REGIONAL CLIMATIC CHARACTERIZATION OF PACIFIC NORTHWEST, USA, GREEN-TYPE *POA ANNUA*

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ABSTRACT

Poa annua L. (annual bluegrass) has become one of the most dominant naturally invading turfgrass species of older, highly maintained golf courses. The most intensively-managed areas of the golf course are the greens, where many unique, high-density biotypes of *P. annua* thrive. The objective of this study was to relate agronomic and collection site parameters of *P. annua* f. *reptans* (Hausskn.) T. Koyama accessions (biotypes) to their climatic region of origin in the Pacific Northwest, USA. Accessions of *P. annua* f. *reptans* distinguished in morphology were collected from 78 golf courses throughout Washington, Oregon, and Idaho. For each accession, three cores were transplanted into a field plot on 0.6 m spacing at Pullman, WA arranged in a randomized complete block with three replications. In addition to six collection site parameters, accessions were evaluated for 10 agronomic parameters in field trials from September 1999 to August 2000. The 78 golf course sites were placed into six climatic regions by unweighted pair-group method using arithmetic averages (UPGMA) cluster analysis based on long-term data for temperature, rainfall, snowfall, and growing degree days from 26 weather stations in close proximity to the golf course collection sites. Analysis of variance and principle components analysis differentiated climatic regions based on accession parameters. Accessions from the cool-moist, primarily, coastal region of northwestern Oregon and southwestern Washington were the most unique. In particular, these accessions were characterized by good turfgrass quality and produced few seedheads, which would make a superior greens-type turfgrass but could place limitations on seed production.

Abbreviations

CR, Climatic region(s); GTPA, Greens-type *Poa annua*; PNW, Pacific Northwest

Keywords

Annual bluegrass, Annual meadowgrass, Cluster analysis, *Poa annua* f. *reptans*

INTRODUCTION

Annual bluegrass has had a significant impact on the turfgrass industry worldwide. Its persistent and wide-spread abundance from temperate to subtropical climates has been attributed to a high genotypic variation within the species (Gibeault, 1971; Tutin, 1952; Warwick and Briggs, 1978). The two main subspecies of *P. annua* are *P. annua* f. *annua* and *P. annua* f. *reptans*. *P. annua* f. *annua* has an annual life cycle, erect growth habit, prolific seed production, and is found in a wide range of climates (Gibeault, 1971; Tutin, 1957; Wells, 1974). *P. annua* f. *reptans* exhibits a prostrate growth habit, nodal rooting of decumbent shoots, secondary tillering, and survival surpassing one growing season. It commonly forms a highly dense turf in closely mown and fertile conditions (Lush, 1988; Tutin, 1957; Warwick and Briggs, 1978; Wu et al., 1987; Youngner, 1959).

P. annua f. *reptans* has become one of the most dominant naturally-invading turfgrass species of older, highly cultured golf course tees, fairways, and greens (Christians, 1998; Gibeault, 1971; Huff, 1998). Huff (1999) described *P. annua* f. *reptans* from putting greens as being unique and "greens-type." During the past 100 years, lower mowing heights and increased irrigation and fertility of golf course putting greens have selected for dense, high quality greens-type *P. annua* (GTPA).

A wide diversity of *P. annua* biotypes occupy golf courses (Huff, 1999). However, there is only one commercial cultivar of *P. annua* f. *reptans* and seven *P. annua* biotypes listed in the United States Department of Agriculture Germplasm Resources Information Network (GRIN). Genetic variability and life cycles have been correlated to habitat (Ellis et al., 1971; Gibeault, 1971; Tutin, 1957; Warwick and Briggs, 1978). In a GTPA collection by Poole (2001), numerous agronomic differences were noted among accessions.

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Since *P. annua* is wild, abundant, with thousands of morphologically distinguished biotypes, there is a need to characterize variation within the species so diverse germplasm can be made available to plant breeders for the development of improved GTPA. Previous research by Poole et al. (2001) indicated differences between GTPA collected east or west of the Cascade Mountain Range in the Pacific Northwest, USA. Since *P. annua* is located over such vast areas in the Pacific Northwest (PNW), there is the need to characterize biotypes adapted to specific climates (or regions) to better assist in the collection of GTPA germplasm. Developed biotypes could potentially be used to establish or overseed golf course putting greens in specific regions throughout the PNW. The objective of this study was to relate agronomic and collection site parameters of PNW GTPA accessions to their climatic region(s) (CR) of origin, which were derived from statistical analyses of historical weather data.

