TURFGRASS SCIENCE

Seedling Growth, Fertilization Timing, and Establishment of Bahiagrass

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ABSTRACT

Bahiagrass (*Paspalum notatum* Flügge) makes a useful turf, but establishes slowly from seed; thus, cultivar selection and post planting practices may be important. Objectives were to compare the seedling growth, establishment, and long-term performance of three cultivars and to evaluate the effect of fertilization timing. Seedlings of 'Argentine', 'Pensacola', and 'RCP-1' bahiagrasses were harvested and weighed at weekly intervals for 10 wk after planting in a glasshouse. Cultivars did not differ in mean relative growth rate (RGR). A single 4-wk post planting fertilization fostered equal biomass by 38 wk, compared with repetitive weekly fertilization. Bahiagrasses were planted in a nonirrigated field at 5.6 g seed m^{-2}. Post planting fertilization (4.9 g N, 0.5 g P, and 2.0 g K m^{-2}) was applied 0, 5, or 10 wk after planting, along with a nonfertilized control. Only Argentine and RCP-1 achieved acceptable establishment (a visual estimate of canopy coverage, uniformity, and absence of weeds) in the second year after planting, and only when fertilized 5 wk after planting. Fertilization at 5 wk, when there were three leaves per seedling, was probably optimum because the root systems were adequate to capture nutrients that earlier might have stimulated weeds or have been leached. In another field study, Argentine maintained higher quality ratings over 4 yr and achieved higher root biomass (1870 g m^{-2}) compared witb Pensacola (1370 g m^{-2}) and RCP-1 (1340 g m^{-2}), while shoot biomass did not differ. In both field and glasshouse, Argentine had greater proportion root dry weight (mean 43%) than Pensacola (39%) and RCP-1 (38%). Superior rooting may explain the long-term competitive advantage of tetraploid ($2n = 40$) Argentine compared with the diploid ($2n = 20$) cultivars.

BAHIAGRASS makes a useful turf for highways and other nonirrigated, open landscapes in warm, humid regions. These are often extensive utility sites, which are apportioned low inputs for establishment. Bahiagrass grows more slowly than most other warm-season turfgrasses (Busey and Myers, 1979). Seedlings are reportedly weak and therefore sensitive to competition (Beaty and Powell, 1978) and slow to establish. Knowledge and manipulation of seedling growth should help improve bahiagrass establishment, because of the early vulnerability to weeds.

Post planting fertilization and cultivar selection are methods to enhance establishment, and their effect may be related to seedling growth characteristics. RCP-1 (rapid coverage polycross) bahiagrass has faster lateral spread, 61 and 12% greater than Argentine and Pensacola, respectively (Busey, 1989, p. 40–45). RCP-1 achieves acceptable establishment under weedy, nonirrigated conditions at 12 g seed m^{-2}, which is lower than is required for Argentine and Pensacola under the same conditions. It is not known whether the seedling growth rate of cultivars differs, thereby explaining establishment differences. Fertilizer applied at the time of planting decreases bahiagrass seedling numbers by 19% (Burton, 1940) and stimulates growth of annual weeds (Beaty and Powell, 1978); thus, post planting fertilization may be most appropriate. Objectives were to compare the seedling growth, establishment, and long-term performance of three bahiagrass cultivars and to evaluate the effect of fertilization timing.

MATERIAL AND METHODS

Glasshouse Study

A factorial experiment was initiated 20 Aug 1986, involving three bahiagrass cultivars (Argentine, Pensacola, and RCP-1) combined with three fertilization treatments (weekly application, single application, and nonfertilized control). Repetitive weekly fertilizer application, from 1 through 7 wk after planting, totaled 3.7 g N m^{-2}, 0.4 g P m^{-2}, and 2.3 g K m^{-2} over 7 wk; single application at 4 wk after planting was 3.4 g N m^{-2}, 0.4 g P m^{-2}, and 2.1 g K m^{-2}. Nutrient sources were all water soluble. The experimental unit was a 2.2-L plastic pot (152 mm in diam. at the top, 118 mm in diam. at the bottom, and 154 mm deep). Pots were filled with medium sand (a sieved siliceous, hyperthermic Quartzic Psammaquent) and underlaid with 31-mm potting mix [5:3:1 pine (*Pinus* sp.) bark/Florida peat/sand] to prevent sand from falling out the drainage holes at the bottom. Pots were planted with 69, 78, or 45 seeds of Argentine, Pensacola, or RCP-1, respectively, based on estimated rates of emergence; this resulted in 20 to 25 seedlings by 3 wk after planting. Seeds were covered with 8 mm of medium sand and watered with an average of 11 mm wk^{-1}, in order to maintain a moist seedbed. Cleaned seed weight was 3.37, 1.75, and 2.06 mg seed^{-1} for Argentine, Pensacola, and RCP-1, respectively. Seedlings were randomly thinned to six seedlings per pot at 4 wk after planting. Subsequently emerging seedlings were counted and removed weekly. Root and shoot growth through 10 wk post planting did not seem restricted by container size or interplant competition.

