Zoysiagrass (Zoysia spp.) History, Utilization, and Improvement in the United States: A Review

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ABSTRACT
Since its introduction into the United States in 1892, zoysiagrass (Zoysia spp. Willd.) has made a tremendous impact on the US turfgrass industry. Three species of zoysiagrass [Z. japonica Steud., Z. matrella (L.) Merr., and Z. pacifica (Goudswaard) M. Hotta & S. Kuroki] collected from East Asia and the Pacific Islands were introduced into the United States and are used directly as turf or by turfgrass breeders in the development of advanced lines. Golf courses, lawns, grounds, sod farms, athletic fields, road-sides, and airports are some of the many locations where zoysiagrass is used. While almost 50 improved cultivars of zoysiagrass have been developed to date, active efforts to improve zoysiagrass further and expand its utilization are ongoing. These continued improvements in stress and pest tolerance allow for expanded use of this low-input turf species. This review summarizes the history of zoysiagrass in the United States; summarizes species introduction and utilization; addresses and discusses strengths and shortcomings of the species; evaluates breeding history, methodology, and challenges; and suggests future prospects and potential for zoysiagrass.

1 The genus Zoysia was named after Karl Von Zois (Karl von Zois zu Laibach, 1756–1800) by Carl Ludwig von Willdenow (Nightingale and Weiller, 2005).
2 Willd. is short for Willdenow (Carl Ludwig von Willdenow, 1765–1812), who was a leading German botanist (von Humboldt, 1996).
3 Zoysia macrantha Desvaux (Layt, 2009), Z. macrostachya Franchet & Savatier (LeCroy, 1963), Z. sinica Hance (Engelke et al., 1983) were also introduced into the United States, but their production and use by breeders in improvement programs is limited.
4 Steud. is short for Steudel (Ernst Gottlieb von Steudel, 1783–1856), who was a German physician and botanist with a specialization in grasses (Poaceae) and sedges (Cyperaceae) (Erickson, n.d.).
5 L. is short for Linnaeus (Carl Linnaeus or Carl von Linné, 1707–1778), who was the Swedish botanist who formalized binomial nomenclature (Stearn, 1959).
6 Merr. is short for Merrill. Elmer Drew Merrill (1876–1956) was an American botanist stationed in Manila, Philippines, for 22 yr who was a renowned authority on the flora of the Asia-Pacific region (Merrill, 1912). Merrill was involved in several botanical societies in different roles and was a Fellow of the American Association for the Advancement of Science (Robbins, 1958).
Zoysia pacifica (Goudswaard\textsuperscript{7}) M. Hotta & S. Kuroki\textsuperscript{8} were introduced into the United States from East Asia and the Pacific Islands and are used directly as turf or by turfgrass breeders in the development of advanced lines. These species are indigenous to different regions and have variable adaptation, growth, and development. Once considered “unimportant” (Hitchcock, 1935), zoysiagrass is now utilized extensively throughout much of the United States. This review summarizes the history of US zoysiagrass; summarizes species introduction and utilization; addresses and discusses strengths and shortcomings of the species; evaluates breeding history, methodology, and challenges; and suggests future prospects and potential for zoysiagrass. Since its introduction over 125 yr ago, many scientists and practitioners have contributed to the advancement of zoysiagrass in the United States. As such, this paper summarizes efforts and profiles key individuals, and the authors acknowledge the contributions of many other scientists and practitioners not mentioned.

**INTRODUCTION OF THE SPECIES**

Frank Lamson-Scribner\textsuperscript{9} first described zoysiagrass (Zoysia pungens\textsuperscript{9} Willd.) use in the United States in 1894 amongst a list of several grass species, which “form close, leafy mats over the surface of the ground, and usually possess considerable value for grazing or for lawns...” (Lamson-Scribner, 1895). Lamson-Scribner and many early agrostologists used Zoysia pungens Willd. to describe a type of Zoysia spp., but these early US introductions were later identified as two distinct species: Zoysia japonica [also called Osterdamia japonica (Steud.) Hitchc. in early publications] or Zoysia matrella [Osterdamia matrella (L.) Kuntze, O. zoysia Honda, Agrostis matrella L., and Z. pungens Willd. are all synonyms in early taxonomic literature] (Hitchcock, 1920; Childers and White, 1947).

In his 1894 account of zoysiagrass (Zoysia spp.) use in the United States, Lamson-Scribner describes two “allied” zoysiagrass species (Lamson-Scribner, 1895). The first species was described as “common on maritime sands of tropical and eastern Asia, Australia, and New Zealand” and a second closely “allied” species was described as originating from Korea. The first species was described as “successfully grown” (Lamson-Scribner, 1895) and “hardy as far north as Connecticut” (Lamson-Scribner, 1896). The source of the introduction of the first species is not provided in text or in subsequent accounts of zoysiagrass history, but our investigation led us to discover that J.B. Olcott\textsuperscript{10}, a Manchester, CT, agronomist with great interest in turfgrasses, was responsible for its introduction. Olcott was appointed by the Connecticut State Agriculture Experiment Station to collect grasses beneficial for the state (Connecticut State Library, 2009). He collected various grass specimens and managed and evaluated them in his turf garden (Piper and Oakley, 1917). Olcott’s personal records in his garden plat book list korai shiba (Koraishiba in Japanese is also called Korai, which is Z. matrella) in Row 2 of the garden beginning in his 1892 to 1893 records (Fig. 1) (Olcott, 1892). Photographs of his garden contain an image labeled “Korai shiba” (Fig. 1) (Connecticut State Library, n.d.; Manchester Historical Society, n.d.). The Z. matrella Olcott planted was from the Yokohama Nursery Company, Yokohama, Japan, according to other notes in Olcott’s records (Fig. 1) (Olcott, 1892). Olcott’s turf garden contained various species of potential turfgrass from collections he made on travel to Europe, Australia, and New Zealand (Piper, 1921), as well as plant material he requested from abroad. He also wrote many letters requesting that domestic or foreign grass sod or seed be sent to him for evaluation in his garden. It is unclear whether Olcott traveled to Japan or if the plant material was sent via his request.

The second species (likely Z. japonica) is identified by Lamson-Scribner (1895) as seed sent to the USDA in 1894 by John M.B. Sill, consul-general at Seoul, Korea, who served in that role from 1894 to 1897 (Lamson-Scribner, 1895; Rhee et al., 1922). Record keeping of plant introductions to the United States did not become official until 1898, when the USDA created the Section of Seed and Plant Introduction.

According to this account of zoysiagrass by Lamson-Scribner (1895) and personal and governmental recordkeeping, it is possible to say with some certainty that Z. matrella was introduced into the United States from Japan in 1892, and that Z. japonica was introduced into the United States from Korea in 1894 (Fig. 2). Not long afterward, the performance of zoysiagrass as a lawn species from the Carolinas to Washington, DC, is described in popular press (Barron, 1906; Corbett, 1906).

The first official introduction of zoysiagrass was made later by Reverend W.M. Baird, who was a Korean

\textsuperscript{7} P.C. Goudswaard was a plant systematic student from the Netherlands who proposed the name Zoysia matrella var. pacifica with the western Pacific variety of Z. matrella, rather than Z. tenuifolia or Z. matrella var. tenuifolia (Goudswaard, 1980). Later, Hotta and Kuroki (1994) treated Zoysia matrella var. pacifica Goudswaard as a distinct species, Z. pacifica.

\textsuperscript{8} Frank Lamson-Scribner (1851–1938) became the first agrostologist—agrostology is the scientific study of the grasses—in the United States (USDA Division of Agrostology) in 1894. Prior to this position, he was professor of botany and horticulture and a botanist to the agricultural experiment station of the University of Tennessee. His career awards include being named Fellow of the American Association for the Advancement of Science (Hilty and Peterson, 1997).

\textsuperscript{9} pungens is Latin for prick. As such, this specific epithet refers to the sharp–pointed leaf blades of Zoysia (Clifford and Bostock, 2007).

\textsuperscript{10} James Bradford Olcott (1830–1910) maintained a turf garden in South Manchester, CT, starting in 1890. This garden contained various species of potential turfgrass from collections he made on travel to Europe, Australia, and New Zealand (Piper, 1921). In 1881, J.B. Olcott was invited to be a trustee for the Storrs Agricultural School, now the University of Connecticut, where turf research continues to this day.
missionary responsible for several collections of economically important plants to the USDA, including a prominent soybean variety [Glycine max (L.) Merr.] (Shurtleff and Aoyagi, 2014). Baird selected two varieties of Zoysia pungens in Pyeong Yang, Korea (PI 6404, PI 6405), in 1901 and commented that the grass was “used in Korea for lawns” (USDA Bureau of Plant Industry, 1905) (Table 1). The following year, David Fairchild also selected and submitted two varieties of Zoysia pungens (Table 1). The first selection from Yokohama, Japan, in August 1902 was of a “very fine-leaved” Zoysia spp. described as a “lawn grass which forms a most beautiful velvet-like turf. The plant is said to have originated in southern Japan, to be sensitive to frost, but to be one of the prettiest lawn grasses in the country” (USDA Bureau of Plant Industry, 1905). Further, the entry was labeled with the name “Birodoshiba.” The description of being imported from a southern location, velvet-like in appearance, and sensitive to frost leads the authors to believe that this could be either Z. matrella or Z. pacifica. Birodoshiba in Japanese is translated as velvet grass, and this name is typically assigned to Z. pacifica (Maki, 1976; J.S. Choi, personal communication, 2016). However, its identification as Z. matrella is more likely based on the current known distribution of Zoysia spp. in Japan (Tanaka et al., 2016b). A second selection from Yokohama, Japan, in August 1902 was described by Fairchild as a “coarser leaved species of lawn grass than No. 9299, but otherwise of similar habit” (USDA Bureau
| Pl   | Species identifier (likely species)† | Submitter          | Date received | Origin                          | Reference                                | Notes                                                                 |
|------|-------------------------------------|--------------------|---------------|---------------------------------|------------------------------------------|----------------------------------------------------------------------|
| 6404 | *Zoysia pungens* (Z. *japonica*)‡   | Rev. W.M. Baird    | 3 May 1901    | Pyeng Yang, Korea (North Korea) | USDA Bureau of Plant Industry, 1905      | “Used in Korea for lawns” Baird                                      |
| 6405 | *Zoysia pungens* (Z. *japonica*)‡   | Rev. W.M. Baird    | 3 May 1901    | Pyeng Yang, Korea (North Korea) | USDA Bureau of Plant Industry, 1905      | “Used in Korea for lawns” Baird                                      |
| 9299 | *Zoysia pungens* (Z. *matrella* or Z. *pacific*‡)§ | D. Fairchild       | Aug. 1902     | Yokohama, Japan                 | USDA Bureau of Plant Industry, 1905; Fairchild, 1938 | Biodoshiba. A very fine-leaved lawn grass which forms a most beautiful velvet-like turf. The plant is said to have originated in southern Japan, to be sensitive to frost, but to be one of the prettiest lawn grasses in the country. It should be tested in California and Florida, where good lawn grasses are desired. Fairchild. PI 40609 is also identified by the name “Biodoshiba” from the same location but is identified as *Osterdamia tenuifolia*. |
| 9300 | *Zoysia pungens* (Z. *japonica*)‡   | D. Fairchild       | Aug. 1902     | Yokohama, Japan                 | USDA Bureau of Plant Industry, 1905      | A coarser leaved species of lawn grass than no. 9299, but otherwise of similar habit. It is said to be harder than no. 9299. Fairchild.                                      |
| 19425 | *Zoysia pungens* (Z. *japonica*)‡   | F.N. Meyer         | 13 Nov. 1906  | Ai-djou, North Korea            | USDA Bureau of Plant Industry, 1908      | “A perennial grass growing but a few inches high, well adapted for lawn purposes. Probably a very valuable grass.” Meyer also submitted PI 20840 and PI 20841 from Shanghai, China, in 1907, PI 21634 from Shantung, China, in 1907, and PI 38177 from Taianfu, Shantung, China, in 1914 (USDA Bureau of Plant Industry, 1908, 1917). |
| 19426 | *Zoysia pungens* (Z. *japonica*)‡   | F.N. Meyer         | 13 Nov. 1906  | Yalu river bank, North Korea    | USDA Bureau of Plant Industry, 1908      | “…excellent for golf links, lawns, etc.” Meyer                                                                  |
| 29016 | *Osterdamia matrella* (L.) Knutze [Z. *matrella* (L.) Merr.][§] | Anonymous          | 5 Nov. 1910   | Yokohama, Japan                 | USDA Bureau of Plant Industry, 1911      | “A valuable lawn grass.” Later, PI 40609, PI 43011, and PI 43023 (var. Korai) were also purchased by the Yokohama Nursery Company. Koraishiba in Japanese is also called Korai which is Z. *matrella* (Choi, personal communication, 2016). |
| 34657 | *Osterdamia matrella* (L.) Knutze [Z. *matrella* (L.) Merr.][§] | C.V. Piper         | 4 Dec. 1912   | Philippine Islands (likely Luneta National Park in Manila) | USDA Bureau of Plant Industry, 1915b     | “This grass is abundant near the seashore in the Philippine Islands. Where closely clipped it makes a beautiful lawn.” Piper |
| 35073 | *Osterdamia matrella* (L.) Knutze[§] | Haage & Schmidt, through C.V. Piper | 20 Mar. 1913  | Efurt, Germany                  | USDA Bureau of Plant Industry, 1915a     | –                                                                                                                                 |
| 41509 | *Osterdamia tenuifolia* (Trin.) Knutze[¶] | J.B. Thompson     | 1912          | Bonin Islands (Ogasawara Islands), through Guam | USDA Bureau of Plant Industry, 1918      | “used for lawn purposes” and “was originally described from the Mascarene Islands” Piper |
| 42389 | *Osterdamia matrella* (L.) Knutze[§] | J.H. Maiden        | 1 Apr. 1916   | Sydney, NSW, Australia          | USDA Bureau of Plant Industry, 1920      | “A grass of considerable value on littoral swamps and dry flats near the sea.” “…it is found sometimes forming compact turf…” “Grass from the Far East…” |
| 42678 | *Osterdamia matrella* (L.) Knutze[§] | M. Takata          | 6 May 1916    | Tainoku, Formosa (Taiwan)       | USDA Bureau of Plant Industry, 1920      | “Grass from the Far East…” |
| 42839 | *Osterdamia matrella* (L.) Knutze[§] | J.C. Koningsberger | 6 June 1916   | Buitenzorg, Java (Indonesia)    | USDA Bureau of Plant Industry, 1920      | “A creeping grass, important for binding coast sands, which does well on alkaline soils and also as a lawn grass.” |

† When identified as *Zoysia pungens* in introduction documentation, the authors have indicated in parentheses the likely species identification based on the description and plant collection location.
‡ *Zoysia pungens* Willd. is an early synonym for *Zoysia japonica* Steud. (also called *Osterdamia japonica* (Steud.) Hitchc.) (Hitchcock, 1920).
§ *Osterdamia matrella* (L.) Knutze, *O. zoysia* Honda, *Agrostis matrella* L., and *Z. pungens* Willd. are all early synonyms for *Zoysia matrella* (L.) Merr. (Childers and White, 1947).
¶ *Osterdamia tenuifolia* (Willd. ex Thiele) Knutze and its synonym *Zoysia tenuifolia* Willd. ex Trin. were later reclassified as *Zoysia pacifica* (Goudsw.) M. Hotta & S. Kurô (Anderson, 2000).
of Plant Industry, 1905). It is also described as “hardier than No. 9299” by Fairchild. The description of coarser (wider) leaves and hardiness (assumed to mean cold hardiness) likely identifies this Z. pungens submission as Z. japonica. However, despite evidence to the contrary, both PI 9299 and PI 9300 are labeled as Z. matrella in the US National Plant Germplasm System (NPGS). Neither are available today for examination and correct identification. Based on these collections by Baird and Fairchild and previous undocumented introductions from the same areas, the common names Korean lawngrass and Japanese lawngrass are used often in early literature as common names for Zoysia spp., particularly Zoysia japonica (Table 2). Although Z. japonica is also native to China, the name Chinese lawngrass is reserved for centipedegrass [Eremochloa ophiuroides (Munro) Hack.] (Christians et al., 2017).

