Weed Technology

cambridge.org/wet

Weed Biology and Competition

Cite this article: Prince CM, MacDonald GE, Ferrell JA, Sellers BA and Wang J (2018) Impact of Soil pH on Cogongrass (*Imperata cylindrica*) and Bahiagrass (*Paspalum notatum*) Competition. Weed Technol 32:336–341. doi: 10.1017/wet.2018.3

Received: 1 September 2017
Accepted: 13 December 2017

Associate Editor:
Scott McElroy, Auburn University

Nomenclature:
Cogongrass, *Imperata cylindrica* (L.) P. Beauv.; bahiagrass, *Paspalum notatum* Fluegg. var. *saurae* Parodi PASNS.

Key words:
Invasive; pasture; rangeland; replacement seriesvar.

Author for correspondence:
Candice M. Prince, Environmental Horticulture Department, University of Florida, P.O. Box 110675, Gainesville, FL 32611. (E-mail: cprince14@ufl.edu)

Impact of Soil pH on Cogongrass (*Imperata cylindrica*) and Bahiagrass (*Paspalum notatum*) Competition

Candice M. Prince[1], Gregory E. MacDonald[2], Jason A. Ferrell[2], Brent A. Sellers[3] and Jingjing Wang[4]

[1]Graduate Student, Environmental Horticulture Department, University of Florida, Gainesville, FL, USA, [2]Professor, Agronomy Department, University of Florida, Gainesville, FL, USA, [3]Associate Professor, Agronomy Department, University of Florida, Gainesville, FL, USA and [4]Former Graduate Student, Agronomy Department, University of Florida, Gainesville, FL, USA

Abstract

Cogongrass is commonly found in disturbed areas in Florida, where it is increasingly becoming a problem in bahiagrass pastures. Soil pH has been suggested as a possible mechanism for this invasion; to evaluate this, replacement series competition studies were conducted under greenhouse conditions at two soil pH levels: pH 4.5, or pH 6.8. Cogongrass ramets and bahiagrass seedlings were planted at proportions of 0:40, 1:20, 2:10, 4:1, and 8:0, respectively. Aboveground biomass was measured after 8 weeks and used to calculate relative yield, relative crowding coefficients, and aggressivity values. At soil pH 4.5, the relative competitiveness of cogongrass and bahiagrass was similar, with both species contributing equally to relative yield. At soil pH 6.8, bahiagrass seedlings showed greater competitive ability than cogongrass ramets. Relative crowding coefficient and aggressivity values supported this, with bahiagrass showing increased competitiveness under higher soil pH. This indicates that decreases in soil pH, often associated with poor soil fertility, is likely a contributing factor for cogongrass invasion into bahiagrass pastures. Soil amendments to raise pH may provide a cultural management tool for cogongrass infestations in pastures.

Ranching is of great economic importance in Florida, a state ranked 10th nationally in beef cattle production and 18th in total cattle production (USDA NASS 2016). There are approximately 3 million hectares of rangeland in Florida (Nair et al. 2007), and these sites are commonly characterized as acidic, nutrient-poor, and comprised of C_4 bunchgrasses (Swain et al. 2013). Improved pastures commonly contain bahiagrass, the most widely utilized forage species in Florida, which covers an estimated 1 million hectares in the state (Chambliss 1996).

Bahiagrass has a deep, fibrous root system that allows it to persist in dry and infertile soils, requiring little to no irrigation or fertilization (Beard 1980; Chambliss 1996). This perennial C_4 species is commonly established via seed, although its seedlings are slow to establish in shaded conditions and can be weak competitors with other species (Beard 1980; Busey and Myers 1979). Florida soils are naturally acidic, and nonlimed pastures in the state have been reported to exhibit soil pH as low as 4.3 (Silveira et al. 2007). The optimum soil pH for bahiagrass is 5.5, although it is able to grow on soils as acidic as pH 4.5 (Newman et al. 2010). Liming to maintain soil pH between 5.5 and 6.5 is recommended for bahiagrass pastures, and low soil pH has been suggested as a mechanism that encourages an increase in weed populations in bahiagrass pastures (Mackowiak et al. 2008; Stephenson and Rechcigl 1991). Soil pH can impact competitive ability by altering nutrient availability and affecting soil microflora, and different weed species have shown varied growth responses to pH (Buchanan et al. 1975; Magidow et al. 2013; Pierce et al. 1999). Increasing soil pH has been shown to reduce weed density and increase forage growth in Florida pastures (Stephenson and Rechcigl 1991).

