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Volume 3, Number 9
May 1, 2004

PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Developing Annual Bluegrass Cultivars for Putting Greens

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SUMMARY

Poa annua is one of the world's most widely distributed invasive weed species. Research continues at Penn State University to develop improved *Poa annua* cultivars for putting greens. This project made much progress toward that goal and much infoormation has been learned about this highly variable species.

- When the annual bluegrass breeding program was initiated in July, 1994, thousands of *Poa annua* samples were collected from existing golf course greens. To date, the project has collected and evaluated tens of thousands of *Poa annua* plants.
- *Poa annua* plants evolve an increasingly perennial nature as the level of turfgrass management increases. This process continues on the golf green until plants eventually become entirely perennial and lose the ability to set viable seed all together.
- Selection pressures of the green environment are so intense that on greens as young as 60-years-old, it is common to observe a special type of *Poa annua* known as dihaploids. Dihaploids occasionally produce a flower stalk, but are absolutely seed sterile and thus exist entirely as vegetative perennials. Such dihaploids represent some of the densest, finest, and highest turf quality strains yet observed.
- The main obstacles that need to be overcome for the successful cultivation of *Poa annua* seed for the commercial market are 1) low seed yield, 2) the indeterminacy of seed maturity, and 3) the control of undesirable forms of *Poa annua* within seed production fields.

Poa annua L., the Latin name for annual bluegrass, has long been recognized to provide high quality turf of fine texture and high shoot density that is uniform and tolerant of close mowing (1). In 1927, legendary USGA Agronomists, Piper and Oakley (14) described the value and high quality of *Poa annua* for golf course putting greens. More recently, Warwick (16) observed that if grown in a monoculture, *Poa annua* provides an excellent putting surface.

However, not everyone reached the same conclusion concerning the utility of *Poa annua*. Thus, while some turfgrass agronomists have encouraged the use and cultivation of *Poa annua* as turf (7, 15, 17), others have focused on its eradication as a weed (2, 12). In fact, most instances of *Poa* literature describe the grass as an invasive weed whose eradication should be pursued at all costs. This article focuses on the utility and genetic improvement of *Poa annua* for use as putting surfaces.

Variable with a World-wide Distribution

Poa annua is one of the world's most widely distributed invasive weed species. *Poa annua*, in all its forms, is found on every continent of planet Earth. From Europe to Asia, from South Africa to Alaska, from the searing heat of Arizona to the bitter cold of Antarctica barrier islands, *Poa annua* is present. The mechanisms that enable this grass species to so widely disseminate its progeny and enable it to survive, adapt, and persist in such a wide range of environmental conditions are currently not known. One thing we do

Figure 1. *Poa annua* exhibits a range of perenniality as shown by the number of daughter tillers produced at the time of first flowering (anthesis) of the parent tiller. The number of daughter tillers, from left to right, are: 3, 6, 9, 11, 13, 16, 52 (dihaploid plant). *(Photo courtesy J. Borger).*

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USGA Turfgrass and Environmental Research Online 3(9):1-8.
TGIF Record Number: 97543

"Annual" annual bluegrass	"Perennial" annual bluegrass
- Favored by constant surface disruption	- Favored by surface stability (little disruption)
- Produces lots of seed	- Produces little to no seed
- Dominates soil seed bank	- Scarce in the soil seed bank
- Quick to germinate, quick to flower	- Slower to flower
- Extremely sensitive to environmental stress (heat, cold, drought)	- Likely more tolerant of environmental stresses (heat, cold, drought)
- Easier to kill with chemicals, although numerous reports of evolved resistance.	- More likely to tolerate herbicides
- Individual reproduce throughout a growing season	- Individuals reproduce during a specific period during a season (typically spring only)
- Most individuals die within a season	- Most individuals live multiple seasons and per haps some are long-lived
- Lots of small lime-green tufts on a golf green	- Lots of variable-size, variable-color patches on a golf green
- Tolerates close mowing heights	- Adapted to close mowing heights
- Low shoot density, course texture, tall stature	- High shoot density, fine texture, short stature
- Ugly, Bad	- Beautiful, Good

Table 1. Comparison of characteristics typically associated with either the annual or perennial forms of *Poa annua*

know is that *Poa annua* is a highly variable species. It contains forms that behave as annuals and other forms that behave as long-lived perennials.

Traits typically associated with either annual or perennial forms are listed in Table 1. Basically, the annual form has a bunch-type, upright growth habit of low shoot density and is found in open fields, orchards, and meadows. Plants of the annual form tend to behave more as annuals in that they are non-creepers and are prolific seed producers.