The next set of zoysiagrass introductions were from the well-known plant explorer Frank N. Meyer. Starting in 1905, Meyer covered tremendous ground in Asia in the 13 yr he collected samples (Cunningham, 1984). Not long into his exploration, Meyer submitted two zoysiagrass varieties in 1906. The first selection (PI 19425) was from Ai-djou, North Korea (USDA Bureau of Plant Industry, 1908) (Table 1). Meyer described this entry as “a perennial grass growing but a few inches high, well adapted for lawn purposes. … probably a very valuable grass” (USDA Bureau of Plant Industry, 1908). A second collection submitted simultaneously was collected near the Yalu River bank in North Korea and was described as “…excellent for golf links, lawns, etc.” (USDA Bureau of Plant Industry, 1908). These were the first submissions of zoysiagrass by Meyer. He also submitted PI 20840 and PI 20841 from Shanghai, China, in 1907, PI 21634 from Shantung, China, in 1907, and PI 38177 from Taianfu, Shantung, China, in 1914 (USDA Bureau of Plant Industry, 1908, 1917). Zoysiagrass was just one of the 2500 live plant specimens and thousands of sacks of seed Meyer collected in Asia (Stoner and Hummer, 2007). A detailed account of his life and the importance of many of the economically significant crops he collected are chronicled in the book Frank N. Meyer, Plant Hunter in Asia by Isabel Cunningham (Cunningham, 1984).

Charles V. Piper introduced the next zoysiagrass (Z. matrella), PI 34657, from the Philippines in 1912 (USDA Bureau of Plant Industry, 1915b) (Table 1). Piper described this grass as “…abundant near the seashore in the Philippine Islands” and “where closely clipped it makes a beautiful lawn” (USDA Bureau of Plant Industry, 1915b).

11 David Grandison Fairchild (1869–1954) was an American botanist and early plant explorer. In 1898, he was named the first chief of the Section of Seed and Plant Introduction of the USDA in Washington, DC (Stoner and Hummer, 2007). Fairchild’s department employed many plant explorers including Frank N. Meyer and P Howard Dorsett, who would go on to make significant zoysiagrass collections. Fairchild was also a famous plant explorer in his own right and introduced many species, including zoysiagrass (Fairchild, 1938; Stoner and Hummer, 2007). Ironically, Fairchild’s father was the first president of the Kansas State College of Agriculture (now Kansas State University) (Fairchild, 1938), where today an active zoysiagrass research program is ongoing under the leadership of Dr. Jack Fry.

12 The theory that this sample was possibly Z. pacifica is supported by a later plant introduction, PI 40609. Plant introduction 40609 was also identified by the name “Birodoshiba,” was from the same location, and may have even been the same genotype, but was identified as Ostendania tenuifolia, an early synonym for Z. pacifica (Table 2).

13 Frank Nicholas Meyer (1875–1918) was born Frans Nicolaas Meijer in the Netherlands (Cunningham, 1984). He was a plant explorer who worked for the USDA and collected plant samples throughout Asia. Meyer submitted over 2500 live plant specimens and thousands of sacks of seed during his 13 yr of collection trips in Asia (Stoner and Hummer, 2007). Tragically, Frank Meyer died unexpectedly while traveling on the Yangtze River in China (Cunningham, 1984). While it is likely that he drowned after accidentally falling off a riverboat shortly after dinner one evening, “the real cause of his death will remain a mystery,” exclaimed his good friend David Fairchild (Fairchild, 1938; Cunningham, 1984). His friends and colleagues helped to create a medal honoring Meyer “in token of affection and appreciation of his work for American agriculture and horticulture” (Cunningham, 1984). Today, this award is administered by the Crop Science Society of America (Madison, WI) in “recognition of his contributions to the plant germplasm collection and use in the United States and his dedication and service to humanity through collecting, evaluating, or conserving earth’s genetic resources.”

14 Charles Vancouver Piper (1867–1926) was an American agrostologist who worked for the USDA’s Division of Forage Plants (Woods, 2006). His early work was focused on forages, and he published the text Forage Plants and Their Culture in 1914. He was president of the American Society of Agronomy in 1914. Later in his career, his interests shifted from forages to turfgrass. He coauthored Turf for Golf Courses in 1917 with Russell A. Oakley. In 1920, Piper became the first chairman of the Green Section of the United States Golf Association (USGA). He held that position from 1920 until his death in 1926 (Woods, 2006).

Table 2. Naming history of Zoysia species used in the United States.

| Scientific name | Etymology of binomial name | Historical binomial names (formerly) | Historical common names | Common name used in the US |
|-----------------|---------------------------|-------------------------------------|------------------------|----------------------------|
| Zoysia japonica Steud. | Japanese zoysiagrass | Z. pungens Willd.; and Osterdama japonica (Steud.) Hitchc. (Hitchcock, 1920) | Japanese lawngrass, Korean lawngrass | Zoysiagrass |
| Z. matrella (L.) Merr. | Diminutive mother of zoysiagrass (matris means mother in Latin and-mella means diminutive) (Clifford and Bostock, 2007) | Agrostis matrella L.; Osterdama matrella (L.) Kuntze; O. zoysia Honda; and Z. pungens Willd. (Childers and White, 1947) | Korean lawngrass, Malaysian grass | Zoysiagrass |
| Zoysia pacifica (Goudsw.) M. Hotta & S. Kuroki | Zoysiagrass from the islands of the Pacific | Osterdama tenuifolia (Willd. ex Thiele) Kuntze; Zoysia matrella var. pacifica Goudsw.; Zoysia tenuifolia Willd. ex Trin. (Anderson, 2003) | Masekrenegrass, Korean velvetgrass | Zoysiagrass |
Piper also describes that this grass occupies >90% of the grounds and has gradually displaced bermudagrass [Cynodon spp. (L.) Rich] at this location. Manila is the capital of the Philippines, and this entry is assigned the common name “Manila grass.” Manilagrass remains a common name for Z. matrella to this day (Table 2), although it is indigenous to the larger Southeast Asian region between the Ryukyu Islands (southern Japan) to Malaysia (Goudswaard, 1980; Engelke and Anderson, 2003), which the Philippines sits between. Piper also helped introduce PI 35073, a Z. matrella, through Efurt, Germany, the following year, although the original source of this material is not documented (USDA Bureau of Plant Industry, 1915a). Cataloging of other Z. matrella introductions occurred later in 1916 from various locations including Australia, Indonesia, and Taiwan (USDA Bureau of Plant Industry, 1920) (Table 1).

An additional key plant introduction catalogues one of the early entrances of Z. pacifica in the United States. In 1912, PI 41509 was submitted by J.B. Thompson from the Guam Agricultural Experiment Station (USDA Bureau of Plant Industry, 1918) (Table 1). A note in the submission states that he obtained the sample from the Bonin Islands (Ogasawara Islands). This sample was labeled as Zoysia tenuifolia Trin. in the submission, with the common name Mascarene grass. Two similar species of zoysiagrass, Z. pacifica and Z. tenuifolia Thiele, are thought to be indigenous to different regions but difficult to distinguish from one another by their morphology (Fig. 3). The key to identifying these three species is as follows (modified from Anderson, 2003):

1a. Leaf blades to 0.5 mm in diameter; racemes with 3 to 12 spikelets; peduncles (the stalk of a whole inflorescence) included or extending to 1 cm beyond the leaf sheaths of the flag leaves (Z. pacifica)

1b. Leaf blades 0.5 to 5 mm wide; racemes with 10 to 50 spikelets; peduncles extending (0.3) 1 to 6.5 cm beyond the sheaths of the flag leaves (Z. japonica)

2a. Pedicels (the stalk of a single flower in an inflorescence) 1.6 to 5.0 mm long; spikelets ovate, 1 to 1.4 mm wide; culm internodes 2 to 10 mm long; leaf blades ascending (spreading horizontally, then becoming erect), flat or margins involute (leaf margins rolled inward), typically 2.5 to 5 mm wide (Z. japonica)

2b. Pedicels 0.6 to 1.6 mm long; spikelets lanceolate, 0.6 to 1 mm wide; culm internodes 5 to 40 mm long; all plants with at least some internodes more than 14 mm long; leaf blades patent (spreading, erect), involute or flat, typically 1.5 to 2.5 mm wide (Z. matrella)

Zoysiagrass, the most economically important zoysiagrass cultivar to date. United States Department of Agriculture plant explorers P.H. Dorsett and W.J. Morse traveled to China, Japan, Manchuria, and Korea between 1929 and 1931 in search of new grasses and other useful crops, particularly soybean (USGA Green Section, 1930; Stoner and Hummer, 2007). Dorsett and Morse collected Zoysia spp. seed in Korea that they felt would have improved cold hardiness over previous plant introductions and be useful for airports, golf course tees and fairways, and lawns (USGA Green Section, 1930). Zoysiagrass was collected in North Korea and Manchuria (Northeast China), and small lots of seed and some plants were shipped back to the United States (USGA Green Section, 1930). The accessions were propagated in the Arlington Turf Gardens in the 1930s.

ZOYSIA SPP. Morphology

Zoysia japonica, Z. matrella, and Z. pacifica are distinguished from one another by their morphology (Fig. 3). The key to identifying these three species is as follows (modified from Anderson, 2003):
A Comparison of the Species

The nomenclature for *Zoysia* spp. has varied throughout history (Anderson, 2000). A summary of the naming history of *Zoysia* species in the United States is included here (Table 2). *Zoysia japonica* was originally called Japanese (or Korean) lawngrass in the United States. The etymology of its binomial name suggests that Japanese lawngrass is appropriate (Table 2), despite the species also being native to Korea. The etymology of *Zoysia matrella* is unique. Translated from Latin, it means “diminutive mother of
zoysiagrass” (Table 2) (Clifford and Bostock, 2007). While “diminutive” is used to contrast Z. matrella with Z. japonica, the use of “mother” is also interesting in the epithet, considering that Zoysia spp. readily hybridize with one another (Forbes, 1952). A third species, mascarenergrass or Korean velvetgrass (Z. pacifica), is mostly used in US breeding programs to develop finer-texture progeny from crosses with Z. japonica or Z. matrella. Its revised epithet of “pacifica” correctly describes its indigenous territory (Table 2), but the common name mascarenergrass does not accurately reflect its origin (see footnote 17).

Today, all three species are commonly referred to as zoysiagrass in the United States by both practitioners and scientists (Table 2).

Aside from morphological differences, the adaptation of these species is variable (Table 3). These adaptive differences often dictate the use and distribution of species in the United States. Cold hardiness is variable, with Z. japonica > Z. matrella > Z. pacifica (Forbes, 1952; Patton and Reicher, 2007). Zoysia matrella has slightly better shade tolerance than Z. japonica, but this is highly cultivar dependent (Riffell et al., 1995; Trappe et al., 2011d; Wherley et al., 2011). The shade tolerance of Z. pacifica is not well evaluated in the United States but is thought to be good to excellent according to the authors observations and a report by Aldous and Chiwers (2002). Although Z. matrella is less cold hardy than Z. japonica, it is more tolerant to salinity and insect pests (Patton, 2009). The salinity tolerance of Z. pacifica is similar to Z. matrella (Marcum et al., 1998), but its insect tolerance is largely unknown. Together, cold hardiness and shade tolerance highly influence the use and distribution of these species in the United States.

### Species Identification

Many zoysiagrass cultivars are interspecific hybrids of Zoysia spp., which makes it difficult to place specific genotypes into groups by species (Yaneshita et al., 1997; Kimball et al., 2013). Zoysiagrass hybrids or progeny with unknown pedigrees are commonly identified by phenotype or the “type” (Z. japonica or Z. matrella) of species they most closely resemble, even though the progeny may actually be hybrid. Through genetic characterization of these hybrids and cultivars of Z. matrella and Z. japonica, a continuum of genetic variability was observed within and among species (Kimball et al., 2013). This has furthered the early theory proposed by Forbes et al. (1955) that Z. japonica and Z. matrella may not be separate species but instead one species with different eco-types (Kimball et al., 2013). Additionally, this supports the utilization of the single common name of zoysiagrass, rather than Japanese lawngrass or Manilagrass, as the common names for Z. japonica and Z. matrella, respectively.

### UTILIZATION

#### A Decided Acquisition

Professor L.C. Corbett was the Horticulturist at the Arlington Experimental Farm and one of the first to write about the utilization of zoysiagrass in the United States (Corbett, 1906). In the first publication by the USDA on the care of lawns, Corbett describes both how to establish and maintain a lawn. Further, he covers the selection of “grasses adapted to lawn making” (Corbett, 1906). Corbett introduces readers to “Korean lawn grass” from Asia and Australia and discusses the value that this species provides from Washington, DC, to Charleston, SC, and southward. He encourages readers to consider zoysiagrass for lawns south of Washington, DC, calling it a “decided acquisition,” referring to the fact that few grasses are well adapted to lawns in the southeastern United States22. The

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Table 3. Comparison of Zoysia spp. used in the United States. Performance of individual cultivars within each species can vary widely.†

| Species       | Leaf width | Shoot density | Shade tolerance | Cold hardiness | Optimal mowing heights | Primary use | Establishment methods | Distribution in USA          |
|---------------|------------|---------------|-----------------|----------------|------------------------|-------------|-----------------------|----------------------------|
| Zoysia japonica † | >2.5       | Medium        | Good to fair    | Moderate       | 13–64                  | Golf courses, lawns, sod farms, sports turf, roadsides, and airports | Seed, sprigs, plugs, sod  | Transitional, warm-humid, and warm-arid climatic zones |
| Zoysia matrella | 1.5–2.5    | Medium        | Good            | Poor           | 6.4–51                 | Golf courses, lawns, sod farms | Sprigs, plugs, sod | Warm-humid and warm-arid climatic zones |
| Zoysia pacifica | <1.5       | High          | Good to excellent | Very poor    | 2.5–13                 | Breeding of fine-textured zoysiagrass hybrids | Sprigs, plugs, sod | Warm-tropical |

† Compiled from Beard and Beard (2005) and authors observations. Wear tolerance, drought tolerance, evapotranspiration rate, recuperative rate, and salinity tolerance differences between Zoysia species is largely unknown.

† Zoysia japonica cultivars can be classified into two types. One type has a leaf width >3.5 mm and is primarily used for golf course rough, lawns, and grounds. Often, this type will have longer internodes and is quicker to establish. This first type can be thought of as a “common” type. Currently used cultivars that fit these criteria include Carrizo, Chisholm, Compadre, Crowne, El Toro, Empire, Palisades, and Zenith zoysiagrass. A second type has a leaf width that is often 2.5 to 3.5 mm and these types are used for golf course fairways, tees, and roughs in addition to lawns and grounds. Cold hardiness is variable by cultivar within both types. This second type can be thought of as a Meyer type. Currently used cultivars that fit these criteria include BA-189, Cutlass, DeAnza, GN-Z, KSLU 0802, Marion, Meyer, Serene, Southern Gem, and Zoyboy.