Cogongrass has become an increasingly important pest species in Florida's pastures and rangelands. This perennial, warm-season grass has an extensive rhizome system, which allows it to preclude the establishment of other desirable species (MacDonald 2004). It thrives in areas of anthropogenic disturbance, where it quickly establishes and spreads via airborne seeds and rhizome segments (Brook 1989). Cogongrass is highly competitive, often forming monotypic stands. These stands interfere with growth and yield of desirable species through competition, allelopathy, and physical injury (Eussen 1979).

Cogongrass is common throughout Florida, where it infests several thousand hectares of reclaimed phosphate mines, pine forests, and roadsides (Shilling 1997). It is regularly found in rangeland settings along fence lines and other areas of anthropogenic activity, but until recently it has not been observed within bahiagrass pastures. The absence of cogongrass invasions in pastures may be attributed to one of several causes: 1) limited site disturbance, 2) lack of propagule pressure, or 3) competitive ability of forage species. Studies have demonstrated that bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass have shown promise as forage species capable of suppressing cogongrass reinfestation (Gaffney 1996). Willard and Shilling (1990) showed that established bahiagrass has greater competitive ability against cogongrass, particularly when integrated with mowing. Conversely, bahiagrass seedlings were found to be less competitive than cogongrass ramets; however, the effect of soil pH was not reported. Cogongrass is commonly found on soils with pH as low as 4.7, and although both species are able to survive on low-fertility soils, it appears that low soil pH may have a greater impact on bahiagrass than cogongrass (Shilling 1997; Wilcut et al. 1988).

Due to cost restrictions, land managers are often forced to forego improvements to soil fertility. Native Florida soils have low pH, and without amendments such as lime they are likely to become progressively more acidic in bahiagrass pastures due to nitrogen fertilizers and untreated manure (Mackowiak et al. 2008; Silveira et al. 2007). Therefore, the objective of this study was to evaluate competition between bahiagrass seedlings and cogongrass emerging from rhizomes under two levels of soil pH (4.5 and 6.8). We hypothesized that the relative competitiveness of these two species will be altered by soil pH, with cogongrass having greater competitive ability under conditions of lowered pH. If cogongrass is found to have enhanced competitiveness at a particular pH level, it would inform cultural management strategies; soil amendments to raise pH may limit the ability of cogongrass to invade into bahiagrass pastures.

Materials and Methods

A greenhouse experiment was conducted at the University of Florida in Gainesville, FL. Single-node cogongrass rhizome fragments (10 cm in length) were harvested from a population in Gainesville, placed in plastic flats filled with commercial potting mix (Fafard® Super-Fine Germination Mix, Sun Gro© Horticulture Canada Ltd., Agawam, MA), and watered daily. Fertility was maintained at 45.4 kg ha^{-1} N (Osmocote® 14-14-14, The Scotts Company LLC, Marysville, OH). After 2 wk, plants with two leaves attached to a single node were selected for use in the competition experiment. Bahiagrass seeds (var. *saurae* Parodi.) (B&G Seed Processors, Inc., Williston, FL) were planted under similar conditions; after 3 wk, two-leaf seedlings of approximately equal size were selected for further use.

Selected plants of both species were transplanted together into 4-liter pots at desired densities and maintained in a greenhouse under a 16-h photoperiod with day/night temperatures of 30/20 C. Soil was a Chandler fine sand, gathered from the University of Florida Plant Science Research and Education Center in Citra, FL. Soil was obtained from adjacent locations, one from an agricultural field that was currently in production, the other from an undisturbed area that had never been in production. This resulted in soils with two pH levels: pH 6.8 from the production field and pH 4.5 from the undisturbed area. Prior to planting the replacement mixtures, the soils were amended with slow-release fertilizer at 45.4 kg ha^{-1} N (Osmocote 14-14-14) for consistent growth and to negate any differences in base fertility between the two soils. This did not impact soil pH levels.

For each pH treatment, a replacement series model was established to evaluate competition between the two species. Initial cogongrass densities were 0, 1, 2, 4, and 8 shoots per pot, with corresponding bahiagrass densities of 40, 20, 10, 1, and 0 plants per pot, respectively. The resulting proportions were 0:40, 1:20, 2:10, 4:1, and 8:0 for a single pot; these proportions were based on findings by Shilling (1997). The experiment was a two by five factorial in a completely randomized design, with four replications per treatment (one pot was considered to be one replication). The study was conducted in August and repeated in October of the same year. New soil was obtained for the second experimental run.

