environment for human activity. Extensive pastures sometimes served as arenas for sports and recreational activities, including early ball-and-stick games conducted on foot or on horseback. Thus, *pasture* grasses also served as *amenity* grasses where livestock grazing and human recreation both occurred at the same sites.

## Lawn Turf

Locally adapted grasses were sometimes planted intentionally as part of designed landscapes. The use of amenity grasses in residential gardens dates back to the early Persian gardens, established many thousands of years ago. As depicted in some Persian garden carpets, these "pleasure gardens" often included rectangular beds of low-growing flowering plants—the forerunners of contemporary lawns. Persian gardens spread throughout the Hellenistic world with the conquests of Alexander of Macedonia (356–323 BCE), and then to other parts of Europe by the Romans. Initially, their use was restricted to schools and public meeting places. Eventually, they were used around residences as settings for relaxation and entertainment.

Monastic gardens during the medieval period included plant communities composed primarily of adapted grasses and other turf species. Irrigation, with rainwater collected from the cloister gutters, and hand scything were used to keep the turf "short and green and never allowed to go brown like uncut hay" (Landsberg, 1995). These turfs were used for various purposes, including the "cloistered garth," which lay along side of the church where the monks walked and studied lessons, or read prayers at regular intervals throughout the day and evening.

According to Hugh of St. Victor (Paris), founder of the Victorine tradition in spiritual and mystical thought, the color green was "a metaphysical symbol of both rebirth and everlasting life." Also in the 12th century, Hugh of Fouilloy, prior of St. Laurent, wrote: "The green turf which is in the middle of the material cloister refreshes encloistered eyes and their desire to study returns. It is truly the nature of the color green that it nourishes the eyes and preserves their vision." William of Auvergne, bishop of Paris in the 13th century, attributed its tranquilizing nature to "being half way between black which dilates the eyes and white which contracts it" (Eco, 1986). In Queen Eleanor's 13th-century garden at Winchester Castle in England, the center was "filled with turf, because the expanse of green in a garden serves the same purpose as space in art, silence in music, or a pause in speech" (Landsberg, 1995).

While European gardens adjacent to dwellings were private and walled, some of their Colonial American counterparts were open, so that settlers could keep a lookout for hostile Native Americans. These sprawling yards or "homestead meadows" were often regarded as an American idiosyncrasy (Madison, 1971). Some believe that the American lawn as it is known today was actually born in the 1870s when several developments combined to make them possible (Pollan, 1998). The first was the creation of the suburbs—then known as the *borderlands*—to which city dwellers began to move in large numbers. The newly built commuter

## 12TH-CENTURY LAWNS

Albertus Magnus, a 12th-century Dominican friar who achieved fame for his comprehensive knowledge of and advocacy for the peaceful coexistence of science and religion, provided the following instructions for establishing a lawn from cut sod (translated by Harvey 1981):

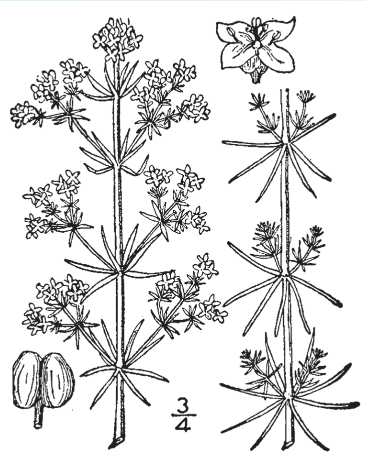
"The sight is in no way so pleasantly refreshed as by fine and close grass kept short. It is impossible to produce this except with rich and firm soil; so it behooves a man who would prepare the site for a pleasure garden, first to clear it well from the roots of weeds, which can scarcely be done unless the roots are first dug out and the site leveled, and the whole well flooded with boiling water so that the fragments of roots and seeds remaining in the earth may not by any means sprout forth. Then the whole plot is to be covered with rich turf of flourishing grass, beaten down with broad wooden mallets and trodden into the ground until they can scarcely be perceived. For then little by little they may spring forth closely and cover the surface like a green cloth."

## MEDIEVAL TURF BENCHES

A 15th-century poem titled *Floure and the Leafe* provides an impression of a "turf bench" in a medieval garden (Pearsall, 1962):

That benched was, and with turfes new
freshly turved, whereof the greene gras,
so small, so thicke, so short, so fresh of hew,
that most like unto green welwet it was.

"Benched" refers to manmade earthen benches covered with hand-harvested sod containing grass species—presumably red fescues (*Festuca rubra*) and colonial (browntop) bentgrass (*Agrostis capillaris*)—and other "turf plants," such as English daisy (*Bellis perennis*), healall (*Prunella vulgaris*), creeping speedwell (*Veronica filiformis*), ground ivy (*Glechoma hederacea*), and Lady's bedstraw (*Galium verum*), that were popular in English medieval gardens (Landsberg, 1995).



*Galium verum*. (USDA-NRCS PLANTS Database/N.L. Britton and A. Brown. 1913. *An illustrated flora of the northern United States, Canada, and the British Possessions.* Vol. 3:258.)

*Glechoma hederacea*. (Photo by G.A. Cooper, courtesy of Smithsonian Institution) railroad system enabled those who were part of the rapidly expanding middle class to commute to work and thus "keep one foot in the city and the other in the countryside." In developing the grounds surrounding their homes, they attempted to emulate the estate lawns in England by "cutting the vast manorial greenswards into quarter-acre slices everyone could afford" (Pollan, 1998). Another essential factor favoring the growing popularity of the American lawn was the availability of light-weight affordable lawn mowers. And, according to Pollan (1998), "the man who did the most to advance the cause of the American front lawn" in the post–Civil War era was Frank J. Scott (1870), who wrote, "A smooth, closely shaven surface of grass is by far the most essential element of beauty on the grounds of a suburban house."

## Sports Turf

Historically, grassed sites have been preferred for sports and recreation. In cool, moist climates where grass is plentiful, outdoor sports are almost always played on the grass. Kept short in ancient times by grazing—usually by sheep and cows, sometimes by rabbits—the grassed surface is relatively cool, free of dust and mud, and provides stable footing for man and animals.

The ancient sport of chogân—today called polo—was first played on extensive meadows in Persia (Suren-Pahlav, 1998). As the use of light cavalry spread throughout the Iranian plateau and elsewhere, so did this rugged game played on horseback. It became a popular sport throughout Asia among nobles and mounted warriors for many centuries, but it nearly disappeared as the great eastern empires collapsed. The British were introduced to polo in the mid–19th century when military officers and tea planters in India witnessed the game played by Manipuri tribesmen. The British are credited with spreading polo worldwide in the late 19th and early 20th centuries.