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22 Many of the desirable lawn species used today in the southeastern United States were not available until the mid-20th century. St. Augustinegrass [Stenotaphrum secundatum (Walt.) Kuntze cv. Bitter Blue] was introduced in the 1930s, centipedegrass [Eremochloa ophiuroides (Munro) Hack, cv. Common] in 1947, and hybrid bermudagrass [Cynodon dactylon (L.) Pers. × C. transvaalensis Burtt Davy cv. Tifway] became available in 1960.
“surpassing beauty of *Zoysia matrella* lawns” was so great and its production so new that its sod commanded a price of US$30 m⁻² in the 1930s (Halsey, 1956), which is over six times higher than today’s price of $4.75 m⁻² (Waltz, 2015).

Within the United States, *Z. japonica* was quickly recognized as having special value in the “crabgrass belt,” which was an early euphemism for the transitional climatic zone where it is often too stressful in the summer for cool-season grasses, resulting in abundant crabgrass invasion, but too cold in the winter for most warm-season grasses (Forbes and Ferguson, 1947, 1948). *Zoysia matrella* was recognized to have special value as a shade-tolerant lawn species in the southeastern United States (Sturkie, 1941; Forbes and Ferguson, 1948). Despite these special values, early zoysiagrass utilization and expansion was limited by a lack of commercial seed production and seed dormancy factors that resulted in “extremely poor germination” (Forbes and Ferguson, 1948). These factors remain a challenge today; as such, vegetative planting as sod, sprigs, or plugs remains the commonly used establishment method for zoysiagrass, with only a few *Z. japonica* cultivars available by seed.

*Zoysia matrella* was introduced in the US territory of the Commonwealth of Puerto Rico in 1936 from the Florida Agriculture Experiment Station (FAES) (Childers and White, 1947). Plant material from FAES likely originated from early plant introductions, as its culture in Florida is referenced as early as 1920 (Hitchcock, 1920; Fairchild, 1938). From only 0.05 m² of sod introduced into Puerto Rico, *Z. matrella* covered ~2.0 ha some 11 yr later (Childers and White, 1947).

The first zoysiagrass cultivar in the United States, ‘Matrella’ (FC 13521), was released in the mid-to-late 1930s, according to discussion in the trade journal American Nurseryman (Sturkie, 1941; Ruemmele and Engelke, 1990). Zoysiagrass was immediately popular in the southeastern United States in the 1940s because few well-adapted species and cultivars for lawns were available (USGA Green Section, 1944; Halsey, 1956). Although there is more acreage of *Z. japonica* planted in the United States today than *Z. matrella*, this was not always the case, as *Z. matrella* was once “by far the most widely used of the genus” (Halsey, 1956). The release of Matrella was closely followed by the release of Meyer, ‘Sunburst’, and ‘Emerald’ in the 1950s (Grau and Radko, 1951; Hanson, 1965) (Table 4). Meyer and Emerald quickly became industry standards for zoysiagrass, and it was not until the 1980s that many other zoysiagrass cultivars became commercially available (Table 4, Fig. 4). Today, Meyer is still the most popular zoysiagrass cultivar in the transition zone, almost 70 yr after its release into the marketplace.

**Expansion of the Species: A Slow Start**

Zoysiagrass is used predominantly on golf courses and residential and commercial lawns in the United States. The first zoysiagrass tees and fairways were used in Florida in the 1920s, where *Z. japonica*, introduced from an unknown source, was planted at the Palm Beach Country Club and Miami Country Club (Piper, 1923). Later in the 1930s, *Z. matrella* from the Arlington Turf Gardens was distributed to the Westwood Country Club, St. Louis, MO, and the Audubon Country Club, Louisville, KY, for use on golf course tees (Noer, 1942; Linkogel, 1947). These golf courses used zoysiagrass to replace cool-season Kentucky bluegrass (*Poa pratensis* L.) fairways that failed during summer due to heat, drought, and disease. Later, Meyer zoysiagrass, and occasionally Sunburst zoysiagrass, were used because they performed so well, especially in the transitional climatic zone, and few other cultivars were available prior to 1980 (Table 4). Several golf courses were early adopters of zoysiagrass by 1960, but only sections of fairways were planted to zoysiagrass (Grau, 1960). Due to the expensive cost of Meyer zoysiagrass and the rising popularity of ‘U-3’ common bermudagrass (*Cynodon dactylon* (L.) Pers.), it was not until the winter of 1969 to 1970 and the catastrophic loss of bermudagrass from winterkill that Meyer zoysiagrass popularity sharply increased (Zontek, 1983; Dunn, 1989). Golf courses around the country started to use zoysiagrass to replace bermudagrass suffering from winterkill. Zoysiagrass is most commonly used on golf course fairways in the United States, but it is also used on roughs, bunker faces, tee boxes, and approaches. It is rarely used on US putting greens.

While the species was new and there was great excitement about its performance, turf scientists and practitioners were still learning how to manage the species. Several golf course superintendents were pioneers in zoysiagrass management research and provided key insights through trial and error. Two such examples include Mel Anderson, Alvamar Hills Golf Course (currently The Championship Course at Alvamar) in Lawrence, KS, and David Stone, The Honors Course, Ooltewah, TN. Both were the first to establish successful zoysiagrass fairways in their region. Anderson sprigged his own Meyer zoysiagrass nursery and then used that plant material 1 yr later to sprig the fairways and tees on the entire 18-hole golf course in 1967 (Clausen, 1969). Alvamar is thought to be the first 18-hole US golf course with zoysiagrass fairways (D. Stone personal communication, 2010), and today zoysiagrass comprises the majority of the rough on the course, as well (A.J. Patton, personal observation). At The Honors Course, Stone was responsible for the difficult task of converting fairways from ‘Midiron’ bermudagrass to Meyer zoysiagrass in 1984 (Dye and Shaw, 1995). After the renovation, The Honors Course was the first 18-hole golf course with zoysiagrass fairways in the southeastern United States (Walker, 1995). Stone experimented with herbicides, fungicides, fertility, cultivation, new zoysiagrass cultivars, and more to learn how to best care for zoysiagrass. Both men were
Table 4. Cultivar name, experimental designation, propagation type, species, breeder or supplier, release date, and patent or introduction information for zoysiagrass cultivars commercially used in the United States. Sorted by year released.

| Name               | Experimental | Type† | Species          | Breeder or supplier                      | Year released‡ | Patent, protection, or introduction no./application |
|--------------------|--------------|-------|------------------|------------------------------------------|----------------|-----------------------------------------------------|
| M60§               | M60          | Veg   | Z. matrella      | Bladerunner Farms, Poteet, TX            | 2017           | USPP27289                                           |
| M85§               | M85          | Veg   | Z. matrella      | Bladerunner Farms, Poteet, TX            | 2015           | USPP27189                                           |
| TBA§               | KSUZ 0802    | Veg   | Z. japonica × Z. matrella | Kansas State University, Manhattan, KS, and Texas A&M AgriLife Research, Dallas, TX | 2015           |                                                     |
| L1F§               | L1F          | Veg   | Z. matrella      | Bladerunner Farms, Poteet, TX            | 2014           | USPP25203                                           |
| Cutlass§           | LR1          | Veg   | Z. japonica      | Bladerunner Farms, Poteet, TX            | 2013           | USPP25380                                           |
| Chisholm§          | DALZ 0102    | Veg   | Z. japonica      | Texas A&M AgriLife Research, Dallas, TX, and Kansas State University, Manhattan, KS | 2012           | PI666039                                            |
| Aloyzia§           |              | Veg   | Z. japonica      | Aloyzia Blue, Sarasota, FL               | 2011           | USPP22168                                            |
| Icon§              | MAC03        | Veg   | Z. macrantha     | DIG Plant Co., Mt. Pleasant, SC           | 2011           | USPP23108                                            |
| Geo§               | BK-9         | Veg   | Z. japonica × Z. pacifica | Sod Solutions, Mt. Pleasant, SC         | 2010           | US20150020273 P1                                     |
| Innovation§        |              | Veg   | Z. japonica      | Sod Solutions, Mt. Pleasant, SC           | 2010           | US20150067937 P1                                     |
| Marion§            |              | Veg   | Z. japonica      | Heritage Turf, Midway, AL                | 2008           | USPP1417                                            |
| Serene§            |              | Veg   | Z. japonica      | Heritage Turf, Midway, AL                | 2008           | USPP15218                                            |
| Southern Gem§      |              | Veg   | Z. japonica      | Heritage Turf, Midway, AL                | 2008           | USPP1417                                            |
| Shadow Turf§       | Ivey-1       | Veg   | Z. matrella      | Ivey Gardens Greenhouses, Lubbock, TX    | 2007           | USPP20266                                            |
| Carrozio§          | 6136         | Veg   | Z. japonica      | Bladerunner Farms, Poteet, TX            | 2006           | USPP17808                                            |
| Leisure Time Zoysia (LTZ)§ | Y2         | Veg   | Z. japonica      | Bladerunner Farms, Poteet, TX, and Patten Seed Co, Lakeland, GA | 2006, 2015 | USPP17824                                            |
| Toccoa Green (formerly = PristineFlora§) | BA-305 | Veg   | Z. japonica × Z. pacifica | University of Florida, Belle Glade, FL | 2005           | USPP18415                                            |
| BA-189 (formerly = UltimateFlora§) | BA-189 | Veg   | Z. japonica      | University of Florida, Belle Glade, FL    | 2005           | USPP23716                                            |
| Himeno             |              | Veg   | Z. japonica      | Zoysian Japan Co., Akashi, Japan          | 2002           | USPP13267                                            |
| Royal§             | DALZ 9006    | Veg   | Z. japonica × Z. matrella | Texas A&M University, Dallas, TX         | 2001           | USPP14395                                            |
| Zorro§             | DALZ 8510/9601 | Veg | Z. matrella      | Texas A&M University, Dallas, TX         | 2001           | USPP14130                                            |
| Empress§           | SS-300       | Veg   | Z. japonica      | Sod Solutions, Mt. Pleasant, SC           | 2000           | USPP11495                                            |
| Empire§            | SS-500       | Veg   | Z. japonica      | Sod Solutions, Mt. Pleasant, SC           | 1999           | USPP11466                                            |
| J-14               | Seed         | Z. sinica | Jacklin Seed Company, Post Falls, ID | 1999 | USPP977450                                           |
| Cavalier§          | DALZ 8507    | Veg   | Z. matrella      | Texas A&M University, Dallas, TX         | 1996           | USPP10778                                            |
| Crowne§            | DALZ 8512    | Veg   | Z. japonica      | Texas A&M University, Dallas, TX         | 1996           | USPP11570                                            |
| Diamond§           | DALZ 8502    | Veg   | Z. matrella      | Texas A&M University, Dallas, TX         | 1996           | USPP10636                                            |
| J-36               | Seed         | Z. japonica | Jacklin Seed Company, Post Falls, ID | 1996 | USPP9300288                                           |
| J-37               | Seed         | Z. japonica | Jacklin Seed Company, Post Falls, ID | 1996 | USPP9300288                                           |
| JaMur§             |              | Veg   | Z. japonica      | Bladerunner Farms, Poteet, TX            | 1996           | USPP13178                                            |
| Palisades§         | DALZ 8514    | Veg   | Z. japonica      | Texas A&M University, Dallas, TX         | 1996           | USPP11515                                            |
| Zeon§              |              | Veg   | Z. matrella      | Bladerunner Farms, Poteet, TX            | 1996           | USPP13166                                            |
| DeAnza§            | Z88-8        | Veg   | Zoyisia hybrid   | University of California, Riverside, CA   | 1995           | USPP9127                                             |
| Victoria           | Z88-14       | Veg   | Zoyisia hybrid   | University of California, Riverside, CA   | 1995           | USPP9135                                             |
| Z-3, ZoyBoy™§      | Z-3          | Veg   | Z. japonica × Z. matrella | Quality Turfgrass, Waimanalo, Oahu, HI | 1994           | USPP8553                                            |
| Compadre (formerly = Compatibility, Companion§) | ZMB-2 | Seeded | Z. japonica | Seed Research of Oregon, Corvallis, OR | 1993           |                                                     |
| Zenith§            | ZNW-1        | Seeded | Z. japonica      | Patten Seed Co, Lakeland, GA              | 1993           |                                                     |
| Marquis            | TC 2033      | Veg   | Z. sps.          | Turf Center, Spencerville, MD             | 1991           |                                                     |

† Type of establishment (propagation) method typically used by practitioners for each cultivar. Genotypes available by seed are typically seeded, with other genotypes typically established vegetatively (Veg) by sprigs, plugs, or sod.
‡ Year released or made available to public.
§ Indicates that the cultivar was commercially available in the United States in 2017. TBA = Cultivar name to be announced.
¶ Species was identified in the plant patent as a Zoyisia japonica Steud. × Zoyisia tenuifolia Wild. ex Thiele hybrid. Because Z. pacifica (Goudswaard) M. Hotta & S. Kuroki was incorrectly name as Z. tenuifolia, the cultivar is best described as Z. japonica × Z. pacifica (Anderson, 2000).
# Genetic analysis indicates that Emerald could possibly be Z. matrella × Z. pacifica (Anderson, 2000). More recent analysis by Kimball et al. (2013) does not identify the parents but supports Emerald being classified as a hybrid.
regarded as mentors for the challenges they had overcome, their willingness to take risks, and the value they placed in experimenting with new plant material (USGA Green Section, 1972; Hollister, 2016).

The latest figures for zoysiagrass use on golf courses, as of 2015, estimate that 10,375 ha of zoysiagrass are planted in the United States, with 78% of the zoysiagrass being used on golf courses in the transition zone and 17% being used on golf courses in the US Southeast (Gelernter et al., 2017). Although the majority of zoysiagrass is used in the transitional climatic zone, use in the southeastern United States in warm-humid climates is increasing, with many improved cultivars in recent years (Fig. 4) and increased sod production in that region (Fig. 5). From 2005 to 2015, zyosiagrass use on US golf courses increased in several regional markets (Lyman et al., 2007; Gelernter et al., 2017). From both a percentage and an acreage standpoint, zoysiagrass use increased more than any other warm-season turfgrass during that period (Gelernter et al., 2017). However, zyosiagrass use on US golf courses comprises only 4.9% of the warm-season turfgrass use, with bermudagrass used in 88% of situations (Gelernter et al., 2017).

Since Meyer zoysiagrass is established vegetatively, sod farms that realized the potential value of this species were also instrumental to the distribution of the species and growth in its popularity. Summit Hall Turf Farm in Poolesville, MD, which became the first commercial producer of Meyer zoysiagrass in 1951 (Anonymous, 1992), and Winrock Grass Farm, which began growing Meyer in 1955, are just two examples of such farms (Tiller, 1987). Today, at least 125 sod farms in the United States produce zoysiagrass.

Cultivar selection in the United States is highly influenced by local availability of sod because of its vegetative establishment. For example, although nine cultivars of zoysiagrass are available in Florida from 29 different sod producers, ‘Empire’ is the most commonly planted cultivar, as ~1000 of the ~1500 ha in zoysiagrass production is Empire (C. Broucqault, personal communication, 2017).

Fig. 4. Number of zoysiagrass cultivars released in the United States by decade with cultivars commercially available and cultivars no longer commercially available (unavailable). Data from Table 4 as of 2017.

