ABSTRACT

FACTORS INFLUENCING COMPETITION OF ANNUAL BLUEGRASS (POA ANNUA L.) WITHIN ESTABLISHED TURFGRASS COMMUNITIES AND SEEDLING STANDS

By

James E. Bogart

Phenological observations and controlled climate growth chamber studies were used to investigate the growth responses of annual bluegrass (*Poa annua* L.), Merion Kentucky bluegrass (*Poa pratensis* L.), and Penncross creeping bentgrass (*Agrostis palustris* Huds.). Measurements of root and shoot dry weights were made at each of seven constant temperature treatments. Annual bluegrass seedhead production and seed germination were also observed.

The phenological observations, when combined with the temperature findings, indicate that Penncross creeping bentgrass and Merion Kentucky bluegrass began spring growth prior to annual bluegrass. Penncross creeping bentgrass and Merion Kentucky bluegrass initiated new shoot growth between 50° and 55°F, while established plants of annual bluegrass did not initiate new spring growth until the soil temperature exceeded 55°F.

Penncross creeping bentgrass produced maximum root dry weight at 60°F while Merion Kentucky bluegrass and annual bluegrass produced maximum root dry weights at 70°F. Annual bluegrass root growth was significantly higher than Merion Kentucky bluegrass and Penncross creeping bentgrass at temperatures from 50° to 80°F. All three species produced maximum shoot dry weights at 60°F. Penncross creeping bentgrass was adapted to a wider range of temperatures having produced superior root and shoot dry weights at the extreme temperatures of 40° and 90°F.

Maturity of the three species was attained quicker at 80°F. The root systems of all three species had begun to turn brown at 80°F. Annual bluegrass plants at 80°F produced seedheads during the first 15 days of the constant temperature treatment. However, seedheads at 60°, 70°, and 90°F were not produced until after day 15.

Annual bluegrass seed germination did not differ significantly at constant temperatures from 40° to 70°F. However, very substantial decreases were observed at 80° and 90°F.

A second phase of the investigation involved a study of the competitive ability of annual bluegrass as influenced by cutting height. Annual bluegrass plants were grown in established Merion Kentucky bluegrass sod and in monostands. Measurements were made of shoot dry weight, root organic matter, tiller number, and shoot density of the annual bluegrass.

Cutting height treatments significantly influenced the shoot dry weight, tiller number, and shoot density. The 1.0 inch cutting height ranked highest in shoot dry weight and tiller number production. It was concluded that the optimum cutting height for annual bluegrass is 1.0 inch.

The final competitive factor investigated was root growth and development. Annual bluegrass, Penncross creeping bentgrass, and Merion Kentucky bluegrass were compared using special root observation boxes with slanting glass faces. Root growth and development was observed over 15-day and 30-day periods where one set of plants remained uncut while the other set was clipped three times weekly at 1.0 inch.

The rooting depth among the three species was non-significant at the end of both growing periods. Root organic matter produced during the 30-day period was also non-significant among species. However, visual observations during the initial 10 day period indicated that annual blue-grass root growth was more rapid. The root organic matter production after 15 days supported this observation. Cutting the plants at 1.0 inch reduced the rooting depth of all three species. Penncross creeping bentgrass was the most severely reduced. These findings showed that annual bluegrass is not shallow rooted as is commonly believed. Furthermore, the initial superiority in rooting capability of annual bluegrass could play an important role in its competition within a turfgrass community.

FACTORS INFLUENCING COMPETITION OF ANNUAL BLUEGRASS (*POA ANNUA* L.) WITHIN ESTABLISHED TURFGRASS COMMUNITIES AND SEEDLING STANDS

By

James E. Bogart

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1972

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation to the following persons without whose help and guidance this study would not have been possible:

The United States Golf Association Greens Section through whose grant this investigation was partially supported.

My loving wife Joan who aided in the preparation of this manuscript and without whose inspiration and encouragement this investigation may have never been completed.

Dr. W. F. Meggitt and J. M. Vargas Jr. for their assistance and suggestions as members of the author's guidance committee.

Dr. P. E. Rieke for his constructive criticism during the preparation of this manuscript and for serving on the guidance committee.

And finally, Dr. J. B. Beard; major professor, teacher, and above all friend; whose inspiration and guidance, throughout the course of study and this investigation, were greatly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Annual bluegrass (*Poa annua* L.) is considered by many as one of the most common turfgrass pests. Originally native to Europe, annual bluegrass is now distributed throughout the United States as well as in varied parts of the world. The species grows under a wide range of cultural, soil, and climatic conditions. Annual bluegrass has been found growing from seashore to mountain regions. It grows under both low and high fertility levels as well as a wide range of cutting heights. Annual bluegrass is comparatively well adapted to compacted soil conditions.

Several problems cause annual bluegrass to be classified as a turfgrass pest. The most objectionable of these characteristics is the lack of tolerance to environmental stresses. Annual bluegrass is susceptible to high and low temperature injury. Furthermore, the plant lacks hardiness to drought stress. The second major problem is its prolific seedhead production. An individual annual bluegrass plant can produce hundreds of seeds over a growing season. The ability of the plant to produce abundant seeds occurs even at close cutting heights. A new problem with annual bluegrass is being recognized in this modern era of atmospheric pollutants. It is highly susceptible to smog damage.

Much has been said and written over the years concerning the annual bluegrass problem in intensively cultured turfs. Most research projects conducted with annual bluegrass have dealt with methods of chemical control. Many herbicides have been evaluated in an attempt to produce an effective control program. The results have been erratic. Variability within the annual bluegrass species may be one of the reasons for the erratic control. Because of this, many professional turf managers have abandoned chemical control programs and have chosen to "live" with annual bluegrass. Some have been quite successful in this endeavor, while others have failed due to a lack of knowledge concerning the cultural requirements of annual bluegrass.

The objectives of this investigation were to define some of the cultural and environmental conditions which influence annual bluegrass infestations. Temperature response, cutting height, fertility level, and root development rate were studied to determine their effects on the competitiveness and survival of annual bluegrass. These effects were studied within both seedling and established turfgrass communities. The annual bluegrass responses were compared with Merion Kentucky bluegrass (*Poa pratensis* L.) and Penncross creeping bentgrass (*Agrostis palustris* Huds.) throughout the investigation.

LITERATURE REVIEW

General Description

Annual bluegrass (*Poa annua* L.) is a diminutive, low growing plant. Although generally considered a bunch-type grass some strains are creepers (7). Annual bluegrass possesses a light green to greenish-yellow color (7, 22). Sprague and Burton (34) reported that annual bluegrass remained vivid green as autumn approached. Tutin (37) reported that annual bluegrass was a cross between *Poa infirma* H.B.K., an annual plant, and *Poa supina* Schrad. a perennial plant. The chromosome number of annual bluegrass is 2n=28 (27). The species possesses two large chromosomes and one small chromosome. In addition, Koshy (27) reported that annual bluegrass had three groups of chromosomes containing 2, 4, and 5 chromosomes respectively. Juhren, et. al., (24) observed that annual bluegrass reached the 2-leaf stage of development one week after emergence. Some plants were observed by Arber (2) to have replaced their leaf traces with branch traces. She also observed a strong tendency of the inflorescences to remain leafless.

Annual bluegrass is reported to be among the first turf-grasses to resume growth in the spring (25, 34). In addition, Kerr (26) felt that the rapid shoot growth of annual bluegrass contributed to its highly competitive nature. The growth rate was observed to become more rapid when the seedling plant had developed to the third leaf stage (24). Although most abundant in spring, annual bluegrass plants began to disappear in midsummer (34). Monteith (31) also reported the disappearance of annual bluegrass in May. The lack of tolerance to heat and drought stresses may have accounted for these observations. Sprague and Burton (34) concluded that midsummer conditions in open areas were unfavorable for the growth of annual bluegrass. They found that the most favorable conditions occurred after mid-August. Sprague and Burton (34) further believed that annual bluegrass began its growth in the late summer/early fall period. They reported that annual bluegrass would continue to grow in the fall as long as the soil remained unfrozen.

Younger (39) explained the growth pattern of annual bluegrass by reporting that high soil moisture levels were common to annual bluegrass survival. Sprague and Evaul (35) also showed that annual bluegrass was more tolerant of excess moisture. They found that maximum growth was achieved when the soil moisture level was 50-60% of the soil water holding capacity. It was also reported that annual bluegrass was eliminated at low moisture levels (39). This would explain the disappearance of annual bluegrass during midsummer drought periods. Excessive wear during the midsummer period was another factor contributing to the disappearance of annual bluegrass (26).

The leaf structure of annual bluegrass is similar to the other bluegrasses. Annual bluegrass possesses the boat-shaped leaf tip which is characteristic of all bluegrasses. Brobrov (11) observed the ligule of annual bluegrass to be larger than the ligule of Kentucky bluegrass (*Poa pratensis* L.) and similar to the ligule of rough bluegrass (*Poa trivialis* L.). Brobrov (11) described the leaf as being strap-shaped and parallel veined with a prominent mid-rib. The leaf also possesses pairs of bulliform cells flanking the mid-rib (2, 11). Arber (2) reported a simple leaf epidermis consisting of smooth-walled cells. Brobrov (11) reported that the epidermal cells were rectangular shaped. The cuticle layer covering the epidermis was found to be thinner on the upper leaf surface than the lower (11). Brobrov (11) observed that the upper and lower leaf surfaces were not parallel. She also observed stomata to be more abundant on the upper surface.

Rooting

Annual bluegrass is commonly referred to as a shallow-rooted species although the limited research work suggests otherwise. This widely accepted concept has resulted from casual observations of annual bluegrass in the field. However, in the field annual bluegrass is frequently found under conditions which are not conductive to optimum growth of the plant. These conditions include soil compaction and close mowing. Under close clipping, root growth is decreased in most species (1, 10). Kerr (26) listed the problems associated with annual bluegrass and blamed the lack of tolerance to heat stress on the plants' high transpiration rate combined with a shallow root system. Renney (32) reported that annual bluegrass will root almost entirely in the mat layer. Gibeault (17) referred to the shallow root system of annual bluegrass as being associated with frequent irrigation under putting green conditions. Normal root depths for the turfgrasses were listed by Gibeault (17) (Table 1). Based on this table, annual bluegrass was reputed to produce a root system 1.0 - 4.0 inches in depth. This was considerably less than the rooting depths listed for creeping bentgrass and Kentucky bluegrass.

Although the concensus holds that annual bluegrass is shallow rooted; limited research suggests that the opposite is true. The earliest of these studies was conducted by Sprague and Burton (34) in New Jersey. It was concluded that under identical soil and cultural conditions annual bluegrass developed a similar root system to Kentucky bluegrass and colonial bentgrass. Sprague and Burton (34) also concluded that annual bluegrass produced a far denser root system in well aerated soils than in compacted soils. Beard (7) compared the rooting of annual bluegrass to that of Poa pratensis. He also referred to the shallow rooted nature of annual bluegrass under compacted conditions (8).