Lacrosse evolved centuries ago from ball-and-stick games played by Native Americans on open meadows or prairies. It was called *baggataway* by the Algonquin and *tewaarathon* by the Iroquois—meaning *the little brother of war*, as it was sometimes used to settle tribal disputes (Lund, 2007). As the stick reminded early French missionaries of a Bishop's crozier—*la cross* in French—*lacrosse* soon emerged as the generally accepted name for this sport.

Football (called *soccer* in the United States) is another ancient sport that is preferably played on grass fields. According to legend, rugby evolved in the early 1800s from football when a student at the Rugby Boys School in England "with a fine disregard for the rules of football first took the ball in his arms and ran with it." However, some have argued that the legend is probably mythical, as games that involved running with the ball had existed for centuries (Fagan, 2000). American football derived from rugby. While the first intercollegiate *running* game (kicking was not allowed) was played between Rutgers and Princeton in 1869, the rules establishing the game as it is played today were proposed by Yale University coach Walter Camp—considered the "father of American football"—in 1880.

Cricket is believed to have originated sometime in the 12th or 13th century in England, and it became a popular sport throughout the British Empire. Its principal playing surface, called the *pitch*, is maintained by close and frequent mowing and rolling to create and maintain a firm surface that supports the unique requirements of the game (Morgan-Mar, 2006). While cricket may be considered England's national summer sport, baseball—characterized as America's pastime—has been its counterpart in the United States. Alexander Cartwright, known as the "father of baseball," devised the first rules for the modern game and invented the modern baseball field (Peterson, 1973).

An early version of croquet was played by 13th-century French peasants, who used crudely fashioned mallets to whack wooden balls through hoops made of willow branches. In 1867, Walter Whitmorec, considered the inventor of croquet, developed the modern game in England (Charlton and Thompson, 1977). After lawn tennis was introduced, the popularity of croquet declined considerably. Lawn tennis can be traced back to 1858 when British Army Major Henry Gem marked out the first court on a lawn in Edgbaston; however, the true inventor of the modern game may actually be Major Walter Wingfield, a retired cavalry officer who in 1874 published his rules, developed a rubber ball that would bounce on grass, and patented the game under the Greek name *Sphairistike* (Masters, 1997b). The first Wimbledon championships were held in 1877, and the Lawn Tennis Association was launched 11 years later in 1888. Today, the All England Lawn Tennis and Croquet Club at Wimbledon features 19 (excluding practice courts) exquisitely maintained perennial ryegrass (*Lolium perenne*) courts, including the historic Centre Court, which usually hosts the finals of the main singles and doubles events at the annual championships and seats about 14,000 people, and Court 1, which holds about 11,500 people and occasionally plays host to the Davis Cup matches.

The game of bowls may have originated with the ancient Egyptians, as artifacts found in tombs dating back to about 5000 BCE suggest. As the sport spread, it took on a variety of forms, including *bocce* (Italian), *bolla* (Saxon), *bolle* (Danish), *boules* (French), and *ula miaka* (Polynesian); however, not all were played on grass. The oldest bowling green—located in Southampton, England—has been in operation since 1299 CE (Masters, 1997a). According to legend, Sir Frances Drake was involved in a game of bowls when he was notified of the approach of the Spanish Armada in 1588. He allegedly responded: "We still have time to finish the game and to thrash the Spaniards, too." Lawn bowls continues as a popular sport throughout the former British Empire. Since it is not a physically demanding sport, it is especially popular among older players. According to the *English Rule Book for All Sports*, published in 1856: "Unlike football, . . . it is a very quiet game, and calculated rather for the steady old gentleman, than for his rackety old son."

The bowling green and the golf green are similar in their construction and maintenance, but the two games are very different. The bowl is a relatively large, radially asymmetrical ball that one attempts to roll closer to a smaller white ball, called the jack, than one's opponent is able to do. Golf is a ball-and-stick game, and the much smaller golf ball is not rolled but struck with a club and aimed at a hole. In addition, bowls is played entirely on the green, while the game of golf is played from tees onto fairways—and, sometimes, roughs—and then onto greens.

## Golf Turf

The origin of golf, as it is known today, began in 15th-century Scotland. Some claim it was derived from *kolf*—a game played on frozen canals in the Netherlands during winter—that was introduced to the eastern coast of Scotland by Dutch sailors and businessmen (Sanchez, 2007). Others claim that it actually originated in Scotland from a variety of earlier ball-and-stick games, with two predominant forms emerging: the "long game," played on the links by the wealthy with specially made clubs and feather balls, and the "short game," played on town streets and churchyards by the common people with homemade sticks and balls (Hamilton, 1998). These games became so popular that King James III banned 'ye golf' in 1471, as they—especially the short game—interfered with the practice of archery by men called on to serve as foot soldiers in times of war. The short game faded out in the mid-1600s as town populations increased and struck balls posed serious—sometimes lethal—hazards to passersby. The long game, however, survived—and grew in popularity, as clubs and balls became more affordable through mass production—and became the modern game of golf.

The Scottish links are the undulating sandy coastal lands separated from the beaches by sand dunes. Stabilized by natural populations of marram grass (*Ammophila arenaria*), the dunes afford a measure of protection for the links from off-shore winds. The term *links* refers to the perceived role of these narrow strips of land as a link between the beaches and the interior agricultural lands. Because of the cool temperate-oceanic climate of Edinburgh (average annual temperature of 8.5°C [47.3°F], ranging from a monthly average of 3.1°C [37.6°F] in January to 14.5°C [58.1°F] in July; and uniformly distributed annual rainfall of 66.5 cm [26.2 in]) and nearby coastal cities and towns in the east coast of Scotland, native grasses of browntop (colonial) bentgrass (*Agrostis capillaris*) and red fescue (*Festuca rubra* L.) formed natural turfs of acceptable playing quality. These turfs remained in good condition during the winter golfing season—when farming operations ceased and farmers and businessmen had time for leisure—due to mild temperatures, frequent light rains, and generally good internal drainage. The quality of these turfs was enhanced by natural mowing and fertilizing provided by grazing animals and frequent topdressing with sand, which sometimes occurred naturally but could also be accomplished by manually distributing a layer of sand over the turf. "Mair saund, Honeyman," urged Tom Morris, the legendary keeper of the green

## "OLD" TOM MORRIS

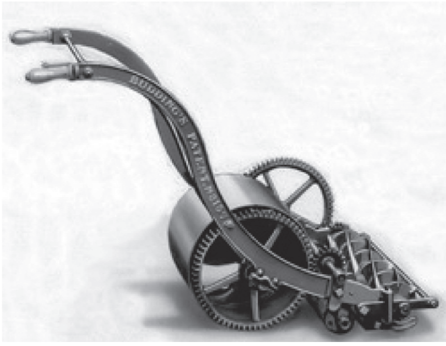
"Old" Tom Morris claimed that "neither broom nor scythe" had been used at St. Andrews until the mid–19th century, indicating that the golf links along the eastern shore of Scotland required little maintenance, except for cup placement and, as indicated, some topdressing. In the earliest days of links golf, even the holes were naturally occurring, with rabbit holes providing the target for play. Drawn to the lowest elevations, where higher soil moisture provided the best growth of the grass, the rabbits also grazed the areas around the holes—creating the forerunners of greens, and fertilized—building the sand's nutrient content. With this unique combination of conditions, early golf courses on the linklands of eastern Scotland could be characterized as natural ecosystems.

