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Goosegrass Seedling Emergence and Growth in Bermudagrass Canopy and Divots

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Abstract. **Goosegrass, *Eleusine indica* (L.) Gaertn., is a serious weed in bermudagrass, *Cynodon* spp. Rich., golf and sports turf. Reduction of canopy gaps such as divots might discourage goosegrass establishment because turf canopy reduces sunlight that could stimulate goosegrass seed germination. The objective was to compare goosegrass seedling emergence and growth under different conditions of bermudagrass canopy, including bare soil and divots of different ages, and the effect of fertilization rates. The first experiment compared surface treatments. Goosegrass seeds were planted monthly for 12 months in bare soil and divoted pots in a glasshouse. Initial goosegrass seedling emergence was large in the first month after planting, 23% in divots and 20% in bare soil, compared with only 9% emergence from canopy. Reduced emergence occurred from 2 to 8 months in canopy, divots, and bare soil. Cumulative goosegrass emergence was 44% in divots, 40% in bare soil, and 31% in canopy. In a second experiment, goosegrass seeds were planted in divots 0, 2, 4, 6, 8, and 10 weeks old. Divots were visibly closed within 4 to 6 weeks. By 9 weeks after seed planting, goosegrass seedling emergence was reduced 72% after planting in 10-week-old divots compared with fresh, 0-week divots. Goosegrass continued to emerge through all 63 weeks observed after seed planting. High fertilization rate, 123 g N/m^2/year, from 10 to 63 weeks reduced cumulative late seedling emergence 34%, compared with half-rate fertilization, probably due to denser canopy under high fertilization. In a third experiment, goosegrass seedlings planted in closed bermudagrass canopy grew 90% less, in root and shoot fresh and dry mass, compared with seedlings planted in divots. Across all experiments, goosegrass emergence and growth were reduced by increased canopy.**

Goosegrass, *Eleusine indica* (L.) Gaertn., is a serious weed in bermudagrass, *Cynodon* spp. Rich., golf and sports turf in warm climates. In tropical climates, goosegrass seeds likely germinate continuously, and there is a "diminished role" of preemergence herbicides for goosegrass control (Wiecko 2000). Postemergence herbicides are not always effective in killing mature goosegrass and can weaken turfgrass (Busey 2004). Effects of cultural management were documented in 10 reports on crabgrass, *Digitaria* spp. Hall., in cool-season turfgrasses. There were primarily strong reductions of crabgrass at higher rates of N fertilization and at taller mowing heights (Busey 2003). Several mostly perennial weed species in St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntze turf, are affected in different directions by irrigation, mowing height, and fertilization rate (Busey and Johnston 2006). One report on green kyllinga, *Cyperus brevifolius* (Rottb.) Hassk. (syn. *Kyllinga brevifolia* Rottb.) in bermudagrass showed that in weak turf, high fertilization reduces, and low mowing increases, green kyllinga infestation (Lowe et al. 2000).

Cultural management of goosegrass can be improved by knowing its biology, including the relationship of management on goosegrass seedling emergence and growth, seedbank size, and seed longevity. Hawton and Drennan (1980) cited a report of 5 × 10^9 goosegrass seeds/ha and reported seedling emergence of up to 68% in the first year, 2% in the second, and 0.2% in the third year, implying reduced longevity. In contrast, Masin et al. (2006) reported goosegrass having more than 50% viability after 1200 d of burial. Goosegrass showed half-yearly cyclical germination behavior, germinating in both late spring and autumn.

There are few reports of cultural management of goosegrass in turfgrass. Bermudagrass canopy cover, not compaction, more readily explains the infestation of goosegrass due to traffic in sand soil; in competition with bermudagrass, goosegrass seedling emergence is reduced 58% at 2.5-cm mowing height compared with 1.3-cm mowing height (Arrieta et al. 2009). Small canopy gaps in lowland forest increase seedling recruitment (Dupuy and Chazdon 2008), a concept useful in turfgrass as well as forests. Canopy gaps caused by loss of turfgrass cover under traffic could foster goosegrass infestation.

Goosegrass seeds germinate strongly in response to daily fluctuating temperatures of 20 and 35 °C (Nishimoto and McCarty 1997) resulting in 99% goosegrass seed germination within 37 d. Conditions of fluctuating temperature would occur in canopy gaps such as bare ground and scalped and thin turf, which could result from traffic. Divots are a kind of canopy gap caused by golf strokes and provide a model for understanding the relationship of goosegrass establishment and turf canopy damage. There are differences in divot resistance among bermudagrass and zoysiagrass, *Zoysia* spp. Willd. cultivars (Trappe et al. 2011). Recovery of bermudagrass from divots is predicted in a one-phase exponential model (Karcher et al. 2005). There is no report on the rate of goosegrass seedling emergence and seedling growth in turfgrass canopies and divots. The objective of this study was to compare goosegrass seedling emergence and growth under different conditions of bermudagrass canopy, including bare soil and divots of different ages, and the effect of fertilization rates.