Table 4. Continued.

| Name          | Experimental | Type† | Species         | Breeder or supplier                               | Year released‡ | Patent, protection, or introduction no./ application |
|---------------|--------------|-------|-----------------|--------------------------------------------------|----------------|----------------------------------------------------|
| Omni          | CD 2013      | Veg   | Z. matrella     | Bladerunner Farms, Poteet, TX                     | 1991           |                                                    |
| Cashmere§     | P-1          | Veg   | Z. matrella     | Pursley Turf Farms, Palmetto, FL                  | 1989           | USPP6529                                           |
| ZT-11, GN-ZTM§, OakZTM§ | ZT-11 | Veg   | Z. japonica     | Greg Norman Turf Company, Jupiter, FL             | 1989           | USPP7074                                           |
| BK-7§         | R52-25       | Veg   | Z. japonica     | Craft Turf Farms, Foley, AL                       | 1987           |                                                    |
| Belair§       | UCR#1        | Veg   | Z. japonica     | USDA, Beltsville, MD                              | 1985           |                                                    |
| El Toro§      |              | Veg   | Z. japonica     | University of California, Riverside, CA           | 1984           | USPP5845                                           |
| Midwest       |              | Veg   | Z. japonica     | Indiana Agricultural Experiment Station, West Lafayette, IN | 1963           |                                                    |
| Emerald§      | 34-35        | Veg   | Z. japonica × Z. pacifica§ | USDA, Beltsville, MD, and the USGA, Far Hills, NJ | 1955           |                                                    |
| Sunburst      | Z-73         | Veg   | Z. japonica     | USDA, Beltsville, MD, and the USGA, Far Hills, NJ | 1952           |                                                    |
| Meyer§, Amazoy§ | Z-52  | Veg   | Z. japonica     | USDA, Beltsville, MD, and the USGA, Far Hills, NJ | 1951           |                                                    |
| Matrella§     | FC 13521     | Veg   | Z. matrella     | Alabama Agr. Experiment Station, Auburn, AL       | 1930s          | PI 48574                                           |

† Type of establishment (propagation) method typically used by practitioners for each cultivar. Genotypes available by seed are typically seeded, with other genotypes typically established vegetatively (Veg) by sprigs, plugs, or sod.
‡ Year released or made available to public.
§ Indicates that the cultivar was commercially available in the United States in 2017. TBA = Cultivar name to be announced.
¶ Species was identified in the plant patent as a Zoysia japonica Steud. × Zoysia tenuifolia Willd. ex Thiele hybrid. Because Z. pacifica (Goudswaard) M. Hotta & S. Kuroki was incorrectly name as Z. tenuifolia, the cultivar is best described as Z. japonica × Z. pacifica (Anderson, 2000).
# Genetic analysis indicates that Emerald could possibly be Z. matrella × Z. pacifica (Anderson, 2000). More recent analysis by Kimball et al. (2013) does not identify the parents but supports Emerald being classified as a hybrid.

Winrock is shorthand for Winthrop Rockefeller (1912–1973), who was a philanthropist and Governor of Arkansas.
Further, despite many well-adapted cultivars in the national marketplace, there are typically a limited number of cultivars available locally. This is particularly true in areas where cold hardiness limits the adaptation of cultivars. Most sod producers in the transition zone grow Meyer zoysiagrass because of its superior cold hardiness. Of the 49 zoysiagrass cultivars currently in production or previously in production in the United States (Table 4), 41 are commercially available in 2017. Thirty-eight (93%) were released since 1980, 33 (80%) were released since 1990, 24 (59%) were released since 2000, and 10 (24%) since 2010 (Fig. 4). Two US maps are provided that show the percentage of turf producers (sod farms) in each state producing zoysiagrass and the recommended cultivars for different US climatic regions (Fig. 5 and 6).

Although there was great interest in zoysiagrass lawns as early as the 1930s (Halsey, 1956), zoysiagrass use on lawns has increased slowly. Initially popular in the South, lack of Z. matrella plant material and improvements in bermudagrass, centipedegrass, and St. Augustinegrass [Stenotaphrum secundatum (Walt.) Kuntze] slowed its expansion (see footnote 22). The introduction of Meyer zoysiagrass increased zoysiagrass expansion, particularly in the Midwest and throughout the transitional climatic zone. In Arkansas, for example, which was the epicenter of zoysiagrass sod production in the 1980s and 1990s, an estimated 15,550 ha of commercial and residential lawns are zoysiagrass (Patton, 2010) (Fig. 7). In the Midwest, greater use of zoysiagrass has occurred, in part through marketing of Meyer (sold by some as Amazoy) zoysiagrass plugs to homeowners through radio, television, newspapers, and magazines since 1953 (Anonymous, 1992). Homeowners across the United States mail ordered zoysiagrass plugs to plant in their lawns to access its benefits. More recently, zoysiagrass use in the homeowner market has increased primarily through the expansion of Empire zoysiagrass sod in the US Southeast (Fig. 7).

As discussed below, the superior wear tolerance (Youngner, 1961a; Beard and Beard, 2005; Lulli et al., 2012) of zoysiagrass would seemingly make it well suited for athletic fields. However, its reputation for slow recovery from traffic injury (Augsdorfer, 1995; Beard and Beard, 2005; Turgeon, 2012), particularly observed with Meyer zoysiagrass, and the high cost of establishment have led most to recommend...
it only for stadium-type fields with limited or modest traffic (Minner, 1999; Lulli et al., 2012). As such, zoysiagrass use on athletic fields is infrequent, and bermudagrass and Kentucky bluegrass remain the most commonly used turfgrasses on US athletic fields (Christians et al., 2017). In Asian countries like Korea, zoysiagrass is more commonly used on athletic fields than in the United States (Kim, 1989). However, increased daily light integral in the United States, compared with the low-light environments in East Asia, favors bermudagrass growth in high-traffic environments (Christians et al., 2017).

Zoysiagrass is occasionally used in other areas such as airports, cemeteries, coastal sand dunes, parks, roadides, and seed production fields in the United States (Fig. 8). Although Monteith (1942) recognized the potential for zoysiagrass use on roadides and airports early on, adoption is slow, primarily due to the high cost of vegetative establishment in large acreage developments and the difficulties in establishing zoysiagrass from seed (Samudio, 1996; Patton et al., 2007c). Zoysiagrass has been used in other areas such as horse racetracks (Augsdorfer, 1995), but these attempts were unsuccessful, similar to experiences in Japan (Maki, 1976). Although zoysiagrass is used as a forage in Japan, it is rarely used for that purpose in the United States (Hatch and White, 2004).

**Strengths and Shortcomings of Zoysiagrass**

**Strengths of Zoysiagrass**

**Turf Quality**

Various author descriptions of zoysiagrass are found in the literature that speak to the high-quality turf that zoysiagrass creates. Comments about zoysiagrass as a lawn include: “highly prized” and “highly commended as a lawn grass” (Lamson-Scribner, 1895), “a most beautiful
Fig. 7. Zoysiagrass use on golf courses and lawns in the United States: (A) Diamond zoysiagrass fairways at the Highlands Course, Atlanta Athletic Club, Atlanta, GA, in 2010; (B) Cavalier zoysiagrass fairways at the Blessing Golf Club, Fayetteville, AR; (C) Meyer zoysiagrass fairways, Honors Course, Ooltewah, TN; (D) *Zoysia japonica* lawn (cultivar unknown) at W.H. Daniel’s former residence, West Lafayette, IN; (E) Meyer zoysiagrass lawn, Fayetteville, AR; and (F) Empire zoysiagrass turf in a driveway, Naples, FL.

Fig. 8. Zoysiagrass use on athletic fields, cemeteries, roadides, sod farms, and other areas in the United States: (A) dormant Meyer zoysiagrass covering over 1 ha of cemetery grounds at Ames Cemetery in Paoli, IN, likely from a family member who planted zoysiagrass plugs on a grave site in the 1960s; (B) El Toro zoysiagrass grown on a Little Rock, AR, sod farm (photo courtesy Fred Miller, University of Arkansas); (C) zoysiagrass outcompeting bahiagrass (*Paspalum notatum* Flügge), centipedegrass, and common bermudagrass in a roadside median near Lakeland, GA; (D) Zenith zoysiagrass at the Cincinnati Zoo (Cincinnati, OH) in the Cheetah exhibit (photo courtesy Tim Bowyer, Patten Seed Co.).
velvet-like turf” (USDA Bureau of Plant Industry, 1905), “a valuable lawn grass” (USDA Bureau of Plant Industry, 1911), “beautiful turf” (Piper and Oakley, 1917), “a very beautiful dark-green turf” (USDA Bureau of Plant Industry, 1918), “one of the best lawn grasses” (Sturkie, 1941), “superior” lawn grass (Childers and White, 1947), and “surpassing beauty” (Halsey, 1956). Comments on zoysiagrass use on golf courses include: “excellent for golf links” (USDA Bureau of Plant Industry, 1908), “perfect green carpet” (USGA Green Section, 1921), “a panacea for many turf ills” (USGA Green Section, 1944), “tough” (USGA Green Section, 1945), “provide(s) ideal shot making turf” (Grau, 1960), “sheer beauty” (Tiller, 1987), and “a high-quality playing surface that is aesthetically appealing” (Engelke, 1988). One author commented that Z. patifica (Z. tenuifolia in the article) “is the most attractive” and that Z. japonica is “the least attractive in appearance” (Halsey, 1956). Regardless, many agree that Zoysia spp. can produce excellent turf. Turf quality is influenced largely by leaf texture, as noted by Halsey (1956), but must also be assessed by a cultivar’s intended use (roadside, lawn, golf course putting green, etc.). Additionally, the turf quality produced by different zoysiagrass cultivars varies regionally by adaptation to various local abiotic and biotic stresses (Patton, 2009).

Drought Tolerance

Zoysiagrass drought resistance is not always favorably discussed when compared with other species, especially bermudagrasses (Watson, 1989). However, many of these drought response observations were based on early cultivar releases. Newer cultivars, especially Z. japonica, perform more favorably in response to drought (Wherley et al., 2014). Recent findings summarized here shed light on mechanisms that will allow for greater zoysiagrass drought improvements in the future. Much of the initial research on zoysiagrass response to drought was conducted in Georgia or Texas with Meyer or Emerald zoysiagrass. Kim and Beard (1988) evaluated several warm-season species for evapotranspiration (ET) and found that Meyer and Emerald zoysiagrass were similar or had higher ET rates than tested bermudagrasses in College Station, TX. Subsequently, Beard and Sifers (1997) evaluated the drought resistance of 26 bermudagrasses and nine zoysiagrasses following a 158-d period of drought stress and concluded that zoysiagrass has inferior dehydration avoidance and recovery than bermudagrass. The authors did note the existence of intraspecific differences within the tested zoysiagrass lines. Carrow (1996) further reported that Meyer zoysiagrass performed poorly compared with other warm- and cool-season species for leaf firing, wilting, and total root length through periods of drought in Georgia. Qian and Engelke (1999) compared the performance of five turfgrasses under linear gradient irrigation in Dallas, TX, and discovered that the irrigation required to produce acceptable turf was higher for Meyer zoysiagrass than ‘Nortam’ St. Augustinegrass, ‘Tifway’ hybrid bermudagrass, and ‘Prairie’ buffalograss [Buchloë dactyloides (Nutt.) Engelm]. Again, these results were not favorable for zoysiagrass.

White et al. (2001) later evaluated osmotic stress of 15 improved zoysiagrasses and noted the existence of cultivar differences and potential for development of drought-resistant zoysiagrass. In a more recent linear gradient irrigation study that compared several bermudagrass and zoysiagrass cultivars, the watering requirements of the grasses tested were Cynodon spp. ≤ Z. japonica < Z. matrella (Wherley et al., 2014). The authors did state that the modern, improved cultivars of Z. japonica (Empire, ‘JaMur’, and ‘Palisades’) possess improved drought resistance compared with Meyer and other earlier cultivar releases (Wherley et al., 2014). Additionally, Fuentealba et al. (2016) determined that modern zoysiagrass germplasm had lower ET rates and less soil water consumption than common bermudagrass and St. Augustinegrass. Previously, Meyer zoysiagrass was reported to have a higher ET rate than ‘Midlawn’ bermudagrass (Qian et al., 1996).

Although ET rates and water consumption are higher for C. dactylon than Z. japonica and Z. matrella (Fuentealba et al., 2016), the rates of root depth development and root length densities at increased soil depths are higher for C. dactylon than Z. japonica and Z. matrella (Fuentealba et al., 2015). Lastly, Zhang et al. (2017) compared transpiration ratios and leaf firing of four C. dactylon lines, four S. secundatum lines, three Z. japonica lines, and three lines of Z. matrella. In their study, they concluded that Zoysia spp. initiated leaf firing sooner than other species, which was likely related to a deeper C. dactylon root system and access to a greater volume of soil water. However, the data also indicated that, once initiated, leaf firing progressed more rapidly in C. dactylon than Zoysia spp. (Zhang et al., 2017).

This research on zoysiagrass response to drought supports that current zoysiagrass germplasm has a lower ET rate than other species, shallower roots, and an earlier onset of wilting and leaf firing during drought. As defined by Huang (2008a), zoysiagrass drought resistance mechanisms are to avoid drought stress through early stomatal regulation, and tolerance through osmotic adjustment is likely a contributing factor for some genotypes that are able to slowly progress through leaf firing. Under severe drought, zoysiagrass tolerates drought by entering a dormant state and subsequently fully recovers after significant rainfall, even after long dormancy periods (Beard and Sifers, 1997; Steinkie et al., 2009). The components of water use and drought resistance described suggest that zoysiagrass will remove less water than other species (due to lower ET rate and shallower roots) from a soil profile and result in overall soil water savings in the absence of supplemental irrigation. In contrast, a more deeply rooted species or one with a higher ET rate will remove more water from the
soil profile, even during periods of drought. Subsequent recharge of the soil profile will require more rain in this scenario versus a soil planted with zoysiagrass.

Breeding programs are working to develop more deeply rooted zoysiagrasses. The combination of deeper roots, lower ET rates, and prolonged progression of leaf firing potentially offer the greatest water savings to reduce the need for irrigation and lessen the amount of water removed from the soil profile. Current zoysiagrass breeder germplasm pools have extensive variation in rooting depth ability and potential for improvement compared with current cultivars (K. Kenworthy, unpublished data, 2016). Modern cultivars of zoysiagrass exhibit good drought resistance and should be recommended for use in regions with frequent occurrences of acute drought stress. If dormant turf is acceptable, the use of zoysiagrass is also suggested in areas that experience chronic drought.

Salt Tolerance
Zoysiagrass is among a group of species classified as moderately tolerant of salinity (Beard and Beard, 2005); however, Z. matrella is considered highly salt tolerant and Z. japonica is considered salt sensitive when classified by species (Marcum and Murdoch, 1994; Loch et al., 2006). Within the Zoysia spp., salinity tolerance is related to the ability of the genotype to secrete salt through specialized salt glands (Marcum and Murdoch, 1990), with a higher density of salt glands resulting in improved salinity tolerance (Marcum et al., 1998). Wide variation of salinity tolerance within Zoysia is related to the indigenous environments these species occupy, with Z. matrella and Z. macrostachya (indigenous coastal environments) more salt tolerant than Z. japonica (indigenous mainland environments) (Loch, 2015). With this variability, Marcum et al. (1998) concluded that there was great potential for the development of improved salinity-tolerant cultivars.

Wear Tolerance
Wear is the scuffing, tearing, and abrasive forces experienced from traffic in a turfgrass system (Trenholm et al., 2000). Zoysiagrass is noted for its superior wear tolerance (USGA Green Section, 1945; Youngner, 1961a; Beard and Beard, 2005; Lulli et al., 2012). This wear tolerance is conferred by the high plant fibers, hemicellulose (Washburn and Seamans, 2012; Trappe, 2015), and lignin (Lulli et al., 2012) compared with other turf species. Plant fiber is helpful in improving wear tolerance (Shearman and Beard, 1975) and deterring certain pests (discussed below). Additionally, high zoysiagrass stem and tiller density is associated with its high wear tolerance (Lulli et al., 2012) and resistance to divoting (Trappe et al., 2011c). Few reports comparing the wear tolerance of Zoysia spp. are available, although one report noted that Z. matrella had superior divot resistance to Z. japonica (Trappe et al., 2011c).

