Bahiagrass (*Paspalum notatum* Flügge) is an important forage grass for the southeastern United States, being well adapted to conditions such as sandy or poorly drained soils, drought, and heavy continuous grazing. Current bahiagrass cultivars germinate over an extended period of time and the slow emergence produces incomplete stands, allowing weeds to compete and delay grazing or first cutting for hay. A recurrent restricted phenotypic selection (RRPS) program began in 1996 and continued for four cycles for improving the emergence and establishment rates within Tifton 9 bahiagrass (‘Pensacola’ type). The resulting cycle-4 (C4) rapid-emergence ‘TifQuik’ was then increased and tested for seedling emergence, vigor, and establishment. TifQuik had a fourfold improvement of emergence compared to Tifton 9 after 1 wk in greenhouse trials. Emergence rates after 1 and 2 wk were significantly greater for TifQuik compared to Tifton 9 in replicated field trials. Plant heights after 3 wk from planting were 0.12 m for TifQuik versus 0.08 m for Tifton 9. The first-harvest dry-matter yield of TifQuik was 3128 kg ha⁻¹ compared with 1539 kg ha⁻¹ for Tifton 9 and the total establishment year dry-matter yields were 9230 kg ha⁻¹ and 7466 kg ha⁻¹ for TifQuik and Tifton 9, respectively. TifQuik had greater first-clipping yields than Tifton 9 at Ona, FL, in 2005. The accelerated emergence and establishment of TifQuik will be useful in sod-based rotation systems with cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.).
Though yields have been improved through breeding, early germination of the seed, faster emergence, and subsequent rapid establishment of bahiagrass remain inadequate. West and Marousky (1989) concluded that germination of bahiagrass is controlled by the restriction of water uptake and embryo expansion by the lemma until the lemma opens with ageing. Research to hasten Tifton 9 bahiagrass establishment under field conditions by ageing seed (Gates and Dewald, 1998) or by seed coat removal and varying planting date (Gates and Mullahey, 1997; West, 1992) has been unsuccessful. However, it was discovered that in the process of selecting for more vigorous plants in the RRPS system, Burton had also improved the rate of emergence (Burton, 1989; Gates and Burton, 1998). Seed of ‘Tifton 18’ (Burton and Anderson, 2008), resulting from 18 selection cycles was compared to Tifton 9 for seedling emergence. Tifton 18 seed exhibited greater emergence (14.4 and 43.9%) than Tifton 9 (8.7 and 35.6%) 7 and 14 d after planting, respectively.

In other species, Schaaf and Rogler (1960) first reported the transmission of low seed dormancy from parents to progeny in green needlegrass [Nassella viridula (Trin.) Barkworth]. Recurrent selection in kleingrass (Panicum coloratum L.) (Tischler and Young, 1987) was successful in reducing seed dormancy, but it did not result in faster germination. Their results indicated that dormancy and fast germination are two separate mechanisms. Recurrent selection for both fast and slow rate of germination was performed within populations of blue panicgrass (Panicum antidotale Retz.) (Wright, 1978). The mean range in days to 50% germination was 5.5 to 13.8 d for the fast and slow rate selections, respectively. Wright (1980) found that selection for fast germination resulted in much greater growth rates during seedling and young-plant growth rates, which would suggest that quick germination results in faster emergence and faster overall stand establishment.

Given the positive attributes of bahiagrass for rotation with row crops such as peanut and cotton and the pressures to develop alternatives to chemical pest control methods, it is increasingly important that methods be developed to establish bahiagrass rapidly and with full stands on high-value crop land. In rotation schemes, an extra year required for establishment or the presence of undesirable weedy species in the bahiagrass stand would increase the cost of bahiagrass as a pest-management alternative. Additionally, rapid establishment would increase the likelihood of at least some revenue (hay or grazing) from the rotation crop. The purpose of this study was to select for increased rate of germination and emergence by employing the RRPS procedure and measure the subsequent effect on stand establishment.