(referring to the entire golf course, not just the *greens*) at St. Andrews, Scotland, from 1865 to 1904, to his assistant whenever the remedial effects of sand were required to maintain the turf in a playable condition (Hamilton, 1998; Beard, 2002).

In the earliest links courses, there was no distinction between greens, tees, and fairways. The playable portions of the links were called the greenways, while the forerunners of roughs were the more elevated portions of the landscape that established the shape and size of the greenways. Later, specific sites within the greenways were selected and subjected to more intense grazing, fertilizing (with manures), and topdressing to form the tees and greens. With the development of the reel mower in 1830 by Edwin Budding (an English textile engineer who adapted the rotary sheer—used for cutting the nap on carpets—for mowing grass), animal grazing was eventually supplanted by mechanical mowing for turf maintenance; however, cutting the grass with manual and horse-drawn mowers was still considered a novelty in 1901 (Hamilton, 1998). In the 1920s, the tractor began to appear on farms and soon found its way onto golf courses as an alternative to the horse for pulling fairway mowing units.

Golf and golf courses became popular throughout the British Isles and around the world in the 19th and 20th centuries. They were introduced to India in 1829, France in 1856, Canada in 1873, the United States and Belgium in 1888, the Netherlands in 1890, Switzerland and Hong Kong in 1891, Germany and Spain in 1895, China in 1896, Austria in 1901, Sweden and Italy in 1902, Denmark and Japan in 1903, the Czech Republic in 1904, and Poland in 1906. The first surviving golf course in the United States was St. Andrews in Yonkers, New York, which was built in 1888. The popularity of golf courses grew rapidly in the United States, with 74 new courses constructed over the next seven years (Beard, 2002).

The unique combination of locally adapted grass species, well-drained soils, and a gentle climate along the linklands of the Scottish east coast is ideal for golf turf, and it is duplicated at few other places in the world. Early attempts at maintaining golf courses at other locations often produced disappointing results. The more severe climatic conditions encountered in the United States posed even greater challenges for managing golf turf. According to Walter Travis (1901), champion golfer and golf writer in the early 1900s, "The climate in this country can hardly be said to lend itself to the growth or development of natural greens of the first rank. The extreme heat and cold are not favorable allies." In the U.S. climate, irrigation was necessary to sustain the turf during periods of drought, and severe disease was commonplace, especially if irrigation was excessive and drainage inadequate. Major adjustments in cultural practices—developed through trial and error—were needed to address these and a multitude of other problems. Other grass



**Photograph of early greens mower, designed by Edwin Budding. (Photo courtesy of Ransomes Jacobsen Ltd., Ipswich, England)**

species had to be used where summertime temperatures and diseases limited the adaptation of red fescue and browntop bentgrass. This led to the substitution of creeping bentgrass (*Agrostis stolonifera*) in temperate-continental climates and bermudagrasses (*Cynodon* spp.), as well as some other locally adapted warm-season species, in subtropical and tropical climates. In the absence of grazing by sheep or other animals, hand-operated and horse-drawn mowers were used to cut the grass, and unprocessed manures provided nutrients for sustaining healthy growth (Beard, 2002). Bordeaux mixture, made from copper sulfate, $CuSO_4$, and hydrated lime, $Ca(OH)_2$, was used in early attempts to control diseases; while it provided some short-term suppression of brown patch (caused by *Rhizoctonia solani*), it was ineffective against a more pervasive disease, later identified as dollar spot (caused by *Rutstroemia floccosum*), and it posed a serious risk of turfgrass injury from copper accumulations in the soil (Latham, 1996). Solutions of nicotine sulfate, $(C_{10}H_{14}N_2)_2H_2SO_4$, made by extracting nicotine from tobacco (*Nicotiana* L.), were used in attempts to control some sucking insects but were highly toxic to humans and other mammals. And weed control was accomplished primarily with a knife. The inability to effectively control many of these pest problems often resulted in poor playing conditions and sometimes required extensive replanting operations to reestablish the turf.

## EVOLUTION OF TURFGRASS SCIENCE AND TECHNOLOGY

The state of turfgrass science and technology in the early 20th century was captured in a number of contemporary books, including those by Doogue (1912), Piper and Oakley (1917), Lees (1918), Beal (1924), and Noer (1928). The problems encountered in golf turf culture at that time could not be adequately addressed by trial-and-error experimentation at the local level. Formal research was needed to investigate the causes of problems that threatened turf quality and, with the insights gained, to find satisfactory solutions. Early research trials were initiated in 1885 by J. B. Olcott at South Manchester, Connecticut, with the development of the Olcott Turf Garden (under the auspices of the Connecticut Agricultural Experiment Station). Olcott was one of the founders of the Storrs Agricultural School, which later became the University of Connecticut. Mr. Olcott traveled widely and made an extensive collection of amenity grasses for evaluation, which he continued until his death in 1910. Noticing the wide variation evident within each species, he vegetatively propagated the most promising selections to ensure the greatest possible uniformity. While it is not known if he crossbred any of his selections, his propagation of specific selections constituted a rudimentary form of plant breeding, probably establishing him as the first American turfgrass breeder. He concluded that specific strains of creeping bentgrass and red fescue provided the highest-quality turf for New England conditions (Piper and Oakley, 1917).

