APRIL 1978

RESEARCH REPORT 352

FARM SCIENCE

FROM THE MICHIGAN STATE UNIVERSITY AGRICULTURAL EXPERIMENT STATION EAST LANSING

ANNUAL BLUEGRASS (*Poa annua* L.)

DESCRIPTION, ADAPTATION, CULTURE AND CONTROL

BY J. B. Beard, P. E. Rieke, A. J. Turgeon, and J. M. Vargas, Jr.

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Cover: Annual bluegrass is the predominant turfgrass species found on fairways and tees on many golf courses in the cool humid region of the U.S. Continuing research, such as in the field plots shown, is needed to understand more fully the science and practice of optimum annual bluegrass maintenance. (Photos—P. E. Rieke)

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DESCRIPTION, ADAPTATION, CULTURE AND CONTROL

BY J. B. Beard, P. E. Rieke, A. J. Turgeon, and J. M. Vargas, Jr.*

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ACKNOWLEDGEMENTS

Extensive investigations of annual bluegrass were conducted at Michigan State University by the four authors from 1965 into the early 1970's. A major portion of the investigations concerning the description, adaptation, and cultural practices affecting annual bluegrass growth and development were supported by a series of grants from the United States Golf Association Green Section Research and Education Fund, Inc. Much of the information derived from these studies served as the data from which this bulletin has been prepared.

The authors would also like to acknowledge the assistance of the Agronomic staff of the Green Section of the United States Golf Association, W. H. Bengeyfield, W. G. Buchanan, J. B. Moncrief, A. M. Radko, C. Schwartzkopf, S. J. Zontek, and two former staff members, F. L. Record and H. M. Griffin for their comments and review of this manuscript. Their recommendations on the culture of annual bluegrass served as the basis for preparing the Section on Cultural Programs for Annual Bluegrass Turfs.

INTRODUCTION

Annual bluegrass is a factor in the culture of most irrigated sports turfs and ornamental lawns either as (a) a weed to be controlled or (b) a substantial component of the turfgrass community that must be considered when selecting the appropriate long-term cultural program. In 1937, Sprague and Burton (100) published the only other bulletin on annual bluegrass and its growth requirements. Their objectives were, "to determine the conditions under which the species makes its most satisfactory growth, and also the factors responsible for its unwanted invasion of turf areas and replacement of preferred grass."

The objectives of this publication are essentially the same plus a review of chemical control options available. The cultural conditions and framework in which annual bluegrass is grown in the 1970's are much different than the 1930's. These changes include (a) more intensive use of irrigation and great advances in sophisticated irrigation systems; (b) increased fertility levels, particularly nitrogen; (c) substantial improvements in the turfgrass cultivars utilized in sports and ornamental turfs; (d) major improvements in the equipment utilized in mowing and cultivating turfs; and (e) the development of selective preemergence herbicides, numerous organic systemic and non-systemic fungicides, and a wide range of organic insecticides. A publication is needed which updates and summarizes the existing knowledge of annual bluegrass as it relates to turfgrass culture.

Although annual bluegrass has served as the basis for many articles in trade publications and conference proceedings over the years, the amount of valid published data is rather limited. Most of the scientific literature reported has been concerned with methods of controlling annual bluegrass. Investigations concerning the description, adaptation, establishment, and culture of annual bluegrass are quite limited. It is in this latter area that the authors have concentrated their annual bluegrass research during the past 10 years.

The authors have reviewed the existing literature that is based on sound experimental investigations and placed it in context with modern turfgrass culture. Where information is lacking, this will be indicated. Hopefully, this approach will stimulate further investigations of annual bluegrass. Specific facts will be supported by literature citations. This comprehensive bulletin on annual bluegrass should serve as the basic reference source for both turfgrass researchers and laymen in either the control or culture of annual bluegrass.

PLANT DESCRIPTION

Seedhead Characteristics

The morphological description of the annual bluegrass seedhead as given by Hitchcock and Chase (59) is as follows:

> "Panicle pyramidal, open, 3 to 7 cm long; spikelets crowded, 3- to 6-flowered, about 4mm long; first bloom 1.5 to 2mm, the second 2 to 2.5mm long; lemma not webbed at base, distinctly 5-nerved, more or less pubescent on the lower part of the keel sometimes simulating a web; anthers 0.5 to 1mm long."

Characteristics of the annual bluegrass inflorescence are illustrated in Fig. 1. This description is based on an unmowed sward. The overall size of the panicle is proportionally reduced as the cutting height is lowered. Annual bluegrass is capable of forming an inflorescence and producing viable seed even at a 6mm height of cut.

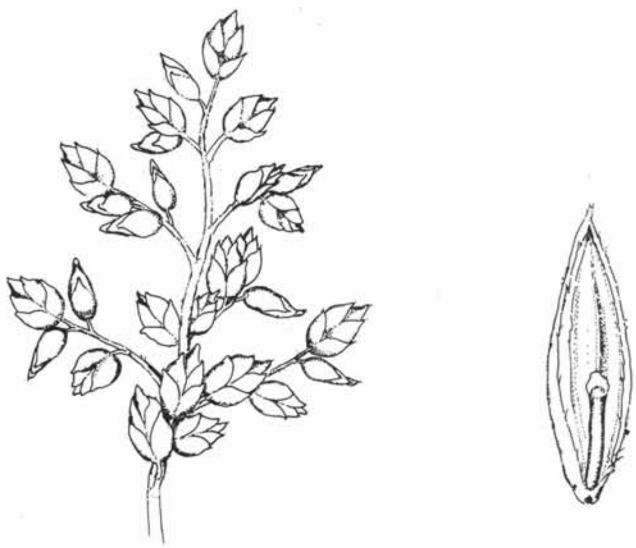

Fig. 1. Panicle (left) and floret (right) of annual bluegrass. (Photo—A. J. Turgeon)

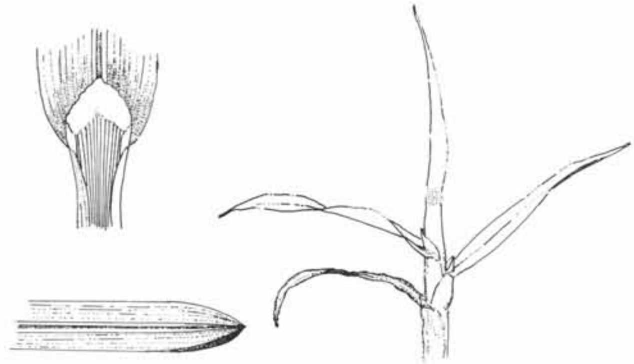

Fig. 2. Vegetative characteristics used in the identification of annual bluegrass: Shoot (right), ligule (upper left), and leaf apex (lower left). (Photo—A. J. Turgeon)

Vegetative Characteristics

Frequently vegetative characteristics must be used in identifying annual bluegrass under mowed turf conditions, because the inflorescence is not always present. This description is presented with the recognition that some variation can occur, depending on the particular strain of annual bluegrass present and the environmental conditions on the site. The vegetative description of annual bluegrass given by Beard (12) is:

> "**vernation** folded; **sheath** distinctly compressed, glabrous, whitish at base, keeled, split with overlapping hyaline margins; **ligule** membranous, 1—3mm long, thin, white, acute, entire; **collar** conspicuous, medium broad, glabrous, divided by the midribs; **auricles** absent; **blades** V-shaped, 2—3mm wide, usually light green, glabrous, soft, boat-shaped apex, transparent lines on each midrib, parallel sided, flexuous transversely, margins slightly scaborus and hyaline; **stems** flat, erect to spreading sometimes rooting at the nodes and forming stolons."

Detailed drawings of some of these vegetative characteristics are shown in Fig. 2. It should be noted that both the noncreeping bunch type and the stoloniferous prostrate growing type of annual bluegrass may occur in turfs (Fig. 3)[1]. This is in contrast to the classical description of annual bluegrass that has been based on nonturf conditions. Actually, a whole range in growth habits occurs rather than just the two extremes. The upper leaf surface has a thinner cuticle layer and greater stomatal density than the lower surface (16).

The vegetative characteristics most commonly used in identifying annual bluegrass under turf conditions include: vernation folded in the bud shoot, long

[1] Figs. 3a and 3b are color pictures located on the inside back cover.

transparent ligule, V-shaped cross section of the leaf blade, and boat-shaped leaf tip. Supporting characteristics that may occasionally be helpful include the presence of seedheads and a turf which tends to be somewhat yellowish green to light green.

Turf Characteristics

Under the close cut, irrigated turfgrass cultural conditions now being utilized, annual bluegrass is capable of forming a dense, uniform quality turf of intermediate leaf texture (12 and 91). Both the density and fineness of the leaves increase as the cutting height is reduced from 5 to 0.6cm. Annual bluegrass is a low growing diminutive plant possessing rooting depths comparable to Kentucky bluegrass and bentgrass.

This is contrary to what has been written in the undocumented literature where it is considered to be inherently shallow rooted. Unfortunately these inferences are drawn primarily from annual bluegrass growing in compacted soils where Kentucky bluegrass and bentgrass can not persist. Experiments where these three species are compared under similar mowing, fertility, and soil conditions reveal the capability of annual bluegrass to possess root growth depths similar to the other two species (100 and 115).

Annual bluegrass turfs tend to be somewhat light green sometimes even greenish-yellow in appearance (12 and 91). When annual bluegrass occurs as scattered clumps in bentgrass, bluegrass, or bermudagrass turfs it tends to disrupt the color of the turf due to this lighter green color. Color should not be used as one of the major characteristics in identifying annual bluegrass, because exceptions occur.

TAXONOMY AND CYTOGENETICS

Poa annua has been classified as a tufted, bunch type annual in the past. Common names used in various parts of the world include annual bluegrass, annual meadowgrass, and wintergrass. It is cross-pollinating with a somatic chromosome number of 28 (13, 77, 78, and 80). Although previously considered an annual it will persist under close cut, irrigated situations as a prostrate creeping perennial that roots at the nodes.

Close examination of annual bluegrass turfs reveals numerous types ranging from (a) the classical tufted, bunch type annual having a characteristic upright growth habit, prolific seed production, and strong seed dormancy to (b) a creeping perennial that roots at the nodes of prostrate stolons and tillers, has restricted seed production potential, and minimal seed dormancy (10, 11, 67, 62, 63, 64, 65, 103, 111 and 117). The former has been given the subspecies classification of *Poa annua* var. *annua* L. Timm, and the latter perennial type subspecies classification of *Poa annua* var. *reptans* (Hauskins) Timm.

The annual types have lower leaf and node numbers, less secondary tillers, and fewer adventitious roots than the perennial types (46). Actually there are many intermediate types between these two extremes even though annual bluegrass is cross-pollinated but apomictic (13, 78, 110 and 111). Although Hovin (64 and 65) concluded that the most common type of annual bluegrass in the United States was the upright annual, Gibeault (46) found a high proportion of perennial types in samples collected in Oregon and Washington. He determined that the presence of annual or perennial subspecies in a turf could be correlated with the watering regime. Areas that were watered infrequently or not at all have mainly annual types, while the perennial subspecies could be anticipated in more frequently irrigated turfs.

Youngner (117) found perennial types of annual bluegrass in golf greens that persisted for several years. They had formed distinct, uniform patches that probably developed from individual seedlings. He collected clones of these biotypes which were then propagated and maintained at a 0.6cm (0.25 inch) cutting height. These turfs persisted, but were severely damaged in the summer by disease-causing organisms, especially *Pythium*.

Eventually, a fertile, amphidiploid selection developed off-type plants while two sterile, amphihaploid selections remained true-to-type. Thus, annual bluegrass is a highly variable species which can adapt to widely differing environmental conditions by natural selection for existing biotypes, or by the development of new biotypes through cross-pollination between genetically different plants. The additional capability of continual reseeding of occupied sites ensures a prominent role for annual bluegrass in intensively cultured turfgrass communities.

ORIGIN AND DISTRIBUTION

Annual bluegrass is a native of Europe and is believed to have originated from a cross between *Poa infirma* H. B. K., an annual species, and *Poa supina* Schrad., a creeping perennial (111). According to Hitchcock and Chase (59), annual bluegrass is found from Newfoundland and Labrador west to Alaska, south to Florida and California, and in high altitudes in tropical America. Gibeault (46) reports its occurrence in Australia, South America, North Africa, and North Asia, in addition to Europe.

Tutin (111) suggested that it is usually limited to areas of human habitation and Hovin (63 and 65) postulates that it was introduced to America by the

Fig. 4. Turfgrass Climatic Zones.

early Spanish explorers. It is apparent from the wide range of reports that annual bluegrass is widely distributed throughout the temperate and sub-tropical regions of the world, particularly where the presence of man tends to be dominant.

A map of turfgrass climatic zones in the United States is shown in Fig. 4. In the warm-humid, semi-arid and warm-arid regions, annual bluegrass may behave as a winter annual; while in the more northerly portions of the cool-humid and cool-arid regions it may behave as a summer annual. In contrast, the perennial creeping types may persist as perennials in closely mowed, irrigated, fertilized turfs for many years in the warmer portion of the cool-humid climate and cooler portions of the warm-humid climate —unless subjected to unusual heat, cold, drought, or wear stresses.

CLIMATIC ADAPTATION

Each of the major aspects of climatic adaptation—temperature, water, light, and atmospheric factors—will be discussed individually based on the limited information available. However, remember that specific plant responses are not determined by one single environmental factor, but by the levels and interaction among all components of the environment impinging on the annual bluegrass plant over both short-term acute and long-term chronic exposures.

Annual bluegrass is a cool-season species that behaves as a winter annual in warm climates. Maximum root production occurs at 18 to 21C (65 to 70F), depending on the subspecies involved (17 and 58).

Seedhead development is most rapid at 27C (80F) and is substantially reduced at lower temperatures (17). The optimum temperature in terms of overall turfgrass performance and quality is in the range of 16 to 21C (60 to 70F) since it gives a more moderate shoot growth rate. It is more important to maintain a favorable temperature for root growth since the shoots can survive greater temperature extremes, particularly heat, without significant detrimental effects to the annual bluegrass plant.