MATERIALS AND METHODS

In a previous study, Poole (2001; Poole et al., 2001) collected *P. annua* f. *reptans* from putting greens at 78 golf courses throughout Washington, Oregon, and Idaho. *P. annua* patches on an individual green with the same leaf color, density, and texture were designated as an accession. Accessions were rated at each golf green (sampling site) for color (1 to 3; 3 = dark green) and texture (0 to 4; 4 = coarse). The diameter of each accession patch on the green was measured. *P. annua* composition (percentage of putting green composed of *P. annua*), age of the putting green, and a golf course maintenance rating (1 to 10; 10 = high maintenance) were also recorded. For each accession, three 1.9-cm-diam. cores were taken to a depth of 7.5 cm. Core samples were wrapped in moist paper towels, placed in a refrigerator at 4°C, transported to Washington State University (WSU), and transplanted within 5 d of sampling at the WSU Turfgrass Research Area at Pullman, WA.

A total of 183 accessions were transplanted in the summer 1999 on 0.6 m centers in a randomized complete-block design with three replications (549 cores = experimental units). Soil was a Palouse silt loam (Pachic Ultic Haploxerolls, fine silty, mixed mesic) with a soil pH of 6.6, 3.3% organic matter, 26 mg g^{-1} phosphorus (P), and 300 mg g^{-1} potassium (K). The plot received 174 kg nitrogen (N) ha^{-1} as ammonium nitrate (NH_4NO_3) in five equal split applications in 1999. Fertilizer was applied as ammonium phosphate-sulfate 22-5-5-15S, containing 11% slow release N, at 149 kg N ha^{-1} in four equal split applications in 2000. Grasses posing a weed problem were periodically hand-rouged while broadleaf weeds were controlled with herbicides. To sustain healthy turf, irrigation was applied to prevent stress.

Fall seedhead production and dormancy ratings were taken every 14 d during fall 1999 as repeated measures over time. Fall seedhead production was rated (0 to 10; 0 = no seedheads and 10 = prolific seedhead production). Fall/winter dormancy (inversely related to fall color retention) was rated (0 to 10; 0 = green and 10 = dormant). Winter injury to space plants following the winter 1999-2000 was rated (0 to 4; 0 = no injury and 4 = dead, in March 2000).

Spring green-up and spring seedhead production ratings were taken beginning March 2000 as repeated measures over time. Spring green-up was rated (1 to 9; 1 = dormant and 9 = green). Spring seedhead production was rated (0 to 9; 0 = no seedheads and 9 = prolific seedhead production). In June 2000, canopy height and seedhead

Table 1. Pacific Northwest climatic regions, weather parameters, and weather station locations.

Climatic region	n†	Max. Temp.(°C)	Min. Temp.(°C)	Mean Temp.(°C)	Rainfall (cm $month^{-1}$)	GDD‡	Snowfall (cm $month^{-1}$)
1. Cool Arid - Eastern WA/Northern ID	41	14§c	2 b	8 c	3.8 d	3005 d	8.9 a
2. Warm Arid - Central and Eastern WA/Western ID	16	17 ab	3 b	10 b	2.3 e	3498 b	4.1 b
3. Warm Arid - Southeastern WA/Southern ID	18	18 a	5 a	12 a	2.8 e	4120 a	2.8 c
4. Cool Moist - Western WA/Western OR	72	17 ab	6 a	11 a	8.1 b	3341 c	1.3 d
5. Cool Moist - Coastal Northern WA	14	14 c	6 a	9 c	6.6 c	2643 e	1.3 d
6. Cool Moist - Northwestern-Coastal OR/Southwestern WA	22	16 bc	5 a	10 b	13.5 a	2605 e	1.5 d

†n - Number of accessions collected within each climatic region.

‡GDD = Growing degree days.

§Means within a climatic parameter (column) with the same letter are not significantly different at $P < 0.05$.