In 1912, Frederick W. Taylor purchased sod of an especially attractive selection of creeping red fescue from Olcott's collection and planted it at his Boxly estate in Highland—near Philadelphia—in Pennsylvania. While the quality of the turf produced from this grass was outstanding in spring and fall, it deteriorated dramatically from disease induced by midsummer heat stress, indicating that its geographic adaptation was limited by high temperatures. Famous for his innovative work in scientific management, Mr. Taylor devoted the last years of his life to golf and the study of putting green construction (Taylor, 1914–1915, 1916). He was the first to study the creation of an "artificial" green in which the components—sands of different sizes, as well as clay, organic amendments, and fertilizers—were brought together in a carefully prescribed fashion to optimize turfgrass growing conditions. Through his design, he attempted to develop a green that was well drained but which incorporated "an underground reservoir and lifting sand" so that the capillary rise of water due to the water potential gradient resulting from evapotranspiration at the surface would provide "a continuous and automatic supply of moisture between the reservoir and the root bearing layer." Although his work was largely ignored at the time, it served as the basis for subsequent research leading to the development of the modern sand-based green designs, including the specifications of successive versions of the U.S. Golf Association (USGA) Green Section design (USGA Green Section Staff, 1960, 1973, 1989, 1993; Moore, 2004). Other sand-based designs were the PURR-WICK (an acronym for Plastic Under Reservoir Rootzone, with upward water movement via capillary or WICK action), developed under the leadership of William H. Daniel at Purdue University (Ralston and Daniel, 1972), and the California Method, developed by John H. Madison and William B. Davis at the University of California (Madison and Davis, 1977; Davis et al., 1990). Some of these systems are now being used to support rooftop putting greens and sports turfs in urban environments, as they can be sustained in specialized containers in which adequate soil drainage and aeration occur, despite their isolation from underlying soils.

The involvement of the USDA in golf turf first occurred in 1906 in response to a request for technical assistance on putting green management from Dr. Walter S. Harban, a member at Columbia Country Club in Washington, DC. His meeting with forage grass experts Charles V. Piper and Russell A. Oakley marked the beginning of their long association with golf courses and golf turf management. In 1915, the executive committee of the United States Golf Association met with Agriculture Secretary David F. Houston and worked out an arrangement that resulted in the establishment of the Arlington Turf Gardens the following year to evaluate and select improved grasses for putting greens (Monteith, 1928). A large pie-shaped green was eventually established in the garden for side-by-side comparison of creeping and colonial bentgrass selections, including Arlington (C-1), Astoria (C-61), Cohansey (C-7), Congressional (C-19), Highland (C-65), Metropolitan (C-51), Norbeck (C-36), Old Orchard (C-52), Seaside (C-60), Toronto (C-15), and Washington (C-50). This led to the production and distribution of several seeded and vegetatively propagated bentgrasses to replace seed imported from Germany (including South German mixed bent, containing 75–85% colonial [*Agrostis capillaris*] and dryland [*A. castellana*] bentgrasses, 10–20% velvet bentgrass [*A. canina*], and 1–5% creeping bentgrasses [*A. stolonifera*]) and elsewhere. Often, in U.S. plantings, only creeping bentgrass persisted, sometimes with small patches of velvet bentgrass). In 1920, E. J. Marshall, an attorney and green committee chair at Inverness Club in Toledo, Ohio, conceived the idea of forming a "Green Section" of the USGA to work in cooperation with the USDA to address golf turf problems. Piper and Oakley became the Green Section's first chairman and cochairman, respectively. While engaged principally in research, both visited golf courses and dispensed advice as time allowed. In 1928, Dr. John Monteith, a USDA plant pathologist, was appointed as director of the Green Section and served in that capacity until 1942, when he was inducted into military service as chief of engineers during World War II. During his tenure, he evaluated grasses for greens on golf courses across the United States. He also conducted experiments to identify and control major turfgrass diseases, which led to the publication of Turf Diseases and their Control (Monteith and Dahl, 1932). The Arlington Turf Gardens were abandoned in the early 1940s to make room for construction of the Pentagon. During World War II, Dr. Fannie Fern Davis, who was active in the development of the herbicide 2,4-D, served as acting director of the Green Section. Following the war in 1945, Dr. Fred Grau, who had served as the first turfgrass extension specialist at Penn State, became the Green Section director. He was a strong promoter of newly developed turfgrasses and the turfgrass industry, and he helped to establish the Turfgrass Management Division of the American Society of Agronomy.

The USGA initiated the Green Section's Turf Advisory Service (TAS) in 1953 to provide a formal program of advisory service to subscribing golf courses. The Turfgrass and Environmental Research Program was initiated in 1983 to improve turfgrasses, address environmental quality issues and concerns, and improve playing conditions for the enjoyment of the game of golf. In the past 20 years, the USGA has funded more than 290 projects and invested more than $25 million in this research program. The USGA also provided funding in 1984 to develop the Turfgrass Information Center at Michigan State University, which currently houses over 100,000 publications covering all aspects of turfgrass science and culture. These publications and other related turfgrass information are available by electronic access through a system called the Turfgrass Information File (TGIF).

Another important development that influenced golf turf research and education in the United States was the formation of the National Association of Greenkeepers of America in 1926 by Colonel John Morley, the greenkeeper at Youngstown Country Club. Under his leadership, the National Association of Greenkeepers of America—later renamed the Golf Course Superintendents Association of America—began publishing a monthly magazine and holding national meetings to promote the exchange of ideas and the adoption of better greenkeeping methods.

Since the earliest efforts at the Connecticut Agricultural Experiment Station in the late 1800s, an increasing number of state agricultural experiment stations housed within U.S. land-grant universities have initiated turfgrass research and educational programs, beginning with Rhode Island in 1890, Virginia and Missouri in 1910, Wisconsin in 1920, Ohio in 1923, New Jersey in 1924, Nebraska, Massachusetts, and Alabama in 1927, and Pennsylvania and Michigan in 1929 (Huffine and Grau, 1969). Today, nearly all land-grant institutions have turfgrass programs that contribute to turfgrass science and technology through their research efforts, prepare students for professional careers in the turfgrass industry through their certificate, undergraduate, and graduate teaching programs, and provide continuing educational opportunities for professional turfgrass managers. While golf turf—which makes up only about 3% of the turfgrass industry—has historically been the driving force in the initiation and operation of these programs, other sectors of the turfgrass industry, including sports turf, landscaping, and lawn care, have benefited from them as well.

In 1953, the Turfgrass Management Division—now called the C-5 Division—was formed in the American Society of Agronomy, which was later moved to its sister organization, the Crop Science Society of America (Shearman, 2006). The current C-5 membership includes more than 500 professional turfgrass scientists and educators, mostly from American land-grant universities. The International Turfgrass Society held its first research conference in Harrogate, England, in 1969, with 78 registrants—mostly from academic institutions—representing 12 countries. The 10th conference was held 36 years later in Llandudno, Wales, with 262 registrants from 25 countries.