The perennial form has either an upright growth habit of diminutive stature or a more prostrate, spreading growth habit capable of rooting and producing new shoots from the upper nodes of the decumbent shoots. In addition, the perennial form produces a high shoot density which contributes to the appearance of a rather tight turf. The perennial biotype of annual bluegrass is also more restricted in the timing of seed formation than the annual form, and allocates more of its resources (photosynthates) into vegetative growth rather than seed production. As a result, the perennial form is almost exclusively found growing in closely mowed turfs such as old, established golf greens. Thus, one's perception of whether *Poa* is a weed (either annual or perennial forms) or a valuable putting surface (a highly evolved perennial form) depends on which form is present in the turf.

Annual or Perennial?

The problem in designating an annual bluegrass plant either an annual or a perennial is that there is a range or spectrum of variability of what ecologists call "life-history characteristics" that exists within the species. One way to measure the perennial nature of a particular *Poa annua* plant is to determine if it grows faster than it dies. In other words, one needs to consider if a growing shoot (also known as a tiller, the basic unit of a grass plant) replaces itself before it flowers, because once a tiller flowers, it dies. And if it does, how many replacements does it produce?

If a tiller replaces itself with just a single daughter tiller before it flowers (i.e. a one-to-one replacement), that would seem to be a precarious position for a perennial to be in because any number of mishaps or events would easily eliminate the one vegetative offspring. In addition, most of

Source of *Poa annua*	Number of daughter tillers
Rough	1-3
Fairway	4-8
Greens	>9

Table 2. Number of daughter tillers produced at the time of flowering (anthesis) of the parent tiller

the tiller's energy would be invested in seed versus a single vegetative tiller offspring and so the parent tiller would likely be survived by its seed progeny and not by its only vegetative tiller. This tiller would be behaving as an annual plant. However, if a tiller were to produce many tillers before it flowered (i.e. many-to-one replacement), it would be behaving as a perennial plant.

In experiments conducted at Penn State University, a range of annual bluegrasses were evaluated for this trait by counting the number of daughter tillers produced at the first sign of flowering (anthesis) of the parent tiller. The results are presented in Table 2 and indicate that *Poa annua* plants evolve an increasingly perennial nature as the level of turfgrass management increases. This process continues on the golf green until eventually plants become entirely perennial and lose the ability to set viable seed all together (Figure 1). It is these later classes of evolutionary products, those that still set viable seed and are highly perennial and those that do not set viable seed and are entirely vegetative, that have served as the raw material for cultivar development in the Penn State *Poa annua* breeding program.

Penn State's Breeding Program

When the annual bluegrass breeding program was initiated in July, 1994, thousands of *Poa annua* samples were collected from existing golf course greens. To date, the project has collected and evaluated tens of thousands of *Poa annua* plants. These early selections exhibited a wide range of genetic variation in nearly every imaginable trait including tiller density, color, seedhead production, disease resistance, and environmental stress tolerance (Figure 2). Subsequent collections have yielded similar variability.

Improvements to these initial collections have been achieved by successfully applying several fundamental principles of plant breeding. Primarily, the breeding process has improved turf quality regarding not only shoot density, color, and uniformity of appearance, but also in increased tolerance to several biotic (disease) and abiotic (environmental) stresses. The progress and result of the breeding effort directed at improving *Poa annua* for golf green use are depicted in Figures 3a & b. Figure 3a shows a plot evaluation trial of *Poa annua* at University

Figure 2. Initial collections of *Poa annua* early in the breeding program exhibited a wide range of genetic variation in nearly every imaginable trait, including tiller density, color, seed head production, disease resistance, and environmental stress tolerance.

Figure 3. The Penn State breeding program has made improvements in greens-type *Poa annua* in overall turf quality (primarily shoot density, color, uniformity of appearance) and in several biotic and abiotic stress tolerances. (A) University research plots at Penn State. (B) On-site testing at Nevellwood GC near Pittsburgh, PA *(Photo courtesy K. Flesik).*

Park, PA, while Figure 3b shows an on-site trial of three of Penn State's cultivars at Nevellwood GC near Pittsburgh, PA.