Annual bluegrass growth declines and eventually ceases as temperatures are increased or decreased from the optimum. It is quite prone to injury or complete kill from heat or cold stress in comparison to such commonly used cool season turfgrasses as creeping bentgrass and Kentucky bluegrass.

Heat Stress

As temperatures increase above 21C (70F), the following series of growth responses are observed: The roots of annual bluegrass begin to turn a distinct brownish color at 27C (80F) or above, indicating a reduction in normal functions. Individual plants also reach maturity much more rapidly as temperatures are increased above 27C (80F) (17). Annual bluegrass plants mature and die quite rapidly in the temperature range 30 to 35C (85 to 95F) (21, 25 and 58).

Lethal heat stress of annual bluegrass occurs at temperatures near 40C (104F) (40). These tests were conducted in a controlled environment under near 100% humidities so that a known leaf temperature could be produced without interference from transpirational cooling activity. The first heat injury symptoms appear on annual bluegrass at the junction of the leaf sheath and the leaf blade of the second and third youngest leaves (Fig. 5).

The actual lethal temperature will vary with the duration of exposure. For example, two hours expo-

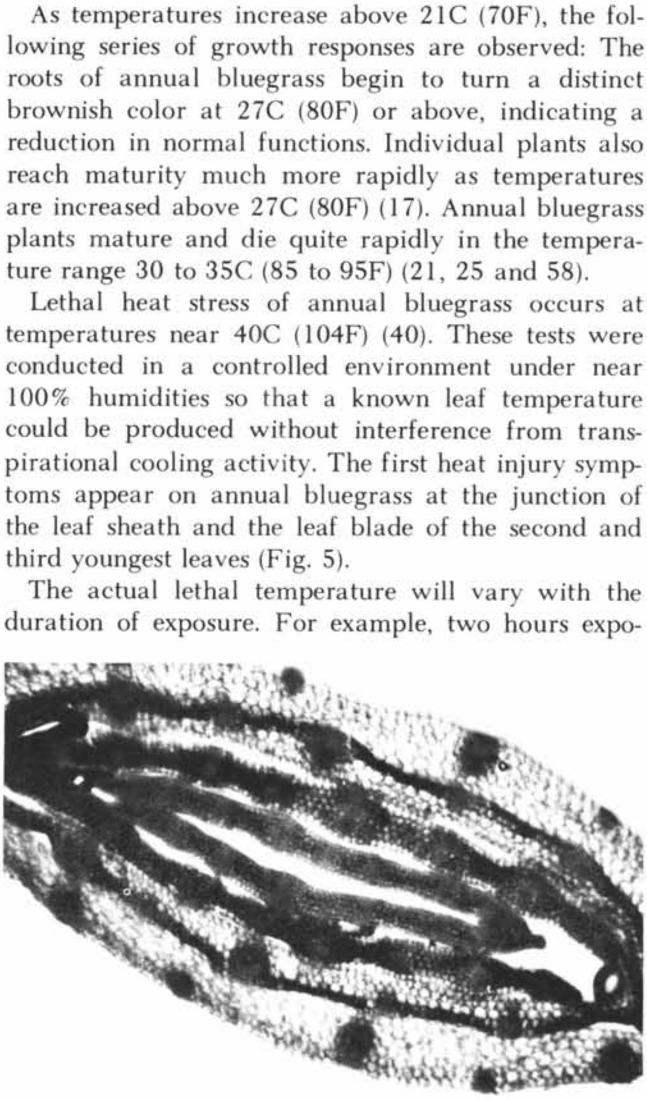

Fig. 5. Heat injury symptoms in annual bluegrass as shown by a cross-section at the junction of the leaf sheath and leaf blade at the second youngest leaf. (Photo—J. B. Beard)

sure to 42C (108F) under 100% humidity conditions resulted in complete kill of annual bluegrass plants; while 10 hours exposure to 38C (100F) at near 100% humidity was lethal. A distinct series of degradation processes occurs during heat stress including: protoplasmic granulation, followed by coagulation against the cell wall, cell wall breakdown, and eventually total collapse of the cell wall (40).

Low Temperature Stress

As soil temperatures are decreased below 10C (50F), annual bluegrass shoot growth is reduced, eventually ceases at lower temperatures, and subsequently enters winter dormancy. Annual bluegrass is more prone to low temperature kill than Kentucky bluegrass or creeping bentgrass (7) (Fig. 6)[2]. A longitudinal section through the crown of an annual bluegrass plant (Fig. 7)[2] shows that the lower portion of the crown responsible for initiating the root system is killed at slightly higher temperature than the upper portion of the crown responsible for initiating shoot growth (5).

The specific killing temperature varies with the hydration level of the tissue as well as seasonally (7). For example, annual bluegrass which has been allowed to harden in late fall to a crown moisture content of 78 to 80% will be killed from a 5-hour soil temperature exposure at -20C (-5F); while in early spring prior to spring greenup, annual bluegrass is killed by a 5-hour soil temperature exposure at -15C (5F) (Table 1). Annual bluegrass growing on poorly drained sites is particularly prone to low temperature kill (8 and 21).

Ice Covers

Ice covers are a potential stress problem on annual bluegrass turfs during the winter period. However, the potential for kill by ice covers is not nearly as great as by direct low temperature kill. More commonly, annual bluegrass turfs can be readily killed in low areas where standing water occurs prior to freezing, or during thawing of ice causing increased crown hydration followed by lethal low temperature stress (Fig. 8)[2].

If exposed to long periods of ice coverage, which is a rare occurrence, annual bluegrass is substantially more susceptible to kill than Kentucky bluegrass or creeping bentgrass (6). For example, when subjecting low temperature-hardened annual bluegrass turfs to extended periods of ice coverage at -32C (-26F), they were uninjured after 60 days, 20% thinned after 75 days, and could be killed after 90 days of ice coverage (Fig. 9).

Fig. 9. The comparative tolerance to 105 days ice coverage at -3C(26F) of Toronto creeping bentgrass (left), Merion Kentucky bluegrass (center) and annual bluegrass (right). (Photo—J. B. Beard)

Table 1. The seasonal variation in proneness to low temperature kill of annual bluegrass when exposed to five temperature levels for 5 hours.

Temperature treatment °C(°F)	Percent low temperature kill Dec. 5	April 10	June 5
-6 (20)	0	2	65
-9 (15)	0	35	100
-12 (10)	0	70	100
-15 (5)	5	95	100
-18 (0)	70	100	100

[2]Figs. 6, 7 and 8 are color pictures located on the inside back cover.

Spring Green-up

Overwintering annual bluegrass plants can initiate growth at about 13C (55F), while for creeping bentgrass and Kentucky bluegrass new growth occurs at somewhat lower temperature in the range of 10C (50F) (17). This might suggest that early spring nitrogen fertilization while temperatures are still cool, should enhance the competitive ability of the latter two species when they occur in a polystand compared to annual bluegrass. However, there are nontechnical reports that annual bluegrass is one of the earliest grasses to initiate growth in the spring. It has been suggested that the early spring green-up is due to germination of annual bluegrass seeds in small open areas of bare soil in the turf which warm up more rapidly in the spring encouraging germination.

Water

Moist to wet soil conditions are particularly favorable for annual bluegrass growth and actually enhance its competitive position. However, annual bluegrass is much more readily injured from internal plant water deficits created by either atmospheric or soil drought than other perennial cool season species such as Kentucky bluegrass and creeping bentgrass (10, 11 and 21). Under soil drought, annual bluegrass cannot readily make the appropriate physiological adjustments in terms of: increased carbohydrate accumulation, alteration of protein characteristics to an increased bound water content, and the subsequent decrease in the tissue moisture content, plus an increased capability to bind the remaining moisture within the plant tissues.

The physiological processes occurring during cold and drought stress are quite comparable. Measurements of crown water content during cold hardening reveal that the bentgrasses are capable of a lower relative water adjustment of as much as 20% and the Kentucky bluegrass of approximately 5%, while annual bluegrass will have little change (7).

The potential for water stress tends to influence the occurrence of certain annual bluegrass subspecies. The prostrate creeping biotypes tend to dominate where moisture stress conditions are minimal. The annual bunch biotypes, through their drought escape mechanism, tend to be dominant in regions subjected to periodic moisture stress (46). Annual bluegrass is also quite prone to winter desiccation compared to other cool season turfgrasses. This is attributed to its inability to readily harden into a physiological condition where it has increased capability to hold moisture within the tissues against a strong outward gradient.

Fig. 10. The comparative tolerance of annual bluegrass to submersion after 2, 3, 4, and 5 days at a 30C(86F) water temperature. (Photo—J. B. Beard)

Annual bluegrass is well adapted to wet soil conditions, but it is not equally tolerant to water submersion when compared to the other commonly used cool season turfgrasses. Toronto creeping bentgrass ranks superior in submersion tolerance; Kentucky bluegrass is in a comparable range and red fescue is substantially less tolerant of extended submersion (Fig. 10).

The water temperature strongly affects proneness to injury from submersion. For example, annual bluegrass is killed in approximately 5 days at water temperatures of 30C (86F), while it requires 20 days of exposure at water temperatures of 20C (68F) for more than 50% kill to occur and only 15% injury occurs after 20 days exposure to water at a temperature of 10C (50F). In contrast, exposure to water temperatures above 40C (104F) will result in kill within a matter of minutes (9).

Light

Maximum growth in annual bluegrass occurs at high light intensities and longer photoperiods as long as heat or moisture stress are not associated with these higher light levels (71). Annual bluegrass is also well adapted to shade, most probably due to the cooler temperatures associated with this environment. It is frequently observed growing in densely shaded areas where other turfgrass species have not been able to persist (100). This is partially attributed to its ability to escape environmental stresses associated with shaded areas by producing seeds which remain dormant in the soil until conditions are favorable for germination and growth. The annual bunch biotype, which is capable of prolific seedhead production, is well adapted to this situation, but the creeping perennial biotypes do not have this ready regenerative capability.

Annual bluegrass has a strong light requirement for seed germination compared to Kentucky bluegrass and creeping bentgrass (89 and 32). Thus, dense stands of turf which shade the soil surface are capable of preventing annual bluegrass seed germination and invasion. However, openings in the turf resulting from disease damage, divots, or similar adverse stress conditions will permit light penetration to the surface. The result is rapid germination of the existing annual bluegrass seeds followed by seedling growth and invasion of the area (10 and 11). In terms of the photoperiod requirement for maximum floral induction, annual bluegrass is classified as a short photoperiod plant. That is, it responds most favorably in terms of seedhead induction to day lengths of less than 12 hours (71 and 104).

In addition, annual bluegrass has the ability to continue flower induction and development throughout the remainder of the growing season over a wide range of photoperiods. Seedhead development is usually most intense during the late spring and early summer period, but the original floral induction occurred the previous fall under cool, short-day conditions.

Atmospheric Pollutants

Annual bluegrass is more prone to injury from atmospheric pollutants than most of the commonly used cool season turfgrasses. Its susceptibility to smog, in the form of peroxyacetyl nitrate and ozone, is particularly high (16). So much so that this plant has been used in Los Angeles as a biological indicator of acute smog exposure. This high susceptibility to peroxyacetyl nitrate and ozone injury can cause problems in the culture of annual bluegrass in densely populated urban centers. It is already a problem along the east and west coasts of the United States where these two atmospheric pollutants are significant, persistent problems.

Sulfur dioxide is another atmospheric pollutant that may occasionally cause problems, particularly in industrialized urban areas where high sulfur coal and oil are burned. Annual bluegrass ranks intermediate in susceptibility to sulfur dioxide injury, while creeping bentgrass and red fescue are particularly sensitive and bermudagrass is relatively insensitive (1 and 3). Finally, toxic fluoride gases such as hydrogen fluoride and silicone tetrafluoride may be occasional problems in the immediate vicinity of certain industries. If present, they can cause serious problems to annual bluegrass, especially hydrogen fluoride. Kentucky bluegrass is more tolerant (3).

EDAPHIC ADAPTATION

Physical Soil Properties

Annual bluegrass has long been recognized as a grass which is quite capable of growing on compacted soil sites (10, 11, 29, 58 and 100). In fact, it is considered an asset on heavily-trafficked, compacted soils where it is often the only grass which persists (44 and 55). But annual bluegrass has been described as short rooted grass (39, 49 and 81). Its susceptibility to moisture stress (10) and nutrient deficiencies (29) tend to support the short-rooting theory.

As early as 1937, however, Sprague and Burton studied root growth of annual bluegrass (100). They observed that when annual bluegrass, Kentucky bluegrass, and colonial bentgrass were grown in uncompacted soils, there was essentially no difference in rooting among these three grasses in the top 7.6 cm (3in) or at the 12.7cm (5in) depth.

This was substantiated by Wilkinson and Duff (115) comparing annual bluegrass, Kentucky bluegrass, and Penncross creeping bentgrass rooting. They found no differences in rooting among the grasses. Nor was there any difference in rooting of annual bluegrass in a sandy loam soil compacted to densities of 1.1, 1.25, and 1.4 grams oven dry soil/cc. Field observations, however, have revealed reduced rooting under compacted soil conditions (12, 100 and 117).

Sprague and Burton (100) reported that annual bluegrass was better able to tolerate poor soil aeration during cooler seasons, resulting in its encroachment into desirable turfs. Youngner (117) indicated that annual bluegrass can survive low soil oxygen levels, and thus is more competitive than other grasses under compacted conditions.

Cultivation has been suggested as a practice to either encourage or discourage annual bluegrass. Conditions at the time of cultivation have a marked effect on the competition between annual bluegrass and other species in polystands (101). Youngner (118, 119 and 120) has suggested that a regular coring program during the spring and fall is essential to growing annual bluegrass on compacted soils under California conditions.

Any cultivation practice which exposes the soil under environmental conditions that favor annual bluegrass seed germination will likely result in increased encroachment. Morgan *et al* (86) found reduced annual bluegrass on a compacted green which had been intensively hand-cored and over-seeded with Seaside creeping bentgrass. There was an increase in oxygen diffusion reading (a measure of available soil oxygen) and water infiltration rates after this intensive treatment.