## Grass Development

Many turf management operations are designed to alter the natural environment to favor the desired turfgrass. These alterations often include measures to improve surface and internal drainage, reduce shade through tree pruning or removal, supply supplemental moisture through irrigation, adjust the soil pH upward through liming, enhance soil fertility through fertilization, and control diseases and insects by various means, including the use of appropriate pesticides. In performing these operations, the turf manager attempts to bring the environment and management into balance with the genotype by satisfying its unique requirements and compensating for its specific deficiencies. Another alternative is to change the genotype so that it more nearly fits the existing environment and thus reduce the number and intensity of alterations required. Although better-adapted genotypes can evolve naturally over time, more often turfgrasses are specifically selected from among commercially available cultivars and planted during turf establishment or renovation. These cultivars are developed as products of commercial or academic breeding programs. Traditional breeding involves selection and usually—but not necessarily—hybridization. Once selected, plant "accessions" may be classified, their chromosomes counted, and their self- and cross-fertility relationships established in preparation for further developmental work (Burton, 1969).

## Selection and Hybridization

Three types of selective forces act to modify turfgrass populations, including (i) *natural selection*, by which individuals best adapted to a particular set of environmental conditions survive and produce viable progeny; (ii) *unconscious selection*, by which humans save the most desirable individuals and destroy others; and (iii) *methodical selection*, by which humans systematically attempt to create predetermined changes in populations (Casler and Duncan, 2003). Considerable natural variability can be found among plants within a turfgrass species. With the exception of facultative apomicts (e.g., Kentucky bluegrass [*Poa pratensis*], which forms seed embryos directly from vegetative tissue), turfgrasses are typically self-incompatible and often exist as a polyploid series (e.g., with tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh. = *Schedonorus arundinaceus* (Schreb.) Dumort], several ploidy levels ranging from diploids—containing two sets of chromosomes, to decaploids—containing 10 sets). And since many turfgrasses freely exchange genes with closely related plants (not only within species, but within some genera—such as *Cynodon* and *Zoysia*), highly heterogeneous populations with unlimited numbers of potential genotypes exist, with additional ones being created from successive pollinations. Natural selection pressures operating within specific climates drive the evolutionary development of turfgrass populations with specific mixtures of interbreeding phenotypes. As a consequence, turfgrass populations occurring in one environment may differ substantially from populations of the same species in another.

Unconscious selection—also called *domestication*—is evolutionary development under human influence. Initial domestication of turfgrasses was probably linked to the domestication of livestock. Intensive animal grazing induced genetic shifts, resulting in shorter basal internodes, a more prostrate growth habit, higher shoot densities, later flowering, and greater longevity of individual plants. Also, since grass-covered playing fields afforded some measure of safety for participants in often-violent early ball games, selection for these activities probably contributed to the evolution of turfgrasses as well. Selection pressures associated with turf management practices, while paralleling natural selection pressures by herbivores, also differed in their nature and intensity, thus driving evolutionary development toward more diminutive plants and denser plant populations. Finally, global climate change—induced by the accumulation of greenhouse gases in the atmosphere—may continue to impose selection pressures, resulting in genetic shifts within turfgrass populations that favor plants that are best suited to the changes.

Methodical selection is the purposeful breeding of turfgrasses to utilize genetic variation created by natural—and, to some extent, unconscious—selection. This variability can be discovered and, if desired, manipulated to develop improved cultivars. Passage of the Plant Variety Protection Act (PVPA) in 1970 profoundly impacted the development and release of improved turfgrass cultivars, allowing breeders and breeding institutions to protect their cultivars and obtain a greater and more consistent return on their investments in developing new cultivars, and therefore heightening interest in new cultivar development (Shearman, 2006).

Many improved cool-season turfgrass cultivars—such as ‘Merion’ and ‘Touchdown’ Kentucky bluegrasses, ‘Lynn’ perennial ryegrass, ‘Seaside’ creeping bentgrass, and ‘Kentucky 31’ tall fescue—have been developed simply by propagating naturally occurring populations or individual genotypes that were discovered on golf courses, natural meadows, or other sites. Some naturally occurring populations are used to create synthetic cultivars through hybridization. Since Kentucky bluegrass produces seed via facultative apomixis, most of the seedlings are identical to the maternal parent. C. Reed Funk and colleagues at Rutgers developed techniques for intraspecific hybridization (interbreeding between genetically divergent individuals from the same species) of Kentucky bluegrass that led to the development of numerous successful cultivars, including ‘Adelphi’, ‘America’, ‘Eclipse’, ‘Midnight’, and ‘Shamrock’ (Shearman, 2006). ‘Penncross’ creeping bentgrass was developed from three intercrossing vegetatively propagated parents by H. B. Musser and released in 1955. This cultivar set a new standard of putting green quality for seeded creeping bentgrasses and still persists as a popular cultivar today. Since the introduction of Penncross, this standard has been raised again and again with the release of superior creeping bentgrasses. Arguably the highest quality is currently obtainable with the ultra-high-density Penn A- and G- series creeping bentgrasses, both developed by Joseph M. Duich at Pennsylvania State University. Most new turfgrass cultivars are created by successive cycles of recurrent selection, each involving the evaluation of a large number of individual plants and subsequent selection and intercrossing of the best individuals (Casler and Duncan, 2003). 'Manhattan' perennial ryegrass is an example of a synthetic cultivar that was developed from parents selected at Central Park in Manhattan, New York (Funk et al., 1969). 'Rebel', released in 1981, was the first turf-type tall fescue, differing from the earlier forage types in texture, density, color, and persistence. Even more diminutive dwarf and semidwarf types were released in 1989 and 1991, respectively. While the turf quality of a particular cultivar typically reflects its genetic makeup, other factors, such as fungal endophytes, may also be involved. Fungal endophytes are organisms that grow entirely within—and exist in a symbiotic association with—their turfgrass hosts. Endophytes *Neotyphodium lolii* in perennial ryegrasses, *Neotyphodium typhinum* and *Epichloe typhina* in red and hard fescues, and *Neotyphodium coenophialum* in tall fescues have been shown to improve drought resistance, foliar-feeding insect tolerance, and resistance to some diseases (Zhang et al., 2006). Direct use of naturally endophyte-infected germplasm in breeding programs provides an opportunity for enhanced turfgrass performance that extends beyond the genetic characteristics of the grass genotype.

With respect to some warm-season turfgrasses, the first hybrid bermudagrasses, 'Tiffine' and 'Tifgreen', were developed by Glen Burton in the mid-1950s. These were sterile, interspecific (between two different species) triploid hybrids of common bermudagrass (*Cynodon dactylon*) and African bermudagrass (*C. transvaalensis*). They were followed by the release of 'Tifway' for use as a fairway and sports turf, and 'Tifdwarf', a natural dwarf mutant selected from a Tifgreen putting green growing in South Carolina. These cultivars are still extensively used throughout the southern United States. More recently, breeders have released common bermudagrasses with improved turfgrass quality and seed yield. Examples include 'NuMex Sahara' by Arden Baltensperger at New Mexico State University and the more cold tolerant 'Riviera' by Charles Taliaferro at Oklahoma State University. Today, the ultradwarf hybrid bermudagrasses, such as 'TifSport', 'Miniverde', and 'Champion', are gaining popularity because they tolerate the same close mowing heights as those used with the ultra-high-density bentgrasses.