Weather station locations within each Climatic region:

1. Spokane, WA; Pullman, WA; Colville, WA; Ellensburg, WA; Coeur d'Alene, ID
2. Yakima, WA; Wenatchee, WA; Chelan, WA; Pomeroy, WA; Pendelton, OR; Jerome, ID
3. Walla Walla, WA; Kennewick, WA; Lewiston, ID; Boise, ID
4. Seattle, WA; Tacoma, WA; Portland, OR; Salem, OR; Eugene, OR
5. Bellingham, WA; Everett, WA; Anacortes, WA
6. Astoria, OR; Corvallis, OR; Olympia, WA

Table 2. Pacific Northwest golf course collection site parameters and climatic regions.

Parameter	Climatic region 1	2	3	4	5	6
Color (rated 1 to 3; 3 = dark green)	ns†	ns	ns	ns	ns	ns
Texture (rated 1 to 4; 4 = coarse)	2.6 b‡	3.1 ab	2.9 ab	3.2 a	2.7 ab	3.1 ab
Patch diameter (cm)	28.2 b	29.0 b	24.4 b	47.5 b	56.1 ab	143.1 a
Poa annua composition (%)	84 b	60 c	43 d	97 a	95 a	93 a
Putting green age (years)	72.1 ab	48.8 de	40.7 e	66.4 bc	54.7 cd	83.0 a
Golf course maintenance (rated 1 to 10; 10 = high level of maintenance)	8.0 bc	7.7 c	8.1 abc	8.6 a	8.4 ab	8.2 abc

†ns - Parameter was not significantly different between regions.

‡Means within an evaluation parameter (row) with the same letter are not significantly different at $P < 0.05$.

height were measured from ground level to their estimated mean height. During August 2000, core diameter was measured. Summer stress tolerance was rated (0 to 9; 0 = green and 9 = dead/dormant). Leaf density was rated (1 to 9; 1 = low density and 9 = high density).

Accession collection sites were designated into six CR using UPGMA cluster analysis (Romesburg, 1984). The analysis utilized historical (20- to 40-yr means) climatic aspects of growing degree days (GDD), temperature, rainfall, and snowfall from 26 weather stations at municipal locations in close proximity (<32 km) to the collection sites (Table 1). GDD were calculated using 7.2°C as the base temperature.

Analyses of variance (ANOVA) were performed on agronomic and collection site parameters with SAS and means were separated with Fisher's protected LSD ($P < 0.05$) (SAS Institute, 1985). Repeated measures analyses were performed for fall seedhead production, fall dormancy, spring seedhead production, and spring green-up parameters assuming compound symmetry of covariance. Principle component analysis was performed on the agronomic parameters using SAS.

RESULTS AND DISCUSSION

CR within the PNW and weather station locations for each CR are listed in Table 1. Differences have been documented in precipitation and temperature between regions on opposing sides of the Cascade Mountain Range that extends through Washington and Oregon (Poole et al., 2001). Low rainfall in CR 2 and 3 (both located in the arid area east of the Cascade Mountain Range) is similar, as is low GDD in CR 5 and 6, and low snowfall in CR 4, 5, and 6 (all located west of the Cascade Mountain Range). Climatic parameters show similarities in temperature between CR 3 and 4, although these CR are on opposite sides of the Cascade Mountain Range.

Differences were found between CR for all the golf course collection site parameters except color (Table 2). Accessions from CR 4 had the coarsest texture and were different from those from CR 1. Golf courses in CR 4 had a higher level of maintenance than those in CR 1 and 2. Golf course greens in CR 4, 5, and 6, with the highest rainfall (Table 1), contained the greatest percentage (range 93 to 97%) of *P. annua* (Table 2). Greens in CR 6 were the oldest, contained the greatest amount of *P. annua*, and had the largest *P. annua* patch size. Those in CR 3 were the youngest, had the least amount of *P. annua*, and the smallest patch diameter. Although greens from CR 1 were older in age and contained greater than average *P. annua* composition, patch size was very small. CR 1, 2, and 3 were arid and had the greatest temperature extremes (Table 1). This could have hindered establishment, growth, and development of *P. annua* patches on putting greens in those regions.

Accessions from CR 1 and 3 exhibited greater fall seedhead production than those from other regions (Table 3). Although CR 1 and 3 were different for all climatic parameters, both were characterized by a wide temperature range (i.e., maximum to minimum) and low rainfall (Table 1). Wide floral variation and delayed flowering of *P. annua* from golf courses are well documented (Gibeault, 1971; Lush, 1989; Warwick and Briggs, 1978). Evidence suggests that *P. annua* is a day neutral species capable of flowering at any time throughout the year (Cooper and Calder, 1964); however, Johnson and White (1997) reported seasonal flowering with selected genotypes of *P. annua* f. *reptans*. Our study indicated that accessions from a cool, arid climate (CR 1 and 3) exhibited increased fall seedhead production for PNW GTPA.