Growth Rate
The growth rate of zoysiagrass is a strength and shortcoming. Like two sides of the same coin, the shortcoming of its slow growth rate, described in detail in a section below, is also its strength. Compared with bermudagrass, zoysiagrass grows more slowly (Busey and Myers, 1979), is less likely to encroach on golf course putting greens and gardens, and requires less trimming around paths and golf course bunkers. A reduced clipping yield compared with Bermudagrass is another strength of zoysiagrass (Trappe et al., 2011b). Within zoysiagrass, ‘Cavalier’, ‘Diamond’, Meyer, and ‘Zorro’ have lower clipping yields than bermudagrass, with ‘El Toro’ and Palisades having clippings yields similar to bermudagrass (Trappe et al., 2010, 2011b). The advantage of a cultivar with low clipping yield is that it will require less frequent mowing and consequently less fossil fuel consumption (Law et al., 2016). Likewise, turf managers using plant growth regulators will note that fewer applications are required on zoysiagrass. For example, Atkinson et al. (2012) reported that trinexapac-ethyl applications did not reduce clipping yield or increase turf quality of Diamond zoysiagrass grown in full sun. However, trinexapac-ethyl applications did reduce Diamond zoysiagrass clipping yield and increase turf quality in shade.

Nutritional Requirement
Directly associated with this slow growth rate is the low nutritional requirement of zoysiagrass. Turfgrasses with slower growth rates require less nutrient input (Kussow et al., 2012). Whereas zoysiagrass was once thought to have a similar nutrient need to bermudagrass and as much as 342 kg N ha⁻¹ yr⁻¹ was recommended in warm-humid climates (Holt, 1969), current N fertility recommendations for zoysiagrass (Christians et al., 2017) are much lower than recommended some 50 yr ago (Wise, 1961; Holt, 1969). Similarly, rates of 195 to 293 kg N ha⁻¹ yr⁻¹ were once recommended in the transitional climatic zone (Juska et al., 1969), whereas rates ≤98 kg N ha⁻¹ yr⁻¹ are now used throughout most of the United States. Dunn et al. (1995) concluded that ≤98 kg N ha⁻¹ yr⁻¹ was adequate in Missouri for Meyer zoysiagrass nutrition, and that root growth was maximized when N fertility was ≤98 kg N ha⁻¹ yr⁻¹. Similarly, Patton et al. (2010b) found that although turf quality of three zoysiagrass cultivars was highest when ≥98 kg N ha⁻¹ yr⁻¹ was applied in Arkansas, turf quality was never unacceptable (turf quality < 6 on a 1–9 scale) for the unfertilized plots. Trappe and Patton (2013) also reported that, regardless of N source, both Meyer and Cavalier zoysiagrass provided acceptable turf quality when fertilized at 98 kg N ha⁻¹ yr⁻¹. In Texas, where the growing season is longer, Kenworthy and Engelke (1999) reported that 98 to 195 kg N ha⁻¹ yr⁻¹ produced the highest quality turf at a fairway mowing height. Similar results were reported in Florida by Schwartz (2008). As described by Murray and
Morris (1988), inappropriate management of zoysiagrass will diminish its strengths. Applying too much N is an example. In South Carolina, Hale (2006) reported excessive thatch accumulation and subsequent scalping of *Z. matrella* cultivars receiving annual N rates $\geq 146$ kg N ha$^{-1}$. Further, Schwartz (2008) reported increased *Bipolaris* leaf spot [*Bipolaris spicifera* (Bainier) Subramanian] when excessive N was applied. As Murray and Morris (1988) stated previously, “zoysiagrass will provide a high-quality turf at a lower maintenance level than most other turfgrasses.”

**Cold Hardiness**

Similar to growth rate, cold hardiness of zoysiagrass is both a strength and a shortcoming. As mentioned previously, cold hardiness is variable among *Zoysia* spp., with a ranking by species of *Z. japonica* $>$ *Z. matrella* $>$ *Z. pacifica* (Forbes, 1952; Patton and Reicher, 2007). This ranking is predictable considering the centers of origin for these species: *Z. japonica* is native to Korea and Japan (temperate climate), *Z. matrella* is native to a broad geography in Asia (both temperate and tropical climates), and *Z. pacifica* is native to the Pacific islands (tropical climate) (Engelke and Anderson, 2003; Tanaka et al., 2016b). Although *Z. japonica* has better cold hardiness than other *Zoysia* species, Patton and Reicher (2007) found large differences in response to freezing temperatures and winter injury between cultivars. Only select cultivars are recommended in locations whose climate offers severe winter stress (Patton, 2009; Fig. 6). The strength of select winter-hardy zoysiagrass cultivars, such as Meyer, is that they offer reliable winter performance (i.e., survival) in climates where bermudagrass winterkill is predictably too frequent. For example, in a severe winter in West Lafayette, IN, in 2013 to 2014, $>50\%$ winterkill was observed on large areas of two established, cold-hardy bermudagrass cultivars (‘Patriot’ and ‘Riviera’), but $<2\%$ winterkill occurred on a large Meyer zoysiagrass fairway at the same site. Furthermore, unlike bermudagrass, which is susceptible to the hard-to-control disease spring dead spot (*Ophiophaerella korrae* Walker and Smith) that is most severe after cold winters (Nus and Shashikumar, 1993), zoysiagrass is not commonly damaged by this disease with the exception of a few isolated reports (Tisserat et al., 1994; Tredway and Butler, 2007).

**Shade Tolerance**

As mentioned previously, the increased shade tolerance of *Z. matrella* compared with other warm-season grass species in the southern United States was the catalyst that led to its early adoption and use (Sturkie, 1941). Several experiments have examined the shade tolerance of *Zoysia* germplasm. Two comprehensive experiments on the shade tolerance of zoysiagrass cultivars were conducted in Dallas under $90\%$ shade from southern live-oak (*Quercus virginiana* Mill.) (Riffell et al., 1995; Wherley et al., 2011). Cultivars were assigned a turf performance index value of one each time they appeared in the top statistical grouping when rated for coverage, quality, color, and density and a value of zero when not in the top statistical group (Wherley et al., 2011). Across the two experiments, ‘Crowne’, Diamond, Palisades, ‘Royal’, and Zorro were near or in the top groupings for their performance in shade (Riffell et al., 1995; Wherley et al., 2011). In both experiments, Meyer had the poorest performance in Texas shade. Even in the transition zone, Meyer zoysiagrass, along with other cold hardy genotypes such as Chinese Common, exhibited poor performance in natural shade (Peterson et al., 2014). Trappe et al. (2011d) also reported that Cavalier, Diamond, El Toro, Palisades, and Zorro all performed well in $50\%$ shade, Meyer performed fair, and ‘Zenith’ performed poorly. At a species level, *Z. matrella* is considered more shade tolerant than *Z. japonica* (Riffell et al., 1995; Sladek et al., 2009; Trappe et al., 2011d; Wherley et al., 2011). To improve the shade tolerance of *Z. japonica*, crossing with *Z. matrella* to create hybrids is an effective method to enhance shade tolerance (Okeyo et al., 2011a).

**Weed Tolerance**

Another strength of zoysiagrass is that relatively few weeds colonize established, healthy swards because of its high shoot density. Several authors highlight the scarcity of weeds in zoysiagrass turf (Forbes and Ferguson, 1947; Halsey, 1956; Kemmerer and Weinard, 1957; Rueemmele and Engelke, 1990; Diesburg, 2001; Fry et al., 2008). Although the high plant density does not allow for “freedom from weeds,” as Forbes and Ferguson (1947) proposed, zoysiagrass typically has fewer weeds than bermudagrass (A.J. Patton, personal observation). Most problematic are winter annual weeds such as annual bluegrass (*Poa annua* L.). However, weed encroachment increases when zoysiagrass is overirrigated (Zhang et al., 2013) or exposed to prolonged drought stress (Qian and Engelke, 1999). Fall or winter fertilization also increases the abundance of winter annual weeds such as annual bluegrass, Australian waterbuttons [*Goutanum australis* (Sieber ex Spreng.) Hook. f.], common chickweed (*Stellaria media* L.), and henbit (*Lamium amplexicaule* L.) (Henry et al., 1989; Dunn et al., 1993). Further, overfertilization of zoysiagrass in summer months increases the risk of common bermudagrass invasion (Doroh and McElroy, 2010), as well as witer colonization by henbit (Weston and Dunn, 1985).

**Sport Surface**

Zoysiagrass creates an excellent fairway surface and is noted in popular literature for the excellent ball lie created by its stiff leaf blades (Hurley, 1976; Bevard et al., 2005). Under mown, fairway conditions, $>92\%$ of the golf ball is exposed above the turf canopy, with ball lie similar between *Z.
japonica and Z. matrella (Richardson et al., 2010; Trappe et al., 2011a). Although ball lie is similar between bermudagrass and zoysiagrass in closely mown turf (Trappe et al., 2011a), golfers prefer playing from zoysiagrass over bermudagrass when hitting from golf course roughs, as the golf ball remains largely suspended at the top of the zoysiagrass canopy, making recovery shots easier (Stone, 1990).

**Shortcomings of Zoysiagrass**

**Growth Rate**

An early report on the use of zoysiagrass notes that it would be a “panacea for many turf ills” and an “ideal grass” was it not for its slow growth rate (USGA Green Section, 1944). Sturkie (1941) described the slow growth of zoysiagrass as its “chief weakness.” Slow growth, particularly during establishment, causes three main issues. First, a slow growth rate results in slow recovery from injury such as divot and traffic injury. Although zoysiagrass is noted for its superior wear tolerance (Youngner, 1961a; Beard and Beard, 2005; Lulli et al., 2012) and its traffic tolerance is similar to bermudagrass (Trappe et al., 2011d), its utilization for athletic fields is limited because of its slow recuperative rate from injury (Beard and Beard, 2005; Turgeon, 2012) and intolerance of compacted soils compared with bermudagrass (A.J. Patton, personal observation). Therefore, zoysiagrass use is often restricted to athletic fields with reduced traffic stress, such as baseball and softball. Use on American football and soccer (football) fields is rare. Even on low-use zoysiagrass athletic fields, high-traffic areas will require additional time to recover or damaged areas replaced with sod.

A second issue caused by a slow zoysiagrass growth rate is delayed establishment. For homeowners, this results in a long period from plugging to full lawn establishment. Establishment from plugs may take two or more years. For turf producers, slow growth results in a slow production cycle. Time from sprig planting to sod harvest is 12 to 24 mo for Meyer and Emerald zoysiagrass, compared with 6 to 12 mo for hybrid bermudagrass (Cynodon dactylon × C. transvaalensis) (McCarty et al., 1999). Time from an initial harvest to second harvest is 14 to 18 mo for zoysiagrass and 3 to 6 mo for hybrid bermudagrass. A third issue is that a slow production cycle results in an increased cost to establish zoysiagrass vegetatively (Patton and Boyd, 2007; Waltz, 2015). A delayed production cycle increases sod grower expenses, which are passed on to the consumer. Estimates of the long-term management cost for maintaining zoysiagrasses would be helpful to homeowners, landscape professionals, municipalities, and golf courses as they consider renovation with new cultivars that are developed. This information is either not currently available, or easily attainable, for the general and specific use of currently grown cultivars in different regions.

To reduce establishment costs, many golf courses have established zoysiagrass using a strip-sodding method (Zontek, 1983). Strip sodding is the process of planting 7.6- to 25.4-cm (3- to 12-in.) wide strips of sod in long rows with 0.3- to 0.6-m (12- to 24-in.) spaces between them (Christians et al., 2017). The strips then spread into adjacent bare areas or turf from stolons and rhizomes. Strip sodding is more expensive than plugging but less labor intensive. Establishing zoysiagrass by strip sodding may require 2 to 3 yr for complete cover to be established (Patton et al., 2006), but at a savings of $27,182 ha⁻¹ (Patton et al., 2006; Christians et al., 2017).

Concerns over a slow growth rate are legitimate but also highly influenced by the slow growth rate of early commercial cultivars (Table 4). Meyer (1951 release) and Emerald (1955 release) are amongst a group of cultivars with a slow establishment rate and slow stolon growth rate (Patton et al., 2007d). Other cultivars released since 1984 such as ‘Carrizo’, ‘Chisholm’, Palisades, and El Toro establish twice as fast as Meyer (Patton et al., 2007d). Patton et al. (2007a) found that fast-establishing zoysiagrass genotypes partition more dry matter for the production of stems (stolons and rhizomes) than slow-establishing genotypes. With greater stem production, the recuperative capacity of improved zoysiagrass cultivars such as El Toro and Palisades is superior to Meyer (Karcher et al., 2005) and equivalent to ‘Tifway’ hybrid bermudagrass (Trappe et al., 2011b). Although other new cultivars like Diamond establish more slowly than Meyer, Diamond zoysiagrass’s increased rhizome density allows for a quicker regrowth after sod harvest (Engelke and Murray, 1989).

**Cold Hardiness**

Cold hardiness is a shortcoming of Z. matrella and Z. pacifica and some Z. japonica cultivars (Forbes, 1952; Patton and Reicher, 2007). Winter injury response among Z. matrella is variable between cultivars (Patton and Reicher, 2007), but the most cold-hardy Z. matrella germplasm will not often survive north of the transitional climatic zone (Fig. 6). Little progress has been made in identifying cold-hardy Z. matrella germplasm, but some progress has been made in the creation of Z. japonica × Z. matrella hybrids with enhanced cold hardiness and an intermediate leaf texture (Okeyo et al., 2011b; Genovesi and Chandra, 2015b; Chandra et al., 2017a) (Fig. 9). A recently released hybrid with enhanced cold hardiness, ‘KSUZ0802’, is now available with licensing to turf producers forthcoming (Chandra et al., 2017a).

**Winter Color**

As with other warm-season turfgrasses, zoysiagrass enters winter dormancy after chilling temperatures and subsequent autumn frosts. When dormant, zoysiagrass foliage has a dormant straw or golden color. While considered
desirable by some cultures, including Koreans (Engelke, 1988), many Americans find the dormant, golden color undesirable in comparison with cool-season turfgrasses that maintain their green foliage into winter (Grau, 1960). This attitude is most prevalent in cool-humid climates where cool-season turfgrasses such as Kentucky bluegrass predominate. In climates less favorable to the growth of most cool-season grasses, such as the transitional climatic zone, zoysiagrass winter color is accepted, and the species is championed as one of the few that make an excellent lawn in summer, when outdoor activities are highest. Although differences in fall color retention exist among zoysiagrass cultivars (Pompeiano et al., 2014), cultivars with excellent fall color retention are often those with inferior cold hardiness that are best adapted to warm-humid climates (Okeyo et al., 2011b).

**Insect Tolerance**

Although originally thought to be free of insect pests (Forbes and Ferguson, 1947), zoysiagrass is susceptible to various insect and mite pests like most warm-season grasses (Christians et al., 2017). Fall armyworm (FAW) (*Spodoptera frugiperda* J.E. Smith) and tropical sod webworm (TSW) (*Herpetogramma phaeopteralis* Guenée) are among the most injurious caterpillars to zoysiagrass in the United States. Cultivar susceptibility to caterpillar feeding is variable. Meyer is susceptible to FAW and TSW feeding, whereas improved *Z. matrella* cultivars Cavalier and Zorro are highly resistant to FAW and TSW feeding (Reinert and Engelke, 2001b; Reinert et al., 1994, 1997, 1998, 2009). The hunting billbug (*Sphenophorus venatus vestitus* Chittenden) is a challenging pest of zoysiagrass, and its incidence is increasing (Reinert and Engelke, 2001a). *Zoysia japonica* cultivars are more susceptible to hunting billbug feeding than *Z. matrella* (J.A. Reinert, personal communication, 2007; Huang, 2008b). Among the cultivars, Meyer and Zenith are the most susceptible, with BA-189, Emerald, Royal, ‘Toccoa Green’, ‘Zeon’, and Zorro being resistant to hunting billbug feeding (J.A. Reinert, personal communication, 2007; Huang, 2008b) (Fig. 9). Similarly,
Meyer zoysiagrass was the most susceptible to bluegrass billbug (Sphenophorus parvulus Gyllenhal) damage, with Chisholm and Z. matrella × Z. japonica hybrids being resistant (Fry and Cloyd, 2011). The zoysiagrass mite (Eriophyes zoysiae Baker, Kono, and O’Neill) is a modern problem on zoysiagrass since its introduction into the United States in 1982 (Baker et al., 1986) (Fig. 9). Among the zoysiagrass cultivars, ‘Belair’, Cavalier, Diamond, and Meyer are highly susceptible, whereas Emerald and Royal are highly resistant to zoysiagrass mite (Reinert et al., 1993). Although some progress is documented in breeding enhanced pest resistance into zoysiagrass germplasm, recent successes at using genetic sequencing technologies to map pest resistance genes and quantitative trait loci in zoysiagrass may allow for more rapid selection and improvement in future breeding efforts (Huang et al., 2016).