Annual bluegrass responds to high soil moisture conditions. It is commonly found on moist sites where it competes favorably with both cool and warm season turfgrasses (10, 46, 55, 99, 100, 95 and 117). However, it does not tolerate waterlogged conditions and submergence for any period of time (9, 99 and 100). On the other hand, annual bluegrass is quite susceptible to water stress and wilting (10 and 29).

Frequent irrigations not only make soils more susceptible to compaction, but also provide the moist environment that is conducive to annual bluegrass encroachment. In an irrigation study on an annual bluegrass-bermudagrass polystand, Youngner (117) found that annual bluegrass persisted during the summer when irrigated with 1.3cm (½ in) of water every 3 to 4 days. The annual bluegrass did not survive the heat and water stress conditions when 1.9 cm (¾ in) of water was applied every 10 days while the bermudagrass grew well.

Sprague and Evaul (99) found that annual bluegrass grew best on a fine-textured soil held at 50—60% of the soil water holding capacity and only fair to poor at higher and lower moisture levels. Maintaining the soil moisture at 30% of the water holding capacity resulted in very little annual bluegrass in the polystand. Beard (10) pointed out that annual bluegrass is best adapted to moist, fine-textured soils, but will persist on coarser-textured soils if irrigated frequently.

Adequate drainage is suggested as being necessary for maintaining annual bluegrass (10). Drainage is also important in keeping the "desired" species when arsenicals are being used to control annual bluegrass (22). The arsenate can be reduced to a more toxic form under high soil moisture conditions which can result in serious injury to the desired turfgrasses.

Chemical Soil Properties

Soil pH is an important factor in retaining annual bluegrass in turfs. Most authors recommend pH levels between 6.0 and 7.0 for favorable annual bluegrass growth (12, 85 and 88). However, Roberts *et al* (95) suggested that annual bluegrass is not likely to be controlled by reducing the soil pH below optimum levels because other turfgrasses do not compete favorably on acid soils either.

Several studies have shown that annual bluegrass grows better at a soil pH of 6.5 than at 5.0 or 5.5 (22, 74 and 100). Carrow (22) observed this response on four different mineral soils ranging in texture from a loamy sand to a silty clay loam, as well as on a peat soil. Juska and Hanson (74) reported better growth of annual bluegrass and more seedhead formation at pH 6.5 than at 4.5 on a loamy sand, but there was no effect of pH when grown on a silt loam soil. They also found that annual bluegrass grew better on the acid (pH 4.5) silt loam soil than did Kentucky bluegrass. Ferguson (39) suggested that low soil pH's result in reduced seed germination of annual bluegrass. He found less annual bluegrass on plots receiving acid- forming fertilizers.

When using calcium arsenate for annual bluegrass control, Carrow (22) observed that raising the soil pH to 6.5 or 7.5 reduced the ability of calcium arsenate to control annual bluegrass. The arsenate is less available to the plant at higher pH levels, thus reducing its toxicity. To encourage the growth of annual bluegrass in turfs which have been treated with calcium arsenate in the past, one can reduce the arsenate toxicity by liming to raise the soil pH or by applying phosphorus (22, 28, 41 and 73).

There is little data published on the effects of soluble salts on annual bluegrass. Beard (10) ranked the salt tolerance of annual bluegrass as low compared to other turfgrasses. Youngner (118) reported that annual bluegrass is highly susceptible to salt injury. Salts tend to accumulate near the soil surface during hot weather in dry climates and can be a result from regular, light syringing. Occasional deep irrigation is needed to leach salts out of the turfgrass root zone under these conditions.

PESTS

This section on pests is based on the experiences of the authors and that of others in their respective fields. Because annual bluegrass has been considered a weed little in-depth research has been conducted on its pest problems. Most of the information available is from observation and little data is published from scientific experiments conducted under controlled conditions.

It is hoped that questions raised in this section about certain pests will stimulate research to find some needed answers. For current suggestions to control the pests discussed herein, consult you Cooperative Extension Service representative or other qualified turf specialist.

DISEASES

The major diseases on annual bluegrass are anthracnose, caused by *Colletotrichum graminicola* Ces. Wils.; brown patch, caused by *Rhizoctonia solani* Kuehn; dollar spot, caused by *Sclerotinia homeocarpa* F. T. Bennett; *Fusarium patch*, caused by *Fusarium nivale* (Fr.) Ces.; *Pythium blight*, caused by *Pythium* spp.; red thread, caused by *Corticium fuciforme* (Mc Alp.) Wake; *Typhula* blight, caused by *Typhula* spp. Of these diseases, anthracnose appears to be the most important and can be a limiting factor in successfully growing annual bluegrass during periods of hot, humid weather.

Other diseases which are reported to occur on annual bluegrass are leaf mold, caused by *Alternaria* spp.; stem rust, caused by *Puccinia graminis* Pers.; leaf rust, caused by *Puccinia poae-sudeticae* (West.); stripe smut, caused by *Ustilago striiformis* (West) Niessl. f. spp. *poae-annuae*; *Ophiobolus* patch, caused by *Ophiobolus graminis* Sacc.; and melting out, caused by *Helminthosporium vagans* Drechler. Table 2 lists the important diseases which attack annual bluegrass and their cultural controls.

If melting out does occur on annual bluegrass, it is of minor importance in terms of turfgrass injury. Although fungicides are applied in the spring for the control of melting out on golf course turfs, Vargas (112) has not observed the problem even in fairways

Table 2. Symptoms and cultural controls for important diseases of annual bluegrass.

CASUAL ORGANISM	DISEASE SYMPTOMS	CULTURAL CONTROL
ANTHRACNOSE *(Colletotrichum graminicola)*	Irregular shaped patches varying in size from 6 inches up to several feet, eventually covering entire fairways or greens. Spots first appear yellow, turning quickly to bronze during hot humid weather.	Moderate nitrogen fertilization will reduce the severity especially during cool weather.
BROWN PATCH *(Rhizoctonia solani)*	Large brown circles, 0.5 to 4 feet in diameter. Outer edge sometimes having a dark purple band of mycelium.	(1) Avoid high nitrogen levels. (2) Increase air circulation.
DOLLAR SPOT *(Sclerotinia homeocarpa)*	Tiny spots, 0.5 to 3 inches in diameter; straw to bleached colored, sometimes coalescing to form larger spots. The brown banding lesion found on other grasses is not present on annual bluegrass.	(1) Increase the nitrogen fertility level. (2) Remove dew and guttation water in early morning.
FUSARIUM PATCH Pink Snow Mold *(Fusarium nivale)*	Spots are circular, reddish brown, usually 1 inch to 2 feet in diameter when occurring without snow cover. Under snow cover the spots are bleached tan to straw colored with red to pinkish margins.	Avoid fall fertilizations that result in succulent turf prior to the first snow.
PYTHIUM BLIGHT *(Pythium spp.)*	Water soaked spots, later fading to light brown, 1-6 inches in diameter, which may rapidly coalesce to form larger irregular spots. Spots sometimes have purple or white colored mycelia of the fungus present around the perimeter.	(1) Improve soil drainage. (2) Increase air cirulation.
RED THREAD *(Corticium fuciforme)*	Light tan to pinkish spots, ranging in size from 2-6 inches. Red colored stroma (threadlike structures) of the fungus usually present in spots.	Increase nitrogen level.
TYPHULA BLIGHT Gray Snow Mold *(Typhula spp.)*	Circular 0.5 to 2 feet spots, gray in color immediately after snow fall when mycelium of the fungus is present; later fading to a straw color as they dry. Reddish brown to dark brown sclerotia are usually present in spot. Occurs only under snow cover.	Avoid fall fertilization that results in succulent turf prior to snow fall.

where Kentucky bluegrass patches were severely thinned by disease. Jackson and Smith (68) also report *Helminthosporium* as not being a problem on annual bluegrass in England. *Helminthosporium* is very destructive on many susceptible Kentucky bluegrass, chewings fescue, and red fescue cultivars. This gives annual bluegrass a distinct advantage over the other species because it competes well in the spring when the *Helminthosporium* susceptible cultivars are being severely thinned.

Anthracnose

Anthracnose is a disease that occurs on annual bluegrass in both cool and warm weather. The disease turns annual bluegrass yellow in cool weather (Fig. 11)[3]. The yellow, infected annual bluegrass plants turn a bronze color at air temperatures above 29C (85F) and die if a fungicide treatment is not applied within 48 hours.

Increased nitrogen fertilization may help reduce the severity of anthracnose if it occurs during cool weather, but increasing the nitrogen level just prior to the advent of warm weather will increase the severity. Anthracnose can be easily recognized, with the aid of a hand lens, by the black fruiting bodies (acervuli) which occur in rows in the interveinal areas of the leaf blades (see Fig. 12). These black fruiting bodies contain spines called setae (97 and 112).

Fig. 12. Closeup of acervuli with setae of *Colletotrichum graminicola* (anthracnose) growing in interveinal areas on annual bluegrass. (Photo—J. M. Vargas, Jr.)

[3]Fig. 11 is a color picture located on the inside back cover.

Brown Patch and Pythium Blight

Brown patch can be a severe problem on annual bluegrass. It is a disease which occurs at temperatures about 29C (85F), along with a high atmospheric humidity and night temperatures remaining about 21C (70F). High nitrogen fertility levels preceding an infection can increase the severity of the disease. *Pythium* blight is a warm weather disease like brown patch. Disease activity is favored by air temperatures about 32C (90F), high atmospheric humidity, and water saturated soils. Improved air movement and surface water drainage will help reduce the severity of both *Pythium* blight and brown patch.

Dollar Spot

Dollar spot is the most common disease of annual bluegrass over a wide range of soil, environmental, and cultural conditions. It is a problem from late spring through early fall in the cool humid climatic region. There are apparently two distinct strains of the fungus. One causes larger 5 to 7.6cm (2 to 3 in.) spots which occur in cooler weather of 16 to 24C (60—75F), while another strain causes smaller 1.3 to 2.5cm (0.5—1 in.) spots at higher temperatures of 24 to 29C (75—85F). This means that dollar spot can be a problem for most of the growing season in some areas.

Fusarium Patch

This is a cool weather problem occurring at temperatures below 16C (60F), and is also favored by wet weather. It will continue to grow under a snow cover where it is commonly known as pink snow mold. High nitrogen, liming, and higher pH's will increase disease severity on annual bluegrass (97).

Red Thread

Red thread is favored by cool temperatures of 13 to 24C (55—75F), and prolonged periods of light rain. It is primarily a disease problem on slow growing turfs and is usually associated with low nitrogen fertility levels. It is one of the few diseases which can be controlled with a reasonable level of nitrogen fertilization. However, the possibility of increased snow mold or winter desiccation problems from late fall nitrogen applications must also be taken into consideration when using nitrogen for red thread prevention.

Typhula Blight

Typhula blight occurs only under a snow cover, or its equivalent, such as leaves. It is a destructive disease that can result in death of infected plants. Avoiding fall nitrogen fertility that will result in succulent growth prior to snow fall helps reduce the severity of this disease.

INSECTS

Ataenius spretulus grubs, turfgrass weevils, and grubs from the *Scarabaeide* family are insect pests specifically associated with annual bluegrass. Other insect problems associated with annual bluegrass include billbugs, chinch bugs, cutworms, and sod webworms. Information concerning the suspected problems was compiled from Beard (12), Madison (82), and App and Kerr (4).

Ataenius spretulus Grub

Ataenius spretulus Hald. is a small, black beetle whose larval (grub) stage can cause severe damage to annual bluegrass turf (90) (Fig. 13)[4]. It has been observed to be a problem in the northeast and midwest on annual bluegrass, Kentucky bluegrass, and bentgrass. Officially, it does not have a common name, although many have called it a dung beetle.

Small grubs (Fig. 14)[4] of the insect are responsible for the damage. Initial symptoms are the wilting of large, irregular shaped patches of turf. The beetle overwinters as an adult and lays eggs in the spring. The larvae emerge in late June and July at which time they can cause severe damage to annual bluegrass, which is already under high temperature stress, by feeding on the roots. This results in wilting and eventual death.

Chinch Bug

Chinch bugs (*Blissus* spp.) can be a problem on annual bluegrass. Adult chinch bugs are 0.4 to 0.5cm (1/6 to 1/5 in.) long and black with white wings folded over the back. Eggs are laid in the annual bluegrass crown area. The nymphs grow from a red pinhead size with a white band across the back to brownish, 0.5cm (1/5 in) long adults. They go through approximately five instar stages in six to eight weeks.

Chinch bugs prefer hot, dry weather and turfgrass damage is most severe under these conditions. Injury initially appears as irregular, yellowish patches, 61 to 81cm (2—3 ft) in diameter, usually in sunny areas. These patches can coalesce and spread to involve larger areas. The grass will eventually turn brown and die if the pest is not controlled.

If chinch bugs are suspected as a problem, they can be diagnosed by removing both ends of a coffee can and firmly pushing it into the sod on the edge of the infected area. The can should then be filled with water and held in position for 5 to 10 minutes. Any chinch bugs present will float to the surface of the water.

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[4]Figs. 13 and 14 are color pictures located on the outside back cover.

Grubs

Grubs are root feeding larvae and are represented by many species of beetles belonging to the family *Scarabaeide*. The larvae are 2.5 to 3.8 cm (1—1.5 in.) in length and white to pale yellow in color. They have brown heads, six legs, and are usually found in a curled position. These larvae feed on the turfgrass roots. The sod can be easily lifted when severe infestations occur and are easily seen upon lifting the sod. Other indications of grub activity include the presence of moles, birds, and skunks which feed on the grubs by tearing up the turf.

Sod Webworm

Sod webworms *(Crambus* spp.) are the larvae of small whitish or grayish lawn moths that can be observed flying over turfgrass areas in the evening. The larvae feed on the turfgrass leaves and build themselves silk lined tunnels or burrows just below the soil surface. They are most active at night when they chew off grass blades near the soil surface. Silky webs covering the tunnel are sometimes evident early in the morning.