Fall/winter dormancy can be a trait indicative of plant adaptation. Accessions from CR 1 and 3 exhibited the greatest dormancy and were different from those of all other regions, except CR 2 (Table 3). CR 6 accessions retained the greenest color throughout the fall and had

Table 3. Effect of climatic region on agronomic parameters evaluated during 1999-2000 at Pullman, WA.

	Climatic region					
Parameter	1	2	3	4	5	6
Fall seedhead production (rated 0 to 10; 0 = none, 10 = prolific)	4.4 a†	1.0 b	3.9 a	0.4 b	1.2 b	0.2 b
Fall/winter dormancy (rated 0 to 10; 0 = growing , 10 = dormant)	3.0 a	2.7 ab	2.9 a	2.2 c	2.4 bc	1.5 d
Winter injury (rated 0 to 4; 0 = no injury, 4 = dead)	0.9 ab	0.8 ab	0.9 ab	1.2 a	1.0 a	0.4 b
Spring green-up (rated 1 to 9; 1 = dormant, 9 = green)	6.0 bc	5.5 c	6.1 bc	5.5 c	6.5 ab	7.1 a
Spring seedhead production (rated 0 to 9; 0 = none, 9 = prolific)	5.2 b	4.8 b	6.5 a	4.8 b	5.5 b	3.1 c
Leaf density (rated 1 to 9; 1 = low, 9 = high)	6.13 d	6.75 abc	6.38 cd	7.11 ab	6.64 bcd	7.22 a
Canopy height (cm)	7.3 ab	6.74bc	7.9 a	6.3 c	7.4 ab	4.5 d
Seedhead height (cm)	10.9 ab	9.6 bc	11.8 a	8.5 c	10.7 ab	6.2 d
Core diameter (cm)	18.1 a	15.0 c	17.7 ab	15.7 bc	19.1 a	12.5 d
Summer stress tolerance (rated 0 to 9; 0 = green, 9 = dead/dormant)	3.2 a	2.7 a	3.3 a	2.8 a	2.9 a	2.0 b

† Means within an evaluation parameter (row) with the same letter are not significantly different at $P < 0.05$.

the greatest leaf density. CR 4, 5, and 6 accessions exhibited the least fall/winter dormancy. Visible changes in leaf color are often based on temperature thresholds (Larcher, 1995). Others have noted less dormancy in *P. annua* was correlated to growth habit (density) (Tutin, 1957; Warwick and Briggs, 1979).

Winter injury was observed in the field following the winter of 1999-2000 at Pullman, WA. Accessions from CR 4 and 5 had the greatest winter injury, and were different from those from CR 6, which had the least winter injury (Table 3). Accessions from CR 1, 2, and 3, which were characterized by the most extreme temperatures, were intermediate in winter injury (Table 1). It would seem that extreme temperature variations common to CR 1 and 3 should promote natural selection of the fittest plants with the least winter injury (Larcher, 1995). However, accessions from CR 6 (cool, moist mostly coastal region) unexpectedly showed the least winter injury, which was not observed in accessions from CR 4 and 5, with similar cool, moist climates.

Early spring green-up is a desirable characteristic of improved turfgrass cultivars. In Kentucky bluegrass (*P. pratensis* L.), spring green-up was positively correlated with turfgrass potential (i.e., an accession's ability to be produced as a marketable turfgrass selection (Johnston et al., 1997). Accessions from CR 5 and 6 exhibited the quickest spring green-up, while those from CR 2 and 4 had the poorest spring green-up (Table 3). GDD in CR 5 and 6 were the least of all the CR in this study (Table 1), which suggests that spring green-up could be strongly correlated to climate.

Research has suggested flowering of *P. annua* predominantly occurs during late May and early June (Danneberger and Vargas, 1984; Johnson, 1995; Wells, 1974;). Johnston et al. (1997) found flowering of the USDA-ARS Kentucky bluegrass germplasm collection occurred mainly between 25 May and 3 June at Pullman, WA. This also appears to be the case with the PNW GTPA collection, as spring seedhead production and flowering peaked on 25 May 2000 at Pullman, WA. Accessions from CR 3 produced the most spring seedheads, while those from CR 6 produced the fewest spring seedheads (Table 3). Results were fairly consistent between spring and fall seedhead production. Climatic data indicated the greatest difference between CR 3 and 6 were in rainfall and GDD (Table 1). These climatic factors appear to play an important role in the natural succession of flowering in GTPA.