For the nine cultivar × fertilization combinations, there were 10 wk of destructive harvest in three randomized complete blocks, resulting in 270 experimental units. (Supplemental plants, not harvested within 10 wk but otherwise treated and managed identically, were used subsequently in 12-wk treatments, below.) Data obtained from 1 to 10 wk included leaf number and root and shoot dry weight per live seedling. Nine percent of seedlings died. Air temperature was a daily high of 38.8 °C ± 1.4 SD and low of 24.8 °C ± 0.7 SD during the first 7 wk. From Weeks 7 to 10, the high air temperature was 36.0 °C ± 1.3 SD and the low was 22.4 °C ± 1.0 SD. Daytime soil temperature 10 mm deep was 38.3 °C ± 5.7 SD. Because of their high similarity ($r^2 = 0.97$, 265 df), and to develop a growth-

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Abbreviations: ANOVA, analysis of variance; RCP, rapid coverage polycross; RGR, relative growth rate.

rate interpretation, root and dry shoot weights were initially combined (seedling dry weight).

Mean relative growth rate (Fisher, 1920) was determined for treatments by least-squares regression of $\log_e$ (mean seedling dry weight) over harvest weeks (Radford, 1967). Natural log transformation was appropriate because I assumed seedlings grew exponentially according to $y = e^{bx + a}$. In this expression, y = dry weight per seedling, b = mean RGR (Radford, 1967), x = time (wk), and $a = \log_e$ (intercept). For purposes of understanding relative seedling growth, the intercept was ignored. In order to portray graphically the relative seedling dry weight of various cultivars differing greatly in seed weight, seedling dry weight was divided by seed weight. In addition, treatment means were compared within individual weeks, based on ANOVA and the Waller–Duncan Bayesian k-ratio t-test ($k = 100$). The relative allocation to roots and shoots was interpreted based on the ratio of root dry weight to the sum of dry weights of roots plus shoots, and was analyzed by a general linear model involving cultivars and fertilization treatments as classification variables, and weeks as a continuous variable.

For plants not harvested at 10 wk, half received a 12-wk supplemental fertilization (3.1 g N m^{-2}, 0.3 g P m^{-2}, and 1.9 g K m^{-2}) superimposed on the preceding nine cultivar × initial fertilization treatments. The 18 resulting treatment combinations were arranged in three randomized complete blocks, for a total of 54 experimental units. Plants were harvested after 26 wk (38 wk post planting), roots and shoots were weighed, and dry weight calculated on an area basis. These plants had completely intermingled and covered the pot surfaces. Data were analyzed by ANOVA, and fixed effects were tested based on pooled residuals (Model I). When the higher-level interaction (e.g., cultivar × block) did not have a larger ($P = 0.25$) mean square than its lower-level interaction (e.g., cultivar × fertilization × block), then mean squares were pooled (Sokal and Rohlf, 1981).

Field Establishment

A field experiment was initiated 19 July 1985 at Fort Lauderdale Research and Education Center in Davie, Broward County, Florida. Three cultivars (Argentine, Pensacola, and RCP-1) and four fertilization treatments (fertilization at 0, 5, and 10 wk post planting and a nonfertilized control) were arranged in six randomized complete blocks. Plots 2.4 by 3.0 m were rototilled to 16-mm depth, broadcast seeded at 5.6 g m^{-2}, gently raked, mulched with 580 g m^{-2} small-grain straw, and packed with a Brillion seeder (Brillion Iron Works, Brillion, WI). Post planting fertilization was 4.9 g N m^{-2}, 0.5 g P m^{-2}, and 2.0 g K m^{-2}, with 0.6 g Fe m^{-2}. Fertilizer and seed were applied to each plot by hand from individually weighed portions. Nitrogen source was entirely water soluble, and was derived from NH_4 (75%) and NO_3 (25%) Seeds were not scarified and weighed 2.58, 1.51, and 1.69 mg $seed^{-1}$ for Argentine, Pensacola, and RCP-1, respectively; pure live seed proportions were 79, 91, and 90%, respectively.