A more detailed study of root growth under compacted conditions was conducted in Rhode Island by Wilkinson and Duff (38). Annual bluegrass, Kentucky bluegrass, and Penncross creeping bentgrass were compared at three soil bulk densities. Root weight measurements of each species were

TABLE 1. Approximate root depths of cool and warm season turfgrasses. (From Gibeault 17)

TURFGRASS SPECIES	ROOT DEPTH (inches)
Annual bluegrass (*Poa annua* L.)	1-4
Creeping bentgrass (*Agrostis palustris* Huds.)	4-18
Colonial bentgrass (*Agrostis tenuis* Sibth.)	9-18
Kentucky bluegrass (*Poa pratensis* L.)	9-30
Red Fescue (*Festuca rubra* L.)	9-30
Tall Fescue (*Festuca arundinacea* Schreb.)	18-48
Bermudagrass (*Cynodon doctylon* (I.) Pers.)	18-98
Zoysiagrass (*Zoysia japonica* Steud.)	18-72
St. Augustine grass (*Stenostaphaphrum secundatum* (Walt.) Kuntze)	18-72

made after eight and twelve weeks. There was no significant difference in the total root weight of the species at bulk densities of 1.25 and 1.4. However, at a bulk density of 1.1 Kentucky bluegrass produced less roots after eight weeks. The root weights decreased with depth in all cases but increased with bulk density. Similar findings were reported by Sprague and Burton (34) who listed the percentages of root weights found in the upper 3 inches under compacted conditions. Kentucky bluegrass possessed 92% of its roots in the upper 3 inches. By comparison colonial bentgrass possessed 88% and annual bluegrass 86.8% in the upper 3 inches (34). Based on their results, Wilkinson and Duff (38) conclude that (1) a bulk density 1.4 was not high enough to limit root growth, and (2) the root growth of annual bluegrass is equal to that of Poa pratensis and Agrostis palustris.

The effects of nutritional levels on root growth of annual bluegrass were reported by Juska and Hanson (25). They observed the effects of various combinations of N, P, and K at each of two levels. These combinations were applied to two soil types at each of two pH levels. Root weights of annual bluegrass were not increased materially with any of the fertilizer treatments used. With certain fertilizer treatments, a significant decline in rooting was observed on the loamy sand soil but not on the silt loam. The same treatments produced increases in shoot growth of annual bluegrass. Working with the loamy sand soil, Juska and Hanson found that a pH of 6.5 increased root weights significantly compared to a pH of 4.5.

Beard and Daniel (10) investigated the root growth and development of creeping bentgrass. Bentgrass root production was observed at temperatures from 60°F to 90°F. The growth rates at 60°F, 70°F, and 80°F were similar but a significant reduction was observed at 90°F. However, total root production decreased sharply as the temperature was increased. The initial growth rate was rapid at each temperature with the peak rate occurring between days 8 and 10 following transplanting of the bentgrass plugs. Daily clipping of the plugs produced a further reduction in root growth.

Due to the similarity in root development between annual bluegrass and other turfgrass species, it is possible that rooting is more important in the competiveness of annual bluegrass than was previously thought.

Seed Germination and Dissemination

Seedhead production has long been recognized as one of the major problems associated with annual bluegrass under turfgrass conditions. Seedhead formation occurs throughout the growing season but is most intense in late spring (7). During the growing season annual bluegrass seedheads are extensive and unsightly in highly maintained turfgrass areas. Annual bluegrass has the ability to produce seedheads at very close cutting heights (32). Beard (8) noted the ability of annual bluegrass to flower even at a 0.25 inch height of cut. Renney (32) found that a single annual bluegrass plant produced 360 seeds in a growing season. This observation was made in British Columbia during a four month period from May through August. Based on this observation, Renney (32) estimated that the surface layer of soil might contain 30,000,000 annual bluegrass seeds per acre. Although seedhead production was most prolific during the growing season; Arber (2) observed that annual bluegrass also flowered in the winter in England. Cockerham and Whitworth (13) observed flowering in February in New Mexico. Furthermore, they collected viable seed in mid-March. Annual bluegrass is often referred to as a winter annual in the warm humid climatic regions.

Seeds of annual bluegrass can be disseminated by wind, water, animals, and man. In addition, turfgrass mowing equipment would have to be considered a prime mode of transportation for the seeds. Pollination of annual bluegrass is also aided by these means. Lynch (30) first observed that annual bluegrass was not a self-fertilizer. Koshy (28) discussed the cross-pollination of annual bluegrass and also stated that viable seed had been obtained 24-48 hours following pollination. Pollination was observed to take place during the early morning hours (30). Juhren, et. al., (24) found that *Poa annua* plants reached the flowering stage in 5-7 weeks. Based on the findings of Gibeault (16) these plants would be classified as annual types. His investigation showed that plants of the annual subspecies (var. *annua*) flowered in 50 days compared to an 81 day period for the perennial subspecies (var. *reptans*).

Several investigations dealing with seed germination of annual bluegrass have been reported. One of the most detailed studies was conducted by Engel (14) who observed the effects of four temperature regimes on seed germination of annual bluegrass and colonial bentgrass (Agrostis tenuis). Three regimes were observed with and without light. The 86°F regime was observed under dark conditions only. The annual bluegrass seed produced higher germination rates throughout the study when it received eight hours of light per day. Hovin (21) and Renney (32) both reported that annual bluegrass seed germination was favored by light. Juhren, et. al., (24) stated that the optimum conditions for germination consisted of a 16 hour photoperiod with a maximum of 5000 ft. cdle. When Engel (14) compared colonial bentgrass (Agrostis tenuis Sibth.) germination with that of annual bluegrass, he showed bentgrass germination rates to be higher under both light and dark conditions. Engel also showed that germination of both species was reduced at 86°F with annual bluegrass being more severely reduced. Germination during the first two weeks was higher at 66°F than with a 59°-86°F regime (14). This agreed with Cockerham and Whitworth (13) who concluded that 60°F was the best temperature for annual bluegrass seed germination. However, alternate low (50°F) and high (70°F) temperatures have been shown to promote germination of unripe seeds (21). The time necessary for germination became longer as temperatures were lowered. It was observed that germination took 18-22 days under cold (17°C day 11°C night) conditions compared to seven days under optimal conditions (23°C day 17°C night) (24). Jackson (22) reported germination in six days.

Seed germination is also affected by varability within the annual bluegrass species. Hovin (21) observed that seed of perennial types germinated immediately following harvest. Koshy (28) made a similar finding when he observed seed germination occurring within panicles which had been removed from the parent plant. He reported 14% germination by the fourth day. A more recent investigation supported these earlier observations pertaining to perennial type annual bluegrass plants (16). Gibeault (16) also showed that seed of the annual subspecies possessed a post-harvest dormancy. This explained the statement by Cockerham and Whitworth (13) that freshly harvested seed would not germinate. The annual subspecies is better able to perpetuate itself through post-harvest dormancy by avoiding the heat and drought stresses of midsummer. Due to post-harvest dormancy of the annual subspecies, Beard (7) concluded that germination is most active during the moist cool period of late summer.

Ecotype Variability

It has been observed that variations exist within the annual bluegrass species. Arber (2) noted that annual bluegrass had no fixed periodicity. She further observed that annual bluegrass could produce several generations in a single year or could become perennial in nature. Arber (2) also found that some annual bluegrass plants possessed stolons which produced flowering shoots. Perenniality in annual bluegrass was later suggested by Sprague and Burton (34). They felt that annual bluegrass would survive up to two years under favorable conditions. Annual bluegrass also has the ability to form new shoots from its upper nodes (21). Based on the above observations, Beard (7) concluded that although annual bluegrass is generally considered a bunch-type grass there are strains which exist in turfs as creepers.

The first detailed research concerning the variability within the annual bluegrass species was conducted by Gibeault (16). He characterized both annual and perennial subspecies of annual bluegrass. Lower leaf, node, secondary tiller, and adventitious root numbers were associated with the annual subspecies. Gibeault's investigation showed that annual plants were more erect growing than the perennial plants. The annual types predominated in non-irrigated areas such as golf course roughs. Golf greens and other areas which receive moderate or intensive supplemental irrigation were ideal locations for development of the perennial subspecies. This is substantiated by the observations of Adams (1) who found that the annual bluegrass strains which persist in intensely maintained English sports turfs were prostrate and stoloniferous. The perennial plants were more prostrate in growth habit. Gibeault (16) found that the perennial subspecies possessed either stolons or rhizomes that were capable of producing tillers and roots at their nodes. Further differences between the two subspecies involved seedhead production. Although the annual subspecies produced seed earlier than the perennial subspecies; the seed exhibited a post-harvest dormancy period. Gibeault's (16) study dealt with the two extremes. Between these extremes were ecotypes which possessed all possible combinations of genetic characteristics.

Variability within the annual bluegrass species probably contributes to the results in chemical control programs. Turgeon (36) found this to be the case when working with endothall in Michigan. He reported that the perennial types severely limited the chemical's effectiveness. Based on this finding Turgeon concluded that the effectiveness of chemical control programs depends to a great extent on the nature of the annual population. Control programs will be less effective where a high degree of variability exists in the annual bluegrass stand.

Adaptation

Annual bluegrass grows under a wide range of climatic, soil, and cultural conditions. Although annual bluegrass was originally a native of Europe, it is now distributed throughout the world (6). It is not only observed throughout the world, but is considered a major turfgrass pest in most areas (1, 29, 33). Arber (2) reported annual bluegrass plants growing 12,000 feet above sea level in the Himalaya mountains. Annual bluegrass was observed growing equally well along the seashore of England. Adams (1) reported that annual bluegrass invaded greens where non-adapted species were washed with sea water. This suggested a possible tolerance to salt. However, Beard (8) reported a poor tolerance to high soil salinity.

Moist, fine-textured, fertile soils are particularly favorable for annual bluegrass growth (7, 34). Beard (7) also indicated that a slightly acid soil (pH 5.5-6.5) was preferred. Juska and Hanson (25) observed a four-fold increase in the seedhead production of annual bluegrass when grown at a pH of 6.5 on a loamy sand. They also reported a doubling of shoot growth at pH 6.5. Annual bluegrass was capable of growing at low fertility levels but responded to fertilization (26).

Annual bluegrass was also stimulated by irrigation (7). However, it would not withstand waterlogged conditions (8). Work was conducted in New Jersey concerning the effect of moisture levels on annual bluegrass growth. Sprague and Evaul (35) found that maximum growth of annual bluegrass occurred when the soil was kept at 50-60% of the water holding capacity. The growth of annual bluegrass was considerably reduced above and below this range. It was concluded from these findings that annual bluegrass was more tolerant of excess moisture and compacted soils than the more desirable species. Furthermore, annual bluegrass is well adapted to moist shaded conditions.

Sensitivity to smog damage is a growing problem on annual bluegrass plants in southern California. Brobrov (11) described smog damage as a transverse tan band near or above the mid-blade of mature leaves. She also reported the appearance of the band within several hours following exposure to the atmospheric pollutants. Juhren, et. al., (24) found that damage was greater to plants grown in an eight hour photoperiod than at sixteen hours. They also showed that plant sensitivity was affected by environmental conditions but was not correlated with plant size or growth rate. Plants grown in hot conditions did not become sensitive until flowering (24). However, Brobrov (11) reported a correlation between sensitivity and the degree of stomatal opening. She also reported that damage commonly occurred to cells just reaching maturity with cells bordering the substomatal chamber being first damaged. It was shown that senescent and very young leaves were usually not sensitive to smog damage.

Temperature-Growth Relationships

Beard (5) listed several factors that influence the air and soil temperatures surrounding a turfgrass plant. These factors include: (a) latitude, (b) altitude, (c) topography, (d) season of the year, and (e) time of day. Hawes (19) discussed the relationships between soil and air temperatures. He reported that the soil temperature at a 1.0 inch depth would not quite reach the maximum reported air temperature. It was shown that the greatest variation in temperature was at a height of 1.0 inch above the soil surface (3). Carroll (12) reported the upper layer of a bare soil as generally being warmer than the air temperature in the summer. Furthermore, he observed that large fluctuations occurred in the upper layers. Beard (3) reported that temperature fluctuations within the upper 2.0 inches of soil were practically the same as the air temperature at a 1.0 inch height. The soil temperature remained 5°-10°F warmer during the nocturnal low temperature period (19). Beard (5, 6) defined optimum as that temperature at which the activity of a particular plant process occurred at its highest rate. The optimum temperature for root growth was shown to be more important for overall plant growth than the shoot optimum (6). Plant growth declines and eventually ceases as the temperatures are increased or decreased from the optimum.