Materials and Methods

Field observations. Mature goosegrass plants were observed in a population in a managed soccer playing field in Pine Island Park, Plantation, FL, USA. The diameters of 1093 plants were measured with a ruler, in 136 quadrats 0.5 × 0.5 m along a transect. Tillers per plant and racemes per tiller were counted, length of racemes was measured, the spacing of spikelets on racemes was measured, and florets per spikelet were counted. Goosegrass seeds were harvested by hand on 8 Jun 2007 from a temporarily unmanaged population that grew tall and dense because of construction on the edge of a turf sports field in Pine Island Park, Davie, FL, USA. Seeds were kept refrigerated at <0 °C until used in glasshouse experiments. To determine the characteristics of divots, 30 were created by golfer Marcus Prevatte and measured with a ruler on tees and a fairway at Crandon Park Golf Course, Key Biscayne, FL, USA.

Glasshouse experiments. Experiments were conducted in an unheated glasshouse at the University of Florida/Institute of Food and Agricultural Sciences Fort Lauderdale Research and Education Center, 3205 College Ave., Davie, FL, USA, using goosegrass seeds from the Davie sports turf field. Plastic pots, 7.6-L volume, 20.5-cm diameter at the soil line, or 330 cm^2 soil surface area, were filled at the bottom with a 5-cm layer of pine bark to keep the root zone mix from leaking

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through holes in the bottom. The remainder of pot volume was filled with a sand-peat turf root zone mix. Except for bare soil pots, each pot was planted with a plug of 'Tifway' bermudagrass, which was trimmed weekly to a height of 2.5 cm and allowed to grow and covered the surface in 4 months. In all three experiments, after the bermudagrass canopy closed, divots were made using a cardboard template to demarcate ovals, 15 cm long and 9 cm wide, or ~106 cm^2 divot surface area in the center of each pot. Divots were extracted by cutting with a knife through the bermudagrass canopy to a depth of about 2.5 cm, then divots were removed, and holes were filled with sand.

Goosegrass emergence in turf canopy, divots, and bare soil. Each month from 19 Oct 2009 to 19 Sep 2010, goosegrass seeds, 400 per pot, were sown evenly by hand and covered with 40 g dry sand, in pots with bare soil and pots with fresh divots, in four blocked replications in each of 12 months of planting, thus 96 pots. Emerged seedlings were removed and counted on Wednesday each week in each pot, 28 Oct 2009 through 25 May 2011, and for divoted pots were recorded separately for the original divot area and the surrounding turf canopy. Seedling emergence was expressed as a percent of seeds planted. For divoted pots, emergence was prorated based on area in the divot (106 cm^2) and in the canopy (224 cm^2), which data were interpreted as separate treatments along with bare soil pots, making three surface treatments, canopy, divots, and bare soil. Because the experiment was ended less than 1 year after the last seed planting, to provide the same duration for treatments, observations were truncated 243 d after planting, for each planting date. Seedling emergence was summed across monthly intervals of 30.4 d, which did not conform with calendar month of year. Surface treatments (canopy, divot, and bare soil) and blocks were main plots; months of planting were split-plots; and months after planting were split-split-plots. Analysis of variance (ANOVA) was performed on seedling emergence according to the split-split-plot design (Little and Hills 1972).

Goosegrass emergence in divots of different ages and fertilization rates. Divots were cut on six dates at 14-d intervals, 11 Feb 2009 to 22 Apr 2009. On 22 Apr 2009, when there were divots of 0-, 2-, 4-, 6-, 8-, and 10-week ages, all pots were simultaneously planted by hand with 1000 goosegrass seeds per pot and covered with 50 g of dry sand. There were two main plot treatments, pots fertilized at high rate vs. low, and six blocked replications of six divot ages. Pots in the high fertilization treatment were fertilized every 14 d with 210 mL of 14 g/3.8 L Peters Professional 20.0N–8.7P–16.7K fertilizer, thus 740 ppm N, or 4.7 g N/m^2/application equal to 123 g N/m^2/year. Pots in the low fertilization rate treatment were fertilized with one-half the high rate, also applied every 14 d. Split-plots were six divot ages, 0, 2, 4, 6, 8, and 10 weeks old on the day of planting, thus 72 pots. Goosegrass seedlings were removed and counted each weeks from each pot from 29 Apr 2009 until 8 Jul 2010, without distinction whether seedlings were inside or outside the former divot. ANOVA was performed according to the split-plot design (Little and Hills 1972) with blocks and fertilization rates as main plots, and divot ages as split plots.