Soil was a Margate fine sand (siliceous, hyperthermic Mollic Psammaquent, with pH 6.3, 5 mg P kg^{-1}, and 1 mg K kg^{-1}). At planting, the field was dominated by natalgrass [*Rhynchelytrum repens* (Willd.) C.E. Hubb.], and was free of bahiagrass or other perennial grasses, except for small patches of blue maidencane [*Amphicarpum muhlenbergianum* (Schultes) Hitchc.], which were tilled under. Rain was 390, 340, and 160 mm, respectively, during the 5-wk intervals following 0-, 5-, and 10-wk post planting fertilizations. Plots were not irrigated, were mowed three times per year, and received no pest control except for spot treatment with hydramethylnon {tetrahydro-5,5-dimethyl-2(1*H*)-pyrimidinone [3-[4-trifluoromethyl)phenyl]-1-[2-[4-(trifluoromethyl)phenyl] ethenyl]-2-propenylidene] hydrazone} to control fire ants (*Solenopsis invicta* Buren).

Seedling counts were made using a 76-cm^2 sampling ring tossed randomly at four subsample locations per plot. Counts taken at 17 and 25 d after seeding were averaged as repeated measures and reported as absolute 3-wk emergence. Relative emergence was calculated as the percentage of absolute emergence divided by pure live seeds planted. Visual estimate of 3-wk emergence was performed on a scale of 1 to 10, with 1 = no visible emergence, 7 = acceptable emergence (could not step without touching a seedling), and 10 = extremely dense emergence (could not toss a 24-mm-diam. coin three times without hitting a seedling). Weediness was evaluated 3 and 25 wk after planting on a 1 to 10 scale (10 = extremely high weed density and 1 = no weeds). Establishment was evaluated on several dates using a scale of 1 to 10 (1 = worst possible bahiagrass canopy coverage, uniformity, and weediness; 7 = acceptable; and 10 = highest possible bahiagrass canopy coverage).

Supplemental fertilizer was applied to one half of each plot, on a split-block basis, on 1 May 1987 (1.7 yr after planting), at 3.9 g N m^{-2}, 0.4 g P m^{-2}, 1.6 g K m^{-2}, with 0.3 g Fe m^{-2}. Most (78%) of the N was water soluble. Biomass was determined in 1986 and 1987 (1.1 and 2.2 yr after planting, respectively) as the dry weight of bahiagrass shoots and washed roots, obtained from each plot (or split plot) using a 510-cm^2 core removed to $\approx$20 cm depth. This was the depth at which rooted cores broke from the sand subsoil. Root proportion was determined as the ratio of root dry weight to the sum of dry weights of roots plus shoots.

Establishment ratings were combined as repeated measures, within periods: early, three ratings 0.5 to 0.7 yr after planting; late, six ratings 0.9 to 2.0 yr after planting. Dates × treatment interaction was either not detectable ($P > 0.05$) within periods or had a relatively small contribution to total sums of squares. Data were analyzed by ANOVA as described previously. Because the 1.7-yr supplemental fertilization had no effect on subsequent evaluations, the split-plot treatments were pooled for analysis.

A second field experiment was planted under optimum conditions in Margate fine sand in August 1987. Plots were 3.0 by 4.1 m. There were eight randomized complete blocks (replicates) of Argentine, Pensacola, and RCP-1 bahiagrasses seeded at 5.6 g m^{-2}. Soil had been treated with methyl bromide prior to planting. During 6.5 mo of establishment, plots were fertilized with a total of 24.2 g N m^{-2}, 2.7 g P m^{-2}, and 10.0 g K m^{-2}, and were mowed 12 times. Plots were irrigated 4 mm every other night, decreasing to once per week, until March 1988, when irrigation was permanently stopped. Visual estimates of turfgrass quality were made generally each month, with 10 = highest possible density, uniformity, and absence of weeds. Turfgrass quality ratings were pooled within 3-mo intervals as subsamples in time, in order to graphically present overall trends. Root and shoot dry weights were determined in August 1991 using a 510-cm^2 core removed to $\approx$20-cm depth.