Turfgrass Weevil

The turfgrass weevil or Hyperodes weevil *(Hyperodes* spp.) has been identified as an important problem of annual bluegrass in the northeastern United States (102). It was originally identified as a problem on turf in Connecticut (19). Tashiro (102) reports that the weevil feeds on annual bluegrass, clover, bentgrass, and fescue, but rarely on Kentucky bluegrass.

The only significant turfgrass damage has been observed on annual bluegrass. The major damage is caused by larvae feeding. Initial symptoms involve a yellowing of individual, centrally located leaves of the grass plant. Yellow spots less than 2.5cm (1 in.) in diameter appear on greens. Large areas will be damaged if the initial infection is not controlled. Damage is first evident during late May and June and is restricted to areas where annual bluegrass is maintained at a cutting height of 0.5 in. or lower.

According to Tashiro (102) the life cycle consists of the female laying her eggs in the leaf sheath through a small hole she has chewed. After hatching, the larvae feed within the stem on the youngest, most tender tissue. The central leaf becomes yellow and may die. The stems are often hollowed out. The larvae also feed on the crowns and may eventually destroy the entire plant (Fig. 15).

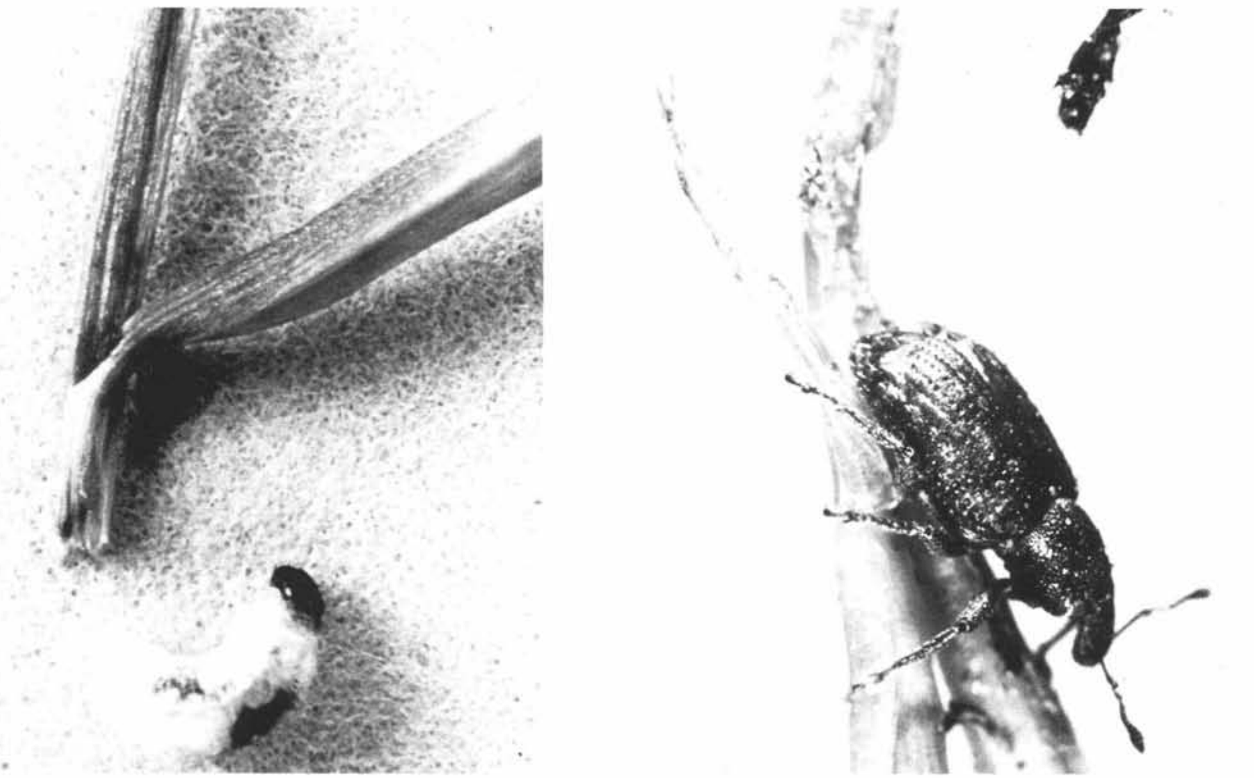

Fig. 15. Closeup of a turfgrass weevil larva (left) and the adult beetle (right). (Photo—H. Tashiro)

Cutworms

Cutworms are mainly a problem on annual bluegrass greens. During the day the larvae live in the holes left by coring. At night they feed around the coring holes cutting the grass off at the soil surface. The damage is unsightly and interferes with putting.

The cutworm larvae are fat and almost smooth, ranging in size from 1½-2 in. (3.8—5.1cm) long. They vary in color from grey to brown to black. They may possess either spots or stripes. The cutworm moths are night fliers and are brown or grey in color. They belong to the family Noctuidae and lay their eggs on the plants. There can be up to 4 generations per season.

NEMATODES

Five species of nematodes have been associated with problems in annual bluegrass. The most common are the: 1-root knot nematode, *Meloidogyne arenaria* (Neal) Chitwood; 2-stylet nematode (a stunt nematode), *Tylenchorhynchus acutus* Allen; and 3—lance nematode, *Hoptolaimus tylenchiformis* Daday (27). Vargas has also found *Tylenchorhynchus dubius* (Butschli) Filipjev. and *Criconemoides* spp. associated with problem annual bluegrass turfs. There are probably many other pathogenic nematodes causing problems in annual bluegrass turfs; but because of its classification as a weed, this problem has also been overlooked.

In general, root feeding nematodes cause symptoms which are associated with poor quality turf. The turf often looks as though it is lacking fertilizer and/or water. The affected areas can appear light green to yellow in appearance or have the purplish color of wilting turf which is caused by the damaged root system. If nematodes are suspected, a soil sample should be sent to a qualified nematology laboratory for examination.

Controlling nematodes can be a difficult problem. Any control short of complete sterilization results in an initial decrease in the nematode population; which in turn, results in a new flush of root growth that allows the nematode population to build back up again. This means a continual cycle of treatments to reduce population build-ups or to control populations at low levels. However, such a program must be followed if the nematodes are causing loss of annual bluegrass turfs. Extreme caution should be taken when using nematicides because most of them are highly toxic, both dermally and orally.

PROPAGATION

Seed Production

The propagation of annual bluegrass is primarily by seed; however, studies with various biotypes of annual bluegrass have shown that vegetative propagation by stolons may also be important in the spread and survival of the plant (10 and 46). Renney (92) observed that a single plant of annual bluegrass growing in western British Columbia, Canada, produced more than 360 seeds during a four-month period from May through August. He estimated that, where annual bluegrass has been growing, the surface layer of soil might contain 30 million annual bluegrass seeds per acre.

Koshy (78) reported that seed formation can proceed following pollination, even when the panicles are removed from the plant on the same day pollination occurs. He concluded that annual bluegrass has a highly efficient sexual reproductive system that contributes greatly to its success as a weed, even under close mowing.

Annual bluegrass is unique. It produces an abundance of seed stalks at all cutting heights (91). Seed formation occurs throughout the growing season but is most intense during mid-spring (100). Youngner (118) determined that temperatures within a range of 10 to 27C (50—80F) had little effect on flowering. Whereas most plants require a specific photoperiod for floral induction, annual bluegrass flowered normally when subjected to 6, 9, 12, or 24 hours of light per day (104).

Youngner (118) also reported that flower induction was not governed by day length. Sprague and Burton (100) determined that annual bluegrass growing in continuous shade or under a 5—hour daily light exposure formed very few seedheads compared to plants growing under longer photoperiods. They concluded that adequate exposure to light is an important factor in the seed production of annual bluegrass. These results reflect differential responses to photoperiod in the case of floral induction and total daily light levels received in the case of floral development.

Seed production has been reported to be affected by fertilization. Nitrogen increases vegetative growth while decreasing seedheads. Seedhead formation increases when phosphorus and potash are applied along with nitrogen. Lime applications reduced seedhead formation, probably because of greater vegetative growth induced by nitrogen. However, Juska and

Hanson (74) found four times as many seedheads on annual bluegrass grown in a sandy loam soil at pH 6.5 compared to a pH of 4.5. No differences were observed when grown in a silt loam soil at the same two pH levels.

Another factor that has been associated with differences in flowering is the morphological variabililty within annual bluegrass. Gibeault (46) found that annual biotypes (var. *annua*) flowered in 50 days compared to 81 days for the perennial biotypes (var. *reptans*). Even more important, the annual biotypes were much more prolific seed producers.

Seed Germination

Germination of annual bluegrass seed is believed to occur primarily during cool, moist conditions in late summer or early fall, with spring germination occurring in some areas (10, 56 and 101). More seed germination was observed at a constant temperature of 16C (60F) than at 10 or 21C (50 or 70F) (25). However, Bogart (17) reported no differences in annual bluegrass seed germination at constant temperatures of 4, 10, 16 or 21C (40, 50, 60 or 70F), but a very substantial decrease at 27 and 32C (80 and 90F). The contradictory results may be due to different biotypes, such as annual vs. perennial.

Engel (32) found that alternating temperatures of 30C (86F) day and 20C (68F) night resulted in higher germination than constant temperatures of 20C (68F) and 30C (86F). Hovin (64) also found that alternating temperatures promoted annual bluegrass seed germination. A study conducted at Michigan State University in 1969 showed uniform seed germination under three alternating temperature regimes, but reduced germination at the lowest temperatures of 13C (55F) day and 2C (35F) night (Table 3). Seedling growth significantly increased with increasing temperatures and longer photoperiods. Thus, it would seem that annual bluegrass germination is most likely to occur during relatively cool periods of the season.

Table 3. Effects of day/night temperature and photoperiod on seed germination and seedling growth of annual bluegrass.

Temperature (day/night)	Photoperiod	Seed Germination	Seedling Height (after 21 days)
(F)	(hrs.)	(%)	(cm)
55/35	8	63.5 a[(a)]	0.71 a[(a)]
65/45	10	83.5 b	1.38 b
75/55	12	81.0 b	1.72 c
85/65	14	84.3 b	2.10 d

(a) Means in column with common letters are not significantly different by the Duncan's Multiple Range Test at the 5% level.

Neidlinger (89) determined that the surface temperatures of bare soil in mid-summer exceeded those under turf by as much as 15C (28F), but the maximum temperatures under a turf on sunny days were within those which permitted annual bluegrass germination in the laboratory. He concluded that seed germination could occur throughout the summer in turf, but that it would be unlikely on bare soil since the higher temperatures measured on bare soil paralleled laboratory test temperatures that inhibited germination.

Numerous researchers have reported that annual bluegrass seed germination is favored by light; however, germination does occur in the absence of light (32, 64, 65, 89 and 92). Tutin (111) reported that seed of var. *reptans* germinated as soon as conditions were favorable while var. *annua* usually required a three month after-ripening period.

Cockerham and Whitworth (25) found that freshly-harvested seed in New Mexico failed to germinate in the laboratory, but germination increased to 26% and 47% after one and two months storage, respectively. Beard (10) concluded that dormancy of the annual types (var. *annua*) of annual bluegrass allowed the seed to remain in a viable condition in the soil for one or more years.

Other factors that have been reported as being important in annual bluegrass seed germination include the nutrient content of the external substrate and pH. Cockerham and Whitworth (25) observed increased seed germination when using KNO_3 in the substrate. Ferguson (39) concluded that acid-forming fertilizers, such as ammonium sulfate, inhibited annual bluegrass germination through a reduction in soil pH.

TURFGRASS COMMUNITY DYNAMICS

Beard (10) characterized annual bluegrass as an opportunistic grass which frequently becomes established in turfs that have been weakened by errors in the cultural program, or because of the lack of competition from non-aggressive bentgrass cultivars. It commonly invades turfgrass communities because competition from existing turfgrasses has been reduced below a critical level at a time when environmental conditions are favorable for annual bluegrass.

Reduction in competition may be due to the development of voids in the turf caused by diseases, insect injury, traffic wear, divots, cultivation, or other stress conditions. The specific time during the growing season when these voids occur determines the likelihood of annual bluegrass invasion. Also, Sprague and Burton (100) found wide differences in the amounts of annual bluegrass in creeping bentgrass due to the relative resistance of different cultivars to invasion. Similarly, Beard reports that annual bluegrass encroachment into dormant bermudagrass is greater with Tifdwarf than Tifgreen under Texas conditions. This occurs because Tifdwarf discolors and enters dormancy earlier than Tifgreen; and at a more favorable time for the seed germination and invasion of annual bluegrass.

Youngner (117) found that light vertical mowing of bermudagrass turf in November resulted in a substantial increase in the annual bluegrass population the following winter. He concluded that removing the heavy bermudagrass mat by vertical mowing encouraged annual bluegrass seed germination under the moist, cool conditions that existed. Annual bluegrass invasions were observed following severe incidences of *Fusarium* blight in Kentucky bluegrass, and red leaf spot *(Helminthosporium erythrospilum)* in Toronto creeping bentgrass.

Low temperature kill of crabgrass in autumn followed by favorable climatic conditions facilitated annual bluegrass invasion into a Kentucky bluegrass turf (Fig. 16)[5]. Annual bluegrass frequently invades golf course tees in bare areas resulting from divoting, and putting greens where tears in the turf occur from landing of golf balls and spiked shoes. Thus, mechanical and biological disruption of the turf should be avoided or quickly repaired to minimize the invasion of annual bluegrass.

Competition from desirable turfgrasses is reduced where prevailing environmental conditions differ substantially from the "ecological niche" of the specific turfgrass. Fig. 17 illustrates the relative positions of Kentucky bluegrass (KB) and annual bluegrass (AB) in an ecological scheme depicting the cutting height and soil moisture regimes as the principal environmental factors affecting adaptation of these species.