New turf-type buffalograsses (*Bouteloua dactyloides*) were developed in response to demands for more water-conserving turfgrasses; the first of these were 'Prairie' by Milton C. Engelke and Virginia Lehman of Texas A&M University in 1989, and '609' by Terrance Riordan of University of Nebraska–Lincoln in 1991. The work at Texas A&M also focused on the development of new zoysiagrasses (*Zoysia* spp.), since they are reasonably drought tolerant and more shade tolerant than the bermudagrasses. Because of problems associated with high concentrations of soil salinity, especially in coastal areas in subtropical and tropical climates, seashore paspalum (*Paspalum vaginatum*) was investigated by R. R. Duncan at the University of Georgia's Griffin Experiment Station, resulting in the release of 'SeaIsle 2000' for greens and tees and 'SeaIsle 1' for fairways and sports turfs, both in 1991.

New turfgrass cultivars are typically evaluated for their turf quality—compared with standard cultivars—at multiple locations, and the results are available online through the National Turfgrass Evaluation Program (NTEP; http://www.ntep.org). The NTEP was the brainchild of Jack J. Murray, a scientist at the USDA Agricultural Research Center in Beltsville, Maryland. It began as a regional Kentucky bluegrass cultivar evaluation trial in the 1970s and later expanded to nationwide trials encompassing all of the most commonly used cool- and warm-season turfgrass species.

## Biotechnology

Turfgrass biotechnology encompasses a number of areas: applications of molecular markers to assist breeding efforts, in vitro manipulations for regenerable tissue culture, and genetic engineering by DNA transfer techniques (Chai and Stricklen, 1998). Molecular markers include protein-based and DNA-based markers. The protein-based markers are isozymes (also called isoenzymes, which are enzymes that differ in amino acid sequence but catalyze the same chemical reaction; they include peroxidase, esterases, and phosphoglucomutases) that have been useful in genotyping—i.e., differentiating between or among some cultivars of—Kentucky bluegrasses, creeping bentgrasses, and red fescues. However, because of the limited array of isozyme forms (i.e., isozyme polymorphism), they have not been suitable for differentiating between closely related genotypes. With the extensive genetic polymorphism associated with differences in DNA sequences, however, the development of DNA-based markers has greatly improved the ability to distinguish among turfgrass genotypes. DNA-based markers include restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), simple sequence repeat (SSR), and amplified fragment length polymorphism (AFLP). Restriction fragment length polymorphism assay is very effective for detecting DNA restriction fragments of different lengths; however, generating these markers requires prior knowledge of DNA sequences for making proper probes. The RAPD method is based on the polymerase chain reaction (PCR), using short (usually 10-nucleotide) primers for investigating genetic variations in unknown sequences. They were used for determining the genetic origins of aberrant plants derived from facultative apomixis (Huff and Bara, 1993); cultivar identification of high resolution was achieved for buffalograss with RAPD-generated DNA profiles of DNA amplification fingerprinting (DAF) (Caetano-Anolles et al., 1991a,b), and high levels of polymorphic DNA profiles were detected in bermudagrass species by digesting DNA templates with restriction enzymes before amplification (Caetano-Anolles et al., 1995). Another type of PCR-based DNA assay is SSR polymorphism. While it is very time consuming, SSR polymorphism can reveal high allelic variation (i.e., different forms of particular genes that, in combinations, determine the traits of specific offspring) throughout the entire genomes and provides a better choice than RFLPs to detect genetic variation in self-fertilized species such as seashore paspalum (Liu et al., 1995). Finally, AFLP is another PCR-based DNA assay, developed to detect the restriction fragments from enzymatic digestion of DNA, but it is less time consuming, does not require prior sequence knowledge, and generates higher genetic polymorphisms than that obtainable from RFLP. Because of these features, AFLPs are promising for rapid identification and mapping in species, including turfgrasses, for which little sequence knowledge currently exists.

In vitro tissue culture is the propagation of plant tissues in a culture medium. It is used for a variety of purposes, including recovering genetically altered germplasm, somoclonal variations, haploids, and existing germplasm with unique features, as well as for micropropagation and aseptic germplasm storage (Chai and Stricklen, 1998). It begins with culturing meristematic and embryonic tissues in auxin (plant hormone)-supplemented media to form callus tissue. Cell suspensions developed from the calli (undifferentiated tissue) are then used to isolate protoplasts (living portion of cells). Many turfgrasses, including bahiagrass (*Paspalum notatum*), bentgrasses, bermudagrasses, bluegrasses, buffalograss, centipedegrass (*Eremochloa ophiuroides*), fescues, Japanese lawngrass (*Zoysia japonica*), ryegrasses, and St. Augustinegrass (*Stenotaphrum secundatum*), have been regenerated using in vitro tissue culture.

Genetic engineering refers to the manipulation of genes by DNA transfer techniques. *Agrobacterium*-mediated transformation involves the use of *Agrobacterium tumefaciens*, a soil bacterium that can effect genetic change in plant cells by transferring its DNA. It has been widely used for genetic transformation of dicots and some grasses, including perennial ryegrass and tall fescue (Cao et al., 2006) and creeping bentgrass (Yu et al., 2000). Other genetic transformation techniques usually involve the direct delivery of DNA to plant tissues, including biolistic bombardment and DNA uptake by protoplasts. Biolistic bombardment involves the use of a "gene gun" to deliver DNA molecules carried by tiny particles of gold into intact cells. This technique has been successfully used for genetically modifying creeping bentgrass, tall fescue, red fescue, and perennial ryegrass (Chai and Stricklen, 1998). Direct DNA delivery into protoplasts has also been successfully used in turfgrasses. With the physical barrier of the cell wall removed, protoplasts can be induced by various methods to absorb DNA from their culture medium. Turfgrasses that have been genetically altered by this technique include creeping bentgrass, tall fescue, and red fescue.

As specific milestones are reached and improved techniques are developed, biotechnology will offer opportunities for improved tolerance to environmental stresses and resistance to diseases and other pest problems. Anticipating some of the challenges the future will likely bring, including higher energy costs, water shortages, and new pest-related problems coupled with pesticide-use restrictions, there will be a need for new and better solutions. This approach is not without its problems, however. The glyphosate-resistant transgenic line of creeping bentgrass developed by Monsanto and the Scott Company is currently facing a significant challenge from the Center for Food Safety. Because of concerns that transgenic bentgrass cultivars could cross with nontransgenic and wild-type creeping bentgrasses in commercial production, a request was filed for an injunction against the USDA, barring release of this grass (Jones, 2005; http://www.centerforfoodsafety.org). Commercial production and distribution of this transgenic turfgrass is not likely to occur until the matter has been satisfactorily resolved.