**METHODS**

**Recurrent Restricted Phenotypic Selection for Fast Emergence**

Initial RRPS research was conducted at Tifton, GA. In the winter of 1996 Tifton 9 breeder seed was planted in flats in Tifton (fine-loamy, kaolinitic, thermic Plinthic Kandiudult) loamy sand soil in the greenhouse to estimate early emergence percentage (within 5–7 d after planting). From this, the number of seeds needed to obtain 1000 early emerging seedlings was determined (approximately 20,000 seeds) to form the next selection cycle. This large population size was maintained in the event that heritability for seedling emergence was low. The plantings were made in 0.30×0.46 m flats at a uniform depth (~10 mm) in the spring of 1997. The first 1000 seedlings that emerged (normally between Days 5 and 7 from planting) were carefully transplanted to 0.05-m-diam. clay pots. These seedlings were transplanted into methyl bromide–treated Tifton soil field plots in April of 1997. Seed from this nursery was hand-harvested at maturity (June 1997) and formed the seed population for the subsequent cycle of selection. One cycle was completed during each year. The fourth cycle (initial TifQuik breeder seed) was completed in 2000. TifQuik seed was planted in a nursery during the spring of 2001 and seed has been harvested each year to supply seed for testing and further increase.

**Evaluation of Fast-Emerging TifQuik**

TifQuik and Tifton 9 seeds harvested from breeder plots in Tifton, GA, in the summer of 2003 were planted in a greenhouse germination study with three replications on 24 Feb. and 31 Mar. 2004 and 22 Jan. 2005. Flats were filled with steam-fumigated Tifton sandy loam soil and placed on greenhouse benches. Seed was planted (100 seeds per replication) at a depth of 10 mm in rows. Emerging seedlings were counted on Days 6, 8, 10, and 13 after planting.

In March 2003 at Tifton, GA, a field site with Tifton sandy loam was lightly tilled, smoothed, fumigated, and fertilized (445 kg ha⁻¹ of 10–10–10 N–P₂O₅–K₂O). Seeds from 2003 breeder plots used in the greenhouse studies were planted in a randomized complete block with four replications. Tifton 9 and Pensacola cultivars were used as checks to compare against TifQuik. Plots were 4.57 m long and 1.54 m wide. Seed was planted 6 May 2003 at the rate of 17.8 kg pure live seed ha⁻¹ with a seven-row (0.22 m apart) drill planter. Plots were irrigated once after planting. Germinating seeds were counted within each plot by counting emerging seedlings within two randomly selected 0.01-m lengths for each row for a total of 14 counts per plot. Germination counts were performed at 7, 14, and 21 d after planting. Day 21 counts were considered final counts and Day 7 and 14 counts were calculated as percentage of final germination. Seedling height was recorded at 3, 4, and 5 wk after planting by averaging 14 measurements (two random areas per row). Visual percentage plant cover was rated 6 and 7 from planting. Stand vigor, recorded as rate of growth, was visually rated at 6 wk (1, low vigor, to 5, very vigorous). Fertilizer was applied at recommended rates (4–1–2 N–P₂O₅–K₂O ratios) after each harvest. The total N application for each year of the 3-yr study was 132, 171, and 157 kg ha⁻¹.

Forage yield was measured by clipping the center 0.91-m width the length of the plot (4.57 m) using a Carter harvester.
(Carter Mfg. Co., Inc., Brookston, IN). Harvests were performed on 8 July, 13 August, 19 September, and 22 October in the establishment year (2003). Plots were harvested 17 May, 21 June, 20 July, 25 Aug., and 1 Oct. 2004; and 26 May, 1 July, 4 Aug., 6 Sept., and 12 Oct. 2005. Dry-matter yields were calculated and used for statistical analyses.