**Disease Tolerance**

An early report by Forbes and Ferguson (1947) declared that zoysiagrass provided “freedom from disease.” A later report in 1957 on zoysiagrass diseases (Wells et al., 1957) provided the first reference to large patch disease (Rhizoctonia solani Kühn AG2–2 LP) on zoysiagrass in the United States. This disease is a limitation to increasing the use of zoysiagrass on US golf courses. Large patch occurs on all warm-season grasses but is particularly problematic on zoysiagrass growing in the transitional climatic zone and warm-humid climates (Fig. 9). It causes considerable thinning of the turf and leads to the encroachment of weeds. Large patch can occur in both lawns and golf courses but is most severe on closely mown zoysiagrass (Green et al., 1994). Due to its severity, fungicide costs to control large patch are a larger portion of a zoysiagrass golf course’s budget in the United States than any other single pest (Fry et al., 2008). Data on large patch susceptibility is scant, but Cavalier, Meyer, and Zoro are thought to be moderately resistant to large patch (Metz et al., 1993). Efforts are ongoing to breed for and select cultivars with improved large patch resistance, to diminish the effect of this disease, and to reduce inputs required to maintain high-quality turf (Genovesi and Chandra, 2015b). In Japan, dog footprint (Curvularia spp.) is often reported as the most frequent disease problem of zoysiagrass (Maki, 1976; Tani and Beard, 1997). Although dog footprint occurs in the United States, especially on Z. matrella, large patch disease is more problematic. While zoysiagrass is not immune to disease, as Forbes and Ferguson (1947) suggested, its relatively few disease problems compared with cool-season turfgrasses allow it to be maintained with far fewer fungicide inputs and reduced costs (Fry et al., 2008). This reduced need for fungicide applications is one of zoysiagrass’s greatest strengths, particularly when compared with creeping bentgrass and perennial ryegrass, which are commonly used turfgrasses on golf course fairways and tees in the transitional climatic zone.

**Seed Yield**

Limited seed availability is a problem of zoysiagrass that dates back to the 1940s, when zoysiagrass use was first increasing (Halsey, 1956). In the 1940s, Z. matrella seed was sold and marketed under the name Flawn (Childers and White, 1947). However, the scarcity of seed led many to believe that the existence of zoysiagrass seed was a hoax (Halsey, 1956). It was not until the 1980s that significant progress on the development of Z. japonica cultivars available from seed occurred, and not until 1993 that a cultivar developed in the United States was commercially available (Nesbitt, 1993; Samudio, 1996). Until then, much of the Z. japonica seed entering the United States was imported from China (Samudio, 1996). Although zoysiagrass seed is now produced in the United States, primarily in Georgia, its production is minimal compared with many other grass species. Limited seed yield is a major roadblock to increased consumer adoption. Low seed yields lead to increased establishment costs and decreased seed availability for consumers. Approximately 112 kg ha⁻¹ of zoysiagrass seed are produced annually (Samudio, 1996). Compared with perennial ryegrass (Lolium perenne L.), which annually produces 1624 kg seed ha⁻¹ (DeFrancesco et al., 2002), or common bermudagrass with seed yields of 412 to 892 kg ha⁻¹ (Ahring et al., 1974), the zoysia seed yield is comparatively low, which reduces the availability of zoysiagrass to consumers. It is unclear how many hectares of zoysiagrass are used for US seed production annually, as producers were reticent to reveal that information when asked.

**Seed Establishment**

The difficulty in establishing zoysiagrass from seed is another major challenge that limits its adoption. Slow germination rates, poor seedling vigor, and rapid weed encroachment are just some of the challenges to establishing zoysiagrass from seed (Portz et al., 1981; Yeam et al., 1981; Samudio, 1996; Patton et al., 2004a, 2004b, 2006; Zuk and Fry, 2005; Zuk et al., 2005). Untreated zoysiagrass seed has a dormancy factor with <10% germination among untreated seeds (Portz et al., 1981). Chemical scarification with potassium hydroxide (KOH) or sodium hydroxide (NaOH) improves germination rates (Yeam et al., 1981, 1985), but not seedling vigor, so weed control in new seedlings is critical to successful establishment (Patton et al., 2004b, 2007b). Further, only two Z. japonica cultivars are currently sold as seed in the United States. While efforts to breed additional cultivars that can be established by seed are ongoing (Genovesi and Chandra, 2015a), no new cultivars are available to date.

**Mowing Quality**

Zoysiagrass leaves are high in neutral detergent fiber (NDF), which is a combined measure of cellulose,
hemicellulose, and lignin (Washburn and Seamans, 2012). In particular, zoysiagrass is high in the plant fiber hemi-
cellulose (Trappe, 2015). Plant fiber is helpful in reducing
insect feeding (Hong et al., 2012) and improving wear
tolerance (Shearman and Beard, 1975), but it causes a
diminishing microbial decomposition rate (Trappe, 2015).
This high NDF concentration may also render zoysiagrass
more difficult to cut with mowers, as zoysiagrass requires
more equipment maintenance than other turf species to
maintain a high quality of cut (Bevard et al., 2005). Qual-
ity of cut is variable amongst zoysiagrass cultivars, with
some more difficult to cut, and Z. matrella types generally
have a lower quality of cut than Z. japonica types (Patton
et al., 2010a).

Saturated Soils
In addition to other abiotic stresses, the intolerance of
zoysiagrass to low-soil-oxygen conditions caused in water-
saturated soils is occasionally problematic. This is associated
with the poor tolerance of zoysiagrass to compacted soils
with low soil oxygen. Meyer zoysiagrass can suffer turf loss
from flooding or saturated conditions during the winter
months in the transition zone in poorly drained soils (Stone,
1990). Additionally, recent cases of more severe damage to
newly developed zoysiagrass cultivars from saturated soils
have surfaced in the transition zone (A.J. Patton, personal
observation). There is no information available in the litera-
ture on which zoysiagrass cultivars might be more or less
resistant to waterlogging, nor is there any information on the
physiological mechanisms as to why some grasses such as
bermudagrass tolerate waterlogging stress better than
zoysiagrass (A.J. Patton, personal observation; Fry, 1991).
It is likely that there are differences in waterlogging toler-
ance between zoysiagrass cultivars, especially considering
that many of these zoysiagrasses grow in low-lying areas in
their native environment in Southeast Asia and the Pacific.
Therefore, tolerance to water-saturated soils deserves fur-
ther investigation.

IMPROVEMENT

Early Improvement: 1940 to 1975
The first documented zoysiagrass breeding work occurred
in Beltsville, MD, in the 1940s. Open pollination, directed
crosses, and irradiation were all methods employed to
create new germplasm from promising plant introduc-
tions (Hanson, 1965). The original breeding goal was to
select for zoysiagrasses that had excellent turf quality, early
spring green-up from winter dormancy, late fall color
retention, and cold hardiness.

Meyer zoysiagrass, named in honor24 of Frank N.
Meyer, resulted from the selections made by Dorsett
and Morse fr om 1929 to 1931 (Hanson, 1965). It was a

24 Frank N. Meyer also had a lemon cultivar named in his honor, Citrus
× meyeri cv. Meyer (Lim, 2012).

promising individual plant selected in 1940 from the
Arlington Turf Gardens and transferred to the Plant
Industry Station in Beltsville prior to the construction of
the Pentagon.25 After increasing for testing in 1947, it
became experimental variety Z-52 (Hanson, 1966). Ian
Forbes, Jr.26, and Marvin Ferguson27 with the USDA-
ARS and Fred V. Grau28 with the USGA are credited
with its selection (Hanson, 1965). The official release of
Meyer, a Z. japonica cultivar, occurred in 1951, and today,
Meyer is produced in 17 of the 19 (89%) US states produc-
ing zoysiagrass.

Sunburst zoysiagrass, evaluated as experimental vari-
ety Z-73, was released in 1952 in cooperation with the
USDA-ARS and the USGA Green Section (Hanson,
1965). It was a selection from Meyer zoysiagrass seed but
had a wider leaf blade than Meyer. It had a good seed yield
and was sold as seed.

Emerald zoysiagrass was released in 1955 by the Georgia
Coastal Plain Experiment Station, Tifton, in cooperation
with the USDA-ARS and the USGA Green Section. It is
not distinguishable from Z. matrella but was reportedly a
hybrid between a Z. japonica parent from Korea and a Z.
pacificaparent from Guam (Hanson, 1965). Genetic analy-
sis indicates it could possibly by a Z. matrella by Z. pacifica
hybrid (Anderson, 2000). It was originally selected at the
Plant Industry Station in Beltsville (Alderson and Sharp,
2014).

25 The Pentagon is the headquarters of the US Department of
Defense. It is located in Arlington County, VA, across the Potomac
River from Washington, DC, which is the former site of the Arlington
Turf Gardens—specifically, the Pentagon parking and access roads
(Grau, 1960). The Arlington Turf Gardens were constructed in
1916, and these plots contained some of the earliest turf research
experiments conducted in the United States (Turgeon, 2009).
26 Ian “Scotty” Forbes, Jr., was an agronomist with the Division of
Forage Crops and Disease in the Bureau of Plant Industry, Soils,
and Agricultural Engineering, USDA. Initially working to improve
zoysiagrass in Beltsville, Forbes transferred to the Georgia Coastal Plain
Experiment Station in Tifton, GA, where he continued his zoysiagrass
improvement program.
27 Marvin H. Ferguson (1918–1985) was born in Buda, TX. He earned
his B.S. from Agricultural and Mechanical College of Texas (now Texas
A&M University) in 1940 and a Ph.D. from the University of Maryland
in 1950 (Beard et al., 2014). Dr. Ferguson worked for the USGA at the
Arlington Turf Gardens and helped relocate plant material, including
zoysiagrass germplasm, to the USDA Plant Industry Station in Beltsville
(Beard et al., 2014). He served in the Navy during WWII. After the war,
he served as USGA Green Section National Research Coordinator.
28 Fred V. Grau (1902–1990) was born in Jefferson, NE, and educated
at Nebraska State College (now the University of Nebraska–Lincoln),
where he earned his B.S. in 1931 (Dernoeden, n.d.). His first
prominent position in the turf industry was as manager of the Arlington
Turf Gardens. He later returned to school and earned his M.S. and
Ph.D at the University of Maryland. He later went on to become
the first full-time turfgrass extension specialist in the United States
(Patton et al., 2013). “During World War II, Dr. Grau entered the Air
Force, where he helped establish grass airfields under the guidance of Professor
Burton Musser (Penn State University), who also was working with the
Air Force at this time. In 1945, he was hired to be Director of the
USGA Green Section...” (Dernoeden, n.d.). In 1987, the C-5 Division of
the Crop Science Society of America (CSSA) created the Turfgrass
Science Award, which was named in honor of Dr. Fred V. Grau
(Dernoeden, n.d.).
pollination of selected clones) was vegetatively propagated and compared with other selections and cultivars (Young
ner, 1986). El Toro (UCR #1) was released in 1984 for its improvement of traits that limited zoysiagrass use in the 1970s and 80s. Compared with Meyer, El Toro has a coarser leaf texture, faster rate of spread, reduced water requirement, shorter period of winter dormancy, and less thatch (White et al., 1993; Gibeault, 2003). A significant amount of El Toro sod is produced throughout the southern United States.

Modern Improvement: 1976 to Current

A zoysiagrass breeding and improvement effort was initiated in the United States in 1980 at Texas A&M University at the Dallas Experiment Station by Dr. Milton (Milt) C. Engelke (Engelke and Murray, 1989). During the same time, J. Jack Murray33 of the USDA-ARS was working to improve zoysiagrass in Beltsville. A few years prior in 1976, a zoysiagrass breeding and improvement program was initiated at the University of Florida by Dr. Phil Busey. This program was transferred to Dr. Brian Scully in 1997 and resulted in the release of BA-189 (commercially available as ‘UltimateFlora’) and BA-305 (commercially available as ‘PristineFlora’ or Toccoa Green) in 2004 and 2005, respectively (Table 4) (Scully et al., 2009, 2012). In 2004, the University of Florida program came under the direction of Dr. Kevin Kenworthy. More recently, efforts to breed and improve zoysiagrass began in 2009 at the University of Georgia by Dr. Brian Schwartz and Dr. Paul Raymer and at North Carolina State University by Dr. Susana Milla-Lewis. Breeding goals of these programs primarily consist of the following: (i) increasing zoysiagrass growth rates, (ii) improving tolerance to temperature extremes, (iii) enhancing rooting characteristics and drought tolerance, (iv) increasing salinity tolerance,

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29 William (Bill) Hugh Daniel (1919–1995) was born in Sparkman, AR. He earned a B.A. degree in Social Science from Ouachita Baptist College (now Ouachita Baptist University) in Arkadelphia, AR. Daniel served as a bomber pilot in the US Air Force during World War II, and after the war, he received a B.S. from the University of Arkansas and M.S. and Ph.D. degrees from Michigan State University. He served on the faculty at Purdue University from 1950 to 1985, where he was known as “Doc Daniel” by students. He was the first turfgrass scientist at Purdue University, although Purdue University forage scientist G.O. Mott was involved in turf education prior to Daniel’s arrival. He was heavily involved in all aspects of turf education and research and was honored by scientific societies, foundations, associations, and the Governor of Indiana for his career efforts (Beard et al., 2014). A 12.1-ha (30-acre) Purdue University (West Lafayette, IN) turf research center is named in his honor: William H. Daniel Turfgrass Research and Diagnostic Center.

30 Kenyon (Ken) T. Payne (1918–1994) was a plant geneticist who worked at Purdue University from 1948 to 1952. From there, he went on to become a professor at Michigan State University and was instrumental in starting their 2-yr turf degree program. He received numerous honors, including career awards from the ASA, CSSA, Golf Course Superintendents Association of America, and USGA (USGA Green Section, 1994).

31 William Cecil LeCroy (1920–1979) was born in Hot Springs, AR. He started his undergraduate education in 1940 at Arkansas A&M College (now University of Arkansas at Monticello) but later finished in 1954 at the University of Rhode Island. In between, he served in the US Marine Corps in the US Pacific effort in World War II. He received a M.S. in Agronomy from the University of Arkansas, Fayetteville, in 1955 and was recruited to Purdue University in 1959 after serving as an Instructor of Agronomy at Arkansas State College (now Arkansas State University).

32 Victor (Vic) Bernard Youngner (1922–1984) was born in Nelson, MN. Youngner served in the Army Air Corps during World War II, and after the war, he received a B.S. and Ph.D. degrees from the University of Minnesota. He was on the faculty of the University of California system from 1955 to 1984 and was active in teaching, research, and the breeding of grasses (Beard et al., 2014).