Goosegrass seedling growth in divots and turf canopies. Goosegrass seedlings were germinated separately in trays and transplanted at the three-leaf stage on 4 Nov 2008 into divots in bermudagrass covered pots and into turf canopies in bermudagrass covered pots without divots. Seedlings were thinned 12 Nov 2008 to three per pot to achieve similarly sized seedlings at least 2.5 cm apart and at least 2.5 cm from the inside edge of the pots. Every 14 d from 19 Nov 2008 until 14 Jan 2009, the three goosegrass seedlings in each of 12 pots were uprooted, washed, and shoots were cut from the roots, and shoots and roots weighed individually, dried at 60 °C for 24 h, and reweighed, to measure goosegrass root and shoot fresh and dry mass. Main plot treatments were divot and turf canopy, in a randomized complete block design with six replications. Split plots were five destructive harvests made every 14 d, thus there were 60 pots. There were three missing values for goosegrass planted in bermudagrass canopy in which all three seedlings died, and variances of goosegrass mass were unequal across treatments. Therefore, ANOVA was performed within each harvest date with 1 *df* for treatment, divot vs. canopy and 5 *df* for error mean square.

Results

Field observations. In the soccer field, there were a mean 32.2 goosegrass plants/m^2 with surface area 61.7 cm^2/plant, thus goosegrass cover was 19.8%. Goosegrass plants had mean 44 tillers (inflorescences)/plant and 3.78 racemes/tiller. Racemes had mean 4.39 cm length, mean 7.64 spikelets/cm raceme length, and 5 florets/spikelet, thus a capacity of 5 caryopses/spikelet. The standing crop was estimated by multiplication as 27,900 seeds (caryopses)/plant or 9.0×10^9 seeds/ha, a minimal estimate of soil seed bank, depending on the number of seed crops per year and half-life of seed. Divots on golf course tees and fairways were oval, mean 16.7 cm long, 7.5 cm wide, and 0.8 cm deep at the center, or ~98 cm^2 divot surface area.

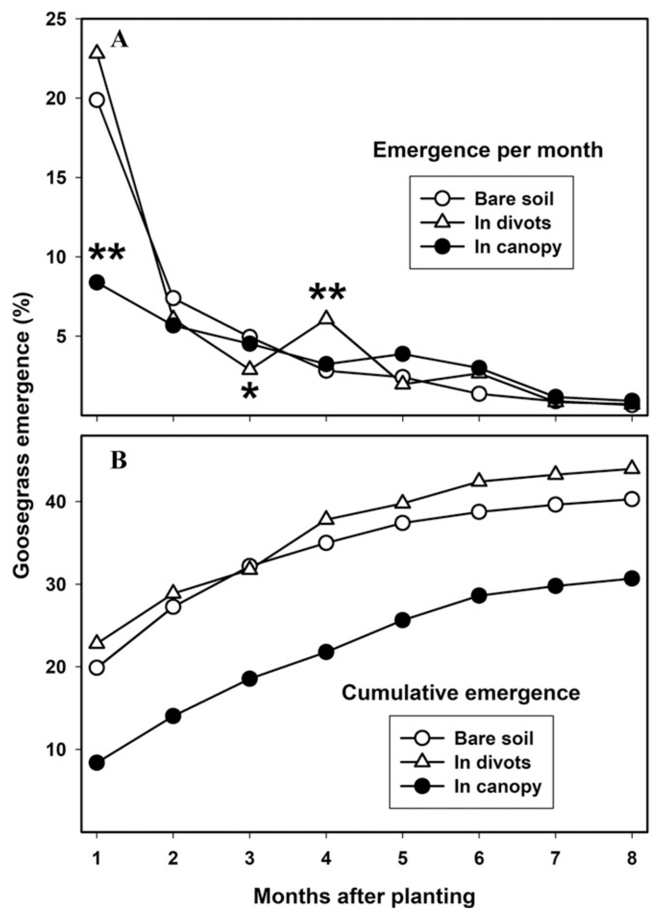

Fig. 1. Goosegrass seedling emergence % in pots in a glasshouse, (**A**) per month and (**B**) cumulative, during 8 months after planting, for three surface treatments (canopy, divots, and bare soil). Based on 400 seeds planted per pot, in four replicated pots and 12 monthly plantings. In divoted pots, emergence was estimated based on proration to divoted area, 106 cm^2, and canopy area outside the divot, 224 cm^2. For comparison of surface treatments within months after planting, *t*-values were 2.05 (*$P = 0.05$) and 2.79 (**$P = 0.01$).