Regional Testing
Subsequent evaluations were performed at Marianna, FL; Ona, FL; and Overton, TX. Field trials having four replications were established with TifQuik, Tifton 9, Pensacola, and Argentine. Plots were planted on 6 May 2004 at Overton, TX, on Bowie very fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudult); on 17 Sept. 2004, at Ona, FL, on Pomonka sandy loam (sandy, siliceous, hyperthermic Ultic Alaquod); and on 20 June 2005 at Marianna, FL, on Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult). The seedling rate was 17.8 kg pure live seed ha⁻¹. Plot size was 1.8 m by 4.6 m at the Ona and Overton locations and 1.5 m by 3.3 m at Marianna with four replications. No fertilizer was applied during the establishment year and weeds, primarily southern crabgrass [Digitaria ciliaris (Retz.) Koel.], were controlled by mowing. Fertilizer was applied at recommended rates (4–1–2 N–P₂O₅–K₂O ratios) after each harvest.

At Ona and Marianna establishment ratings were scored by visually estimating the percentage plot coverage of bahiagrass seedlings 1, 2, 3, and 4 wk after planting at each location. At Ona, plots were harvested on 8 Apr. (initial winter growth), 6 May, 1 July, 28 July, 26 Aug., and 23 Sept. 2005. A 0.42 m strip was harvested from each plot with a rotary-plot harvester cutting at a height of 0.07 m. Fertilizer was applied at recommended rates after each harvest. At Marianna, a 0.91 by 3.0 m strip was harvested from each plot with a rotary-plot harvester cutting at a height of 0.07 m on 8 May, 12 June, 11 July, 14 Aug., 13 Sept., 13 Oct., and 8 Dec. 2006. At Overton, a 1.5-m wide strip was harvested from the center of each plot on 7 June, 20 July, and 19 Oct. 2005 with a Swift Machine Forage Harvester (Swift Machine Inc., Swift Current, SK, Canada).

Characterization of Individual Plant Populations
Seed of TifQuik and Tifton 9 were planted in the greenhouse 15 Mar. 2005. Seedling emergence was recorded as previously described. The first 100 emerging seedlings from each genotype were transplanted into 0.044-m clay pots with sterilized soil. The culm number and culm angle as measured as degrees from ground (ground level = 0°, completely erect = 90°) of the lowest culm to the ground, measured by a protractor, was recorded 4 wk after germination (17 May 2005) and plants were then transplanted to the field. Plants of each entry were space planted 0.26 m apart in a single bed at Tifton, GA. Plant height (ground to base of terminal culm), leaf length (third leaf from culm terminal), and leaf width (third leaf from culm terminal) were recorded on 30 June 2005 in the field as described by Burton and Anderson (2008). Raceme number (average of three inflorescences) and raceme length (average of longest raceme on three inflorescences) were measured on 15 July.

Data were evaluated using Proc GLM (SAS Institute, 2000) and comparison of entry means within tests was performed using the t test for two means and least significant differences (LSD) when F-tests were significant at the 0.05 level of probability or less for multiple means.

RESULTS AND DISCUSSION
Evaluation of Fast Germinating TifQuik
Seedling emergence of TifQuik in the greenhouse studies in 2003 and 2004 was five times that of Tifton 9 after 6 d and significantly higher 8 and 10 d after planting (Table 1). Tischler and Young (1987) observed similar fast emergence after six cycles of selection of kleingrass. They concluded that species such as kleingrass or ryegrass (Lolium multiflorum Lam.) have a much shorter germination time than species such as blue panicgrass that showed significant positive changes in the rate of germination over an extended period of time (Wright, 1978). The four-cycle RRPS TifQuik bahiagrass results are consistent with the results of short germination species such as kleingrass and ryegrass.