## EQUIPMENT AND SYSTEMS DEVELOPMENT

The management of high-quality turf requires a sophisticated array of equipment and systems, including mowers for regularly clipping the grass, cultivators of various types for alleviating soil compaction and controlling thatch, applicators for spraying and spreading materials onto the turf, irrigation systems for supplementing natural rainfall, and drainage systems for removing excess water.

### Mowers

Modern mowers are principally of two types: reel and rotary. Reel mowers have a stationary bedknife and a rotating reel cylinder containing a variable number of blades. Reels with up to 11 blades are used for greens and other closely mowed turfs. A shearing-type clipping occurs once grass shoots are pulled by the rotating reel blades into the forward-moving bedknife, forming an isosceles triangle. After clipping, the shoots spring back to their vertical orientation. As long as the clip of the reel (CR)—defined as the forward distance traveled between successive clips—does not exceed the mowing height (MH), the mowing quality is satisfactory; however, if CR > MH, usually as a result of operating the mower at excessive speeds, an undesirable washboard pattern, called *marcelling*, may be evident in the turf. Early greens mowers were manual units requiring considerable effort to operate. While heavy steam-powered units were introduced, they did not gain wide acceptance. By the 1940s, engine-power units replaced the manual greens mowers. Hydraulically operated triplex riding mowers were introduced in the 1960s and, because of the considerable labor savings realized from their use, became very popular on golf courses throughout the world. A common problem observed with these mowers is the creation of the "triplex ring" in the clean-up pass just inside the perimeter of the green. Since most of the damage is due to wheel traffic, specialized mowers have been developed that vary the position of the mowing units relative to the wheels to better distribute wheel traffic. Large multi-unit fairway mowers were introduced in the 1970s to provide substantial labor savings in fairway mowing, but they eventually lost favor because of the severe soil compaction resulting from their continuous use. Modern fairway mowers are lighter in weight and allow the operator to remove clippings if desired.

Rotary mowers use horizontal knives mounted on a rotating vertical shaft. Clipping occurs as the sharp edges of the knives impact the shoots. Shredding of leaf tips and extensive bruising of leaf blades are indicative of dull cutting edges. Frequent sharpening and balancing of the knife are necessary to ensure satisfactory cutting quality. Small walk-behind or riding rotary mowers have become the standard for residential lawn maintenance. Larger multi-unit riding rotary mowers are used for mowing golf course roughs, commercial landscapes, parks, cemeteries, and roadside turfs.

Photograph of an aerifier taken in 1947. (Photo courtesy of Jim Snow, USGA Green Section)

Photograph of a verticut machine taken in 1953. (Photo courtesy of Jim Snow, USGA Green Section)

Experimentation with robotic mowers guided by a geographic information system linked to global positioning satellites (GIS-GPS) suggests that future mowing on golf courses and other high-value turfs might be conducted at night to minimize interference with play and reduce labor costs.

## Cultivators

The first turf cultivator was a simple pitchfork. Well before any of the modern cultivators appeared, some golf course superintendents would push a pitchfork into compacted sites on greens and elsewhere where water infiltration was slow, or on ridges or sloping sites where rainfall or irrigation water tended to move downslope along the surface, to improve infiltration. Tom Mascaro patented the open-spoon aerifier for alleviating soil compaction in 1946 and the original verticutter for removing thatch in 1952. A variation of the verticutter—or vertical mower—that included a disc seeder for depositing seed into the open grooves created in the turf was developed by golf course superintendent Karl Hophan in the 1960s. Subsequently, numerous versions and alterations of these devices have been developed and used in turfgrass culture. Modern cultivation methods include spiking, slicing, vertical mowing, hollow-tine cultivation solid-tine cultivation, water-injection cultivation, gravel-injection cultivation, sand-injection cultivation, and air-injection cultivation (Turgeon, 2008). Through these equipment innovations and associated technological advances, turfgrass culture has progressed from modest efforts directed at improving infiltration to more substantial modifications of existing turfs directed at improving surface and internal drainage through the provision of bypass drainage columns and curtains throughout the turf.

## Applicators

The materials that are routinely applied to turf—including lime, fertilizers, pesticides, plant-growth regulators, and topdressing soil—must be distributed uniformly and at the proper application rate to achieve the desired results. Furthermore, the application equipment, as well as the vehicle that may be used to carry it, must not damage the turf in the process. Turf applicators include a wide variety of sprayers for applying liquid materials and spreaders for applying dry materials. When properly calibrated and operated according to manufacturers' directions, modern applicators can distribute materials with great precision and uniformity. Some highly sophisticated applicators use direct-injection systems for adding the desired chemicals to the water stream moving toward the spray nozzles and variable-rate controls guided by GIS-GPS.

## Irrigation and Drainage

Modern irrigation systems are designed, constructed, and programmed to apply water uniformly at rates that promote maximum turf infiltration at desired times throughout the day and night. They can also be used to apply small amounts of water—a practice called *syringing*—to stressed turfs to cool tissue temperatures and replenish leaf moisture. When fitted with injection systems, irrigation systems can be used to also apply fertilizer nutrients during irrigation—a practice called *fertigation*. Subsurface drainage systems use perforated drainage pipes that can carry water that has accumulated below the soil surface to a lake, pond, storm sewer, or other receptacle. Where catch basins positioned in depressions in the turf to catch runoff water are connected to the drainage pipes, surface drainage can be enhanced as well. And where a vacuum pump is connected to a series of drainage pipes, the internal drainage process can be accelerated, if desired, on selected sports fields and golf greens. This same system can be used to cool a turfgrass root zone during hot weather—or warm the root zone during cold weather—where the pump is used to blow cooled or heated air through the pipes. Additional technological innovations directed at modifying the turfgrass root-zone environment through enhanced soil aeration and retention of plant-available moisture and nutrients, while sustaining optimum root-zone temperatures, can be anticipated in future years, especially on high-value turfs.

## AGROCHEMICAL DEVELOPMENT

Since the end of World War II, many new chemicals have been developed for use in all types of agricultural operations, including turfgrass management. These *agro*chemicals encompass fertilizers, pesticides, plant-growth regulators, biostimulants, and wetting agents.