Hawes (19) reported an optimum soil temperature for annual bluegrass of 55°-65°F. This was 10°F less than the optimum soil temperature of Penncross bentgrass. Harrison (18) showed that the roots and rhizomes of Kentucky bluegrass weighed more at 60°F than at 80°F or 100°F. In addition, he reported that the grass was denser but shorter at 60°F. Beard (5) further defined the optimum temperatures of annual bluegrass as 60°-70°F for shoot growth and 55°-65°F for root growth. Juhren et. al., (24) reported annual bluegrass shoot growth to be most rapid under warm conditions (78°F day 68°F night) and moderately warm conditions (78°F day 63°F night). They reported that plants grown under cool (68°F day 58°F night) conditions had broad leaves and long internodes on the stems of lateral shoots. The opposite was true of plants grown in hot (86°F day 76°F night) conditions. Hawes (19) compared annual bluegrass and Penncross creeping bentgrass growth over a range of temperatures from 45°-95°F. The annual bluegrass produced more shoot and root growth at 75°F and 65°F. Beard (3) reported higher numbers of bentgrass roots at 60°F although the growth rate did not vary appreciably at 60°, 70°, or 80°F. Annual bluegrass plants did not mature as rapidly at 45°F and

55°F (19). However, annual bluegrass plants growing at 45°F produced two to three times as much shoot and root growth as did Penncross. The annual bluegrass root systems were very long and extensive at 45°, 55°, and 65°F (19). Hawes showed that plants grown at 85° and 95°F matured quickly and died. Annual bluegrass plants grown at a 0.25 inch cutting height responded to temperature treatments similarly to the unclipped plants (19).

Lack of tolerance to temperature stresses is a major problem associated with annual bluegrass. The disappearance of annual bluegrass in midsummer is a direct result of high temperature and drought stresses. High temperature stress involves either indirect or direct injury. Indirect high temperature stress occurs when plant growth is slowly reduced and eventually ceases. The first effect of indirect high temperature injury is a browning and dieback of the root system. Direct high temperature kill involves denaturation of the proteins. It was reported that annual bluegrass could be killed at temperatures as low as 104°F (15). Fischer (15) also showed that the killing temperature was a function of the exposure time. Kentucky bluegrass produced very little growth at 100°F (18). The shoot growth of Kentucky bluegrass decreased considerably at high temperatures. Cockerham and Whitworth (13) reported injurious effects to annual bluegrass at temperatures of 80°-90°F for 18 hours per day. By comparison, Carroll (12) reported that Kentucky bluegrass and bentgrass species were better able to withstand high air temperatures than annual bluegrass. Beard (7) also reported annual bluegrass to be inferior to bentgrass and Kentucky bluegrass in heat hardiness. The upper temperature at which germination failed was 94°-101°F. Engel (14) reported that continuous 86°F temperatures reduced colonial bentgrass (Agrostis tenuis Sibth.) germination 51% while annual bluegrass seed germination was even more severely reduced.

Direct low temperature kill involves mechanical disruption of the protoplasm by ice crystals (9). The actual killing temperature depends on the hydration level of the plant tissue. Carroll (12) stated that the extent of plant injury due to cold stress depends upon the type of plant and the nature of its periodicity. He further stated that Kentucky bluegrass was more low temperature hardy than annual bluegrass. Beard (4) investigated low temperature effects on several turfgrass species including annual bluegrass, Merion Kentucky bluegrass, and Penncross creeping bentgrass. His investigations showed that bentgrasses exhibited greater low temperature hardiness than any other turfgrass. Penncross was found to be seriously injured at soil temperatures below -5°F (4). By comparison Merion and annual bluegrass exhibited extensive low temperature kill below 0° and 5°F respectively. The low temperature kill of each species increased as the soil temperature was decreased (16). Kill of annual bluegrass increased at a greater rate than either Penncross or Merion. Beard (6) also observed turfgrass injury resulting from ice coverage for an extended period of time. He found that annual bluegrass could be injured in 60-70 days. However, bentgrass was not affected for as long as 120 days under an ice cover. These findings indicate that annual bluegrass is inferior to bentgrass and Kentucky bluegrass in low temperature hardiness as well as heat hardiness.

Cutting Height

The reported effects of cutting height on annual bluegrass have been based on general observations. Although several authors (1, 23, 26, 39) have discussed the prominance of annual bluegrass at short (less than 0.5 inch) heights of cut, no actual data has been published concerning the optimum cutting height. Youngner (39) reported a significantly higher number of annual bluegrass plants at the 0.5 inch cutting height compared to 0.75 inch. This was with annual bluegrass grown in a bermudagrass stand. Therefore, the significant increase of annual bluegrass may have been due to a reduction in the competitiveness of bermudagrass at the shorter cutting height.

Several general observations concerning cutting height effects were discussed by Adams (1). Root depth decreases as the cutting height is lowered to between 1.0-1.5 inches. Beard and Daniel (10) showed a similar reduction in root growth of bentgrass cut daily at 0.25 inch. Adams (1) also stated that the effect on rooting was further influenced by the soil type. The plant also became more susceptible to wear damage due to the reduction in root depth. Incremental decreases in the height of cut below 1.0 inch affected the plant in three ways (1). The first of these is reduced rooting depth. Secondly, tiller production is decreased with decreased cutting height. This agreed with Harrison's (18) observation that shorter cutting heights produced less new shoot growth. The third effect of a decreased cutting height was described by Adams as a decrease in the fertilizer requirement of the plant. This appears to be a direct result of decreased tiller production and rooting. Bentgrass and Kentucky bluegrass species are similar in their responses to a decrease in the cutting height.

Fertility Response

Annual bluegrass tolerates both low and high fertility levels (26). Juska and Hanson (25) concluded from their investigation that annual bluegrass would grow reasonably well on relatively infertile soils. However, Beard (7) indicated that a higher intensity of culture was more favorable to annual bluegrass development. He suggested a nitrogen requirement of 0.2-1.0 # N/1000 sq. ft. per month. This was comparable to the common bluegrass species. In addition, it has been shown that complete fertilizers produced the most abundant growth of annual bluegrass (25, 35). Adams (1) observed that repeated nitrogen applications favor annual bluegrass.

Several individuals have studied the effects of individual nutrients on the growth and development of annual bluegrass. Juska and Hanson (25) made a detailed investigation of clipping yields, root weights, and crown weights as affected by the individual elements. They found significant responses for all of the comparisons used in the study. Furthermore, they reported significant interactions from N/P and N/K on clipping yields; N/K on crown weights; and N/P on root weights. Sprague and Evaul (35) noted that urea stimulated annual bluegrass. However, Sprague and Burton (34) reported fewer seedheads where only nitrogen was applied. The use of nitrogen alone would also affect the root development of annual bluegrass. Adams (1) felt that nitrogen was the nutrient that most frequently affects root development on British sport turfs.

Harrison (18) observed the effects of fertilization on Kentucky bluegrass. He found that considerably more shoot growth was produced under continuous nitrogen applications. However, the same plants exhibited death to rhizomes and roots from the high fertilization rate. Harrison also showed that heavy fertilization restricted the plant's ability to replace the dying roots and rhizomes. Plants receiving a nutrient solution without nitrogen produced the opposite response. These plants produced many new rhizomes during the winter months (November-February). Harrison (18) showed that the shoots of the minus-N plants grew very little during the winter period of short days. The plant roots were growing deeper and were more extensive during this period. However, nitrogen became a limiting factor as the days began to lengthen and the plants were at a standstill. In addition, low nitrogen levels decrease the recovery rate of the turf (1).

The effects of nitrogen fertilization on clipping yields were also investigated by Harrison (18). Clipping yields were greater for the first three weeks after a nitrogen application. However, the minus-N plants produced a greater yield at the fourth week. Nitrogen treatments also produced color changes at different temperatures. Harrison (18) stated that plants receiving nitrogen turned dark green at 60°F and 80°F but turned yellow at 100°F. Carroll's (12) results also showed that Kentucky bluegrass and annual bluegrass suffered greater high temperature injury when receiving high amounts of nitrogen. Color changes were not observed in the plants which did not receive nitrogen.

The soil reaction (pH) has also been shown to influence annual bluegrass growth and development. Annual bluegrass prefers a mildly acid soil (34). Juska and Hanson (25) showed that the soil reaction had a marked effect on annual bluegrass yields when grown on a loamy sand soil. They reported a two-fold increase in shoot growth at pH 6.5 compared to pH of 4.5. Sprague and Evaul (35) reported that the best growth of annual bluegrass occurred at pH 6.1, although good growth was observed at pH 4.2 and pH 5.0. Juska and Hanson (25) reported significant increases in shoot growth at both pH 6.5 and pH 4.5 when additional nitrogen was applied. They also reported a significant increase at pH 4.5 resulting from the addition of phosphorus. This reflected the effect of phosphorus becoming limiting in the soil under acidic conditions. It was concluded from this investigation (25) that annual bluegrass could grow better at low pH levels in silt loam soils than Kentucky bluegrass. Because of its preference for slightly acidic conditions, annual bluegrass was least able to encroach on turf treated with lime and an abundance of nitrogen (34). Sprague and Burton (34) also showed that the use of acid forming fertilizers was not enough to introduce annual bluegrass infestations.

MATERIALS AND METHODS

The investigation involved four components of competition within a turfgrass community: (1) temperature-growth relationships; (2) cutting height; (3) nitrogen fertility level; and (4) root growth and development. Field observations and controlled climate growth chamber studies were used in the first phase of this investigation. Cutting height and nitrogen fertility requirements of annual bluegrass were examined under conditions of annual bluegrass encroachment into a Merion Kentucky bluegrass sod. In addition, optimum cutting height determinations were made for an annual bluegrass monostand. The rooting studies involved the use of specially constructed boxes for observing root elongation.

Annual bluegrass was compared with Merion Kentucky bluegrass and Penncross creeping bentgrass throughout this investigation. These three species are commonly used for lawn and recreational turfs in Michigan.

TEMPERATURE-GROWTH RELATIONSHIPS

Phenological Observations

1971 Observations: Five locations in the East Lansing, Michigan area were selected for phenological observations of annual bluegrass. The sites chosen represented varying soil and cultural conditions under which annual bluegrass occurred. The descriptions of the locations were as follows:

1) Creeping Bentgrass Green: A portion of a bentgrass green at the Michigan State University turfgrass research plots was observed to contain about 25% annual bluegrass. An individual annual bluegrass plant growing in bare soil near the edge of the green was chosen for observation. The green is on a level well drained site. It was built on a loamy sand soil with a pH of 7.5. The cultural conditions at this location included: (a) mowing at 0.25 inch six times per week with clippings removed; (b) a nitrogen fertility level of five pounds per 1000 sq. ft. per year; (c) control of pests as necessary but no cultivation or dethatching; and (d) irrigation as needed to prevent wilt.

2) Kentucky Bluegrass Turf: An annual bluegrass plant growing in a dense Kentucky bluegrass turf at the Michigan State University turfgrass research plots was chosen as the second observation site. The conditions found here were comparable to a home lawn receiving minimal traffic. This was an unshaded, sandy loam site of pH 7.2. The site was level but well drained. Cultural conditions included: (a) mowing at 1.2 inches twice weekly with clippings returned; (b) a nitrogen fertility level of four pounds per 1000 sq. ft. per year applied in two

applications; and (c) irrigation as needed to prevent wilt.