The center points of each set of concentric rings represent the optimum conditions (ecological niches) for the respective grasses. Each concentric ring proceeding outward from the center points represents decreasing levels of adaptation. Overlapping of the two sets of concentric rings indicates that both species are adapted to the same set of conditions. However, one or the other may be preferred, depending on the specific soil moisture level and cutting height selected. Thus, major shifts within the turfgrass community away from annual bluegrass and toward perennial turfgrasses can occur only when climatic, soil, and cultural conditions favor the desired perennial turfgrass.

[5]Fig. 16 is a color picture located on the outside back cover.

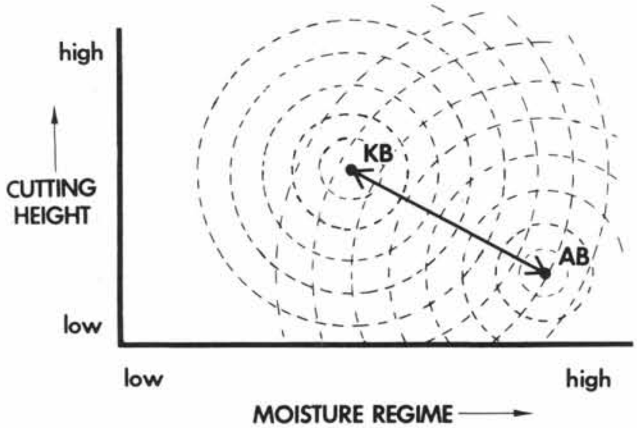

Fig. 17. Ecological scheme depicting the cutting height and soil moisture regimes as environmental factors affecting the adaptation of Kentucky bluegrass (KB) and annual bluegrass (AB). (Photo—A. J. Turgeon).

Irrigation

Sprague and Evaul (99) found that fine textured soils kept at 30 percent saturation had very little annual bluegrass, while higher soil moisture levels were associated with more annual bluegrass. Youngner (117) reported that high soil moisture levels maintained by frequent, light irrigations favored the persistence of annual bluegrass in bermudagrass turf during the summer months in southern California.

Harper (56) and others observed that non-irrigated turfs of Kentucky bluegrass were rapidly changed to predominantly annual bluegrass following frequent irrigation and closer mowing. The water requirement of creeping bentgrass is closer to annual bluegrass than most other species based on field observations. However, basic data on comparative water use rates and irrigation practices are not yet available.

Mowing

Bogart and Beard (18) found the optimum cutting height for annual bluegrass to be 2.5cm (1 in.) based on studies comparing density and shoot weights of populations clipped at 1.3, 2.5, 3.8, 5.1 and 6.4 cm (0.5, 1.0, 1.5, 2.0 and 2.5 in.), in monostands and in polystands with Kentucky bluegrass.

Upon returning clippings to a Kentucky bluegrass turf mowed at 2.5 cm (1 in.) Beard and Rieke found annual bluegrass comprised nearly 30% of the turf while there was only about 1% annual bluegrass when clippings were removed. When mowed at 5 cm (2 in.) there was essentially no annual bluegrass in the turf. Optimum cutting heights for Kentucky bluegrass are generally thought to be within a range of 3.8 to 6.4 cm (1.5 to 2.5 in.).

Youngner (117) reported significantly denser stands of annual bluegrass in bermudagrass mowed at 1.3 to 1.9 cm (0.5 to 0.75 in.) than when mowed at 7.6 cm (3 in.). Variability within the annual bluegrass species is evidenced from reported differences among biotypes in growth habit, shoot density, persistence, and susceptibility to control with chemicals (64, 65, 117, 46, 10, 105 and 106). It is conceivable that biotypes of annual bluegrass might respond differently to various cutting heights which, in turn, could influence their competitive ability.

The effect of mowing height on the competitive relationship between bentgrass and annual bluegrass is not well documented.

Soil Compaction

Beard (10) reported that annual bluegrass is well adapted to compacted soil conditions, while bentgrass has poor compaction tolerance and Kentucky bluegrass is intermediate. A frequent observation in bentgrass fairways is the longitudinal pattern of annual bluegrass invasion corresponding to the traffic pattern and differential soil compaction resulting from mowing equipment.

Sprague and Evaul (99) compared the rooting of three grasses in a clay loam soil under compacted and non-compacted conditions. They found that the total root weight of annual bluegrass was reduced by one-half to two-thirds from soil compaction. Root growth in the top 7.5 cm (3 in.) of the compacted soil was 87% of the total root growth for annual bluegrass, 92% for Kentucky bluegrass, and 88% for colonial bentgrass. Below 13 cm (5 in.) the root growths of all three grasses were also similar, averaging 6 percent of the total.

Wilkinson and Duff (115) found that the rooting ability of annual bluegrass was comparable to creeping bentgrass and Kentucky bluegrass at three soil bulk densities. They concluded that the success of annual bluegrass in compacted soils could not be explained by superior rooting ability, but was probably the result of its continuous seed production and renewal of growth during cool seasons.

Soil Reaction

Soil fertility and pH substantially affect the growth and quality of turfs. Differences in the adaptation and response of turfgrass species to various levels of nutrients and pH can be exploited to shift the turfgrass community toward or away from a particular component of the polystand. Sprague and Burton (100) found that annual bluegrass did not exhibit greater tolerance to soil acidity than other turfgrasses. They also concluded that reducing the soil pH through the use of acid-forming fertilizers was not practical as a means of controlling annual bluegrass because of the poor response of other turfgrasses to high soil acidity.

Juska and Hanson (74) studied the pH preference of annual bluegrass in two soil types. They concluded that annual bluegrass has the ability to grow better than Kentucky bluegrass at a low pH level in a heavy silt loam soil. The response of annual bluegrass to differences in pH depended upon soil texture.

Fertilization

Higher fertility levels enhance annual bluegrass invasion into Kentucky bluegrass turf (42 and 93). Engel (33) reported that cold-weather applications of nitrogen cause an increase in the annual bluegrass content within a creeping bentgrass turf compared to distribution of the applications uniformly over the entire growing season. Rieke and Bay (93) found that using treatments which apply more nitrogen during the spring encouraged annual bluegrass encroachment in a Merion Kentucky bluegrass turf (Table 4).

Table 4. Time of application of ammonium nitrate effect on the composition of a mixed annual bluegrass-Merion Kentucky bluegrass turf after 5 years of treatments, at East Lansing, Michigan.

Date(s) of Application (a)	Annual Bluegrass in Turf
	%
April	89
April, August	71
April, May, August	88
February, May, August	81
May, July	78
April, August, September	63
May, August, November	56
August	56

(a) 4 pounds nitrogen was applied per 1000 square feet annually and divided into the appropriate number of applications.

There is little information reported on the influence of fertilizer carriers on annual bluegrass. But the continued use of activated sewage sludge on Merion Kentucky bluegrass and Pennlawn red fescue turfs has resulted in increased invasion of annual bluegrass compared to urea and ammonium nitrate treatments (93).

Some non-technical literature suggests the spring nitrogen fertilizations should be delayed to avoid encouraging annual bluegrass growth at the expense of bentgrass and Kentucky bluegrass. Bogart (17) determined that Penncross creeping bentgrass and Merion

Kentucky bluegrass actually initiated growth at 2.8C (5F) lower soil temperatures than did annual bluegrass.

However, Hawes (58) found that annual bluegrass made two to three times as much growth as Penncross creeping bentgrass at a soil temperature of 7C (45F). Penncross grew more and had a competitive advantage over annual bluegrass within a soil temperature range of 13 and 29C (55 and 85F). Furthermore, annual bluegrass produced a more horizontal growth at lower temperatures of 7 and 13C (45 and 55F), allowing for more rapid lateral growth into bare areas.

Goss (52) reported an increase in annual bluegrass invasion into a bentgrass putting green in western Washington by applying 56 kg/ha sulfur (1.1 lbs/1000 sq ft) compared to the untreated plot. When the annual sulfur rate was increased to 168 kg/ha (3.4 lbs/1000 sq ft) however, annual bluegrass decreased to no more than was found in the untreated turf.

A CULTURAL PROGRAM FOR ANNUAL BLUEGRASS TURFS

Many irrigated, closely-mowed turfs—especially those on golf courses—are composed primarily of annual bluegrass. So, cultural programs need to be selected that are optimum for maintaining quality, persistent annual bluegrass turf appropriate for the particular use. Unfortunately, detailed information of this type has not been available in past publications.

This publication proposes a cultural system for annual bluegrass. The outline presented is based primarily on experience and observations of the authors, with inputs from the USGA Green Section Agronomists. The cultural system is based on the best available information, but lacks confirmation by research under representative field conditions.

A CULTURAL PROGRAM FOR ANNUAL BLUEGRASS GREENS

Mowing Height: 3/16 to 5/16 inch (5 to 8mm)

Mowing Frequency: Daily

Clipping Removal: Yes

Brushing: Daily during peak seedhead formation and three to four times per week during periods of lighter seedhead development. Same effect can be accomplished with a light vertical mowing, especially for those having a triplex greensmower.

Fertilization—Nitrogen: Requires 0.5 to 0.7 pounds of actual nitrogen per 1,000 square feet per growing month. Apply between 0.25 and 0.5 pound of actual nitrogen per 1,000 square feet per application, spaced at 10 to 20 day intervals. Avoid nitrogen fertilization in the summer when heat stress limits growth.

Fertilization—Phosphorus: Application rate should be based on soil tests using a program that maintains a moderately high level of soil phosphorus. Applications are best made in the spring or the fall, preferably just after coring so that deeper soil penetration can be achieved. Most commonly applied in the form of a complete analysis fertilizer.

Fertilization—Potassium: Apply based on soil tests where finer textured soils are involved; coarse textured soils will probably require 4 to 5 pounds actual K_2O per 1,000 square feet per year. Split into four to six applications over the growing season. Potassium sulfate (K_2SO_4) is safer to use than potassium chloride (KCl) and provides some sulfur as well.

Fertilization—Iron: Apply 1 to 2 oz. of ferrous sulfate per 1,000 square feet per growing month; use the lower levels in the northeast. May need a 3 oz. rate in 3 gallons of water where chronic iron chlorosis occurs. Iron response will be more marked when soil pH is above 7.5.

Fertilization—Other Nutrients: Apply only if visual deficiency symptoms appear. This is quite infrequent except in certain limited locations.

Soil Reaction: Maintain the soil reaction in the pH range of 6.2 to 7.2. Apply lime as needed based on soil test recommendations for turf. Dolomitic limestone is suggested as the liming material for acid soils. A soil test will confirm any need for magnesium in the dolomitic lime.

Irrigation: Maintain a constantly moist soil root zone, usually through daily, light, early morning applications. Syringe as needed to prevent wilt, with the timing based on "foot printing" symptoms.

Vertical Mowing: Use to produce a very light combing effect as needed up to once per week for variable growth and grain control. May be needed a little more frequently during peak seedhead formation periods in spring and fall.

Topdressing: Apply two to four times per year. Suggest a minimum of twice per year with a spring application at 0.2 to 0.3 cubic yard per 1,000 square feet and a late fall application at 0.3 to 0.5 cubic yards per 1,000 square feet. Combine as a followup to cultivation when possible and use higher application rates. Top dressing as often as every 3 to 4 weeks during the growing season may be helpful except during the summer stress periods.

Cultivation: Utilize two to four times per year; use the higher frequencies on intensely trafficked greens on fine textured soils. Suggest a minimum of twice, involving very early spring (as soon as the equipment can be taken on the green), and an early fall timing. Avoid heat stress period if possible.

Spiking: Weekly throughout the summer when the soil temperature is above 70 F.

Weed Control: Control broadleafs as they appear. Suggest using mecoprop (MCPP). Avoid phenoxy herbicides—such as 2,4-D or silvex—because of potential phytotoxicity during heat stress periods. Hand weed goosegrass. Avoid organic arsenicals and preemergence weedy grass herbicides because of potential phytotoxicity.

Disease Control: Use a preventive fungicide program in which several effective fungicides are alternated. Dollar spot and anthracnose are usually the most severe depending on the climatic region.

Insect Control: Apply the appropriate insecticide as the insect problems appear. The *Ataenius spretulus* grub and the turfgrass weevil are of particular concern. Avoid emulsifiable concentrate formulations of insecticides.

Drainage: Adequate drainage is essential for healthy annual bluegrass. If drainage is poor, use surface and subsurface drainage techniques for improvement.

A CULTURAL PROGRAM FOR ANNUAL BLUEGRASS FAIRWAYS AND SPORTS FIELDS

Mowing Height: ½ to ¾ inch (1.3 to 1.9cm)

Mowing Frequency: Three times a week

Clipping Removal: No

Fertilization—Nitrogen: Apply 0.25 to 0.5 pounds of actual nitrogen per 1,000 square feet per growing month.

Fertilization—Phosphorus: Application rate should be based on soil tests.

Fertilization—Potassium: Application rate should be based on soil tests. Use at 50 to 70% of the nitrogen application rate depending on soil if soil tests are not available.

Fertilization—Iron: Iron is usually applied only when a visual iron deficiency appears.

Fertilization—Other Nutrients: Apply if a specific visual deficiency symptom is diagnosed.

Liming: Maintain the pH above 6.0. Apply limestone as indicated based on soil tests.

Irrigation: Maintain a moist but not wet soil through light, frequent irrigations at two to three day intervals, depending on stress conditions.

Vertical Mowing: Not usually practical.

Topdressing: Not practiced.

Cultivation: Core in the spring and fall as needed to encourage new seedling growth and for cultivation.

Weed Control: Applied as needed; usually in the spring and/or fall; be sure to use minimal rates.

Disease Control: Some utilize a low-cost preventive program for dollar spot control, where it is a serious problem. Others follow a rigorous and more costly program.

Insect Control: Apply the appropriate insecticide as needed when serious insect injury appears.