Leaf density is an important aspect of turfgrass quality, especially on putting greens mowed at less than 0.45 cm, where high density is desired for an optimal putting surface (Turgeon, 1999). Accessions from CR 6 had the highest leaf density and were different from accessions from CR 1, 3, and 5, which had the lowest leaf density (Table 3). Since CR 6 had the greatest rainfall and CR 1, 3, and 5 were among those with the least rainfall, density of *P. annua* could be correlated to precipitation (Table 1 and 3).

Most dwarf (low canopy height) accessions exhibited the characteristics of *reptans*, i.e., prostrate tillering and high tiller density (Turgeon, 1999). Dwarf growth habit of *P. annua* makes it well adapted to golf greens (Huff, 1999). The most dwarf accessions were from

CR 6 (Table 3). While dwarf characteristics are desirable for turf quality, it has been negatively correlated with seed production in Kentucky bluegrass (Nelson, 1996). Canopy height was the greatest in regions with the lowest rainfall (CR 1, 2, 3, and 5) (Table 1 and 3). Short seedheads are also a major barrier to commercial *P. annua* seed production due to harvesting difficulties. Accessions from CR 3 had the greatest seedhead height and were different from those from all other CR. Seedhead height was negatively correlated to putting green age (Coeff. = -0.34), which indicated shorter seedheads in accessions from older putting greens.

P. annua patch diameter at collection sites was much greater in CR 6 (Table 2); however, these accessions were the least aggressive (smallest core diameter) as space plants at Pullman, WA (Table 3). Although *P. annua* prevalence on golf courses has been attributed to its profuse seed production, its abundance in closely mown turf appears to occur through vegetative spread (Hutchinson and Seymour, 1982; Tutin, 1957). Research suggests that under high turfgrass culture *P. annua* f. *reptans* will form a dense turf by prostrate vegetative spread through adventitious nodal rooting (Adams and Bryan, 1980; Lush, 1989; Till-Bottraud et al., 1990; Warwick and Briggs, 1978). Larcher (1995) mentions that extreme stress affects the fitness of a species. Since accessions from CR 6 were slow to spread as space plants (Table 3), it may be that less stress due to abundant rainfall and mild temperatures that characterize this region caused these accessions to be less aggressive.

A negative trait of annual bluegrass is its intolerance to heat stress (Beard et al., 1978). Cordukes (1977) visibly assessed heat tolerance of 115 *P. annua* plants after subjecting them to temperatures ranging from 32 to 47°C for 3 h in a growth chamber. Results indicated a short period of tolerance to high temperatures with wide variation among biotypes (Cordukes, 1977). Because irrigation was supplied to the research plot adequately and uniformly in this study, moisture stress was not a factor in the loss of leaf color. The majority of foliar decline in leaf color during the summer was likely due to physiological heat stress. Accessions from CR 6 exhibited the greatest summer stress tolerance (i.e., retained green color) (Table 3). The response of plants to stress can depend on the "survival strategy" of a plant, i.e., yield (vegetative growth) can be compromised for survival (reproduction from seed) (Larcher, 1995).

Principle component analysis was conducted using accession agronomic parameter means for each CR (Fig. 1). The first and second principle components explained 60% of the total variation in all PNW GTPA agronomic parameters, 41% for component 1 and 19% for component 2. Accessions from CR 6 could be differentiated very well. CR 1 and 3 were not different for any of the agronomic parameters, with the exception of spring seedhead production (Table 3). GDD has been documented as being an important factor in *P. annua* seedhead production (Danneberger and Vargas, 1984). Thus GDD, which are numerically similar for CR 2 and 4, could have influenced the similar behavior in accessions from CR 2 and 4. The overlap of CR 1 and 3 might be expected because they are both located primarily in the arid climate of eastern Washington.