3) Putting Green Apron: The third observation site was located at Lake 'O The Hills Golf Club, a par-3 golf course near East Lansing. The annual bluegrass under observation was growing in the apron of a bentgrass green. The green was established on a loamy sand soil. The pH was 6.7. Since the apron sloped from the putting surface, drainage was excellent. The site was unshaded. The cultural conditions included: (a) mowing at 1.0 inch twice per week with clippings returned; (b) a nitrogen fertility level of six pounds per 1000 sq. ft. per year; (c) pest control as necessary; and (d) irrigation 3-4 times weekly to replace moisture lost through evapotranspiration. In addition, daily syringing was practiced in the early morning for dew removal.

4) Golf Tee: The Forest Akers Golf Course at Michigan State University was chosen as an observation site due to the predominance (90-95%) of annual bluegrass on the tee of a par-3 hole. The tee was an unshaded, sandy loam site that received intensive traffic and divots from iron play. The site was well drained with a pH of 7.2. The cultural practices for the tee included: (a) mowing three times weekly at 0.75 inch with clippings returned; (b) nitrogen fertilization at a rate of four pounds per 1000 sq. ft. per

year; and (c) irrigation 3-4 times weekly. This site best fit the description of locations where Gibeault (16) usually found perennial type annual bluegrass plants.

5) Sports Turf: The final site chosen for observing annual bluegrass growth and development was Landon Field on the Michigan State University campus. Landon Field is used for intramural athletics during the spring and summer, and for marching band practice in the fall. Annual bluegrass was widespread at this site due to the compacted nature of the clay loam soil. It was expected that annual bluegrass plants found here would be of the annual type based on Gibeault's (16) characteristic locations. The site was fairly well drained and level. The cultural intensity of this site represented the lowest level of the five. The cultural practices utilized included: (a) mowing every 10-14 days at a height of 2.0 inches with clippings returned; (b) fertilization twice per year to apply two pounds of nitrogen per 1000 sq. ft. per year; and (c) very little supplemental irrigation.

Soil temperatures and shoot length measurements were made at the five locations at intervals throughout the 1971 growing season. These observations were initiated in mid-April and continued until the first frost. Soil temperature readings were at a 1.0 inch depth using a Weston Model 4200 thermometer.

The soil temperatures were taken near mid-day at the time of each observation. The soil temperatures recorded were the mean of three readings per site. The thermometer was shaded from direct radiation to minimize the effect of direct solar radiation. Early observations showed that the soil temperature reading stabilized between 4 and 5 minutes after being inserted into the soil. Therefore, the readings were made five minutes after inserting the thermometer into the soil.

Measurements of shoot length were made at each observation interval. These data were used to determine when growth of the annual bluegrass plant began in the spring and to follow the growth pattern throughout the growing season.

In addition to shoot length and soil temperature measurements observations were made of the weather conditions, plant color and vigor, and seedhead production.

1972 Observations: Further phenological observations were conducted during the early spring of 1972. The observations were expanded to include Kentucky bluegrass and creeping bentgrass in addition to annual bluegrass. All three species were observed in the Michigan State University Horticultural Gardens. This area is a level, well-drained site. Notations were made of shoot growth initiation and green-up in relation to the soil temperature.

Soil temperature measurements were made using a method similar to the one previously described for the 1971 observations. The temperature readings were again made at a 1.0 inch soil depth. The measurements were made four times weekly in the early afternoon. Only one reading was made per individual site. Two sites were measured for each species; one to observe spring green-up and the other for observing shoot growth initiation.

Locations were chosen where each species was predominant. An area six inches square was used to observe the initiation of new shoot growth. The area was defoliated by removing all old leaves and stem material. One square was defoliated for each of the three species.

Areas adjacent to the defoliated squares were chosen to observe spring green-up. The conditions of these areas remained unchanged. The plants contained plant parts which had died during the winter. Furthermore, the area was not clipped as in the defoliated areas. This area was observed to determine plant green-up as a response to soil temperature.

Controlled Climate Growth Chamber Studies

The root and shoot growth of annual bluegrass, Merion Kentucky bluegrass, and Penncross creeping bentgrass was measured at $10^{o}F$ intervals over a range of 40^{o}-$110^{o}F$ using controlled climate growth chambers. A twelve hour photoperiod with a light intensity of 2000 foot candles was used throughout the study.

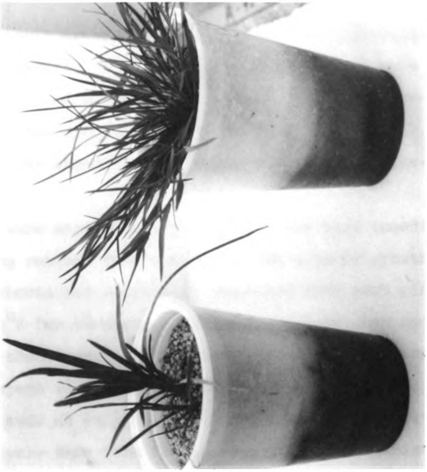
Study I: The turfgrasses used in this investigation were watered daily to prevent wilt and received a complete Hoagland's (20) nutrient solution three times weekly.

The three species were grown in individual sand cultures to facilitate measurement of root and shoot growth. The sand cultures consisted of 180 ml (6 oz.) styrofoam cups placed inside 300 ml (10 oz.) translucent cups (Figure 1). The tops of the two cups were flush and had an inside diameter of 2.5 inches. Holes were placed in the bottoms of the styrofoam cups to allow drainage of water and the nutrient solution into the larger cup. By placing a hole midway up the side of the translucent cup, a well is provided for maintaining the moisture level in the sand cultures. The sand used was # 7 washed quartz.

The plants used in this and other experiments were germinated in 20 x 14 x 3 inch deep greenhouse flats containing a loamy sand soil of pH 6.9. A preliminary study was conducted to determine differences in the seed germination rates of the three species using the same seed source throughout. It was found that Merion Kentucky bluegrass germinated in eight days; annual bluegrass in five days; and Penncross creeping bentgrass in four days under greenhouse conditions. The conditions included daily irrigation; a twelve hour photoperiod of sunlight and flourescent lighting; and soil temperatures in the 70^{o} to 75^{o}F range. Seedlings germinated in this manner were transplanted into the sand cultures at the 3-leaf stage of development. Following transplanting into the sand cultures, the plants were grown for one week before placing in the growth chamber.

The turfgrasses were grown at each of the eight constant temperatures for 30 days. This observation period was preceded by a two week stabilization period, during which the plants

Figure 1. Individual plants growing in sand cultures that were used in controlled climate growth chamber study. Left to right: Annual bluegrass, Merion bluegrass, and Penncross creeping bentgrass.



were allowed to adapt to the conditions within the controlled climate growth chambers. Growth response measurements were made on days 0, 15, and 30 of the experiment. Four replications of each species were measured on each of these days. The entire study was arranged in a completely randomized design.

The plants were washed gently to remove the sand immediately after being removed from the controlled climate growth chambers. The shoots and roots were separated from each plant and dried at 212°F for 48 hours. Measurements were then made of the root and shoot dry weights. Analyses of variance were conducted to compare root and shoot growth of each species. An analysis was made at each temperature. Temperature-growth response curves were made from the results of this investigation. Observations were also made of the seedhead production of the annual bluegrass plants.

Study II: The shoot growth rate was also measured through clipping yields. Plugs, 4,25 inches in diameter, of Merion Kentucky bluegrass and annual bluegrass were grown at each of the eight constant temperatures. They were arranged in a randomized block design with three replications of each species. The turfs were irrigated daily and received a complete Hoagland's (20) nutrient solution three times weekly. Clippings were collected on days 5, 10, 15, 20, 25, and 30 at each constant temperature level from 40° to 110°F. A uniform cutting height of 0.75 inch was accomplished by use of a cardboard collar. The turf plug was placed inside the collar and all plant material above the collar was clipped. The clippings were dried at 212°F for 48 hours and weighed. The turf plugs were allowed to stabilize in the controlled climate growth chambers for two weeks prior to the initial clipping yield measurements. At day 0 the plugs were clipped to the 0.75 inch cutting height.

Study III: Plastic trays, 7.5 inches square by 2.0 inches deep, were used to investigate the seed germination response of annual bluegrass at the eight constant temperature levels. Each tray was filled with loamy sand soil of pH 6.9. Annual bluegrass was replicated three times in trays arranged in a randomized block design. One hundred seeds were planted per tray at a depth of 0.25 inch. A cheesecloth was placed over the seeds as a moisture barrier. The trays were placed in the previously described controlled climate growth chambers on day 0, with germination counts made on day 30. The trays received an application of water daily with the Hoagland's (20) complete nutrient solution applied weekly.

NITROGEN FERTILITY AND CUTTING HEIGHT STUDIES

Mature Sod Experiment: Merion Kentucky bluegrass sod was obtained from the Michigan State University Muck Experimental Farm and transplanted into greenhouse flats. The sod was harvested at a 1.0 inch depth. The flats measured 14 inches by 20 inches by 3 inches deep. A loamy sand soil of pH 6.9 was placed in the flats prior to transplanting the sod at a depth that allowed the soil surface of the sod pieces to be flush with the top of the flats.

The sod was allowed to root for two months following transplanting. The treatments were arranged in a split-block design of six replications. Two nitrogen fertility levels were applied across five cutting height treatments. The cutting heights were randomly assigned to flats of sod. The sods were cut three times weekly with the clippings removed.

The nitrogen fertility treatments were applied monthly with the first application made at the time the sod was transplanted. Ammonium nitrate was applied using water as the carrier at rates of 0.43, or 1.72 gms per flat. This was equivalent to 0.5 and 2.0 # of actual N/1000 sq. ft., respectively. The treatments were applied in 20 inch strips across the cutting height treatments. The sod was allowed to root under greenhouse conditions of daily irrigation and a soil temperature of 70°F. The day length during this study averaged 9-10 hours without additional artificial lighting.

Following a two-month period for rooting of the sod and acclimation to the cultural treatments, annual bluegrass seedlings were transplanted into the Merion Kentucky bluegrass sods. The seedlings were transplanted at the 2-leaf stage of development. Two seedlings were transplanted per flat. Sod cores, 2.0 inches in diameter, were removed from the Merion sod growing in the flats. The resulting holes were filled with soil identical to the soil used in establishing the sod. The annual bluegrass seedlings were then transplanted into the bare soil of the flats.

The annual bluegrass seedlings were removed from the sod flats after a two month treatment period. Measurements made on the seedlings included: (1) tiller number; (2) shoot dry weight; and (3) root organic matter. These measurements were used in comparing the effects of the five cutting heights and two nitrogen fertility treatments on the growth of an annual bluegrass plant in a Merion Kentucky bluegrass stand. The treatment effects were compared statistically using an analysis of variance and the Duncan's Multiple Range Test.

Tiller counts for each annual bluegrass plant were made first. The roots were then washed gently to remove the soil particles. The roots and shoots were separated at the crown meristem of the plant. They were then dried for 48 hours at 212°F. After drying, shoot dry weights were recorded. The dried roots were weighed in crucibles and then ashed at 1000°F overnight. The crucibles and contents were reweighed after ashing to determine the root organic matter.

Annual Bluegrass Monostand Experiment: Monostands of annual bluegrass were established from seed in 4.25 inch diameter by 3.0 inch deep waxed cups. The soil used was a loamy-sand of pH 6.9. A complete Hoagland's nutrient solution (20) was added to the cups once weekly during the experiment. Cutting height treatments were applied to the monostands beginning three weeks after establishment. The five cutting heights used were 0.5, 1.0, 1.5, 2.0, and 2.5 inches. The cups were clipped three times weekly with the clippings removed. Cardboard collars similar to those mentioned earlier were used to assure a uniform cutting height. Clippings were removed by use of hand clippers having a metal basket attached. The soil temperatures of the plugs averaged 75^{o}F during the 45 day treatment period. The photoperiod was twelve hours involving both natural and artificial illumination. Daily irrigation was applied to the turfgrass plugs to prevent wilt.