33 James Jack Murray (1940–1994) was born in Jesup, GA, and was a graduate with a B.S. from the University of Georgia in Agronomy and a M.S. in Plant Breeding from the University of Nevada-Reno. Murray was a research agronomist for the USDA-ARS from 1969 to 1988. Murray initiated a zoysiagrass breeding program with focus on zoysiagrass establishment by seed, an economical way to increase the use of this low-input species. Although he only released one zoysiagrass cultivar, Belar in 1985, his germplasm collection led to the development and release of many other cultivars including Carrizo, ‘Compadre’, ‘Cutlass’, ‘L1F’, ‘Leisure Time’, ‘Lowrider 2’, JaMur, Zenith, and Zeon, amongst others. After retirement in 1988 due to health reasons, he started a private breeding company called Turfgrass Germplasm Services (Samudio, 1996). Although he died of cancer in 1994, his collection is highly used today in the creation of new germplasm. As such, his contributions to zoysiagrass improvement were and continue to be indispensable.
improvement was a lack of diverse germplasm. In an effort to increase diversity, Dr. Engelke and Jack Murray collected zoysiagrass germplasm from several Asian countries in 1982. Approximately 800 accessions were collected from Japan, Korea, Taiwan, and the Philippines (Murray and Engelke, 1983; Engelke and Murray, 1989). A second collection effort occurred in 1993 within the People's Republic of China (Engelke and Anderson, 2003).

All accessions from the 1982 collection trip were planted in field plots in Texas and Maryland (Murray and Engelke, 1983). Dr. Engelke, located at the Texas A&M AgriLife Research and Extension center in Dallas, used the germplasm in the development of Cavalier, Royal, and Zorro zoysiagrasses (Table 4) (Engelke et al., 2002b; Engelke and Reinert, 2003a, 2003b). Prior to utilization of the 1982 collection, Dr. Engelke was working with germplasm obtained from Murray’s collection in Beltsville. Three releases resulted from these breeding efforts and include Diamond (Engelke et al., 2002a), Palisades (Engelke et al., 2002d), and Crowne (Engelke et al., 2002c). In 2007, Dr. Ambika Chandra assumed direction of this program and released Chisholm zoysiagrass in cooperation with Dr. Jack Fry at Kansas State University (Table 4) (Chandra et al., 2015). More recently, Texas A&M University and Kansas State University worked cooperatively to release KSUZ 0802, a dense, fine-textured Z. matrella × Z. japonica hybrid that has cold hardiness comparable with Meyer (Table 4) (Chandra et al., 2017a).

Jack Murray also developed several zoysiagrass lines located at the USDA-ARS headquarters in Beltsville. His initial release in 1985, Belair, was derived from older germplasm of zoysiagrass found at the Beltsville Agricultural Research Center (Murray and O’Neill, 1987). With respect to the germplasm obtained from the 1982 Asian collection trip, Murray developed seeded populations (Engelke and Murray, 1989) that led, after his retirement in 1988 and death in 1994, to the release of two seeded cultivars, Zenith and Compadré, in 2000 by Patten Seed Company (Lakeland, GA) and Seed Research of Oregon (Corvallis, OR), respectively (Table 4). Upon retirement, Murray moved to Bradenton, FL, bringing much of his zoysiagrass collection, and continued breeding through collaboration with SMR Farms (Bradenton, FL). Shortly after Murray’s death, Bladerunner Farms (Poteet, TX) acquired the collection (K. Morris, personal communication, 2016). The collection was planted from seed into fields in Poteet, TX. Progeny from open-pollinated crosses were planted and later selected by Mr. David Doguet, owner of Bladerunner Farms, and resulted in the selection and subsequent release of Zeon zoysiagrass in 1996 (Table 4) (Doguet, 2002b). In honor of Jack Murray, Doguet also released JaMur (an abbreviation of Jack Murray) in 1996 (Doguet, 2002a).

In 2000, Bladerunner Farms acquired the rights to Murray’s collection. Bladerunner Farms is one of several private companies that have released commercial zoysiagrass cultivars. Bladerunner Farm’s first release was ‘Omni’ in 1991, and several additional releases in the 2000s came from the Murray collection. With the assistance of Dr. Virginia Lehman, Doguet used the Murray germplasm to create six additional cultivars including Carrizo, Cutlass, L1F, Leisure Time, ‘M60’, and ‘M85’ (Table 4) (Doguet and Lehman, 2007a, 2007b, 2014, 2015a, 2015b; Doguet et al., 2016). To date, Zeon and JaMur have been the most successful releases from Bladerunner Farms, with Zeon doing particularly well in the golf market.

Sod Solutions (Mount Pleasant, SC) brought Empire zoysiagrass into the US market in 1999 (Table 4). Empire zoysiagrass was developed in Brazil from ‘Esmeralda’ zoysiagrass by Mr. Minoru Ito and Mr. Roberto Gurgel (Ito and Gurgel, 2000b). Due to its wide adaptability, Empire resulted in more widespread use of zoysiagrass in new markets, especially in Florida. Additional zoysiagrass releases from Sod Solutions include ‘Empress’ and ‘Geo’ (Table 4) (Ito and Gurgel, 2000a, Chapman, 2015).

Other private enterprises that have released commercial cultivars of zoysiagrass in the United States include Heritage Turf, Jacklin Seed Company, Aloysia Blue, Dig Plant Company, Ivey Gardens, Zoysian Japan Company, Quality Turfgrass, Turf Center, Pursley Turf Farms, Greg Norman Turf Company, and Craft Turf Farms (Table 4). Of the 49 commercial cultivars listed (Table 4), private companies released 30, and >30 of the total cultivars became available in the last 20 yr. These statistics are strong indicators of the increased interest in zoysiagrass.

With the introduction of so many cultivars in recent years, the turfgrass industry clearly views zoysiagrass as a species with many desired attributes for the future of the industry. Furthermore, environmental awareness has become an important focus for the turfgrass industry during the last 25 yr (Christians et al., 2017). Although a few of the zoysiagrass cultivars were screened and released for having favorable responses to drought stress, freeze stress, shade stress, and insect pressure, more breeding and improvement of zoysiagrass is necessary to increase the sustainability of the turfgrass industry (Engelke et al., 2002a, 2002b, 2002c, 2002d; Chandra et al., 2015).

**BREEDING OF ZOSIAGRASS CROSSING**

All species of zoysiagrass are allotetraploids (2n = 4x = 40; Yaneshita et al., 1999). Cytological examination of meiosis supports this classification (Forbes, 1952; Gould, 1968). The species are self-fertile, but the protogynous nature of most species favors outcrossing. However,
because zoysiagrass is stoloniferous and mat forming, self-pollination will prevail in swards (Forbes, 1952). Three species—Z. minima (Colenso) Zotov, Z. pacifica Mez, and Z. planifolia Zotov—are thought to be cleistogamous (Anderson, 2000). Studies that examined hybridization among the species report that recombination among the species occurs relatively easy (Forbes, 1952; Yaneshita et al., 1997; Anderson, 2000). The ability to outcross and easily produce interspecific hybrids substantiates observations of significant phenotypic variation in the genus (Fig. 10).

Zoysiagrass flowering is temperature and daylength dependent; short days (8–10 h) and warm temperatures (27–30°C) will induce flowering in Z. japonica, Z. matrella, and Z. pacifica (Forbes, 1952; Youngner, 1961b). Nakamae and Nakamura (1984) reported that a combination of low light intensity and low levels of nitrogen induced flowering. Zoysiagrass produces a raceme-type inflorescence, which will contain 30 to 50 seeds for Z. japonica, 20 to 45 for Z. matrella, and 5 to 12 for Z. pacifica. Increased seed set and viability occur under higher temperatures (Anderson, 2000; Engelke and Anderson, 2003).

The occurrence of protogyny in zoysiagrass enables the ability to make controlled crosses without emasculation. Hanna et al. (2013) described a process to increase flowering for preparation of crosses. The method is to cut a piece of sod from the field just prior to peak flowering, versus using a source that has been continuously maintained under controlled lighting in a greenhouse. This change in environment typically causes a flush of racemes. Potting the sod into multiple trays or pots allows for easy movement of plant materials in close proximity when considering specific crosses. Shoot bags will need to be made by either cutting glycine bags to a length of 5.0 to 7.0 cm or using 2.0-mL microcentrifuge tubes (Fig. 11). A short wooden skewer should be glued to the bag or tube to provide support. Small jewelry tags can also be used to identify crosses. Pollen can be captured on glass cover slips or Petri dishes or gathered with a vacuum spore collector to make directed crosses.

To facilitate a cross, seedheads to be used as females should be covered daily with shoot bags as they emerge from the boot stage and prior to stigma emergence. This will prevent accidental pollination from neighboring seed heads or during the process of pollen collection and ensure adequate female flowers. Maximum pollen release occurs from 6:00 to 7:00 AM (Reddi et al., 1988); therefore, each evening prior to making crosses, parents should be moved in close proximity to each other. Arranging male pots and trays at a 45° angle will make pollen collection easier. To take advantage of peak pollen production, jewelry tags should be prepared ahead of time for specific crosses. As much pollen as possible should be collected from the desired male. Subsequently, the protective shoot bags are removed from female inflorescences, and the pollen is transferred to receptive stigmas using a fine artist brush. Once pollinated, the shoot bag is replaced and a labeled jewelry tag is tied around the culm to identify the cross.

Hand-pollination of zoysiagrasses, and subsequently new germplasm with a combination of traits from both parents, is traditionally the most direct means to create predictable genetic variation. The resources needed to produce individual seeds through hand pollination are much greater than those necessary to create a large number of seeds with unknown parentage through open-pollination. However, it has been our experience that the benefit of reducing the incidence of self-pollination and random mating in the next generation when the male parent is known outweighs the relative ease of bulk harvesting, threshing, cleaning, and germination of open-pollinated seed. The use of plot land to evaluate open-pollinated progeny resulting from unintended crossing or selfing is far less productive than creating true hybrids with directed crosses. This is because hand-pollination allows for the creation of more true hybrids than is feasible to test each year given limited land, staff, and funding.

**Genetic Variability**

The USDA Germplasm Resources Information Network (GRIN) is the repository and information system used for plant introduction (PI) germplasm collection, storage, maintenance, and transfer in the United States. To date, 318 zoysiagrass accessions have been incorporated into GRIN, with 92 accessions listed as active (226 inactive). Several inactive (unavailable) accessions are listed as cultivars, such as: Belair, Crowne, Compadre (listed as ‘Compatibility’ in GRIN), Emerald, Empire, Empress, Meyer, and Zenith; numbered entries listed as SS–600, SS 4000, SS 4001, and Q 39585; three from Illinois listed as
A, B, and C; and four from Australia listed as 2, 10, 13, and 18. The oldest zoysiagrass accessions listed were the two *Z. japonica* accessions received in 1901 from Baird, both from North Korea (Table 1). The oldest accessions listed as active (available) (PI 231146, PI 231389, and PI 235334) were received in 1956. A group of 40 accessions collected from China and received in 2007 are the most recently acquired accessions listed as active that are not cultivars. Historical distribution records through GRIN trace back to 1989 and show that 122 requests were made from 1989 to 2016, and that 746 accessions were requested. Several accessions have been requested multiple times, with PI 324185 and PI 324186 being the most requested accessions (each 26 times). The authors suggest that those with access to the inactive cultivars submit new samples to GRIN.

A plant breeder must effectively obtain or create new genetic variability to remain productive over time. In the years prior to 1980, improvement of zoysiagrass slowed as it became more difficult to create useful variation through sexual recombination and selection, making it necessary to make germplasm collection trips to the centers of diversity for many *Zoysia* spp. (Murray and Engelke, 1983; Engelke and Murray, 1989; Engelke and Anderson, 2003). In our estimation, zoysiagrass breeders with access to these collected accessions have an abundance of genetic resources to exploit, but additional exploratory trips for more unique germplasm would certainly be helpful. Genetic gains of pest and disease tolerance are essential to expand the utilization of zoysiagrass. Analysis of the genetic diversity of currently available cultivars illustrates that plant breeding has not decreased zoysiagrass genetic diversity, and that opportunities exist for increasing diversity, especially through the introduction of alleles from less used germplasm (Moore et al., 2017). Future plant collectors will need to understand that each country has varying regulations in regards to access and dissemination of genetic resources, possibly making these endeavors more difficult than in the past (Moore and Williams, 2011).

The development of new *Zoysia* genotypes for use as parents or cultivars in a breeding program is driven by the inheritance of the traits of interest, as well as the resources available to the researchers to manipulate them. The heritability of turfgrass performance characteristics such as turf density, color, and quality, in addition to traits such as plot establishment, spring green-up, fall dormancy, and seedhead density, indicate that improvements can be made through breeding and selection in zoysiagrass (Schwartz et al., 2009). Qian et al. (2000) concluded that salt tolerance could be increased in zoysiagrass according to the estimated broad-sense heritability of this trait. Preliminary research into the narrow-sense heritability of leaf width, stem color, initiation of flowering, and rust (*Puccinia* spp.) response has suggested that these characteristics are under stronger genetic control than leaf color, growth habit, raceme length, and floret color (Flor et al., 2014).

Induction of random variation in plants through exposure to radiation has been used in the development of several warm-season grass cultivars through mutation breeding (Hanna et al., 2013). Chen et al. (2011) irradiated *Z. matrella* calli with varying levels of $^{60}$Co γ rays in the in vitro selection of NaCl-tolerant transgenic lines. Research on the tolerance of Zenith seed to $^{60}$Co γ ray exposure in 50-Gy increments found that germination was not reduced in treatments of 200 Gy and lower, and that 500 Gy was necessary to kill the seed (B.M. Schwartz, unpublished data, 2009). Seedlings from these experiments were planted in the field during 2009 and 2010, but distinct phenotypic variability was not observed and the fertility of these mutation lines was never quantified.

There are efforts to create genetic variability in *Z. japonica* by inducing chromosome doubling with colchicine to make octaploid ($2n = 8x = 80$) genotypes (Schwartz et al., 2013). Research to breed pentaploid ($2n = 5x = 50$), hexaploid ($2n = 6x = 60$), and seaptaploid ($2n = 7x = 70$) zoysiagrasses using germplasm with varying leaf blade widths, drought tolerance, and genetic color is ongoing since 2009. All the *Zoysia* species collected by Jack Murray, Dr. Glenn Burton, and Dr. Wayne Hanna, which include *Z. japonica*, *Z. matrella*, *Z. pacifica*, and *Z. macrantha* Desvaux, were used in the crosses, although this collection has never been subject to morphological or molecular taxonomic characterization. The goal of these efforts has been to breed sterile, vigorous cultivars that persist in a wide range of environments.
Genetic transformation has been used to successfully incorporate nonrandom variation into many crops during the past few decades and has arguably been the driver behind the most significant recent advancements in yield potential for many plant species. Chandra et al. (2017b) thoroughly summarized how new technologies, including polyethylene glycol (PEG)-mediated transformation, biolistic transformation (particle bombardment), and Agrobacterium-mediated transformation, have been used to give zoysiagrasses characteristics that are not found in wild Zoysia germplasm. They also touch on the potential for targeted and precise genome editing in zoysiagrass using biotechnology such as CRISPR/Cas-9-based systems. Their summary indicates that future decisions about the regulation of these traits, social acceptance of this group of technologies, and the potential for profit will all play a major role in whether or not biotechnological advances will affect zoysiagrass development in the future.

Recent completion of high-density genetic maps for Z. japonica (Wang et al., 2015) and Z. matrella (Huang et al., 2016), in coordination with the first report of a draft genome sequence of zoysiagrass (Tanaka et al., 2016a), should allow for more efficient selection and improvement of Zoysia spp. in the near future. The timeframe for zoysiagrass breeders to identify superior cultivars may now be shorter given the advances in molecular biology and comparative genomics, as long as these technologies correctly predict the long-term performance of perennial grasses over many years and environments. When developing annual, seed-propagated crops for food, fiber, or feed, it is undoubtedly critical to use all means necessary to quickly identify superior genotypes so that only top performers contribute to the next generations. Time will tell if it is judicious to invest in molecular tools to further develop perennial, vegetatively propagated turfgrasses with complicated genetics. Consequently, those resources could be better used to create more hybrids evaluated across a wider array of environments in a traditional, phenotypic breeding program.