CONTROL OF ANNUAL BLUEGRASS

Cultural Control

Procedures for effectively controlling annual bluegrass infestations in turf must be developed, taking into consideration the environmental adaptation and cultural requirements of the specific turfgrass species and cultivar(s) in use. A thorough search of available scientific literature consistently revealed two factors associated with annual bluegrass occurrence in turf: (a) reduced competition from the permanent turfgrasses and (b) favorable conditions for annual bluegrass during at least a portion of the growing season.

Reduced turfgrass competition is usually attributed to: close mowing, excessive irrigation, poor drainage, compacted soils, intense traffic, improperly timed soil cultivation and vertical mowing, or use of nonadapted species or cultivars (10 and 117).

Improper fertilization practices are sometimes associated with annual bluegrass invasion. In Illinois, high spring applications of nitrogen fertilizer (2 lb N/1000 sq ft in April and again in May) were found to result in severe *Fusarium* blight incidence on Kentucky bluegrass in August (108). The diseased turfs were subsequently invaded by annual bluegrass, while turfs that had received a more moderate rate of nitrogen fertilizer in spring (1 lb N/1000 sq ft or less in April and May) remained weed-free.

A cultural program should be designed to optimize the competitive ability of the specific turfgrass cultivar in use. This includes: (a) the timing, amount and form of plant nutrient application through fertilization; (b) the amount, frequency, and uniform distribution of water provided through irrigation; (c) the height, frequency, pattern and method of mowing; (d) the method, timing, and severity of cultivation; (e) the proper use of pesticides for controlling problem weeds, diseases, and insects; and (f) reasonable use of the turf.

Frequently, the turfgrass cultural program is selected to maintain a turf at a certain level of quality required for a particular use. Golf course tees are mowed closely to provide firm footing, high shoot density, and low shoot growth for play. Fertilization and irrigation are performed frequently to maintain turfgrass density and to stimulate recovery from wear and divot damage. Fairways are also maintained under close mowing to provide adequate shoot density for a satisfactory ball lie. Irrigation is performed regularly to maintain shoot density, but fertilization is conducted on a modest schedule to prevent excessive shoot growth and, presumably, thatch.

Roughs receive a low intensity of culture and are frequently the only areas on the golf course devoid of annual bluegrass. The same turfgrass may be used for all three turfs; yet the culture of tees, fairways, and roughs can differ widely in intensity. Selection of a specific cultivar or blend of compatible cultivars best adapted to each cultural intensity would be an important consideration in minimizing annual bluegrass invasion.

Different blends can be planted for the tees, fairways, and roughs to achieve the playability characteristics and growth rate desired for each type of turf. Furthermore, the cultural program would have to be carefully programmed based on a detailed knowledge of the cultural requirements of the cultivars in use.

Creeping bentgrass is used for putting greens in temperate climates. Engel and Illnicki (37) indicated that the invasion of a bentgrass turf by annual bluegrass is less likely if irrigation is performed adequately for the bentgrass, but less than required by annual bluegrass. Musser (88) cautioned that water should be applied sparingly in early fall when annual bluegrass seed is germinating.

A suggested program includes provisions for adequate, properly timed soil aeration to encourage vigorous growth of the desirable turf at the expense of annual bluegrass; removal of clippings, where practical, to prevent annual bluegrass seeds from falling into the turf; proper timing of fertilizer applications in late summer, before reestablishment of annual bluegrass; and using organic sources of nitrogen in the fall to encourage bentgrass growth during cool weather.

Engel (32) suggested seeding bentgrass in late summer, when 85° temperatures predominate, to help bentgrass gain a headstart over annual bluegrass. He concluded that in spite of the problems with warm weather seedings associated with watering needs, late summer seedings may still have an advantage over those made in cool fall weather.

Bermudagrasses are used in warm climatic regions for many types of turf—including putting greens, tees, and fairways. Winter dormancy of this species allows invasion by annual bluegrass (Fig. 18)[6] and other weeds, especially if the turf is disturbed by cultivation or other causes (117). Engel and Ilnicki (37) emphasized the importance of spring and summer fertilization to provide a dense stand of bermudagrass by late summer prior to cool weather that favors annual bluegrass seed germination.

[6]Fig. 18 is a color picture located on the outside back cover.

Youngner (117) reported that infrequent, deep irrigation which maintained modest to low soil moisture levels reduces the annual bluegrass content of a bermudagrass turf during the summer months in southern California. He also found that high mowing at 7.6 cm (3 in.) discouraged annual bluegrass invasion into bermudagrass compared to a 1.3 cm (0.5 in.) mowing height.

Bermudagrass greens may be overseeded with cool-season turfgrasses in the fall to provide a green, growing winter turf. The overseeded turfgrasses may persist for three to six months, depending upon location and climatic conditions (96). The rate of establishment and persistence of the overseeded turfgrasses are important in preventing annual bluegrass invasion (113). The particular species, cultivar(s), and/or polystands selected can also determine the competitive potential and eventual extent of annual bluegrass invasion (10).

Chemical Control

Attempts at controlling annual bluegrass with chemicals date back to the 1930's when lead arsenate, then used as an insecticide, was found to discourage annual bluegrass in turf (100). Since then, numerous herbicides varying considerably in their chemistry have been reported as promising for annual bluegrass control. Many have since been shown to have serious limitations, especially those with broad spectrum selectivity.

Inorganic Arsenicals.

Daniel (28) reported that calcium arsenate, lead arsenate, and sodium arsenite were effective in removing annual bluegrass from Kentucky bluegrass and colonial bentgrass turfs. He further indicated that arsenic toxicity was inversely related to the soil phosphorus level. Engel and Aldrich (35) reported substantial reductions in annual bluegrass in colonial bentgrass fairways from successive applications of sodium arsenite in combination with 2,4-D. Turgeon (107) reported that calcium arsenate reduced the stand of annual bluegrass in closely-clipped Merion Kentucky bluegrass turf and held it at approximately 18 percent for one year.

Injury to bentgrass turf has been observed following the application of arsenic compounds (28 and 26). Engel *et al* (38) reported that the quality of bentgrass fairway turfs was often reduced to 50 percent of normal from calcium arsenate. Also, late summer applications were generally more damaging than mid-spring applications.

Turgeon *et al* (109) reported that repeated applications of calcium arsenate to Kentucky bluegrass resulted in thatch development, shallow rooting, higher wilting tendency, higher disease incidence, and reduced water infiltration due to an alteration of soil physical conditions due to the lack of earthworm activity and root growth.

Dickson *et al* (31) observed substantial differences in turfgrass injury to 90 Kentucky bluegrass cultivars from calcium arsenate applied at the rate of 4.8 pounds a.i./1,000 square feet in May and again in September. Merion, Windsor, and Baron showed very little injury; Touchdown, Nugget, Pennstar, and Fylking were moderately to severely injured. They cautioned that new Kentucky bluegrass cultivars should be carefully tested for tolerance to calcium arsenate before embarking on an application program for annual bluegrass control. A similar situation may also exist with other species and herbicides. More information is needed in this area.

Freeborg (41) reported that annual bluegrass is less sensitive to arsenic during short photoperiods compared to longer photoperiods. However, no change in response was observed under varying light intensities. He observed that higher temperatures resulted in an increase in the rate at which arsenic fixation occurred in the soil. However, the sensitivity of annual bluegrass to arsenic also increased with increasing temperature.

Carrow *et al* (23) reported no effect of arsenic applied at rates as high as 800 pounds As/acre on the germination of annual bluegrass seed after incubation of arsenic with soil. Seed germination was inhibited at 400 pounds per acre without incubation.

Freeborg (41) concluded that the arsenic must be concentrated in the surface inch of soil to be toxic to annual bluegrass. Presumably, this is due to the fixation of arsenic that occurs when it is mixed with the soil medium. He determined that less arsenic is retained by organic sand than by silt loam, silty clay loam, or muck soils. Therefore, more arsenic would be required to obtain equivalent amounts of extractable arsenic and, thus, control of annual bluegrass in soils with higher clay and silt contents.

Soil moisture level and pH were also found to affect the amount of extractable arsenic. Carrow (22) determined that increasing the pH reduced the arsenic activity in soils. He also found that the amount of extractable arsenic from treated soils was highest when the soil moisture was maintained at field capacity compared to 85% and 70% of field capacity.

Musser (88) recommended eradication of annual bluegrass in late August with sodium arsenite applied at 40 pounds per acre in 50 to 100 gallons of water. His subsequent renovation procedure called for: four to six passes with a core cultivator to prepare the seedbed; application of lime and fertilizer as needed; pulverize and work cores into the holes; allow annual bluegrass germination to occur; apply sodium arsenite at 25 pounds per acre; and drag, seed, and roll the area.

These rates are quite high. A 5 pound per acre sodium arsenite rate usually kills annual bluegrass. Currently, paraquat is used more commonly than sodium arsenite for renovating annual bluegrass infested turfs. Regardless of the chemical used, successful renovation must also include correction of the basic cause of turfgrass deterioration that led to the annual bluegrass invasion.

Sodium arsenite has been applied to dormant bermudagrass for control of annual bluegrass (116 and 60). Paraquat is more commonly utilized now. Great care must be exercised to ensure that the warm-season turfgrass is completely dormant if injury is to be avoided.

Postemergence Herbicides.

Goetze (47) found that fall applications of neburon gave excellent control of annual bluegrass with no sustained injury to Kentucky bluegrass. Mruk and DeFrance (87) reported fair to moderate control in athletic field turf with DSMA, chloropropham, and neburon. In tests by DeFrance and Kolett (30) several copper compounds showed promise for controlling annual bluegrass without objectionable injury to creeping bentgrass.

Fluorophenoxyacetic acids were reported to induce sterility in annual bluegrass for four to six weeks. Maleic hydrazide (1 pound per acre) reduced the number of annual bluegrass seedheads, but also seriously reduced the bentgrass content in polystands and allowed a substantial increase in white clover (35).

Goss and Zook (51) studied the effects of maleic hydrazide plus chlorflurenol on annual bluegrass infested turfs in Washington. They reported substantial inhibition of seedhead formation with some temporary discoloration of Merion Kentucky bluegrass and bentgrass. Other effects included: reduction of the mowing requirement; control of some broadleaf weeds; reduction of annual bluegrass stands with some increase in the density of perennial turfgrasses; and reduced viability in annual bluegrass seed. Young seedlings of annual bluegrass were reported killed by fall applications. The authors recommended overseeding with desirable turfgrasses in conjunction with autumn applications of maleic hydrazide + chlorflurenol.

Long (79) found that where seedhead suppression occurred following treatment with maleic hydrazide and chlorflurenol, annual bluegrass seeds in the soil were significantly lower in germination compared to seeds from untreated plots. However, even with the most effective chemical treatment there were still more than 30,000 viable seeds per square meter in the surface 1 inch (2.5 cm) of soil. He concluded that a control program based on seedhead suppression alone would not be successful.

Engel and Aldrich (35) reported substantial reductions of annual bluegrass in colonial bentgrass fairways following several applications of endothall in the spring at 0.5 pounds per acre. Cockerham and Whitworth (24) reported selective injury to annual bluegrass in common bermudagrass turf at 4 to 6 pounds per acre, but recovery was rapid, necessitating repeated treatments.

Turgeon *et al* (105) reported a substantial reduction of annual bluegrass in Merion Kentucky bluegrass following a single application in September at both 2 and 4 pounds per acre. However, the best control was obtained with three 1-pound-per-acre applications at two-week intervals. Endothall caused temporary browning of the turf, but the Kentucky bluegrass recovered selectively after three to four weeks. Granular formulations of endothall provided superior selectivity over foliar sprays in greenhouse studies; but field results were variable.

Morphologically differing biotypes of annual bluegrass responded differently to endothall treatments. A root treatment with a 50 ppm endothall solution was adequate to kill an upright-growing, annual biotype; twice that concentration only stunted a prostrate-growing, perennial biotype (Fig. 19). The selectivity of endothall in turfs was attributed to differences in

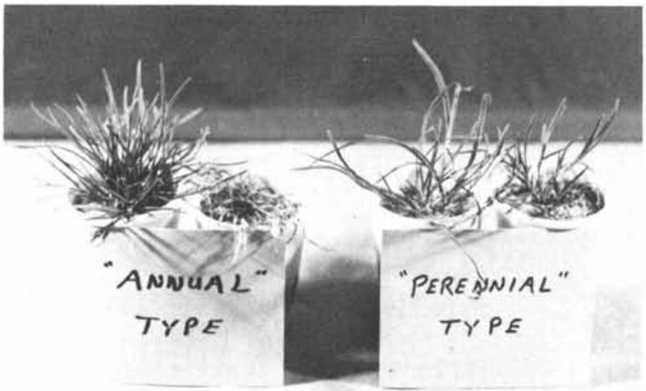

Fig. 19. Comparison of the differential effect of a 50 ppm endothall solution applied to a root zone of annual and perennial biotypes of annual bluegrass. Herbicide application was made to the plants on the right side in each case. (Photo—A. J. Turgeon)

absorption and action of the herbicide in root applications, while morphological differences among turfgrass species, spray retention, and action contributed to selectivity following foliar applications (106).

Where endothall was applied to closely clipped Kentucky bluegrass infested with annual bluegrass, Turgeon (107) found that annual bluegrass quickly reinfested the plots after each treatment. He concluded that it could not be controlled by strictly postemergence herbicides where climatic and cultural conditions were so favorable to annual bluegrass.

Horn *et al* (61) reported the successful use of pronamide for selectively controlling annual bluegrass in bermudagrass turf. They determined that a waiting period of at least 60 days was necessary to allow sufficient time for breakdown of the herbicide between applying of pronamide and overseeding for winter greens. The authors also found that pronamide was very useful in eliminating volunteer ryegrass and other cool-season grasses after the bermudagrass initiated growth in spring.

More recently, Meyers and McCarthy (84) found that applying activated charcoal at 2.5 lb/1000 sq ft, 10 days after treatment with pronamide, deactivated the residual herbicide without reducing the control of annual bluegrass. Thus, the interval between herbicide treatment and overseeding could be reduced substantially through the timely use of activated charcoal.

Johnson (70) reported effective control of annual bluegrass in dormant common bermudagrass turf, with glyphosate or paraquat, applied at 0.5 lb/acre, without injury to the bermudagrass.