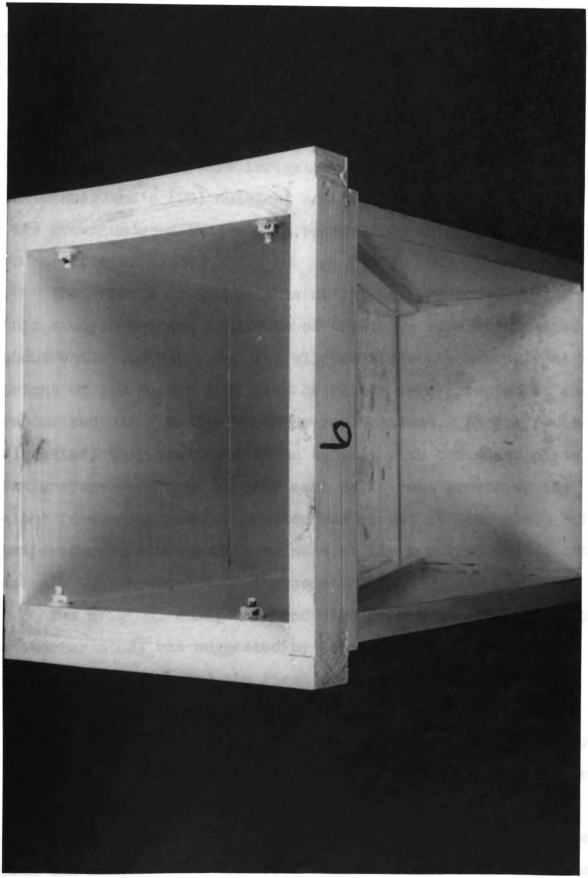
A randomized block design with three replications was used. The study was conducted over a 45 day period after which shoot density counts were made. These data were used in determining the optimum cutting height for annual bluegrass when grown in a monostand.

ROOT GROWTH AND DEVELOPMENT STUDIES

Specially constructed root observation boxes were used throughout these studies. The boxes measured 10 inches square at the top with one side being a glass plate. The glass was slanted toward the rear at a 23^{o} angle. Each box measured 17 inches in height and contained 0.6 cubic foot of soil (Figure 2.). Black plastic and wooden covers were used to exclude light from the glass face. This was done to minimize light influences on root growth. The rooting boxes were first described by Beard and Daniel (10).

Root growth of the three turfgrasses was compared using the root observation boxes. Plants of each species were established in 20 x 14 x 3 inch deep greenhouse flats containing a loamy sand soil of pH 6.9. Staggered seed germination dates were again used as discussed in a previous section. When the

Figure 2. Root observation box with slanting glass face used for observation of root growth and development.



plants reached the 3-leaf stage of development they were transplanted into the rooting boxes. A single plant was placed in the middle of the box 1.0 inch behind the glass plate. The soil in the boxes was a loamy sand having a pH of 6.9. The transplanted plants were irrigated daily and received a complete Hoagland's (20) nutrient solution weekly. The plants were grown under a twelve hour photoperiod using both natural and artificial light.

The effects of two heights of cut were compared during this study. One set of plants of the three species remained uncut while the other set was clipped three times weekly at a height of 1.0 inch. Both sets of plants were arranged in a randomized block design of three replications. As the roots elongated, they would come into contact with the glass plate. Wax crayons were used to mark each day's root growth on the glass face. The root elongation was marked at 1:00 p.m. Soil temperature measurements were made at the two inch soil depth using a Weston Model 4200 thermometer.

The original study was conducted over a period of 30 days. A shorter study was suggested by observations of the root growth patterns during the first study. Therefore, a second study of 15 days duration was also conducted. The procedure for the 15-day study was the same as previously described for the 30-day study. Both clipped and unclipped plants were used.

The plants were removed from the loamy sand greenhouse soil at the conclusion of both studies. After being separated from the plants, the roots were washed to remove the adhering soil. Screens were used to collect all roots. Following washing, the roots were dried at 212°F for 48 hours. The roots were then placed in crucibles, weighed, and ashed at 1000°F overnight. The crucibles and their contents were then reweighed to determine the total root organic matter produced by each plant.

Root depth was also used as a measurement of root growth. The rooting depth of each plant was determined by measuring the deepest penetration of the visible roots on the glass face. This determination was made on the final day of each study. An analysis of variance and a Duncan's Multiple Range Test were conducted to compare the root organic matter production and rooting depths of the three species.

RESULTS AND DISCUSSION

TEMPERATURE-GROWTH RELATIONSHIPS

Phenological Observations

1971 Observations: The phenological observations of annual bluegrass during the spring of 1971 suggested several temperature-growth relationships. The first of these involved the initiation of shoot growth. New shoot growth and development occurred at soil temperatures above 55°F at four of the observation sites. Subsequent shoot growth ceased at soil temperatures below 55°F. This was true even for short low temperature exposure periods of 48 hours. The one exception to this was the annual bluegrass plant growing on the edge of a bentgrass putting green. The plant was growing in bare soil at this location and the 1.0 inch soil temperature was already above 60°F when readings were begun in mid-April. For this reason it was not possible to determine when annual bluegrass growth was initiated at this site.

The second general observation concerning annual bluegrass growth dealt with seedhead production. The first seedheads developed after the soil temperature had surpassed 60°F. The lowest recorded mean soil temperature at which seedheads were produced was 60.3°F. All seedheads were removed at each site in mid-June. New seedheads were produced within one to two weeks. Some seedheads were present on the plants through the first frost in October. Seedhead production was most intense on the sports turf. The least seedheads were produced by the annual bluegrass plant growing on the golf tee.

The seedhead observations further suggested the presence of the subspecies annua and reptans, on the sports turf and golf tee, respectively. A plug of annual bluegrass was removed from the golf tee. Close examination of this plug revealed a stoloniferous growth habit of the annual bluegrass. This substantiated the earlier suggestions (16) that the perennial subspecies would be dominant on the golf tee. By comparison, the plant in the sports turf remained bunch-type in nature throughout the summer. The plant died in early July. This appeared to be a result of drought stress. The plant had survived a single day's soil temperature of 91.3°F in late May. However, when the soil temperature remained above 80°F for an extended period the plant died. Death was probably influenced by the lack of supplemental irrigation.

1972 Observations: Observations made during the early spring of 1972 concurred with the previous year's findings. Again it was observed that annual bluegrass initiated new shoot growth at soil temperatures above 55°F. Annual bluegrass plants growing over steam lines on the Michigan State University campus were also observed. Soil temperatures were taken at this location to compare with the defoliated area being observed. The annual bluegrass was already green and producing seedheads. The 1971 findings were again substantiated since soil temperatures over the steam lines were above 60°F.

In comparison with annual bluegrass, the defoliated areas of Kentucky bluegrass and creeping bentgrass were observed to begin shoot growth earlier. Plants of the latter two species began growing at soil temperatures between 50° and 55°F. An exact soil temperature could not be determined due to intermittent snow covers during the observation period. Kentucky bluegrass regrowth proceeded at the most rapid rate, reaching a height of 1.0 inch five days after beginning growth. Creeping bentgrass regrowth was quite slow by comparison having only attained a height of 0.25 inch. All three species initiated spring green-up at about the same time on the observation area that was not defoliated.

Controlled Climate Growth Chamber Studies

Study I: The results of the sand culture study are presented in the form of temperature-growth response curves. The shoot growth responses are presented in Figure 3 and the root growth responses in Figure 4. The mean comparisons, by Duncan's Multiple Range Test, for the study are presented in the Appendix.

All plants of the three species died during the two-week stabilization period at 110°F. Light and moisture were not limiting. Therefore death was the result of direct high temperature kill. These results agreed with the findings of Fischer (15) that temperatures as low as 104°F could cause direct high temperature kill. Some plants of all three species survived through day 15 at the 100°F temperature treatment. However, the remaining plants were killed before day 30.

Fischer (15) reported similar findings concerning high temperature kill. He showed that the longer a plant was grown under high temperature stress, the lower the killing temperature.

There was essentially no root and shoot growth at 100°F as shown by the lack of significance between days 0 and 15. The most significant amount of root and shoot growth at 40°, 50°, and 90°F was produced between days 15 and 30. Root and shoot growth was negligible between days 0 and 15 at these three temperature treatments. In the middle temperature range (60°, 70°, and 80°F) all three species matured faster with the growth patterns becoming evident by day 15.

Hawes (19) had previously reported that annual bluegrass plants grown at soil temperatures of 85° and 95°F matured quickly and died. However, in this study the annual bluegrass plants matured most quickly at 80°F. Seedhead production was used as a measure of maturity. Seedheads were present on plants at day 30 of the 60°, 70°, and 90°F treatments but none were observed at day 15. In addition, seedhead production was also evident at day 15 at the 80°F temperature. No seedheads were produced at 40°, 50°, or 100°F. This agreed with the phenological (field) observations in which seedhead production of annual bluegrass was not observed until the soil temperature at a one inch depth surpassed 60°F.

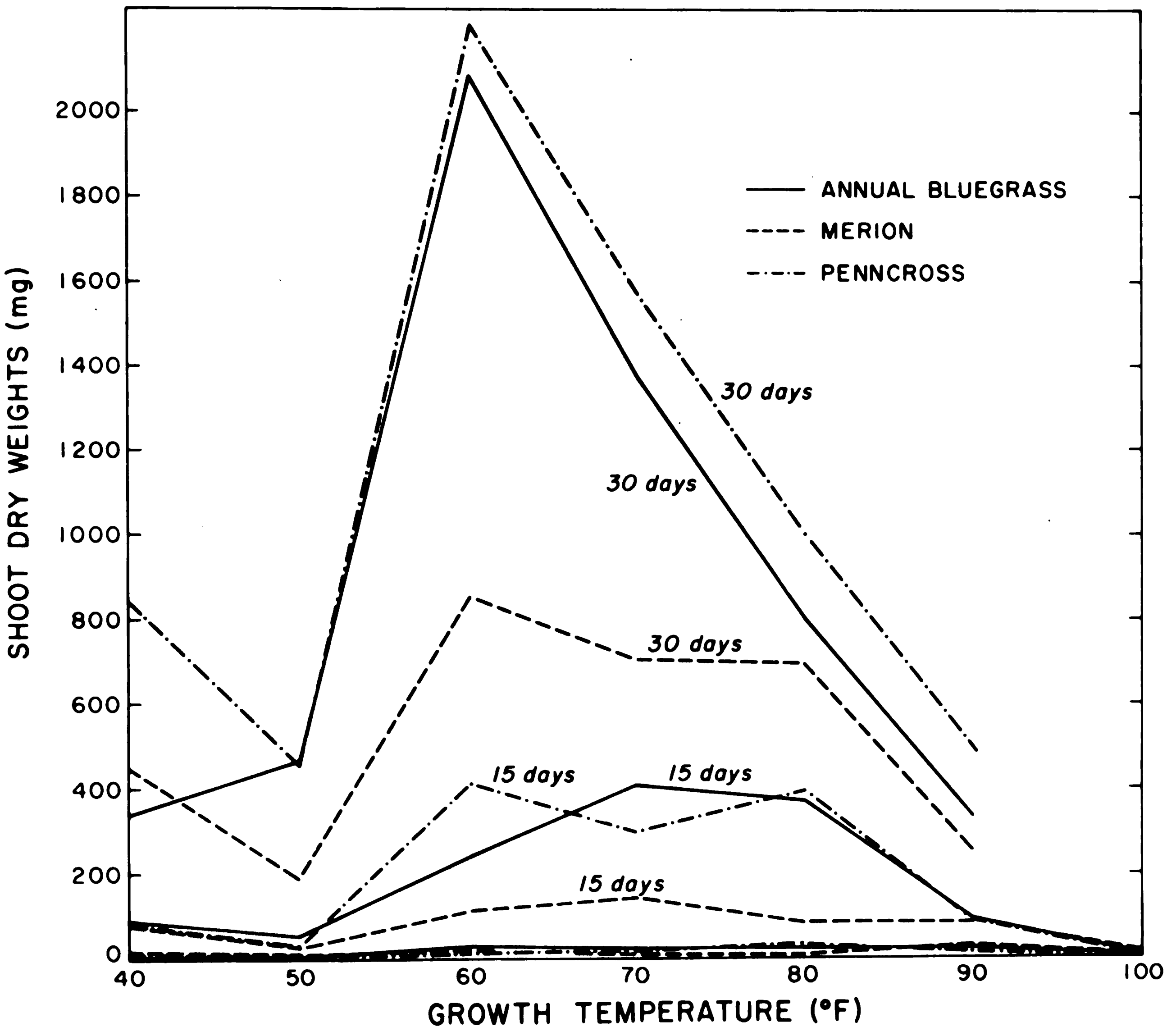
Another indication of plant maturation is the root color. As root systems mature and begin to die they turn brown. The root systems of all three species in this study had begun turning brown by day 30 when grown at 80°F.