Currently, the breeding program has designated a set of the "top-12" cultivars. These cultivars are currently being evaluated on various golf courses and university research facilities around the world. The encouraging news from preliminary reports is that these cultivars are performing well, even better than expected. For instance, at a trial established at Barwon Heads GC located on the southern coast of Victoria, Australia, one-half the plots were irrigated with potable (drinkable) water (Figure 4a), while the other half were irrigated with effluent water that was high in salinity as a result of high levels of sodium and chloride (Figure 4b). Planted along with the Penn State annual bluegrasses were plots of the local, native *Poa annua*, and several cultivars of creeping bentgrass including 'Penn A-4', 'Seaside II', 'Mariner', and 'Penncross'. *Poa annua* is known for its inability to tolerate high saline conditions whereas, bentgrasses are known for their ability to tolerance high saline conditions.

The first years data from this multiple year study (courtesy of J. Neylan, Australian Golf Course Superintendents Association) indicates that the Penn State annual bluegrasses are not only

Figure 4. AGCSA Agronomist John Neylan rates evaluation trials established at Barwon Heads GC located on the southern coast of Victoria, Australia. Planted along with the Penn State annual bluegrasses were plots of the local, native *Poa annua,* and several cultivars of creeping bentgrass including 'Penn A-4', 'SeasideII', 'Mariner', and 'Penncross'. (A) One-half of the plots were irrigated with potable (drinkable) water. (B) The other half were irrigated with effluent water that was high in salinity as a result of high sodium and high chloride levels.

Figure 5. Recovery of Penn State *Poa* (back, right) compared to the local, native *Poa* (back, left) during the late summer of 2004 (Feb-Mar), after the effluent water line broke at the Barwon Heads trial site and the plots were unwatered for 10 days. Plots of bentgrass in the foreground. *(Photo courtesy J. Neylan).*

surviving the high salinity of the effluent water source, but are demonstrating higher turf quality than bentgrasses in many instances during the growing season (Figure 4). Moreover, during the late summer of 2004 (Feb-Mar), the effluent water line broke and the plots were unwatered for 10 days (J. Neylan, personal communication). The Penn State annual bluegrasses fully recovered, while the local native annual bluegrasses all died (Figure 5), demonstrating improved drought resistance of this highly variable species.

Stress Tolerance

Stress tolerance is an important factor which contributes to perenniality. After all, does it really matter how much better turf quality specific selections may have if the plants have little or no inherent ability to tolerate environmental and biological stress? In order to be perennial, turfgrasses must be able to survive and persist month after month, season after season, year after year, through all kinds of heat, cold, disease, and traffic stresses, whereas plants with annual life cycles can simply die and survive these stressful periods as seed.

Most of what we know about *Poa annua* is based on the annual or less-evolved perennial types. For example, both high and low temperatures represent the major environmental limitations to distribution and growth of *Poa annua*. It is generally believed that this lack of tolerance to extreme temperatures makes *Poa annua* a weak turf for at least some part of the year in most locations. Despite this general observation, strains of *Poa annua* have been observed to perform well in irrigated turf areas subjected to the desert heat of Arizona (D. Kopec, 1998, pers.com.). Duff (4) also reported significant differences among strains for heat tolerance. At the other temperature extreme, Dionne et al. (3) reported finding significant differences among strains for tolerance to freezing temperatures.

Poa annua is also widely known for its

susceptibility to many turfgrass diseases, including dollar spot (*Sclerotinia homoeocarpa*), anthracnose (*Colletotrichum graminicola*) and pink snow mold (*Monographella nivalis*). However, the *Poa annua* breeding program at Penn State has identified strains exhibiting excellent field resistance to anthracnose and dollar spot (6, 8). Thus, while most scientific efforts regarding *Poa annua* have been directed towards its eradication, control, or lack of stress tolerance, those research efforts aimed at determining and identifying strains possessing improved stress tolerances have generally been successful.

Invade and Adapt

The evolution of *Poa annua* from wild, weedy, annual forms to the perennial forms adapted to golf, lawn, and athletic field turf has been documented by plant ecologists and plant evolutionists as a classic example of rapid micro-evolution (10, 11, 13). When *Poa annua* first invades a turf area, it typically does so as seed of the annual form. The seedlings become established in damaged or weakened open areas of turf and through phenotypic plasticity, adapt to the given management conditions of that particular turf (i.e. mowing height, moisture availability, fertility).

Poa annua has a unique ability to adjust the height of its flowering culms such that it is capable of flowering and setting seed under nearly any mowing height (i.e. as low as 1/10th inch). Cross-pollination events among annual bluegrass parents produce a range of genetically based morphological variation. Turf management programs act as powerful selection forces. Over time, subsequent generations of *Poa annua* begin to take on the characteristics of a perennial form and ultimately adapt to the particular turfgrass management program. Thus, with every generation, *Poa annua* evolves and adapts in response to the specific cultivation and management practices of a given turf.