The most recent development in postemergence control of annual bluegrass in cool-season turfgrasses was reported by Jacquemin and Henderlong (69). They found that linuron, applied at 3 to 4.5 lb/acre, provided satisfactory selective control of annual bluegrass in Kentucky bluegrass turf. However, creeping bentgrass, hard fescue, and perennial ryegrass were not tolerant of this herbicide.

Preemergence Herbicides.

Neidlinger (89) determined that bromacil applied preemergence to Kentucky bluegrass and annual bluegrass in seed fields provided selective control of annual bluegrass at 0.4 and 0.2 lb/acre. Selectivity was considerably less with post-emergence applications to these species. Gibeault (45) reported that an application of bromacil, at 0.5 lb/acre, provided complete preemergence control of annual bluegrass, but allowed good germination of colonial bentgrass and red fescue that was seeded one week after application of the herbicide.

Goss (48 and 50) found that DCPA, DMPA, trifluralin, bensulide, and diphenamid effectively inhibited both seed germination and subsequent growth of annual bluegrass seedlings in western Washington. His results indicated that overseeding with desirable turfgrasses should be delayed at least 12 weeks after application of these materials. Gibeault (45) observed that DCPA, trifluralin, bensulide, and benefin effectively controlled annual bluegrass that was artificially introduced into a polystand of colonial bentgrass and red fescue.

Cornman *et al* (26) reported injury to bentgrasses with DCPA and DMPA, but not bensulide. However, Callahan (20) reported injury from bensulide following three annual applications to Penncross creeping bentgrass in Tennessee. Injury was caused by increased proneness to wilting, high temperature stress, and disease even though a preventative fungicide treatment program was followed.

Bingham *et al* (15) reported that the rate of bensulide required for annual bluegrass control in overseeded common bermudagrass was partially offset by competing cool season turfgrasses. Studies by Bingham and Schmidt (14) revealed that more herbicide was required to injure milo *(Sorghum bicolor* Pers.) roots in a bioassay of the surface inch of a silt loam soil taken from bensulide treated turf than from lower soil depths. This was positively correlated to higher levels of calcium, phosphorus, potassium, and organic matter in the surface soil.

The persistence of bensulide in the soil varied with formulation (14). The emulsifiable concentrate was degraded more rapidly than the granular formulation. The authors reported also that detectable quantities of bensulide were found to depths of 5 inches in soil after four annual applications. In a study by Mazur *et al* (83) only small amounts of bensulide could be detected in the surface inch of a silt loam soil after four annual applications at 15 lb/acre and there was little or no downward movement of the herbicide.

The residual activity of DCPA in the soil appears to be limited to two or three months (48 and 76). Thus, it would require at least two applications per year to prevent annual bluegrass development from seed in certain parts of the U.S.A. DCPA has caused substantial injury to bentgrass turf, especially the cultivars Toronto (94) and Cohansey (53). Juska *et al* (75) reported that stolons from DCPA treated greens failed to root well and the turf was less dense and ragged in appearance.

DCPA is generally considered safe to use on Kentucky bluegrass turf. Engel and Callahan (36) reported no significant inhibition of root or shoot growth from Merion Kentucky bluegrass plugs that were planted in loam soil treated with 12 lb/acre of DCPA. However, Gaskin (43) measured significant reductions in tillering and rhizome growth from Merion Kentucky bluegrass planted in greenhouse flats containing a mixture of 1/2 sand and 1/2 clay loam and treated with DCPA at 10 lb/acre. Juska and Hanson (72) observed slight but temporary thinning of Kentucky bluegrass growing on a silt loam soil when treated with DCPA in July.

Solon and Turgeon (98) found that oxadiazon could be used in conjunction with vegetative establishment of Kentucky bluegrass from plugs to exclude annual bluegrass and other annual weeds from entering the turf. They concluded that weed-free turf could be established on soils containing a large reservoir of annual bluegrass seed, without requiring expensive soil fumigation.

Current Status of Herbicides for Annual Bluegrass Control.

Few of the herbicides that have been tested for selective control of annual bluegrass have actually been labeled for this use. Of these, some have given way to safer and more effective materials while others have simply disappeared because of difficulties encountered in their production and/or marketing. Table 5 lists the herbicides which have been used on established turf and some of the precautions that should be observed. (NOTE: No herbicide application program for annual bluegrass control should be initiated until adequate, long term testing has been conducted on a small scale to ascertain the specific results obtainable on a particular site and turfgrass cultivar.) Table 6 gives the chemical names for several herbicides suggested for use on turf.

Table 5. Herbicides used for control of annual bluegrass

TURFGRASS SPECIES	HERBICIDE	TYPE OF APPLICATION	COMMENTS
Kentucky bluegrass	benefin	preemergence	Apply early spring and late summer prior to germination of annual bluegrass.
	DCPA	preemergence	Apply early spring and late summer prior to germination of annual bluegrass.
	linuron[a]	postemergence	Apply spring and late summer to turf with small patches (4 in. dia.) of annual bluegrass for selective control.
	calcium arsenate[a]	pre/post	Apply early spring and late summer until selective control of annual bluegrass occurs.
	maleic hydrazide + chlorflurenol	postemergence	Apply early fall after seed germination of annual bluegrass for gradual removal.
	endothall	postemergence	Apply late summer; selective recovery of the Kentucky bluegrass requires 3 to 4 weeks.
Creeping bentgrass	bensulide	preemergence	Apply late summer prior to germination of annual bluegrass. Repeated use may result in bentgrass injury, especially during mid-summer.
	lead arsenate[a]	pre/post	Apply early spring and late summer until selective control of annual bluegrass occurs.
Bermudagrass	paraquat	postemergence	Apply to dormant bermudagrass during winter for removal of annual bluegrass.
	pronamide	postemergence	Apply to selectively remove annual bluegrass; treat with activated charcoal at least 10 days after application of the herbicide where cool season turfgrasses are to be overseeded.

(a) Future commercial availability uncertain.

Table 6. Chemical names of herbicides.

COMMON NAME	TRADE NAME(s)	CHEMICAL NAME
benefin	Balan	*N*-butyl-N-ethyl-ααα-trifluoro-2, 6-dinitro-*p*-toluidine.
bensulide	Betasan, Pre-San	*O, O*-diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl) benzenesulfonamide.
bromacil	Hyvar	5-bromo-6-methyl-3-(1-methylpropyl)-uracil.
Calcium arsenate	Chip-Cal	
chlorflurenol		methyl hydroxyfluorene-9-carboxylate
chloropropham		isopropyl *m*-chlorocarbanilate.
DCPA	Dacthal	dimethyl tetrachloroterephthalate
diphenamid	Dymid, Enide	*N,N*-dimethyl-2-,2-diphenylacetamide
DMPA	Zytron	*O*-(2,4-dichlorophenyl) *O*-methyl isopropylphosphoramidothioate.
DSMA		disodium methanearsonate.
endothall	Endothal	7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid.
glyphosate	Roundup	*N*-(phosphonomethyl) glycine.
lead arseanate		
linuron	Proturf Selective Poa annua control	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea.
maleic hydrazide		1,2-dihydro-3,6-pyridazinedione.
neburon		1-butyl-3-(3,4-dichlorophenyl)-1-methylurea.
oxadiazon	Ronstar	2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ^2-1,3,4-oxadiazolin-5-one.
paraquat		1,1' dimethyl 4,4' bipyridiniumion.
pronamide	Kerb	3,5-dichloro-(*N*-1,1-dimethyl-2-propynyl) benzamide.
sodium arsenite		
trifluralin	Treflan	ααα,-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*toluidine.
2,4-D		(2,4-dichlorophenoxy) acetic acid.

LITERATURE CITED

1. Adams, D. F. 1956. The effects of air pollution on plant life. AMA Archives of Industrial Health. 14:229-245.
2. Anderson, B. R. and S. R. McLane. 1958. Control of annual bluegrass and crabgrass in turf with fluorophenoxyacetic acids. Weeds. 6:52-58.
3. Antipov, V. G. 1959. Gas resistance of lawn grasses. Botanicheski Zhurnal. 44:990-992.
4. App, B.A. and S. H. Kerr. 1969. Harmful Insects. *In* Turfgrass Science. Amer. Soc. of Agronomy. Madison, WI. pp. 336-350.
5. Beard, J. B. and C. R. Olien. 1963. Low temperature injury in the lower portion of *Poa annua* L. crowns. Crop Sci. 3:362-363.
6. Beard, J. B. 1964. Effects of ice, snow, and water covers on Kentucky bluegrass, annual bluegrass, and creeping bentgrass. Crop Sci. 4:638-640.
7. Beard, J. B. 1966. Direct low temperature injury of nineteen turf grasses. Quarterly Bulletin of the Michigan Agr. Experiment Station. 48(3):377-383.
8. Beard, J. B. 1968. Low temperature and *Poa annua*. USGA Green Section Record. 6(4):10-11.
9. Beard, J. B. and D. P. Martin. 1970. Influence of water temperature on submersion tolerance of four grasses. Agronomy Jour. 62:257-259.
10. Beard J. B. 1970. An ecological study of annual bluegrass. USGA Green Section Record. 8(2):13-18.
11. Beard, J. B. 1970. The plant characteristics, dissemination, environmental adaptation, and cultural requirements of *Poa annua* L. Rasen Turf Gason. 2:33-35.
12. Beard, J. B. 1973. Turfgrass: Science and Culture. Prentice-Hall Inc.; Englewood Cliffs, NJ. pp. 1-658.
13. Beddows, A. R. 1931. Seed setting and flowering in various grasses. Welsh Plant Breeding Station Service H. No. 12. pp. 5-99.
14. Bingham, S. W. and R. E. Schmidt. 1967. Residue of bensulide in turfgrass soil following annual treatments for crabgrass control. Agronomy Jour. 59:327-329.
15. Bingham, S. W., R. E. Schmidt, and C. K. Curry. 1969. Annual bluegrass control in overseeded bermudagrass putting green turf. Agronomy Jour. 61:908-911.
16. Bobrov, R. A. 1955. The leaf structure of *Poa annua* with observations on its smog sensitivity in Los Angeles County. American Jour. of Botany. 42(5):467-474.
17. Bogart, J. E. 1972. Factors influencing competition of annual bluegrass (*Poa annua* L.) within established turfgrass communities. MS Thesis. Michigan State University. pp. 1-75.
18. Bogart, J. E. and J. B. Beard. 1973. Cutting height effects on the competitive ability of annual bluegrass (*Poa annua* L.). Agronomy Jour. 65:513-514.
19. Britton, W. E. 1932. Weevil grubs injure lawns. Connecticut Agr. Experiment Station Bulletin. 338:593.
20. Callahan, L. M. 1972. Phytotoxicity of herbicides to a Penncross bentgrass green. Weed Sci. 20:387-391.
21. Carroll, J. C. 1943. Effects of drought, temperature, and nitrogen on turfgrasses. Plant Physiology. 18:19-36.
22. Carrow, R.N. 1972. Soil factors affecting arsenic soil tests and growth of selected turfgrasses. Ph.D. Thesis. Michigan State University. 223 pp.
23. Carrow, R. N., P. E. Rieke, and B. G. Ellis. 1975. Growth of turfgrass as affected by soil phosphorus and arsenic. Soil Sci. Soc. Amer. Proc. 39:1121-1124.
24. Cockerham, S. T. and J. W. Whitworth. 1967. Factors affecting *Poa annua* L. control. Weeds. 15:98-101.
25. Cockerham, S. T. and J. W. Whitworth. 1967. Germination and control of annual bluegrass. The Golf Superintendent. 35(5):10-17, 45-46.
26. Cornman, J. F., F. M. Madden, and N. J. Smith. 1964. Tolerance of established lawn grasses, putting greens, and turfgrass seeds to preemergence crabgrass control chemicals. Northeastern Weed Control Conference Proc. 18:519-522.
27. Couch, H. B. 1973. Diseases of Turfgrasses. R. E. Kruger Publ. Co., Huntington, NY. pp. 1-348.
28. Daniel, W. H. 1955. *Poa annua* control with arsenic materials. Golf Course Reporter. 23(1):5-9.
29. Davies, W. 1938. Vegetation of grass verges and other excessively trodden habitat. Jour. of Ecology. 26:38-49.
30. DeFrance, J. A. and J. R. Kolett. 1959. Annual bluegrass (*Poa annua* L.) control with chemicals. Golf Course Reporter. pp. 14-18.
31. Dickson, W. K., R. E. Engel, and C. R. Funk. 1974. Differential reaction of Kentucky bluegrass varieties, blends, and mixtures to tricalcium arsenate. Rutgers Turfgrass Proc. 5:59-53.
32. Engel, R. E. 1967. Temperatures required for germination of annual bluegrass and colonial bentgrass. The Golf Superintendent. 35(9):20-23.
33. Engel, R. E. 1974. Influence of nitrogen fertilization on species dominance in turfgrass mixtures. Proc. Second Int. Turfgrass Research Conf. pp. 104-111.
34. Engel, R. E. and R. J. Aldrich. 1955. Control of annual bluegrass (*Poa annua*) in fairway type turf. Proc. of the Northeastern Weed Control Conference. pp. 353-355.
35. Engel, R. E. and R. J, Aldrich. 1960. Reduction of annual bluegrass, *Poa annua*, in bentgrass turf by the use of chemicals. Weeds. 8:26-28.
38. Engel, R. E., A. Morrison, and R. D. Ilnicki. 1968. Preemergence chemical effects on annual bluegrass. The Golf Superintendent. 36(2):20-21, 39.
39. Ferguson, N. L. 1936. A greenskeepers guide to the grasses, the meadowgrasses. Journ. of the Board of Greenkeeping Research 4(15):274-279.
40. Fischer, J. A. 1967. An evaluation of high temperature effects on annual bluegrass (*Poa annua* L.). MS Thesis, Michigan State University. pp. 1-42.