The plants of all three species were held longer in the greenhouse prior to being placed in the 40^{o}F temperature treatment. Therefore, the plants were better developed initially. In addition, the temperature in the chamber was not constant. It rose to 60^{o}F for a period of two days until the malfunction was corrected. These factors combined to give inconsistent results at 40^{o}F. All three species were affected similarly. These two variable inputs did not reoccur at the six higher temperature treatments.

All three species produced the maximum shoot growth at 60^{o}F. Penncross creeping bentgrass produced significantly greater shoot growth than either Merion Kentucky bluegrass or annual bluegrass after 30 days at all temperatures except 50^{o} and 60^{o}F where annual bluegrass shoot growth was comparable. Annual bluegrass shoot growth was significantly greater than Merion Kentucky bluegrass except at the extreme temperatures of 40^{o} and 90^{o}F where there was no significant difference. In earlier investigations (4, 7, 12) annual bluegrass was found to be less heat and cold tolerant than Penncross creeping bentgrass or Merion Kentucky bluegrass.

The results of the 40^{o}F treatment show that both Penncross creeping bentgrass and Merion Kentucky bluegrass produced more root and shoot dry weight than annual bluegrass. This in conjunction with the 1972 phenological observations suggest that these two species begin active shoot growth at a lower temperature than annual bluegrass. This is contrary to the earlier report of Sprague and Burton (34) who observed that annual

Figure 3. Shoot growth responses of three turfgrass species to seven constant temperature treatments.

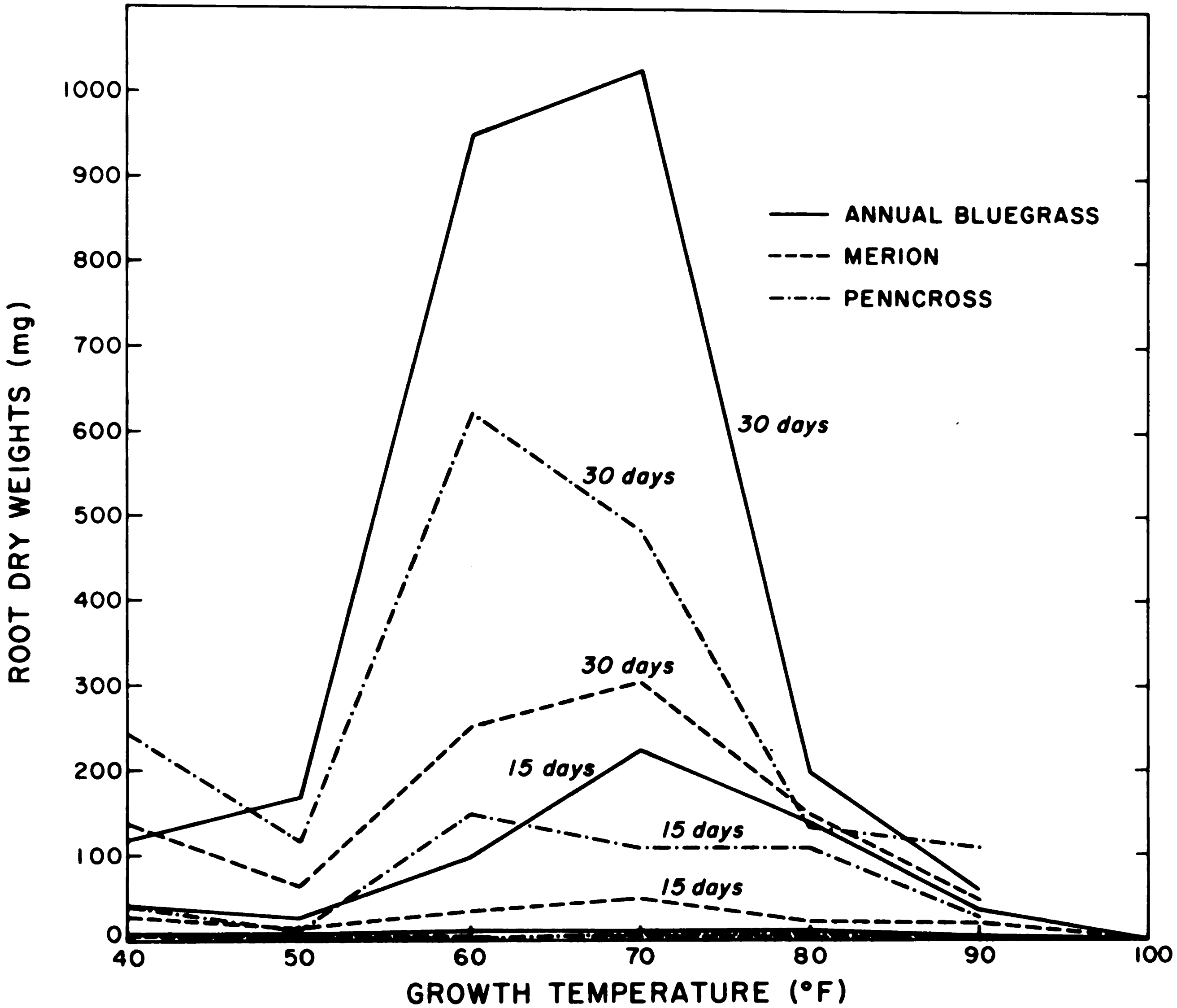

SHOOT DRY WEIGHTS (mg)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
GROWTH TEMPERATURE (°F)
40
50
60
70
80
90
100
ANNUAL BLUEGRASS
MERION
PENNCROSS
30 days
30 days
30 days
15 days
15 days
15 days

bluegrass was among the first grasses to resume growth in the spring. The difference may be due to differences in the annual bluegrass species. The spring green-up rate of the annual subspecies may differ from the green-up rate of the perennial subspecies.

The root growth responses to temperature are depicted in Figure 4. Again, Penncross creeping bentgrass demonstrated a wider range of temperature adaptability with significantly higher root production than the other two species at 40° and 90°F. Root growth of annual bluegrass was significantly greater at the other five temperature treatments. The optimum root growth of annual bluegrass and Merion Kentucky bluegrass was achieved at 70°F. In contrast, Penncross creeping bentgrass root growth reached its maximum at 60°F. These results were quite significant since Beard (6) reported that the optimum root growth temperature is more important to the turfgrass plants' total growth than is the optimum temperature for shoot growth.

The phenological observations and sand culture study are very important for the professional turf manager. These results give an indication of the competitive ability of the three species in response to temperature. Annual bluegrass is least able to compete with Penncross creeping bentgrass and Merion Kentucky bluegrass at the temperature extremes of 40° and 90°F. This suggests that an early spring application of a water soluble nitrogen fertilizer would favor the Penncross creeping bentgrass and Merion Kentucky bluegrass. Annual bluegrass was

Figure 4. Root growth responses of three turfgrass species to seven constant temperature treatments.


ANNUAL BLUEGRASS
MERION
PENNCROSS
30 days
30 days
30 days
15 days
15 days
15 days
ROOT DRY WEIGHTS (mg)
GROWTH TEMPERATURE (°F)
1000
900
800
700
600
500
400
300
200
100
0
40
50
60
70
80
90
100

better able to compete at the higher temperatures than would normally be expected from previous general observations. Cockerham and Whitworth (13) reported injurious effects to annual bluegrass plants grown at 80° to 90°F temperatures for 18 hours per day. However, annual bluegrass still competed quite well at 80°F in this study. Annual bluegrass root production was also superior to the other two species at 80°F.

Study II: Clipping yields were also used as a measure of shoot growth as influenced by temperature. Annual bluegrass and Merion Kentucky bluegrass were compared in this manner. The mean comparisons are presented in Table 2. No clipping yields are reported at 90°F due to death of the plugs during the stabilization period.

There was no significant difference among annual bluegrass clipping yields within the 40°, 50°, 80°, and 100°F treatments. The shoot growth rate was equal throughout the 30 day study. There were no clippings obtained after day 15 at 100°F due to death of the plugs. Significant differences in the clipping yields of annual bluegrass were observed within the 60° and 70°F treatments. The mean dry weights increased from day 5 to day 30 in both cases. This showed that the 60° and 70°F temperatures were most favorable for the shoot growth of annual bluegrass. This confirms the sand culture study in which maximum annual bluegrass shoot growth was attained at 60°F.

The Merion clipping yields were significant within each of the temperatures observed. At 40° and 100°F the clipping yields decreased from day 5 to day 15, and then remained constant through day 30 in both cases. Harrison (18) reported

TABLE 2. Clipping yields of two turfgrass species to six constant temperature treatments.

TURFGRASS SPECIES	DATE OF CLIPPING COLLECTION (1)	TEMPERATURE (^{o}F)					
		40	50	60	70	80	100
Annual Bluegrass	5	198.3 a (2)(3)	147.7 a	86.3 a	51.7 a	20.7 a	15.7 a
	10	165.3 a	169.3 a	116.3 ab	53.3 a	31.3 a	23.0 a
	15	133.3 a	184.0 a	95.0 a	75.7 ab	44.3 a	7.3 a
	20	174.0 a	168.7 a	132.0 abc	96.0 bc	47.0 a	-
	25	150.7 a	191.3 a	177.0 bc	111.7 c	53.7 a	-
	30	152.7 a	204.3 a	185.3 c	112.0 c	29.7 a	-
Merion Kentucky Bluegrass	5	262.7 a	133.0 a	151.3 a	140.3 a	116.7 a	74.0 a
	10	202.7 b	145.7 ab	164.0 ab	149.3 a	142.7 ab	70.7 a
	15	147.3 c	144.7 ab	168.3 ab	238.3 b	235.7 c	26.0 b
	20	134.0 c	176.0 bc	197.7 b	267.0 b	223.3 c	24.0 b
	25	115.3 c	175.3 bc	199.0 b	268.0 b	190.0 bc	29.0 b
	30	121.0 c	207.7 c	257.3 c	310.7 c	228.0 c	24.0 b

(1) Clipping dates are in relation to day 0 following the two week stabilization period.

(2) Values given in each column are the means of three replications.