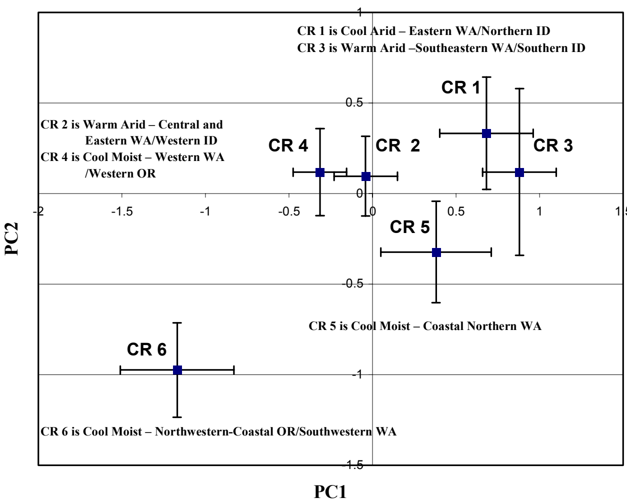

Figure 1. First two principle components for climatic region clusters (CR) derived from weather station data; a 95% confidence interval is shown.

For principle component 1, standardized coefficients were the highest for canopy height, seedhead height, and core diameter. For principle component 2, the most contributing factors were color, spring green-up, fall/winter dormancy, and winter injury. Spring green-up had a negative coefficient while the others were positive. Thus, a combination of greater spring green-up and lower winter injury and fall/winter dormancy explained the relatively low principle component values observed for CR 6 (Fig. 1). In general, summer stress tolerance and fall seedhead production had low standardized coefficients for both principle components indicating less influence on regional differentiation by these parameters.

CONCLUSIONS

Results indicated a high diversity in *P. annua* from golf course putting greens sampled throughout the Pacific Northwest. Earlier evidence had suggested high environmental variance in golf green populations of *P. annua* due to low broad sense heritability for evaluation parameters similar to those used in this study (Till-Bottraud et al., 1990). Recent research on *P. annua* selected from grass seed production fields indicate within population variance was greater than variance among populations (Mengistu et al., 2000). Although variation of *P. annua* has been postulated by many as being random and localized within a golf course, results from this study suggested broader influences due to regional climatic differences throughout the PNW.

Although further evaluation is needed, there appeared to be a high amount of diversity in the collection that was influenced by climatic factors. Accessions from CR 6 were the most unique. They generally had superior turfgrass quality traits (i.e., dwarf growth habit, high density, short seedheads, large patch diameter on older golf greens, and good summer heat tolerance) compared to those from other CR. CR 6 was most distinguished climatically by high rainfall that could have influenced the *P. annua* parameters evaluated in this study. However, CR 6 accessions had few seedheads, which might limit seed production. Results indicated that morphological and physiological variation exhibited by PNW GTPA might have arisen from genotypic differences influenced by environmental factors. These findings agree with others (Ellis et al., 1971; Gould and Shaw, 1983).

P. annua does indeed appear to be a wild species with a high environmental plasticity. Presently, there are an unknown number of biotypes flourishing in the turfgrass ecosystem. This study complimented current research at The Pennsylvania State University involving a national collection of *P. annua* that had limited plant material from the PNW (Huff, 1999). This research has illustrated that there are well-adapted populations of *P. annua* with acceptable putting green quality on PNW golf courses. The CR variability identified in this study can be used in future *P. annua* collection and breeding programs to develop GTPA with superior turf quality and acceptable commercial seed production characteristics. CR 6, the northwestern coastal region of Oregon and southwestern Washington offers the most promise for germplasm collection of GTPA in the PNW.

REFERENCES

Adams, W.A., and P.J. Bryan. 1980. Variations in the growth and development of annual bluegrass (*Poa annua* L.) populations selected from seven different sports turf areas. p. 109-115. *In* J.B. Beard (ed.) Proc. Int. Turf. Res. Conf., 3rd, Munich, Germany. 11-13 July. Int. Turfgrass Soc. and ASA, CSSA, SSSA, Madison, WI.

Beard, J.B., P.E. Rieke, A.J. Turgeon, and J.M. Vargas. 1978. Annual bluegrass (*Poa annua* L.). Description, adaptation, culture and control. Michigan State Univ. Agric. Experiment Stn. Res. Rep. 352.

Christians, N.E. 1998. Fundamentals of turfgrass management. 1st ed. Ann Arbor Press, Chelsea, MI.

Cooper, J.P., and D.M. Calder. 1964. The inductive requirements for flowering of some temperate grasses. J. Brit. Grassland Soc. 5:105-112.