Goosegrass emergence in turf canopy, divots, and bare soil. Surface treatment (canopy, divots, and bare soil) strongly affected goosegrass emergence ($F = 13.6$, $P < 0.01$). Interaction of surface with months after planting was highly significant ($F = 37.1$, $P < 0.001$). Goosegrass emergence was prompt from divots and bare soil, 23% and 20%, respectively, in month 1 after planting, compared with only 9% emergence from canopy (Fig. 1A). In months 2 through 8 after planting, surface treatments differed in goosegrass emergence only slightly and inconsistently. Cumulative emergence (Fig. 1B) was 31%, 44%, and 40%, respectively, in canopy, divots, and bare soil, or a net 30% reduction of emergence in canopy compared with divots. Although planting date across 12 monthly plantings significantly affected goosegrass emergence ($F = 3.3$, $P < 0.01$), month-to-month trends were erratic. The confounding of planting date with month after planting made time of year interpretations statistically unverifiable, but there was a strong surge of seedling emergence in Oct 2010 from different planting dates (data not shown).

Goosegrass emergence in divots of different ages and fertilization rates. Bermudagrass visibly covered over divots within 4 to 6 weeks, but older divots, even the oldest, 10-week divots, may not have been as dense as undivoted canopy. There was a surge of goosegrass seedling emergence 2 to 9 weeks after planting, 6 May 2009 to 24 Jun 2009. Effect of divot age at the time of planting was statistically highly significant ($F = 23.9$, $P < 0.01$). Goosegrass initial emergence (cumulative for 1 through 9 weeks after planting) totaled 35%, 25%, 16%, 14%, 11%, and 10%, respectively, in pots planted at divot ages of 0, 2, 4, 6, 8, and 10 weeks (Fig. 2A). There was thus 72% reduction in initial goosegrass seedling emergence from 10-week divots compared with fresh, 0-week divots. During the first 9 weeks after planting, fertilization rate and fertilization × divot age interaction were not statistically significant, although there was a trend for greater goosegrass germination under high fertilization.

There was a lapse in goosegrass seedling emergence after 9 weeks. A second surge of emergence was observed on 28 Oct 2009, 27 weeks after planting and 2 d after minimum glasshouse air temperature dropped to 15 °C, with a maximum 38 °C later the same day. Except for that drop in temperature, minimum glasshouse temperature was 24 °C or higher every day for the preceding 5 months.

Cumulative mean goosegrass emergence from 10 to 63 weeks after planting (Fig. 2B) decreased significantly under high fertilization compared with low fertilization ($F = 6.61$, $P < 0.05$). Late (10- to 63-week) emergence was 10.0% for high fertilization compared with 15.2% for low fertilization, a reduction of emergence of 34% due to high fertilization. The late effect of high fertilization in reducing late emergence could have been due to unmeasured increase in bermudagrass canopy density from high fertilization. Divot age was not statistically significant in emergence weeks 10 to 63 after planting. When results were combined across 1 through 63 weeks after planting (Fig. 2C), the initial stimulation trend of fertilization increasing goosegrass emergence was negated by the late effect of fertilization in suppressing emergence, so the net effect was not statistically significant. Only divot age at the time of seed planting remained statistically significant for cumulative emergence across 1 to 63 weeks, with divots older at the time of seed planting having smaller cumulative germination, most of this occurring during the first weeks after receiving divots.

Goosegrass seedling growth in divots and turf canopies. Transplanted goosegrass seedlings grew steadily in divots and grew little in turf canopies (Fig. 3A and B). By 4 weeks after planting, goosegrass seedlings planted in divots had larger ($P < 0.05$) root and shoot fresh mass than seedlings planted in turf canopy. At 10 weeks after planting, goosegrass seedlings had 4.63-g shoot and 0.94-g root fresh mass per pot in divots compared with 0.47-g shoot and 0.09-g root fresh mass per pot in turf canopies. Goosegrass seedling mean dry mass (data not presented) was 0.121 g for roots and 0.486 g for shoots, per pot, in divots, compared with 0.012 g root and 0.049 g shoot dry mass in turf canopies. In all four possible comparisons (goosegrass roots and shoots, and fresh and dry masses), there was 90% reduction in goosegrass seedling growth in divots compared with turf canopy.