(3) Means in each column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

very little recovery of Kentucky bluegrass after cutting at 100°F. He reported essentially no new shoot growth after the second cutting. The results were the same at 100°F in this study. The shoot growth rate at 80°F increased through day 15 and then held constant through the remaining 15 days. Clipping yields tended to increase throughout the 30 day period at both 60° and 70°F. Clipping yields of Merion Kentucky bluegrass tended to increase throughout the study at 50°F although there was no significance from days 20 to 30. These results also show that Merion Kentucky bluegrass produces greater shoot growth during the initial 15 days at the low (40°F) temperature than annual bluegrass. This was also observed during the 1972 phenological observations. These results point up the fact that temperature-growth measurements should not be made at only one point in time since the responses varied with the exposure time.

Study III: The seed germination percentages of annual bluegrass as affected by the seven temperatures are shown in Table 3. There was no statistical significance in the annual bluegrass germination at 40°, 50°, 60°, or 70°F. The lowest percentage among these temperatures was 73.7%. The seed germination of annual bluegrass at 80°F was significantly decreased. A further significant decrease occurred at 90°F. This data further delineates the findings of Engel (13) who reported severe reductions in annual bluegrass seed germination at continuous 86°F temperatures. Based on these findings it can be seen that annual bluegrass germinates best in spring and fall as opposed to mid-summer.

TABLE 3. Annual bluegrass seed germination as influenced by six temperature treatments.

TEMPERATURE (°F)	GERMINATION (1) (%)
40	83.3 a (2)
50	78.3 a
70	77.0 a
60	73.7 a
80	49.7 b
90	21.0 c

(1) Values given are the means of three replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Miltiple Range Test.

CUTTING HEIGHT AND NITROGEN FERTILITY STUDIES

Mature Sod Experiment: The cutting height treatments significantly influenced the tillering and shoot dry weights of the annual bluegrass plants. However, root organic matter production was not affected by cutting height. All nitrogen fertility level-cutting height interactions were found to be non-significant. The mean shoot dry weights resulting from the five cutting height treatments are shown in Table 4. The mean shoot dry weight ranked highest at the 1.0 inch cutting height; although not significantly different from the 1.5 or 2.0 inch cutting heights. The lowest shoot dry weight occurred at the 0.5 inch cutting height. This is of particular interest in view of the many reports of favorable annual bluegrass growth at a 0.25 inch cutting height. Apparently annual bluegrass has a better ability to compete at short cutting heights than do the other turfgrass species. Although annual bluegrass possesses this ability, it is even better adapted to a higher cutting height of 1.0 inch or more.

TABLE 4. The influence of five cutting heights on the shoot dry weights of individual annual bluegrass plants grown in a mature Merion Kentucky bluegrass sod.

Cutting Height (inches)	Shoot Dry Weights (1) (mg)
1.0	26.7 a (2)
1.5	24.0 a b
2.0	23.4 a b
2.5	18.7 b c
0.5	16.4 c

(1) Values given are the means of 12 replications across two nitrogen fertility levels.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

Another component of a plant's competitive ability is tillering. The more tillers a plant produces the denser the turfgrass sward will be. As with the shoot growth responses, the 1.0 inch cutting height resulted in the greatest tillering for individual annual bluegrass plants growing in a Kentucky bluegrass stand (Table 5). The 1.5 inch cutting height ranked second and was not significantly different from the 1.0 inch height. However, the tiller production at the 0.5 inch cutting height was superior to the 2.0 and 2.5 inch heights. The lack of tillering by the more diminutive annual bluegrass plants at these higher cutting heights could be the result of shading by the Merion Kentucky bluegrass plants. The plants were more spindly at the higher cutting heights.

TABLE 5. The influence of five cutting heights on the tillering of individual annual bluegrass plants grown in a mature Merion Kentucky bluegrass sod.

Cutting Height (inches)	Tiller Number (1)
1.0	3.0 a (2)
1.5	2.4 a b
0.5	2.3 b
2.0	1.8 b c
2.5	1.3 c

(1) Values given are the means of 12 replications across two nitrogen fertility levels.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

Annual Bluegrass Monostand: A dense, healthy turfgrass sward is the primary defense against weed invasions. Cutting height is one of the cultural practices influencing the shoot density of turf. The effects of five cutting height treatments on the shoot density of an annual bluegrass monostand are shown in Table 6. As in the previous studies, the most influencial cutting height is 1.0 inch. The number of shoots per square inch were significantly higher at the 1.0 inch height. No significant differences were observed among the other four cutting height treatments.

TABLE 6. The influence of five cutting heights on the shoot density of annual bluegrass plants grown in a monostand.

Cutting Height (inches)	Shoot Density (1) (shoots/sq. in.)
1.0	32.1 a (2)
0.5	24.1 b
1.5	23.3 b
2.5	22.9 b
2.0	22.2 b

(1) Values are the means of three replications.

(2) Means in the column followed by the same letter are not significantly different at the 5% level of the Duncan's Multiple Range Test.

Based on the results of these studies it can be concluded that the optimum cutting height for annual bluegrass is 1.0 inch. Most fairways in Michigan are mowed at a height of 0.75 to 1.0 inch. The optimum cutting height for Kentucky bluegrass is 1.5 to 2.0 inches. Therefore, a stress is placed on the Kentucky bluegrass while annual bluegrass is favored when a Kentucky bluegrass fairway is cut at 0.75 to 1.0 inch.

The two nitrogen fertility levels used in this study did not influence (at the 5% level of significance) the root organic matter, shoot dry weight, or tiller number of the annual bluegrass plants grown in a mature Merion Kentucky bluegrass sod. However, the root organic matter production of annual bluegrass under the two nitrogen fertility treatments approached significance (14.7% level) with the higher level (2 # N/1000 sq. ft. per month) causing a reduction in the root organic matter production (Appendix Table 8). This is similar to Harrison's (18) findings with Kentucky bluegrass. He reported greater root and rhizome weights without nitrogen. The lack of significance at the 5% level could have been due to the short-term nature of this study. Root growth may have been further restricted under the influence of a long-term fertility program.

ROOT GROWTH AND DEVELOPMENT

The rooting depths within cutting heights of annual bluegrass, Merion Kentucky bluegrass, and Penncross creeping bentgrass were not significantly different 30 days after transplanting.

This response was similar for both the uncut and cut plants. The data supports the earlier findings of Sprague and Burton (34) and Wilkinson and Duff (38). Annual bluegrass and Penncross creeping bentgrass exhibited a reduction in rooting depth when clipped three times weekly at 1.0 inch (Table 7). Beard and Daniel (10) observed similar results during their study of bentgrass rooting. The rooting depth of Penncross creeping bentgrass was more severely reduced by cutting than the root depths of annual bluegrass.

TABLE 7. The rooting depths of three turfgrass species grown under two cutting treatments for 30 days after transplanting.

	Rooting Depth (1) (inches)	
Turfgrass Species	Uncut	Cut 3 times weekly at 1.0 inch
Annual bluegrass	10.3 a (2)	6.4 b c
Merion Kentucky bluegrass	7.3 a b c	4.6 c d
Penncross creeping bentgrass	8.7 a b	3.3 d

(1) Values are the means of three replications.

(2) Means in the column followed by the same letter are not significantly different at the 5% level of the Duncan's Multiple Range Test.

The root organic matter produced during the 30-day period was also not significantly different among the three turfgrass species. However, there was a high degree of variability between replications within each treatment ($s_{\bar{x}}$ = 47.3). Annual bluegrass ranked highest in the amount of root organic matter under both the cut and uncut conditions. Penncross ranked second with Merion producing the least amount. This was consistent with the results obtained in the controlled climate growth chamber study under similar temperature conditions.

The mean soil temperature during the 30-day period was 72°F. This is slightly higher than earlier reports concerning the optimum root growth temperature of annual bluegrass (5, 19), but is similar to the optimum root growth temperature observed in the sand culture study.

Visual observations indicated that the annual bluegrass roots developed at a more rapid rate during the early phases of this study. Later in the 30-day study it appeared that the Penncross and Merion plants became more competitive in root growth and development. This response occurred during the third week. For this reason a 15-day study was conducted to confirm these observations.

Again, as in the earlier study there were no significant differences in the rooting depths of the three species. This was true for the plants cut at 1.0 inch as well as those that were uncut. Under the uncut conditions annual bluegrass again ranked highest in terms of root depth. However, Merion Kentucky bluegrass ranked highest when cut at 1.0 inch. The effect of cutting at 1.0 inch on rooting depth was not as pronounced during the 15-day study. No significant differences were detected between cutting height treatments (Table 8).

TABLE 8. The rooting depths of three turfgrass species grown under two cutting heights for 15 days after transplanting.

	Root Depth (1) (inches)	
Turfgrass Species	Uncut	Cut 3 times weekly at 1.0 inch
Annual bluegrass	8.0 a (2)	4.5 a
Merion Kentucky bluegrass	7.2 a	4.8 a
Penncross creeping bentgrass	6.3 a	3.0 a

(1) Values are the means of three replications.

(2) Means in the column followed by the same letter are not significantly different at the 5% level of the Duncan's Multiple Range Test.

The root organic matter produced by each species during the 15-day period is shown in Table 9. Analysis of variance showed that the root organic matter production among species approached significance. The uncut plants were significantly different at the 5.5% level and the cut plants were significantly different at the 7% level. The annual bluegrass root organic matter production was not significantly different from Merion Kentucky bluegrass when left uncut. However, Penncross creeping bentgrass rooting differed significantly from annual bluegrass under these conditions. The opposite results occurred when the plants were cut three times weekly at 1.0 inch. Penncross creeping bentgrass and annual bluegrass were non-significant but annual bluegrass rooting was significantly different from Merion Kentucky bluegrass. This suggests that cutting at 1.0 inch causes annual bluegrass and Penncross to initiate additional roots instead of producing deeper roots. The root systems of the three species are shown in Figure 5. The figure shows greater numbers of roots being initiated by the Penncross creeping bentgrass and annual bluegrass plants.

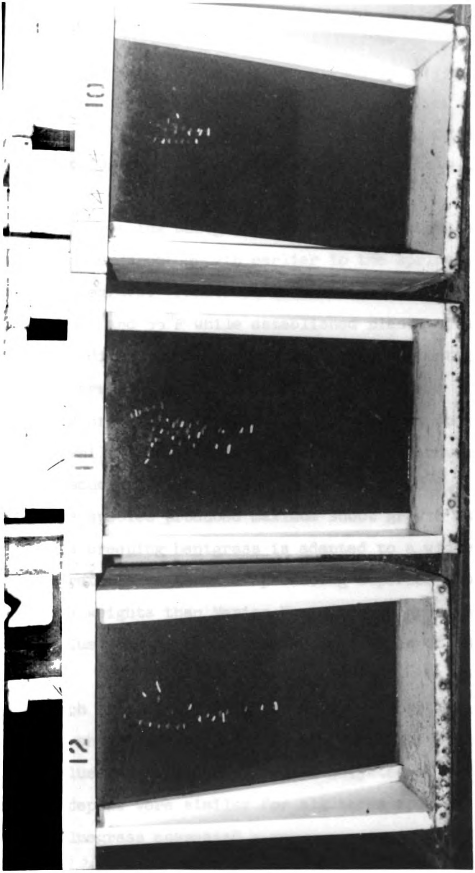
TABLE 9. The root organic matter produced by three turfgrass species when grown under two cutting treatments for 15 days after transplanting.

	Root Organic Matter (1) (mg)	
Turfgrass Species	Uncut	Cut 3 times weekly at 1.0 inch
Annual bluegrass	83.3 a (2)	13.7 a
Merion Kentucky bluegrass	50.4 a b	5.0 b
Penncross creeping bentgrass	31.8 b	5.8 a b

(1) Values are the means of three replications.