Seedling emergence from field studies supported the greenhouse data. TifQuik (75%) emerged faster than Tifton 9 (32%) or Pensacola (18%) after 1 wk (Table 2). Though seeding rate was based on pure live seed, the total number of emerged seedlings of TifQuik (225) after 3 wk was significantly higher than Tifton 9 (109) or Pensacola (139). TifQuik seedlings were taller at 3, 4, and 5 wk after planting and plot coverage was faster than Tifton 9 or Pensacola. The physiological change to bahiagrass after four cycles of RRPS for emergence was thus similar to what Wright (1980) observed with blue panicgrass. As a result of quick emergence and improved seedling vigor, the yields of TifQuik were significantly higher at the first clipping (Table 3). Total dry-matter yields of TifQuik and Tifton 9 were not significantly different for the 3 yr, indicating that genetic differences for long-term yield and persistence were not changed through RRPS for quick emergence.

Regional Testing
TifQuik had faster emergence and resulted in higher establishment ratings for the first 3 wk at Ona, FL (Table 4).

Table 1. Percentage emergence of seed at 6, 8, 10, and 13 d after planting in the greenhouse, Tifton, GA, in 2003 and 2004.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Day 6</th>
<th>Day 8</th>
<th>Day 10</th>
<th>Day 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planted 24 Feb. 2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TifQuik</td>
<td>33a₁</td>
<td>53a</td>
<td>69a</td>
<td>69a</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>5b</td>
<td>19b</td>
<td>41b</td>
<td>47a</td>
</tr>
<tr>
<td>Planted 31 Mar. 2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TifQuik</td>
<td>28a</td>
<td>50a</td>
<td>59a</td>
<td>59a</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>5b</td>
<td>15b</td>
<td>36b</td>
<td>46b</td>
</tr>
<tr>
<td>Planted 22 Jan. 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TifQuik</td>
<td>21a</td>
<td>39a</td>
<td>53a</td>
<td>64a</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>2b</td>
<td>24b</td>
<td>50a</td>
<td>56a</td>
</tr>
</tbody>
</table>

₁Values in a column followed by same letters are not significantly different at the 0.05 probability level.
The faster establishment resulted in a higher initial yield (Table 5) than Tifton 9, Argentine, or Pensacola. Results of field establishment were similar for TifQuik plots at Marianna, FL (Table 6), but initial yields were not significantly higher than Tifton 9 (Table 7). At Overton, 6 wk after planting average height of TifQuik seedlings were 0.15 m compared to 0.06 to 0.08 m for the other entries. Clipping yields at Overton were not taken during the establishment year (2004). However, TifQuik produced numerically higher yields than Tifton 9 in the first two clippings (due to better establishment) when low rainfall resulted in overall lower yields (Table 8).

Characterization of Individual Plant Populations

Plant height, leaf length, and leaf width were significantly different between TifQuik and Tifton 9 among the 100 individual plants measured in the field (Table 9). Numbers of culms, culm angle, raceme number, and length were not significantly different. The taller plant height of TifQuik was attributed to the faster emergence compared to Tifton 9. TifQuik (0.20 and 0.067) had shorter and narrower leaves than Tifton 9 (0.24 and 0.071), which may be due to the nature of the measurements, since the third leaf from culm terminal was recorded on every plant. Leaves tend to become smaller as plants grow taller, as was the case with TifQuik from these results.

The RRPS technique appeared to work well for reducing time to seedling emergence and subsequently improving establishment. Selection among and subsequent planting of large populations (1000 plants) within each cycle of selection was sufficient to maintain a viable and stable population while genetically improving emergence. Wright (1978) noted that four cycles of selection were sufficient to minimize reduced seed dormancy in panicgrass. After six cycles of selection for reduced dormancy in klinggrass, a fivefold increase in germination was reported (Tischler and Young, 1987). It should be noted that dormancy was not a target of selection in our study. Increased seedling emergence was the criteria for selection. Four cycles of selection appeared sufficient for bahiagrass and...
led to better establishment. Dormancy attributes of this material are currently being examined.

Faster establishment of TifQuik should be useful for decreasing weed competition and increasing profitability of a sod-based rotation system by providing earlier grazing or an additional hay harvest in the establishment year. Profits from hay would increase significantly with yields of a ton or better 2 mo after planting.