41. Freeborg, R. P. 1971. Arsenic concentrations required for *Poa annua* control as determined by soil tests. Ph.D. Thesis. Purdue University. 137 pp.

42. Funk, C. R., R. E. Engel, and P. M. Halisky. 1966. Performance of Kentucky bluegrass varieties as influenced by fertility level and cutting height. 1966 Report on Turfgrass Research at Rutgers University, New Jersey Agr. Experiment Station Bulletin. 816. pp. 7-21.

43. Gaskin, T. A. 1964. Effect of preemergence, crabgrass herbicides on rhizome development in Kentucky bluegrass. Agronomy Jour. 56:340-342.

44. Gibeault, V. A. 1965. Annual meadowgrass—a major turf weed? Jour. of the Sports Turf Research Institute. 41:48-52.

45. Gibeault, V. A. 1967. Investigations on the control of annual meadowgrass. Jour. of the Sports Turf Research Institute. 42:17-40.

46. Gibeault, V. A. 1970. Perenniality in *Poa annua* L. Ph.D. Dissertation. Oregon State University. pp. 1-124.

47. Goetze, N. 1956. Research on *Poa annua* control. Midwest Regional Turf Conference Proc. pp. 37-38.

48. Goss, R. L. 1964. Preemergence control of annual bluegrass (*Poa annua* L.) Agronomy Jour. 56:479-481.

49. Goss, R. L. 1964. The ecology of *Poa annua*, annual bluegrass. Proceedings of the 18th Annual Northwest Turfgrass Conference. pp. 6-11.

50. Goss, R. L. 1965. Preemergence control of annual bluegrass (*Poa annua* L.). Golf Course Reporter. 33(3):24-26.

51. Goss, R. L. and F. Zook. 1971. New approach for *Poa annua* control. The Golf Superintendent. 39(1):46-48.

52. Goss, R. L. 1974. Effects of variable rates of sulfur on the quality of putting green bentgrass. Proc. Second Int. Turfgrass Research Conf. pp. 172-175.

53. Griffin, H. M. 1969. Management basics for bent greens in southern areas. USGA Green Section Record. 7(1):10-13.

54. Hackel, E. 1904. Zur Biologie der *Poa annua* L. Osterr. Bot. Zeitsch. 54.

55. Haes, E. C. M. 1956. Annual meadowgrass in turf—an appraisal. Jour. of the Sports Turf Research Institute. 9:216-218.

56. Harper, J. C. 1965. History of *Poa annua*. Turf Conf. Proc. University Massachusetts. pp. 2-9.

57. Hawes, D. T. 1965. Control of annual bluegrass. Turf Conf. Proc., University Massachusetts. pp. 5-10.

58. Hawes, D. T. 1965. Studies of the growth of *Poa annua* L. as affected by soil temperature and observations of soil temperature under putting green turf. M. S. Thesis. Cornell University. pp. 1-79.

59. Hitchcock, A. S. and A. Chase. 1950. Manual of the grasses of the United States. USDA Miscellaneous Publication No. 200. pp. 1-1051.

60. Holt, E. C. 1969. Turfgrasses under warm, humid conditions. *In* Turfgrass Science. Amer. Soc. Agronomy, Madison, WI. pp. 513-528.

61. Horn, G. C., G. S. Smith, M. T. Ayer, B. E. Rehberg, R. Briggs, and L. Reid. 1972. Farewell to *Poa annua*. The Golf Superintendent. 40(8):11-16.

62. Hovin, A. W. 1957. Bulk emasculation by high temperatures in annual bluegrass, *Poa annua* L. Agronomy Jour. 49:463.

63. Hovin, A. W. 1957. Cytogenetic studies on reproduction in *Poa annua* L. Ph.D. thesis, University of California at Los Angeles.

64. Hovin, A. W. 1957. Germination of annual bluegrass seed. Southern California Turf Culture. 7(2):13.

65. Hovin, A. W. 1957. Variations in annual bluegrass. The Golf Course Reporter. 25(7):18-19.

66. Hovin, A. W. 1958. Reduction of self-pollination by high night temperatures in naturally self-fertilized *Poa annua* L. Agronomy Jour. 50:369-371.

67. Hubbard, C. E. 1954. Grasses. Penguin Press. Baltimore Press. pp. 1-428.

68. Jackson, N. and J. D. Smith. 1965. Fungal diseases of turfgrasses. Sport Turf Research Institute Publication (2nd ed). pp. 1-97.

69. Jacquemin, P. L. and P. R. Henderlong. 1976. Selective control of *Poa annua* in Kentucky bluegrass. Proceedings of the Northeastern Weed Science Soc. 30:345-350.

70. Johnson, B. J. 1976. Glyphosate for weed control in dormant bermudagrass. Weed Sci. 24:140-143.

71. Juhren, M., W. Noble and F. W. Went. 1957. The Standardization of *Poa annua* as an indicator of smog concentrations. Plant Physiology. 32(6): 576-586.

72. Juska, F. V. and A. A. Hanson. 1964. Effect of preemergence crabgrass herbicides on seedling emergence of turfgrass species. Weeds. 12:97-101.

73. Juska, F. V. and A. A. Hanson. 1967. Factors affecting *Poa annua* L. control. Weeds. 15(2):98-101.

74. Juska, F. V. and A. A. Hanson. 1969. Nutritional requirements of *Poa annua* L. Agronomy Jour. 61:466-468.

75. Juska, F. V., A. A. Hanson, and A. W. Hovin. 1970. Phytotoxicity of preemergence herbicides. USGA Green Section Record. 8:2-5.

76. Kaufman, D. D. 1972. Persistence and degradation of commonly used turf herbicides in our environment. Proc. of Scotts Turf grass Research Conf. 3:92-130.

77. Koshy, T. K. 1968. Evolutionary origin of *Poa annua* L. in light of karyotypic studies. Canadian Jour. of Genetics and Cytology. 10(1):112-118.

78. Koshy, T. K. 1969. Breeding systems in annual bluegrass, *Poa annua* L. Crop Sci. 9:40-43.

79. Long, F. W. 1976. Control of *Poa annua* L. on turf areas with growth regulators. M. S. Thesis, The Pennsylvania State University. 84 pp.

80. Lynch, R. I. 1903. *Poa annua* not a self-fertilizer. The Gardener's Chronical. 33:380.

81. Madden, E. A. 1967. *Poa annua*—problem weed in New Zealand. The Golf Superintendent. 35(1): 13-14.

82. Madison, J. H. 1971. Practical Turfgrass Management. Van Nostrand Reinhold Co., New York. pp. 1-466.

83. Mazur, A. R., J. A. Jagschitz, and C. R. Skogley. 1969. Bioassay for bensulide, DCPA, and Siduron in turfgrass. Weed Sci. 17:31-34.

84. Meyers, H. G. and W. J. McCarthy. 1974. Effects of activated charcoal and time of application on established Kerb treated *Poa annua*. Proc. of the Florida State Horticultural Soc. 87:513-515.

85. Monteith, J. and A. S. Dahl. 1932. Turf diseases and their control. USGA Green Section Bulletin. 12(4):85-188.

86. Morgan, W. C., J. Letey, and L. H. Stolzy. 1965. Turfgrass renovation by deep aerification. Agronomy Jour. 57:494-496.

87. Mruk, C. K. and J. A. DeFrance, 1957. A comparison of chemicals for the control of annual bluegrass *(Poa annua* L.) in lawn turf. Golf Course Reporter. 25(6):5-7.

88. Musser, H. B. 1962. Turf Management. (Revised) McGraw-Hill Book Co. Inc., NY. pp. 1-356.

89. Neidlinger, T. J. 1965. *Poa annua* L.: Susceptibility to several herbicides and temperature requirements for germination. MS Thesis, Oregon State University, pp. 1-97.

90. Niemczyk, H. D. 1976. A new grub problem in golf course turf. The Golf Superintendent. 44:27-29.

91. Piper, C. V. and R. A. Oakley. 1927. Annual bluegrass (*Poa annua*). United States Golf Association Green Section. 7:128-129.

92. Renney, A. J. 1964. Preventing *Poa annua* infestations. 18th Annual Northwest Turfgrass Conf. Proc. pp. 3-5.

93. Rieke, P. E., and R. Bay. 1976. Soils research report. 46th Ann. Michigan Turfgrass Conf. Proc. 5:1-6.

94. Roberts, E. C. and D. R. Brockshus. 1966. Kind and extent of injury to greens from preemergence herbicides. The Golf Superintendent. 34:13, 16, 18, 36.

95. Roberts, E. C., F. E. Markland and H. M. Pellett. 1966. Effects of bluegrass stand and watering regime on control of crabgrass with preemergence herbicides. Weeds. 14(2):157-161.

96. Schmidt, R. E. 1970. Overseeding cool-season turfgrasses on dormant bermudagrass for winter. Proc. First Int. Turfgrass Research Conf. pp. 124-129.

97. Smith, J. D. 1954. The effect of lime application on the occurrence of Fusarium patch disease on a forced *Poa annua* turf. Jour. of the Sports Turf Research Institute. 9(34):467-470.

98. Solon, E. G. and A. J. Turgeon. 1975. Herbicides for vegetatively establishing Kentucky bluegrass turf form plugs. Agronomy Jour. 67:675-678.

99. Sprague, H. B. and E. E. Evaul. 1930. Experiments with turfgrasses in New Jersey. New Jersey Agr. Experiment Station Bulletin. 497. pp. 1-55.

100. Sprague, H. B. and G. W. Burton. 1937. Annual bluegrass (*Poa annua* L.) and its requirements for growth. New Jersey Agr. Experiment Station Bulletin. 630. pp. 1-24.

101. Stoutemyer, V. T. 1954. Annual bluegrass as a cool season grass for bermudagrass mixtures. Southern California Turf Culture. 4(1):1-2.

102. Tashiro, H. 1976. A serious menace to *P. annua* in Northeast. The Golf Superintendent. 44:35-37.

103. Timm, G. 1965. Biology and systematics of *Poa annua*. Feitschrift fur Ackerund Pflanzenbau. 122(3):267-294.

104. Tincker, M.A.H. 1925. The effect of day length upon the growth and reproduction of some economic plants. Annals Botany, London. 39:721.

105. Turgeon, A. J., D. Penner, and W. F. Meggitt. 1972. Selectivity of endothall in turf. Weed Sci. 20:557-561.

106. Turgeon, A. J., W. F. Meggitt, and D. Penner. 1972. Role of endothall in the control of annual bluegrass in turf. Weed Sci. 20:562-565.

107. Turgeon, A. J. 1974. Annual bluegrass control with herbicides in cool-season turfgrasses. Proc. of the Second Int. Turfgrass Research Conf. pp. 382-389.

108. Turgeon, A. J. and W. A. Meyer. 1974. Effects of mowing height and fertilization level on disease incidence in five Kentucky bluegrasses. Plant Disease Reporter. 58:514-516.

109. Turgeon, A. J., R. P. Freeborg, and W. N. Willis. 1975. Thatch development and other effects of preemergence herbicides in Kentucky bluegrass turf. Agronomy Jour. 67:563-565.

110. Tutin, T. G. 1952. Origin of *Poa annua* L. Nature. 169:160.

111. Tutin, T. G. 1957. A contribution to the experimental taxonomy of *Poa annua* L. Watsonia. 4:1-10.

112. Vargas, J. M. 1976. Disease poses threat to annual bluegrass. The Golf Superintendent. 44:43-45.

113. Ward, C. Y., E. L. McWhirter and W. R. Thompson, Jr. 1974. Evaluation of cool-season turf species and planting techniques for overseeding bermudagrass golf greens. Proc. of the Second Int. Turfgrass Research Conf. pp. 480-495.

114. Watson, W. 1903. *Poa annua* as a lawn grass. Gardener's Chronicle (859):380.

115. Wilkinson, J. F. and D. T. Duff. 1972. Rooting of *Poa annua* L. *Poa pratensis* L., and *Agrostis palustris* Huds. at three soil bulk densities. Agronomy Jour. 64:66-68.

116. Wilson, C. G. and J. M. Latham Jr., 1969. Golf fairways, tees and roughs. Turfgrass Science. Amer. Soc. Agronomy, Madison, WI. pp. 584-602.

117. Youngner, V. G. 1959. Ecological studies on *Poa annua* in turfgrasses. Jour. of the British Grassland Soc. 14(4):233-247.

118. Youngner, V. B. 1965. Annual bluegrass. *Poa annua*. California Turfgrass Culture. 15(2):15-16.

119. Youngner, V. B. 1967. Vertical mowing— aerification —and *Poa annua*. USGA Green Section Record. 5(3):6-7.

120. Youngner, V. G. 1968. Vertical mowing— aerification —and *Poa annua* invasion. California Turfgrass Culture. 18(1):6.

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Figs. 3a and 3b. Annual bunch type (left) versus perennial creeping type (right) annual bluegrass. (From Turfgrass: Science and Culture—Beard, 1973)

Fig. 6. The comparative low temperature tolerance of annual bluegrass (bottom), creeping bentgrass (center), and Kentucky bluegrass (top) when exposed to -15C (5F) soil temperatures for 5 hours. (Photo—J. B. Beard)

Fig. 7. Longitudinal section of an annual bluegrass crown showing that the darkened lower crown tissues have been killed by low temperature stress but the upper crown has survived. (Photo—J. B. Beard)

Fig. 8. Winterkill occurred in this poorly drained spot in a fairway while surrounding annual bluegrass survived. (Photo—P. E. Rieke)

Fig. 11. Anthracnose damage to an annual bluegrass fairway in Michigan. (Photo—J. M. Vargas, Jr.)

Fig. 13. *Ataenius spretulus* damage on an annual bluegrass fairway. (Photo—J. M. Vargas, Jr.)

Fig. 14. Closeup of *Ataenius spretulus* larvae. (Photo —J. M. Vargas, Jr.)

Fig. 16. Annual bluegrass development within the remains of crabgrass plant that was killed by frost in autumn. (Photo—A. J. Turgeon)

Fig. 18. Annual bluegrass invasion in a bermudagrass tee. (Photo—A. J. Turgeon)

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