(2) Means in the column followed by the same letter are not significantly different at the 5% level of the Duncan's Multiple Range Test.

Figure 5. Rooting of three turfgrass species 15 days after transplanting. Left to right: Merion Kentucky bluegrass, annual bluegrass, and Penncross creeping bentgrass.


10
11
12

CONCLUSIONS

The following conclusions may be drawn from this investigation:

1. Penncross creeping bentgrass and Merion Kentucky bluegrass initiated new shoot growth earlier in the spring than annual bluegrass. Penncross and Merion initiated growth between 50^{o} and $55^{o}F$ while established plants of annual bluegrass did not initiate new spring growth until the soil temperatures exceeded $55^{o}F$.
2. Penncross creeping bentgrass produced maximum root growth at $60^{o}F$ while Merion Kentucky bluegrass and annual bluegrass produced maximum root dry weights at $70^{o}F$.
3. All three species produced maximum shoot growth at $60^{o}F$.
4. Penncross creeping bentgrass is adapted to a wider range of temperatures in terms of producing superior root and shoot dry weights than Merion Kentucky bluegrass and annual bluegrass at the extreme temperatures of 40^{o} and $90^{o}F$.
5. A 1.0 inch cutting height produced the highest tiller numbers, shoot dry weights, and shoot density counts for annual bluegrass in both mono- and polystands.
6. Rooting depths were similar for all three species.
7. Annual bluegrass possessed a more extensive, branched

root system thereby resulting in greater root dry weights than Merion Kentucky bluegrass.

8. The rooting depths of all three species were reduced by clipping three times weekly at 1.0 inch. Penncross creeping bentgrass was the most severely effected.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Adams, W. A. 1971. The turf surface. Parks, Golf Courses, and Sprots Grounds, 37:180-184.

2. Arber, A. 1934. _The Gramineae_. Cambridge University Press, London, England. pp. 480.

3. Beard, J. B. 1959. The growth and development of _Agrostis palustris_ roots as influenced by certain environmental factors. M.S. Thesis, Purdue University. pp. 75.

4. Beard, J. B. 1966. Direct low temperature injury of nineteen turfgrasses. Michigan Agricultural Experiment Station Quarterly Bulletin 48(3):377-383.

5. Beard, J. B. 1968. Effect of temperature stress on _Poa annua_. USGA Green Section Record 68(7):10-12.

6. Beard, J. B. 1968. Low temperatures and _Poa annua_. USGA Green Section Record 68(11):10-11.

7. Beard, J. B. 1970. An ecological study of annual bluegrass. US A Green Section Record 8(2):13-18.

8. Beard, J. B. 1970. The plant characteristics, dissemination, environmental adaptation, and cultural requirements of _Poa annua_ L. Rasen Turf Gazon 2/70:33-35.

9. Beard, J. B. and C. R. Olien. 1963. Low temperature injury in the lower portion of _Poa annua_ L. crowns. Crop Science 3(4):362-363.

10. Beard, J. B. and W. H. Daniel. 1965. Effect of temperature and cutting on the growth of creeping bentgrass (_Agrostis palustris_ Huds.) roots. Agronomy Journal 57: 249-250.

11. Brobrov, R. A. 1955. The leaf structure of _Poa annua_ with observations on its smog sensitivity in _Los Angeles_ county. American Journal of Botany 42:467-474.

12. Carroll, J. C. 1943. Effects of drought, temperature, and nitrogen on turfgrasses. Plant Physiology 18:19-36.

13. Cockerham, S. T. and J. W. Whitworth. 1967. Germination and control of annual bluegrass. The Golf Superintendent 35:10-46.

14. Engel, R. E. 1967. Temperatures required for germination of annual bluegrass and colonial bentgrass. The Golf Superintendent 35:20-28.

15. Fischer, J. A. 1967. An evaluation of high temperature effects on annual bluegrass (Poa annua L.). M.S. Thesis, Michigan State University. pp. 42.

16. Gibeault, V. A. 1970. Pereniality in Poa annua L. PhD Thesis, Oregon State University. pp. 124.

17. Gibeault, V. A. 1971. Agronomic factors in irrigation design. Turf-Grass Times 7(4):17.

18. Harrison, C. M. 1934. Responses of Kentucky bluegrass to variations in temperature, light, cutting and fertilzing. Plant Physiology 9:87-106.

19. Hawes, D. T. 1965. Control of annual bluegrass. Turf Conference Proceedings, University of Massachusetts. pp. 5-10.

20. Hoagland, C. R. and D. I. Arnon. 1950. The water culture method for growing plants without soil. California Agricultural Experiment Station Circular 347. pp. 32.

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

22. Jackson, N. 1959. Evaluation of some grass varieties. Journal of the Sports Turf Research Institute 10(35):13-28.

23. Jackson, N. 1964. Further notes on the evaluation of some grass varieties. Journal of the Sprots Turf Research Institute 40:67-75.

24. Juhren, M., W. Noble and F. W. Went. 1957. The standardization of Poa annua as an indicator of smog concentrations. 1. Effects of temperature, photoperiod, and light intensity during growth of test plants. Plant Physiology 32: 576-586.

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

26. Kerr, C. F. 1968. Turf enemy No. 1 - Poa annua. Weeds, Trees, and Turf 7(3):13-43.

27. Koshy, T. K. 1968. Evolutionary origin of Poa annua L. in the light of karyotypic studies. Canadian Journal of Genetics and Cytology 10:112-118.

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

29. Langvad, B. 1969. Turfgrasses in Sweden. Proceedings of the First International Turfgrass Research Conference. p. 13.

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

31. Monteith, J. 1931. Experimental results at Miami Beach Florida. USGA Green Section 11(10):190-194.

32. Renney, A. J. 1964. Preventing Poa annua infestations. Proceedings of the Eighteenth Annual Northwest Turfgrass Conference. pp. 3-5.

33. Robinson, G. S. 1969. Greenkeeping problems in New Zealand. Proceedings of the First International Turfgrass Research Conference. pp. 10-12.

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

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

36. Turgeon, A. J. 1971. The role of 7-oxabicycle (2.21) Heptane-2, 3-Dicarboxylic Acid (Endothall) in annual bluegrass (Poa annua L.) control in turf. PhD Thesis, Michigan State University. pp. 101.

37. Tutin, T. G. 1952. Origin of Poa annua L. Nature 169 (Pt.1):160.

38. 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 Journal 64:66-68.

39. Youngner, V. B. 1959. Ecological studies on Poa annua in turfgrasses. Journal of the British Grassland Society 14:233-237.

APPENDIX

APPENDIX

Appendix Tables 1-7 present the data from which the temperature-growth response curves were drawn. The data is presented as mean comparisons of the root and shoot dry weights at each temperature. The treatment symbols used on the Tables are as follows:

P/30 - Penncross creeping bentgrass plants removed at day 30.

M/30 - Merion Kentucky bluegrass plants removed at day 30.

A/30 - Annual bluegrass plants removed at day 30.

P/15 - Penncross creeping bentgrass plants removed at day 15.

M/15 - Merion Kentucky bluegrass plants removed at day 15.

A/15 - Annual bluegrass plants removed at day 15.

P/0 - Penncross creeping bentgrass plants removed at day 0.

M/0 - Merion Kentucky bluegrass plants removed at day 0.

A/0 - Annual bluegrass plants removed at day 0.

Appendix Table 8 presents the data from the nitrogen fertility level-cutting height study. The data shown deal with the reduced rooting of annual bluegrass when grown at the higher nitrogen fertility level (2 # N/1000 sq. ft. per month).

APPENDIX TABLE 1. The root and shoot dry weights of three turfgrass species grown at a constant 40°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
P/30	241.8 a (2)	835.0 a
M/30	139.3 b	443.5 b
A/30	116.3 b c	332.5 b
A/15	39.8 c d	86.5 c
P/15	39.5 c d	79.0 c
M/15	28.0 d	79.3 c
A/0	9.0 d	7.5 c
P/0	8.8 d	12.5 c
M/0	7.0 d	9.3 c

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Miltiple Range Test.

APPENDIX TABLE 2. The root and shoot dry weights of three turfgrass species grown at a constant 50°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
A/30	169.3 a (2)	465.5 a
P/30	116.8 b	453.3 a
M/30	64.3 c	182.8 b
A/15	24.0 d	50.0 c
M/15	14.8 d	32.3 c
P/15	11.5 d	30.3 c
A/0	5.3 d	7.8 c
M/0	3.8 d	6.0 c
P/0	2.0 d	4.5 c

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

APPENDIX TABLE 3. The root and shoot dry weights of three turfgrass species grown at a constant 60°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
A/30	947.5 a (2)	2084.0 a
P/30	621.5 b	2204.3 a
M/30	252.5 c	849.0 b
P/15	149.0 c d	406.8 c
A/15	96.3 c d	234.0 c d
M/15	32.8 c d	109.5 d
A/0	11.8 d	22.8 d
P/0	4.5 d	14.3 d
M/0	4.0 d	13.8 d

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

APPENDIX TABLE 4. The root and shoot dry weights of three turfgrass species grown at a constant 70°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
A/30	1043.8 a (2)	1364.8 b
P/30	483.5 b	1564.0 a
M/30	302.0 c	697.5 c
A/15	223.0 c d	404.0 d
P/15	108.8 d e	295.5 e
M/15	49.8 e	139.8 f
A/0	9.8 e	18.8 g
P/0	7.8 e	16.8 g
M/0	5.3 e	10.0 g

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

APPENDIX TABLE 5. The root and shoot dry weights of three turfgrass species grown at a constant 80°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
P/30	132.8 b (2)	993.5 a
A/30	199.5 a	791.8 b
M/30	147.8 b	693.3 c
P/15	109.5 b	396.3 d
A/15	138.0 b	367.3 d
M/15	21.0 c	80.0 e
A/0	9.5 c	22.3 e
P/0	7.0 c	22.0 e
M/0	2.8 c	6.5 e

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

APPENDIX TABLE 6. The root and shoot dry weights of three turfgrass species grown at a constant 90°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)		Shoot dry weights (mg)	
P/30	109.5	a (2)	492.3	a
A/30	62.0	b	329.5	b
M/30	45.0	b c	242.8	b c
A/15	33.0	c	89.3	c d
P/15	24.0	c d	90.8	c d
M/15	20.0	c d	82.3	c d
A/0	5.3	d	19.3	c d
M/0	5.0	d	22.5	d
P/0	4.8	d	17.0	d

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

APPENDIX TABLE 7. The root and shoot dry weights of three turfgrass species grown at a constant 100°F temperature.

Treatment (species/date)	Root dry weights (1) (mg)	Shoot dry weights (mg)
M/15	1.3 a (2)	8.8 a
P/15	1.3 a	6.0 a
A/15	1.0 a	5.0 a
M/0	1.5 a	4.5 a
A/0	1.0 a	4.3 a
P/0	1.3 a	3.3 a

(1) Values given are the means of four replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.

Note: Death occurred between days 15 and 30.

APPENDIX TABLE 8. The influence of two nitrogen fertility levels on the root organic matter production of annual bluegrass plants grown in a mature Merion Kentucky bluegrass sod.

Fertility level (# N/1000 sq. ft/mo.)	Cutting height (inches)	Root organic matter (1) (mg)
	0.5	34.5 a (2)
	1.0	34.2 a
0.5	1.5	22.7 a
	2.0	30.8 a
	2.5	21.3 a
	0.5	9.6 a
	1.0	20.6 a
2.0	1.5	24.5 a
	2.0	10.2 a
	2.5	23.7 a

(1) Values given are the means of six replications.

(2) Means in the column followed by the same letter are not significant at the 5% level of the Duncan's Multiple Range Test.