RESULTS

Glasshouse Study

Seedlings fertilized weekly produced an average of 1.1 leaves wk^{-1} (Fig. 1A). Leaf number of weekly fertilized seedlings was greater ($P < 0.05$) than nonfertilized seedlings from 3 to 10 wk post planting, and was greater than single-fertilized seedlings only from 3 to 5 wk post planting. Thus by 6 wk after planting, bahiagrass receiving a single fertilization at 4 wk post planting had recovered the same foliar development as seedlings fertilized weekly. Mean RGR from 1 to

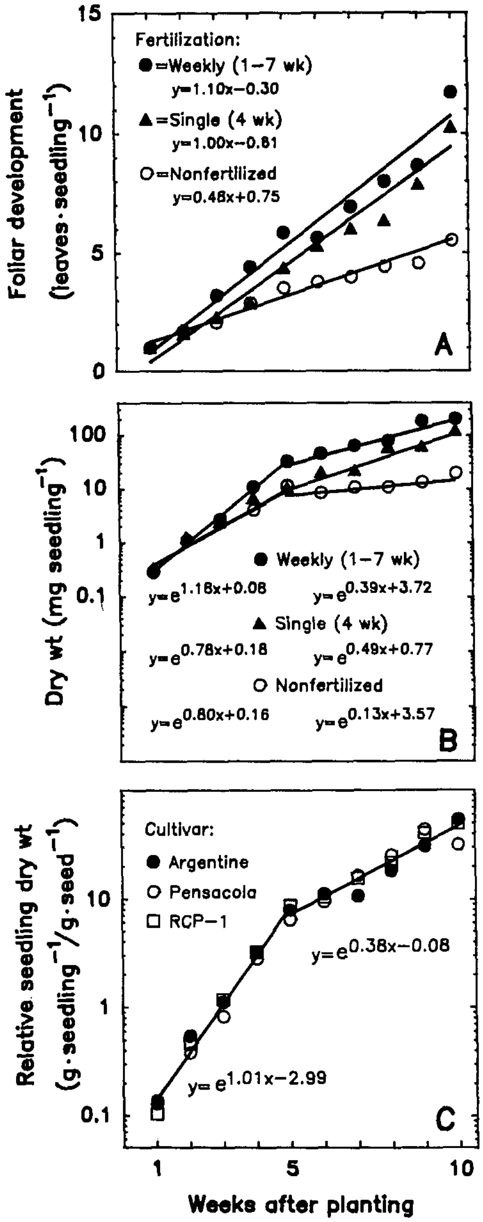

Fig. 1. (A) Foliar development, (B) dry weight, and (C) relative seedling dry weight for seedlings of three bahiagrass cultivars destructively harvested at weekly intervals for 10 wk in a glasshouse. Means of nine observations.

5 wk post planting was greater (Fig. 1B) for weekly fertilized (RGR = 1.18 wk^{-1}) seedlings than other treatments (RGR = 0.78 and 0.80 wk^{-1} for single fertilized and nonfertilized, respectively). All treatments had a noticeable leveling in RGR at 5 wk after planting. From 5 to 10 wk, single-fertilized seedlings nearly caught up to the size of weekly fertilized seedlings.

Mean RGR was equal among cultivars (data not shown), which is obvious when seedling dry weight is portrayed relative to seed weight, which differed among cultivars. By this method, the intercepts were also equalized (Fig. 1C). This predicts equal biomass accumulation for cultivars, when compared on equal weight of viable seeds per area.

Proportion root weight (data not shown) was not affected by week from 1 to 5 wk post planting, but increased slightly ($P < 0.05$) during 5 to 10 wk post planting. Proportion root weight was similar among fertilization treatments during 1 to 5 wk, but differed ($P < 0.001$) during 5 to 10 wk, with single-fertilized seedlings having reduced root weight proportion (35%) compared with other treatments (42%). Cultivars differed ($P < 0.001$) in root weight proportion, with Argentine (42%) greater than Pensacola (37%) and RCP-1 (36%).

Table 1. Dry weight (roots + shoots) of 38-wk-old bahiagrass in a glasshouse, following initial (1- to 7-wk) fertilization treatments and supplemental (12-wk) treatments. Means of three cultivars and three replicates.