Regardless of the methodology, all zoysiagrass breeders face the difficulty of manipulating traits with polyploid inheritance. Although most Zoysia germplasm used for cultivar development are allotetraploids (Forbes, 1952), breeding all the desired turfgrass performance characteristics into one new genotype can be very difficult, as there are potentially more than two alleles for each trait at any given locus. The length of time needed to properly evaluate and screen across multiple environments because of the perennial nature of these grasses further slows each generation cycle. Additionally, the tediousness of hand pollination, seed harvest, breaking seed dormancy, poor germination, prolonged seedling immaturity, and slow growth during the vegetative expansions hinder the rapid development of new zoysiagrass cultivars.

Screening Methodology

The methods and emphases chosen by zoysiagrass breeders during selection are critical to the overall success of the cultivars they develop; however, there is little published discussion on or against specific screening techniques. Both Engelke and Anderson (2003) and Hanna et al. (2013) discussed traits that need to be identified and deployed in Zoysia spp. to have future impact. Largely, they are the same today and include breeding for improved abiotic stress tolerance to drought, saline, freezing, and shaded conditions while also studying responses to biotic antagonists such as pathogens, insects, and plant-parasitic nematodes. Further, the growth habits, recuperative potential, and fertility requirements of promising germplasm should be quantified while also making observations on establishment rate, whether the intended planting method is by seed, sprigs, or sod. Not to be overlooked is the market requirement for developing cultivars with acceptable, if not superior, turf quality characteristics such as density, uniformity, and color. Much of the prior research on these topics has been presented herein, but discussion in this section is included to compare and contrast the utilization of growth chamber, greenhouse, and field trials in a zoysiagrass breeding program. Paramount in this decision is whether or not artificial selection during abbreviated screening procedures correlates with long-term field performance under real-world management practices. Understanding the limitations associated with screening techniques is fundamental for cultivar development.

Abiotic Stresses

Recently, USDA-National Institute of Food and Agriculture (NIFA)—Specialty Crop Research Initiative (SCRI) funding was awarded to several warm-season turfgrass breeding programs with a directive to increase the drought, salinity, freezing, and shade tolerance of zoysiagrass in the United States, all stresses that commonly limit the performance of turfgrasses in the landscape (USDA, 2010, 2015). Breeding for drought tolerance is complicated, and progress is dependent on the mechanisms targeted for improvement. As previously discussed, many zoysiagrasses tolerate drought by entering dormancy in the event that soil moisture becomes limiting. This is an advantageous response as long as there is not competition from more drought-tolerant annual or perennial weed species. Screening for genotypes that maintain acceptable green canopies for extended periods in the absence of irrigation or rainfall is accomplished using potted plants in controlled environments (greenhouse or growth chambers) or in field plots. In theory, greenhouse drydown studies can be used to efficiently identify plants with lower genetic transpiration rates, but with this technique, researchers make a large assumption that the response found using potting media, a limited rootzone,
and a controlled growing environment will translate to the field. As discussed above, zoysiagrass survives acute drought stress. Breeding efforts are commonly aimed at improving the response of zoysiagrass to chronic drought. Measuring genetic potential for deep rooting and high root-length density in lysimeters is helpful in detecting zoysiagrasses that avoid drought conditions by more effectively mining soil moisture to survive chronic drought. Genotypes found using these methods should root deeper in soil, as long as the root growth was not enhanced by the growing conditions within and around the lysimeter. Large-scale field screening trials to determine acute and chronic drought response are conducted in locations with predictable rainfall patterns (White et al., 1993; Qian and Engelke, 1999; Zhang et al., 2013) or under large rain-exclusion structures (Fu et al., 2004; Steinke et al., 2009). Unfortunately, these field trials are subject to significantly more environmental variation due in part to soil-type inconsistencies, uncontrolled disease outbreaks, and mower traffic.

Salinity, freezing, and shade tolerance in the genus Zoysia vary in some respect with species and origin. As with drought, these characteristics can be screened for in controlled environments with an understanding of the limitations of the methods. Preliminary data on the general range in response to each of these stresses for the species being studied are necessary to screen germplasm efficiently, so that critical treatment levels can be imposed that separate good from average and poor performers. This can be accomplished through limited pretesting and from previous reports. Breeders consider whether or not to slowly acclimate the genotypes towards critical stress levels when researching abiotic stresses. Responses from acclimated and nonacclimated trials will almost certainly be different (Patton et al., 2007a, 2007b), which is acceptable if the zoysiagrass breeder is aware of this prior to testing. The value of determining salinity response curves, the repercussions of clipping removal, the effects of flood versus overhead irrigation, and the ability to periodically flush soils all need to be taken into account when assessing salinity tolerance in the greenhouse or in the field. Acclimation treatment, minimum freezing temperatures, repeated freeze–thaw cycles, and plant desiccation should all be considered when researching the cold hardiness of zoysiagrasses in controlled freeze trials, where snow cover must be accounted for if conducting work in the field (Patton and Reicher, 2007). Shade pressure can be relatively easily imposed on field research plots using shade cloth, but researchers should be careful when drawing conclusions, as shade cloth reduces light quantity but exerts little impact on light quality, as do trees, clouds, or smog (Bell, 2011). It is our experience that some zoysiagrass genotypes respond differently under shade cloth than under trees with the same daily light integral, likely due in part to the light quality and competition for soil moisture and nutrients from tree roots.

**Biotic Stresses**

Improvement of zoysiagrass disease tolerance is a common breeding objective in many regions. Large patch is typically considered the most problematic and can be acutely screened for in controlled environments (Metz et al., 1993) or fields after inoculation from a pathogenic source (Obasa et al., 2012). Infection is not always predictable and is often inconsistent from plot to plot, location to location, and year to year. To help explain these variable responses, researchers should include susceptible and resistant genotypes as standards wherever possible. Because of the erratic nature of biotic screening, breeders will often screen new genotypes for their response to disease after directed mismanagement of nitrogen fertility, overirrigation, and inadequate thatch management (Schwartz, 2008). These practices, in combination with evaluation in three or four disease-prone locations with varying soil and environmental conditions over several years, allow for the identification of genotypes with the least sensitivity to large patch, dog footprint, Bipolaris leaf spot, dollar spot (Sclerotinia homoeocarpa F.T. Bennett), rust, and pythium root rot (Pythium spp.) without artificial inoculation.

Screening for insect and plant parasitic nematode response in the greenhouse is an effective method to narrow down selections during the final phases of cultivar release (Schwartz et al., 2008). Zoysiagrass breeders use choice or nonchoice experiments to give an indication of how insects will feed on genotypes in the field when planted in mixed stands or monostands. Similarly, plant-parasitic nematodes, such as the sting (Belonolaimus longicaudatus), lance (Hoplolaimus galeatus), and root-knot (Meloidogyne spp.), are used in inoculation trials to determine if a genotype is a nonhost, is not resistant but maintains continued root growth despite nematode feeding, or is susceptible to these soilborne pests (Murray et al., 1986). Some zoysiagrass breeding programs are able to screen large populations of new hybrids in fields with native soils that contain damaging levels of plant-parasitic nematodes (Nus, 2012), although these tests usually have large environmental variability.

**Management Stresses**

Proper fertility and thatch management when evaluating large populations of elite zoysiagrass germplasm can make it difficult to identify superior genotypes in 2 or 3-yr periods. Purposefully mistimed and overapplication of nitrogen can rapidly lead to thatch development and is an effective method to identify the most disease-prone genotypes. Evaluating zoysiagrasses at varying mowing heights without dethatching can often lead to scalping. This further separates those genotypes with lower potential to
accumulate thatch, an inherent prostrate growth habit, tolerance of mower traffic, or improved recuperative capacity. Additionally, breeders will select promising germplasm from fields planted with little to no irrigation or fertility beyond their initial establishment to identify genotypes that perform well under low inputs. Determining the ideal, yet minimal, management practices for top selections identified under poor management allows for their enhanced performance and persistence over time. An important component of this process is verifying that herbicides labeled for use on other zoysiagrass cultivars do not cause unexpected injury in experimental germplasm (Leon et al., 2014).

**FUTURE PROSPECTS AND CHALLENGES**

As recycled water use and availability continues to increase on US golf courses (Gelernter et al., 2015) and in commercial and residential landscapes, the high salt tolerance of *Zoysia* spp. will allow it to perform well in these landscapes. Among cultivars, Diamond is the most tolerant to salinity; Cavalier, Crowne, ‘DeAnza’, El Toro, Emerald, JaMur, ‘Marquis’, Palisades, Royal, and ‘Victoria’ have intermediate salinity tolerance and Belair, Meyer, Omni, Sunburst, and Zeon are the least tolerant to salinity (Marcum et al., 1998; Qian et al., 2000). Although many newer cultivars have enhanced salinity tolerance, turf breeders must continue to screen for and select salt-tolerant germplasm to allow turf to be managed sustainably in the future. Further, extension specialists will need to continue to provide education for species selection and proper management practices to consumers using recycled water for turf irrigation.

One of the first observations about zoysiagrass was its potential for use on roadsides and “airfields” (i.e., grassed airport runways and grassed areas between runways) due to its wear tolerance, drought tolerance, weed encroachment resistance, and infrequent mowing requirement (Monteith, 1942). Expansion of *Z. japonica* for airports and roadsides to reduce mowing and pest management (weeds) is a potential growth opportunity for *Zoysia* spp. Recent research on both warm- and cool-season grasses has documented that zoysiagrass is desirable for vegetating airfields and airports to reduce aircraft collision risks by reducing Canada geese (*Branta canadensis* L.) populations (Washburn and Seamans, 2012; Kissane, 2013).

Zoysiagrass also makes an excellent roadside grass for these same reasons, although few acres of roadsides in the United States are planted with this species. While recent research has examined best department of transportation sod establishment practices and determined that long-term maintenance costs can be reduced with zoysiagrass use (Jeffries et al., 2017), the lack of available seed and the slow establishment from seed remain as barriers to more widespread use of zoysiagrass on roadsides. Slow establishment is particularly problematic on roadsides, as USEPA policy, via the Clean Water Act, specifies that 70% of the soil surface must be vegetatively covered within 30 d of planting (USEPA, 2003). A second hindrance to expanded zoysiagrass use on roadsides is that little breeding effort is placed towards the creation of coarse, aggressive, vegetatively established *Z. japonica* cultivars well adapted for roadsides, airports, and other infrequently mown areas where crop function and stress tolerance is more important than aesthetics. Release of such “roadside” cultivars, and subsequent adoption by turf producers, would increase the prevalence of zoysiagrass use in this market. While there is still great potential for zoysiagrass use in US markets such as roadsides and airports, the following items are needed for greater adoption: documented long-term benefits from its planting, improvements in establishment procedures, the creation of “roadside” vegetatively established cultivars, and breeding gains in zoysiagrass seed yield and germination.

Early records indicate that US golf course superintendents were interested in the use of *Z. pacifica* (*Z. tenuifolia* in article) for use as a golf course putting surface (USGA Green Section, 1921). However, the opinion was that it was not well suited for putting green use (USGA Green Section, 1921). The release of Diamond zoysiagrass in 1996 created the opportunity for use on golf course putting greens, as this was the finest-textured zoysiagrass cultivar released in the United States. Research on Diamond zoysiagrass establishment and use as a putting surface was conducted in Clemson, SC (Stiglbauer et al., 2009). The authors concluded that Diamond zoysiagrass could produce a quality putting surface within a season, but that putting green speeds would be unacceptably slow for tournament purposes (Stiglbauer et al., 2009). This is a result of the high fiber content and stiff leaf blades of zoysiagrass, as well as the high tiller density, which creates resistance against a rolling golf ball. Recently, a new cultivar called M85 became commercially available and was planted on the putting greens at The Playgrounds golf course at Bluejack National, Montgomery, TX. Currently, a USGA-National Turfgrass Evaluation Program (NTEP) collaborative trial is examining the potential of 11 experimental genotypes for putting green use on low-maintenance golf courses (Morris, 2015). Although some progress towards increased adoption of zoysiagrass on putting greens is evident, utilization of small, “dwarf” species of *Zoysia* such as *Z. pacifica* and *Z. minima* may provide breeders an opportunity to create cultivars with improved putting green performance in the future.

If zoysiagrass researchers are diligent, productive, and successful in the future, their efforts will lead to faster establishment of vegetative cultivars with a measureable gain in tolerance to drought and diseases that also have the recuperative ability to withstand traffic. Some will be
adapted for widespread use in low-management or abandoned areas such as city parks and highway roadides. Golf course putting greens in southern and transition zone locations will be planted with dwarf zoysiagrasses that have equal or better putting quality, heat tolerance, and shade resistance than in currently used species but will require less fertility, plant growth regulators, and mowing. St. Augustinegrass in shady areas that suffer from disease and cold injury will be replaced with new, shade-tolerant Z. japonica cultivars with wider leaf blades. There will also be fine-textured, cold-tolerant seeded Z. matrella cultivars that can be feasibly produced and used due to improvement of seed yield, mechanical harvestability, germination, and seedling vigor. Successful completion of these daunting tasks will be dependent on persistent breeding, fortunate genetic recombination, and serendipitous selection of traits for adaptation to pressures that will likely continue to shift during the future. Undoubtedly, the future will provide more opportunity for new zoysiagrass researchers to pursue solutions to decade-old problems observed by researchers such as Dr. Ian Forbes, Dr. Fred V. Grau, Dr. William H. Daniel, J. Jack Murray, and Dr. Milton C. Engelke, as well as the dedicated zoysiagrass managers in the United States.

CONCLUSION
We agree with Corbett’s (1906) assessment of zoysiagrass as a “decided acquisition” to US specialty crop agriculture. Since its introduction into the United States by early agricultural pioneers, zoysiagrass use has steadily increased as its strengths and value as a low-input turfgrass is increasingly recognized. Shortly after its introduction, Z. matrella found niche use in the South in areas where other grasses were not well adapted and bare soils abounded. The release of the cold-hardy cultivar Meyer in 1951 increased the use of Z. japonica in northern US states and allowed for the management of turf with reduced inputs in climates where winters are too severe for most warm-season grasses and summers are stressful for cool-season grasses. More recent cultivar releases in the 1980s, 1990s, and 2000s greatly increased the use of zoysiagrass from Texas across Florida, on both golf courses and lawns, due to high demand and increased sod production. Although zoysiagrass is not without its shortcomings, environmental stress and pest tolerance are improved thanks to the efforts of turf breeders and scientists over the last 80 yr. Current efforts to breed and select for enhanced environmental stress and pest tolerance are ongoing, thanks in part to funding from the SCRI of the USDA-NIFA (USDA, 2010, 2015) and the USGA. Zoysiagrass has potential for increased utilization in the future, both in existing and new markets. Breeding efforts should continue to focus on developing improved cultivars requiring fewer inputs (labor, energy, nutrient, water, and pest control), but also on improvements in seed production and seedling vigor that will allow for expanded adoption of seed propagation and possibly greater consumer adoption of zoysiagrass. Frank N. Meyer remarked in 1906 that zoysiagrass was “probably a very valuable grass.” (USDA Bureau of Plant Industry, 1908). Today, we can confidently say that, over 110 yr later, zoysiagrass is undoubtedly a very valuable grass with the potential to become much more valuable in the future.

Conflict of Interest
The authors declare that there is no conflict of interest.

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