Establishment of a bahiagrass sod-based rotation system can increase yields of subsequent peanut crops by two- to threefold (Dickson and Hewlett, 1989; Hewitt et al., 2003; Hagan et al., 2003; Katsvairo et al., 2007b), and this has been attributed to disease and nematode suppression (Brenneman et al., 1995, 2003; Katsvairo et al., 2007a). Bahiagrass is better than bermudagrass for improving peanut yields when soil-borne diseases are present and 4-yr rotations of these grasses produced equally high peanut yields with or without nematicides in previously highly infested fields (Baldwin et al., 2003). In the long term, sod-based systems improve soil quality, especially in the form of organic matter (Lal and Kimble, 1997). Katsvairo et al. (2007a) did not observe cotton lint yield increases after bahiagrass; however, root biomass was greater, which indicates improved soil quality. Also, bahiagrass along with winter leguminous cover crops have been proposed for the transition between traditional and organic farming Katsvairo et al. (2007c). TifQuik bahiagrass should further enhance these positive effects through quicker establishment.

Table 7. Dry-matter yields (kg ha⁻¹) of bahiagrass genotypes in 2006 established in 2005 at the North Florida Research and Education Center, Marianna, FL.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TifQuik</td>
<td>498a†</td>
<td>417a</td>
<td>1340ab</td>
<td>3574a</td>
<td>1536a</td>
<td>352ab</td>
<td>8913</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>260abc</td>
<td>391ab</td>
<td>1480a</td>
<td>3560a</td>
<td>1477ab</td>
<td>409a</td>
<td>8647</td>
</tr>
<tr>
<td>Pensacola</td>
<td>246bc</td>
<td>177cd</td>
<td>849bc</td>
<td>3551a</td>
<td>1394ab</td>
<td>262b</td>
<td>7433</td>
</tr>
<tr>
<td>Argentine</td>
<td>129c</td>
<td>79d</td>
<td>479c</td>
<td>3276a</td>
<td>1435ab</td>
<td>300ab</td>
<td>6425</td>
</tr>
</tbody>
</table>

†Values in a column followed by same letters are not significantly different at the 0.05 probability level.

Table 8. Dry-matter yields (kg ha⁻¹) of bahiagrass genotypes in 2005 established in 2004 at Overton, TX.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>7 June</th>
<th>20 July</th>
<th>19 Oct.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TifQuik</td>
<td>540a†</td>
<td>1236a</td>
<td>1221ab</td>
<td>2998a</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>352ab</td>
<td>1148ab</td>
<td>1332a</td>
<td>2832a</td>
</tr>
<tr>
<td>Argentine</td>
<td>237b</td>
<td>740c</td>
<td>975bc</td>
<td>1951b</td>
</tr>
<tr>
<td>Pensacola</td>
<td>279b</td>
<td>843bc</td>
<td>790c</td>
<td>1913b</td>
</tr>
</tbody>
</table>

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Table 9. Comparative means for morphological traits between Tifton 9 and TifQuik on 100 space planted individuals from greenhouse and field, Tifton, GA, 2005.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Culm no.</th>
<th>Culm angle†</th>
<th>Plant height‡</th>
<th>Leaf length‡</th>
<th>Leaf width‡</th>
<th>Raceme§</th>
<th>Raceme length§</th>
</tr>
</thead>
<tbody>
<tr>
<td>TifQuik</td>
<td>9.44a†</td>
<td>33.6a</td>
<td>0.65a</td>
<td>0.20b</td>
<td>0.067b</td>
<td>2.67a</td>
<td>0.12a</td>
</tr>
<tr>
<td>Tifton 9</td>
<td>9.17a</td>
<td>33.7a</td>
<td>0.50b</td>
<td>0.24a</td>
<td>0.071a</td>
<td>2.57a</td>
<td>0.13a</td>
</tr>
</tbody>
</table>

†Recorded as degree angle from ground on potted plants before transplanting in the field on 17 May 2005.
‡Recorded on spaced plants in the field on 29 June 2005.
§Recorded on spaced plants in the field on 15 July 2005.

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