	Initial fertilization treatment			
Supplemental treatment	Repetitive weekly (1–7 wk)	Single application (4 wk)	Non-fertilized	Mean
		g m^{-2}		
Fertilized at 12 wk	930a†	810a	370a	700a
Nonfertilized	580b	510b	110b	400b
Mean	760	660	240	550

† Within columns, means followed by the same letter are not significantly different by the Waller–Duncan Bayesian *k*-ratio *t*-test, $k = 100$, $P \approx 0.05$. All means of initial fertilization treatments (760, 660, and 240) were different ($P < 0.05$). All values for repetitive weekly and single-application fertilized seedlings were different from nonfertilized seedlings in corresponding rows, but not different from one another.

Initial (1 to 7 wk) fertilization treatments (repetitive weekly and single applications) had a greater effect on 38-wk dry weight than 12-wk supplemental fertilization treatments (Table 1). Although significant, the 12-wk fertilization did not compensate for prior differences. As was expected from RGR for 1 to 10 wk, cultivars had equal dry weight at 38 wk. The proportion root dry weight of fertilized Argentine (47%) was greater than Pensacola (42%) and RCP-1 (42%).

Field Establishment

Fertilization at planting time had no effect on 3-wk emergence, but was associated with severe weediness (Table 2). At 25 wk post planting, the 10-wk post planting fertilized plots were most weedy, but not different from the 5-wk post planting fertilization. Fertilization 5 wk post planting resulted in the best establishment rating, based on late evaluations.

RCP-1 had the highest seedling 3-wk emergence (Table 2). There was no difference among cultivars in weediness. Only RCP-1 had acceptable (≥ 7.0) early establishment. Argentine was comparable to RCP-1 in late establishment. There was a cultivar × fertilization interaction in late establishment ratings. This was most apparent in the positive response of RCP-1 to 5-wk post planting fertilization (Fig. 2). Only 5-wk post planting fertilization resulted in acceptably established turf (rating ≥ 7.0), and only for Argentine and RCP-1.

Argentine and RCP-1 had greater root and shoot dry weight 1.1 yr post planting than Pensacola (Table 2). Argentine had greater root dry weight and greater root weight proportion 2.2 yr post planting than Pensacola and RCP-1. The superior rooting of Argentine paralleled its delayed establishment ratings, despite its low 3-wk emergence. There was no cultivar × fertilization interaction for dry weights.

In the second field experiment, there was initially no difference in turfgrass quality ratings among cultivars. Following irrigation curtailment, Argentine sustained high quality ratings throughout the third year (Fig. 3), while Pensacola and RCP-1 declined and were unacceptable (rating < 7.0). Bahiagrasses did not differ in shoot dry weight 4 yr after planting (mean = 2200 g m^{-2}). Root weight proportion did not differ ($P > 0.05$) among cultivars, but was in the same rank as previous data, 43, 41, and 38% for Argentine, Pensacola, and RCP-1, respectively. Root dry weight differed, with Argentine having more root biomass (1870 g m^{-2}) than Pensacola (1340 g m^{-2}) and RCP-1 (1370 g m^{-2}).

DISCUSSION

Successful bahiagrass establishment can be achieved under weedy conditions, at relatively low seeding density (5.6 g seed m^{-2}), when seedlings receive timely (e.g., 5-wk) post planting fertilization. The timeliness benefit is probably derived from seedling growth characteristics. Bahiagrass root systems are probably effective by 4 to 5 wk after planting. At this point, nutrients are crucially needed in sandy soil, and can greatly promote bahiagrass growth, rather than being leached or stimulating weed growth, as was observed from 0-wk fertilization. Late (10- or 12-wk) fertilization is less effective than 4- or 5-wk fertilization, in both the field and the glasshouse. The three-leaf stage (Fig. 1A) is a reasonable field indicator for the best time to fertilize bahiagrass. The abrupt leveling of bahiagrass seedling RGR at 5 wk is intriguing, and it is hypothesized to represent conversion to autotrophic state. Although speculative, this possibility might lead to an explanation for the high sensitivity of 4- to 5-wk seedlings to supplemental fertilization. The large number of RCP-1 seedlings present at 3 wk (Table 2) explains its superior early field establishment and responsiveness to timely, post planting fertilization, but was not translated into long-term performance, for which Argentine was always superior.