### Fertilizers

The capacity to synthesize ammonia ($NH_3$) from atmospheric nitrogen ($N_2$) and hydrogen (H)—typically from natural gas (methane, $CH_4$) in the United States—was developed in Europe at the beginning of the 20th century. The ammonia is then reacted with various acids—nitric acid ($HNO_3$) to form ammonium nitrate ($NH_4NO_3$), sulfuric acid ($H_2SO_4$) to form ammonium sulfate [$(NH_4)_2SO_4$], and phosphoric acid ($H_3PO_4$) to form ammonium phosphates [$(NH_4)H_2PO_4$ and $(NH_4)_2HPO_4$)—to produce the inorganic soluble nitrogen carriers commonly used for turfgrass fertilization. A soluble organic carrier, urea ($H_2NCONH_2$), is formed by reacting ammonia with carbon dioxide ($CO_2$). Slowly soluble nitrogen formulations can be produced by linking two or more urea molecules together by reacting urea with formaldehyde (HCOH) to form various methylene ureas, including methylene diurea, dimethylene triurea, and trimethylene tetraurea. An alternate polymer can be produced by reacting urea with isobutylaldehyde [$(CH_3)_2CHCOH$] to form isobutylidenediurea (IBDU). And urea can also be converted to slow-release nitrogen formulations by encapsulating it in a semipermeable coating of sulfur, plastic, or a combination of sulfur and plastic. Slow-release and slowly soluble nitrogen carriers are collectively called *slowly available carriers*, which are used in many turfgrass fertilizers. Both slowly available and quickly available (soluble) nitrogen carriers can be mixed with other primary nutrients—phosphorus (P) and potassium (K)—to form *complete* fertilizers, as well as with various secondary nutrients—calcium (Ca), magnesium (Mg), and sulfur (S)—and tertiary nutrients—iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo)—to satisfy the broader nutritional needs of turfgrasses. Regardless of the formulations used, many professional turfgrass managers use fertilizer nutrients sparingly to avoid overstimulating turfgrass growth and to minimize the potential for polluting surface and subsurface water resources from leaching and runoff of these materials. The importance of conserving fertilizer nutrients was articulated by W. J. Beal (1887): "Rich soil would defeat our object by causing a rank growth and coarse stalks when we wish a short growth and soft herbage. Let the soil, therefore, be good but not rich."

### Pesticides

While pesticides have been used for at least a century in turfgrass management, the modern era of pesticides began after World War II, with the introduction of 2,4-D, a phenoxycarboxylic acid herbicide for controlling broadleaf weeds; thiram, a dithiocarbamate fungicide for controlling some diseases; and DDT (dichlorodiphenyltrichloroethane), a chlorinated hydrocarbon insecticide for controlling insect pests. Chemical analogs of these pesticides were soon developed that extended their efficacy range and stimulated the search for different chemical families offering even broader control of the spectrum of pests affecting turfgrass growth and turf quality. The publication of Rachel Carson's *Silent Spring* in 1962 generated a firestorm over the environmental consequences of the use of pesticides in general and DDT in particular, eventually resulting in enactment of the National Environmental Policy Act in 1969 and subsequent legislation regulating the use of pesticides. While many of the early pesticides were withdrawn from the market because of environmental and safety concerns, the inventory of commercially available pesticides today is quite broad and provides excellent control of most turfgrass pests.

### Plant-Growth Regulators

While plant-growth regulators (PGRs) have been available for many years, it was not until the newer gibberellin-biosynthesis inhibitors were developed that PGRs had much use in turfgrass cultural programs. Trinexapac-ethyl is a Class-A PGR that is now widely used to reduce mowing and promote lateral shoot growth in turfgrasses. Paclobutrazol and flurprimidol are Class-B PGRs that also inhibit biosynthesis of the plant hormone gibberellin, but earlier in the pathway. They are used principally for differentially suppressing the growth of annual bluegrass (*Poa annua*) in mixed turfs with other cool-season turfgrasses. Mefluidide is a Class-C PGR that works as a mitotic inhibitor; it is principally used to inhibit seed-head formation in annual bluegrass. And ethephon is a Class-E PGR that works by releasing ethylene, a phytohormone, following its absorption by turfgrass leaves. It also suppresses seed-head formation in annual bluegrass.

### Biostimulants

The term *biostimulants* is used for substances that condition plants to better tolerate the effects of environmental stresses by neutralizing destructive concentrations of oxygen radicals—also called reactive oxygen species (ROS), which can destroy call membranes, resulting in the death of plant tissues—by stimulating the production of antioxidants within the plant. Their use is largely confined to the summer months on greens composed of cool-season turfgrasses. While the current inventory of biostimulants is largely derived from extracts of seaweed and other natural materials, it is anticipated that future formulations of selected antioxidants, including low-molecular-weight compounds and their associated enzymes, will be developed and available for specific uses in turfgrass cultural programs.

### Wetting Agents

A wetting agent is a surfactant (surface active agent) used to increase the wetting capacity of water in a hydrophobic (water-repelling) soil by reducing the interfacial tension between the water and soil particle surfaces. Wetting agents are widely used on sand-based greens where hydrophobicity, resulting from the accumulation of waxy coatings on sand particles, is a continuing concern.

## THE TURFGRASS INDUSTRY TODAY

Turfgrass in the United States is a $60 billion industry, with more than 50 million acres (20 million ha) of managed turf (Shearman, 2006). While home lawns comprise about 65% of this total, there are more than 775,000 sports fields and 17,000 golf courses with annual maintenance expenditures of $11 billion and $10 billion, respectively. Turfgrass-related businesses include 40,000 landscape contracting companies and 4500 lawn-care companies. In addition to these businesses, there are 400,000 acres (160,000 ha) in turfgrass sod production and 685,000 acres (277,000 ha) in turfgrass seed production. And there are also the numerous manufacturers and distributors of equipment and materials used to support turfgrass cultural operations. Despite this enormous investment in turfgrass by our society, not everyone is supportive of the use of amenity grasses in modern turfgrass cultural operations. According to Virginia Scott Jenkins (1994), "American front lawns are a symbol of man's control of, or superiority over, his environment." And Michael Pollan (1998) stated that "putting in a lawn represents instead a process of conquest and obliteration, an imposition—except in a very few places—of an alien idea and even, as it happens, of a set of alien species." Many would counter that an "alien species" is not quite the same as a naturalized species that, while introduced from foreign lands, has successfully adapted to its new environment, that natural selection can move the adaptation process further along, and that turfgrass culture is not so much a conquest of nature as it is a partnership that, using Pollan's own words, requires "give-and-take between the gardener and a piece of land." Just as turfgrass science and technology—and how they are perceived both within and outside of the industry—have evolved over time, they will continue to evolve in ways that reflect what we have learned and the values we embrace.

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