On old golf course putting greens, this evolutionary process results in strains of highly-evolved perennial annual bluegrasses that are becoming known as "greens-type" *Poa annua* (3, 6). These greens-type *Poa annua* are perennials that possess a short stature, extremely high shoot densities, and are vegetatively aggressive. Seedhead production may be a fact of life in any future commercial cultivar of greens-type *Poa annua*. The main problem, currently, is not the production of seedheads, but rather the lack of any seed supply of an improved *Poa annua* for golf green use.

Greens-type *Poa annua* may begin to appear on golf greens as young as 10-years-old. Such a "rapid" evolutionary event is an indication of the extreme selection forces existing by golf greens (primarily mowing height and wear). The selection pressures of the green environment are so intense that on greens as young as 60-years-old, it is common to observe a special type of *Poa annua* known as dihaploids. Dihaploids occasionally produce a flower stalk, but are absolutely seed sterile and thus exist entirely as vegetative perennials. Such dihaploids represent some of the densest, finest, and highest turf quality strains yet observed (Figure 6, reference 8).

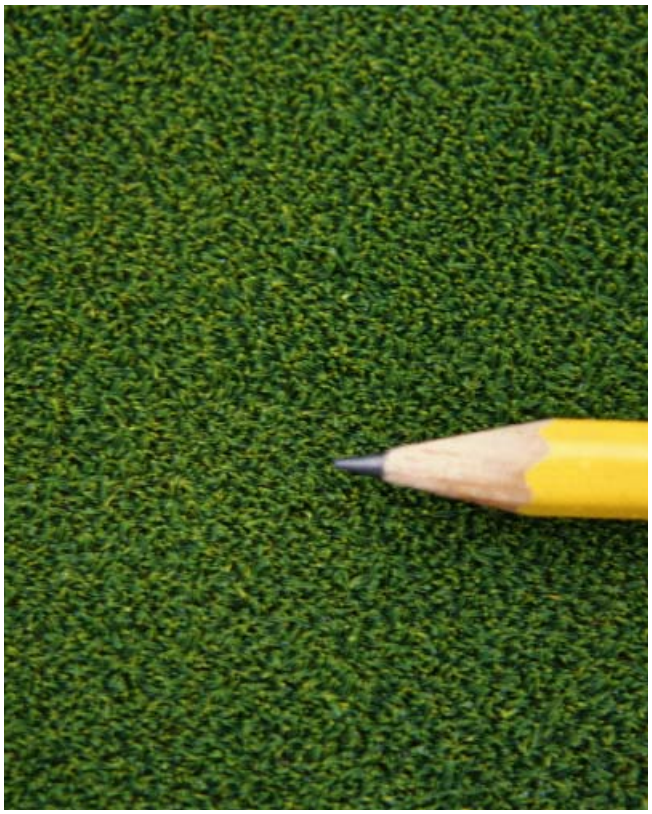

Figure 6. Dihaploid *Poa annua* represents some of the densest, finest, and highest turf quality strains yet observed and are of great value to the breeding program.

Realizing the Potential

Over the years and throughout the world, turfgrass scientists and geneticists have described the potential to breed improved strains of *Poa annua* for the golf industry (4, 10). This is due to the high turf quality and the enormous amount of morphological variation present in the perennial forms of *Poa annua*. However, the main obstacles that need to be overcome for the successful cultivation of *Poa annua* seed for the commercial market are 1) low seed yield, 2) the indeterminacy of seed maturity, and 3) the control of undesirable forms of *Poa annua* within seed production fields.

Overcoming the first two obstacles has been among the goals of the Penn State breeding program with some limited successes to date. Overcoming the third obstacle through reliance on chemical control may only delay the problem as several herbicide resistances has been reported among plants of the annual form (5, 9). We have thus been researching production practices (i.e. rotating seed production field on an annual cycle) that will reduced this obstacle to an acceptable level.

Without doubt, the cultivars perennial greens-type *Poa annua* will have their share of unforeseen problems and our breeding program will continue its search for genetic solutions. Our focus is to develop commercial seed supplies for those golf courses that either have or would like to have annual bluegrass greens. Currently, golf courses that have annual bluegrass greens do not have an adequate seed source for use in routine maintenance, renovations, or new construction. The ultimate goal of Penn State's greens-type *Poa annua* breeding program is not to replace creeping bentgrass as a golf green putting grass, but rather to offer an alternative for those situations where annual bluegrass is simply better choice.

Acknowledgement

The author wishes to thank the USGA's Turfgrass and Environmental Research Program for its support of this project.

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