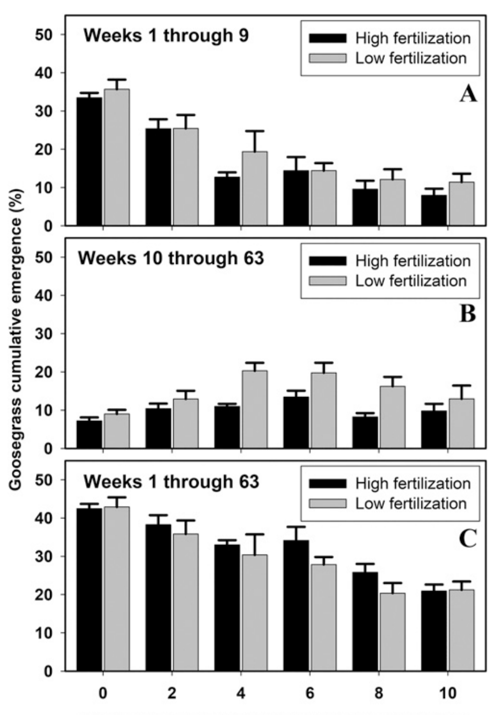

Fig. 2. Goosegrass cumulative seedling emergence % per pot, based on 1000 seeds planted per pot, in six replications, (**A**) means of 1 to 9 weeks after planting, (**B**) means of 10 to 63 weeks after planting, and (**C**) means of 1 to 63 weeks after planting. All seeds were planted on the same date for divots of different ages. Vertical bars are standard errors.

Discussion

Across all experiments, goosegrass emergence and seedling growth were reduced by direct and indirect factors of bermudagrass canopy—for example, 30% long-term reduction in emergence from canopy compared with divots; 72% reduction in emergence in 10-week-old compared with fresh divots; 34% late reduction in emergence due to high fertilization in the divot age experiment, which was probably a canopy effect; and 90% growth reduction of planted goosegrass seedlings under bermudagrass canopy compared with divots.

Results were consistent with multiple cited reports in different species that denser turfgrass canopy, whether by higher rate of nitrogen fertilization or taller mowing height, dramatically reduces weed populations. Goosegrass seedling emergence and growth effects due to canopy, divots, and bare soil closure are consistent with goosegrass seedling emergence reduced 58% at 2.5-cm mowing height compared with 1.3-cm mowing height (Arrieta et al. 2009). Canopy gap stimulation of seedling emergence and early seedling growth are mechanisms in establishment of annual weed populations, and knowing this may foster cultural management of weeds.

Goosegrass standing seed crop is large: 9.0×10^9 seeds/ha in this study and reported elsewhere as 5×10^9 seeds/ha (Hawton and Drennan 1980). These numbers may seem insurmountable for cultural management, especially considering repeated evidence (e.g., Masin et al. 2006) that goosegrass seedlings may be viable in soil for years. However, divot recovery and canopy closure reduce goosegrass emergence and growth and provide strong

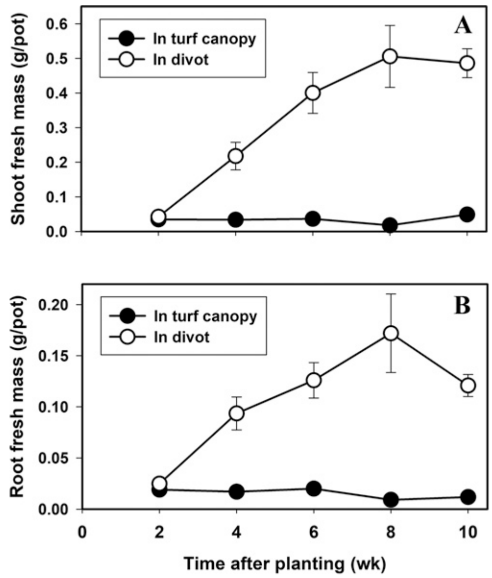

Fig. 3. Goosegrass seedling shoot (**A**) and root (**B**) fresh mass in turf canopies and divots in pots in a glasshouse. Seedlings were germinated in trays and transplanted at time 0, and destructively harvested at sequential 2-week intervals after transplanting. Means of six replications, sum of three seedlings per pot. Vertical bars are standard errors.

cultural management options to reduce goosegrass infestation in golf and sports turf.

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