Cordukes, W.E. 1977. Growth habit and summer dormancy avoidance of a collection of *Poa annua* plants in Canada. Can. J. Plant Sci. 57:1201-1203.

Danneberger, T.K., and J.M. Vargas. 1984. Annual bluegrass seedhead emergence as predicted by degree-day accumulation. Agron. J. 76:756-758.

Ellis, W.M., B.T.O. Lee, and D.M. Calder. 1971. A biometric analysis of populations of *Poa annua* L. Evolution 25:29-37.

Gibeault, V. 1971. Perenniality in *Poa annua* L.; Ph.D. diss. Oregon State Univ., Corvallis. (Diss. Abstr. Int. B31/12:7045).

Gould, F.W., and R.B. Shaw. 1983. Grass systematics. 2nd ed., McGraw Hill, New York.

Hutchinson, C.S., and G.B. Seymour. 1982. Biological flora of the British Isles. J. Ecol. 70:887-901.

Huff, D.R. 1998. The case for Poa annua on golf course greens. Golf Course Management 66:54-56.

Huff, D.R. 1999. For richer, for Poa. USGA Green Section Record 37:11-14.

Johnson, P.G. 1995. Genetics and physiology of flowering in selected *Poa annua* L. Ph.D. diss. Univ. of Minnesota, St. Paul. (Diss. Abstr. Int. B56/07:3528).

Johnson, P.G., and D.B. White. 1997. Flowering responses of selected annual bluegrass genotypes under different photoperiod and cold treatments. Crop Sci. 37:1543-1547.

Johnston, W.J., M.C. Nelson, R.C. Johnson, and C.T. Golob. 1997. Phenotypic evaluation of *Poa pratensis* L.: USDA/ARS plant introduction germplasm collection. Int. Turfgrass Soc. Res. J. 8:305-311.

Larcher, W. 1995. Physiological plant ecology. 3rd ed. Springer Pub., New York, NY.

Lush, W.M. 1988. Biology of *Poa annua* in a temperate zone golf putting green (*Agrostis stolonifera*/ *Poa annua*) I. The above ground population. J. Appl. Ecol. 25:977-988.

Lush, W.M. 1989. Adaptation and differentiation of golf course populations of annual bluegrass (*Poa annua*). Weed Sci. 37:54-59.

Mengistu, L.W., G.W. Mueller-Warrant, and R.E. Barker. 2000. Genetic diversity of *Poa annua* in western Oregon grass seed crops. Theor. Appl. Genet. 101:70-79.

Nelson, M.C. 1996. Development of a Kentucky bluegrass core collection: Phenotypic evaluation of the USDA/ARS plant introduction germplasm collection. M.S. thesis, Washington State Univ., Pullman, WA.

Poole, G.J. 2001. Evaluation and core collection development of annual bluegrass from golf greens in the Pacific Northwest. M.S. thesis, Washington State Univ., Pullman, WA.

Poole, G.J., W.J. Johnston, and R.C. Johnson. 2001. *Poa annua* diversity on golf course greens in the Pacific Northwest, USA. Int. Turfgrass Soc. Res. J. 9:192-197.

Romesburg, H.C. 1984. Cluster analysis for researchers. Lifetime Learning Publ., Belmont, CA.

SAS Institute Inc. 1985. SAS users guide: Statistics. 5th ed. North Carolina. State Univ. Press, Cary, NC.

Till-Bottraud, I., L. Wu, and J. Harding. 1990. Rapid evolution of life history traits in populations of *Poa annua* L. J. Evol. Biol. 3:205-224.

Turgeon, A.J. 1999. Turfgrass management. 5th ed. Prentice Hall Pub., Upper Saddle River, NJ.

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

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

Warwick, S.I., and D. Briggs. 1978. The genocology of lawn weeds. I. Population differentiation in *Poa annua* L. in a mosaic environment of bowling green lawns and flower beds. New Phytol. 81:711-723.

Wells, G.J. 1974. The biology and significance of *Poa annua* L. in grassland. *In* 1974 Herbage Abstr. 44:385-391.

Wu, L., I. Till-Bottraud, and A. Torres. 1987. Genetic differentiation in temperature enforced seed dormancy among golf course populations of *Poa annua* L. New Phytol. 107:623-631.

Youngner, V.B. 1959. Ecological studies of *Poa annua* in turfgrasses. J. Brit. Grassland Soc. 14:233-237.