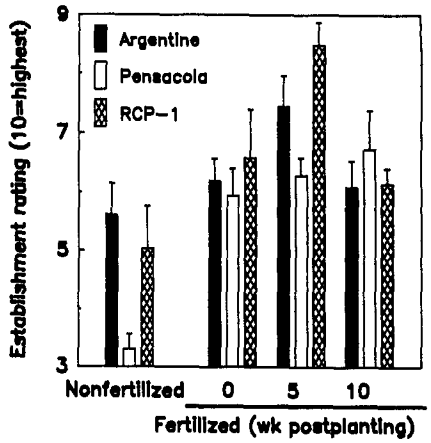

Fig. 2. Late-establishment rating (means of six dates of evaluation 0.9 to 2.0 yr post planting) of three bahiagrass cultivars and four fertilization treatments. Means of six replicates. Bars represent SE.

Seedling growth rates of cultivars were equal, thus the high late-establishment rating and biomass accumulation of Argentine requires explanation. Factors in the field, such as weed competition and delayed emergence, may have varied among cultivars, thereby influencing late-establishment ratings. Argentine is a

Table 2. Seedling emergence, weediness, establishment rating, and dry weight (1.1 and 2.2 yr post planting) of bahiagrass cultivars and post planting fertilization treatments. Based on six replicates.

								Dry weight					
	Seedling 3-wk emergence†			Weediness		Establishment‡ rating		Shoots		Roots		Proportion root dry weight	
Treatment	Absolute	Relative	Visual	3-wk	25-wk	Early	Late	1.1 yr	2.2 yr	1.1 yr	2.2 yr	1.1 yr	2.2 yr
	no. m^{-2}	%	10 = highest					g m^{-2}				%	
					Cultivar								
Argentine	510c	33b	6.3c	4.0	4.5	4.9b	6.3a	332a	510	248a	348a	43	41a
Pensacola	1020b	34b	7.1b	4.4	4.5	5.3b	5.6b	242b	453	158b	267b	39	37b
RCP-1	1560a	58a	8.5a	4.6	4.0	7.1a	6.6a	333a	477	226a	282b	40	37b
					Post planting fertilization treatment§								
0 wk	1080	44	7.4	6.1b	4.1a	5.8	6.2b	344ab	502	241	316	41	39
5 wk	900	38	7.2	3.6a	4.5ab	6.3	7.4a	366a	526	245	324	41	38
10 wk	990	40	7.0	3.6a	4.9b	5.6	6.3b	285b	495	200	295	40	38
Nonfertilized	1150	46	7.4	3.9a	3.8a	5.4	4.6c	213c	398	157	262	41	39
					Analysis of *F*-test probabilities								
Cultivar (C)	**	**	**	NS	NS	**	**	**	NS	**	**	NS	**
Fertilization (F)	NS	NS	NS	**	**	NS	**	**	NS	NS	NS	NS	NS
C × F	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS

*,** Significant at $P < 0.05$ and 0.01, respectively.

† Seedling 3-wk emergence: absolute, based on counts; relative, percent adjusted for seed weight and pure live seed proportion.

‡ Establishment rating: early, means of three 0.5- to 0.7-yr post planting establishment evaluations; late, means of six 0.9- to 2.0-yr post planting establishment evaluations.

§ Within columns, for either cultivars or fertilization treatments, means followed by the same letter are not significantly different by the Waller–Duncan *k*-ratio *t*-test, $k = 100$, $P \approx 0.05$.

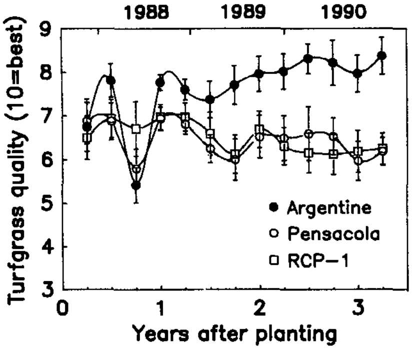

Fig. 3. Turfgrass ratings of three bahiagrass cultivars. Means of eight replicates representing 3-mo intervals. Bars represent SE.

broad-leaved tetraploid, $2n = 40$, while Pensacola and RCP-1 are narrow-leaved diploids, $2n = 20$ (Busey, 1980, unpublished data) This difference, along with the higher proportion of root weight in Argentine in both the glasshouse and field, may confer a competitive advantage to Argentine vs. other cultivars in a humid, nonirrigated environment. Mean root weight proportion, across two field experiments and two glasshouse evaluations, was 43, 39, and 38% for Argentine, Pensacola, and RCP-1, respectively. While establishment can be optimized through timely post planting fertilization, the greatest long-term performance under low maintenance conditions seems tied to differences in allocation of growth to the root system, for which the tetraploid Argentine is consistently superior.

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