Eight weeks after transplanting, aboveground biomass of each species was harvested and oven-dried at 75 C for 72 h to determine dry weight. Competitive indices were based on aboveground biomass per pot. Relative yield (*RY*) (Equation 1) describes the relative biomass of each species in mixture as a percentage of its monoculture biomass under the same growing conditions (de Wit 1960):

$$RY_x = X_{mix}/X_{mono}, \qquad [1]$$

where RY_x is the relative yield of species *x*, X_{mix} is the biomass of species *x* in mixture, and X_{mono} is the biomass of species *x* in monoculture. In contrast, relative yield total (*RYT*) (Equation 2) expresses the relative biomass of each species within a given proportion (de Wit 1960; de Wit and Van den Bergh 1965):

$$RYT = RY_x + RY_y, \qquad [2]$$

where *RYT* is the relative yield total, RY_x is the relative yield of species *x*, and RY_y is the relative yield of species *y*.

Relative crowding coefficient (*RCC*) (Equation 3) measures the relative competitive ability of one species over another (Cousens and O'Neill 1993; de Wit 1960):

$$RCC_x = \frac{(X_{mix}/Y_{mix})}{(X_{mono}/Y_{mono})}, \qquad [3]$$

where X_{mix} and Y_{mix} refer to the respective biomass of species *x* and *y* at a particular proportion, while X_{mono} and Y_{mono} refer to their respective biomass in monoculture. *RCC* is an index: a value of 1.00 indicates equal competitiveness, with *RCC* increasing with the competitive ability of a species.

Aggressivity (*A*) (Equation 4) is another index used to measure relative competitive abilities (McGilchrist and Trenbath 1971):

$$A_x = \frac{1}{2}\left(\frac{X_{mix}}{X_{mono}} - \frac{Y_{mix}}{Y_{mono}}\right), \qquad [4]$$

where X_{mono} and Y_{mono} refer to the mean biomass per plant of species *x* and *y* in monoculture, and X_{mix} and Y_{mix} refer to the mean biomass per plant of species *x* and *y* in mixture, respectively. A value of 0 denotes equal competitive ability of the two species, while positive values are given to species with greater competitiveness.

All data were subjected to a two-way ANOVA in SAS with mean separation at $P < 0.05$, and a replacement series curve model was created based on *RY* and *RYT* for each species grown under the two pH treatments. Data from the two experimental runs were combined because data analysis indicated that there was no interaction between density and experimental run ($P \geq 0.05$).

Results and Discussion

A de Wit (1960) replacement model was used to determine the effects of soil pH on the relative competitiveness of cogongrass ramets and bahiagrass seedlings. Replacement studies are often used to characterize the relative competitiveness of species, particularly under conditions of stress or environmental disturbance

https://doi.org/10.1017/wet.2018.3 Published online by Cambridge University Press

(i.e., increased nutrient availability or water stress) (Gao et al. 2005; Griffin et al. 1989; Li et al. 1999; Santos et al. 1998). Interpretation can be difficult for a replacement series when the species of interest have different growth forms (Radosevich et al. 2007). Willard and Shilling (1990) noted these concerns in a study comparing cogongrass ramets vs. bahiagrass seeds. However, their data provided a practical platform from which to overlay the impact of pH on the competitive interactions between these two species and have applied value in the context of cogongrass-invaded rangelands. Bahiagrass is commonly established via seed, while cogongrass primarily spreads clonally; thus, this experimental design more accurately portrays a realistic management scenario.

Aboveground Biomass

There were no differences in shoot biomass per pot between pH treatments for either species (Figure 1). Cogongrass biomass (Figure 1) per pot increased as its proportion in the mixture increased. A similar trend was observed for bahiagrass (Figure 1). There was a concomitant increase in biomass for both species as the planting density for each species increased. The effect of pH was minimal for cogongrass, with nearly equal amounts of biomass at pH 4.5 and 6.8. However, bahiagrass did show nearly 50% less biomass under pH 4.5 at the 4:1 planting density than it did with the same ratio at the higher soil pH. Under the absence of competition, total aboveground biomass per pot for cogongrass or bahiagrass ranged from 9.5 to 10 g pot^{-1}, indicating the ratios chosen accurately reflected equivalent competitiveness.

Cogongrass biomass on a per plant basis was minimally impacted by pH and declined at greater densities on an individual plant basis, showing intraspecific competition (Figure 2). However, there were no differences in biomass between pH levels within a given planting density. For bahiagrass, shoot biomass also decreased on an individual plant basis as the proportion of bahiagrass in the mixture increased (Figure 2). There was a significant difference in individual plant biomass between the two pH treatments at the lowest ratio of cogongrass to bahiagrass (4:1). At this proportion, bahiagrass biomass was nearly twice as great when plants were grown at pH 6.8 than they were at pH 4.5. However, there were no differences between pH treatments for any of the other density levels. This increase is directly correlated to effects of pH on bahiagrass alone; there were no impacts on cogongrass biomass at this planting density (Figure 2).

Relative Yield

While pH treatments did not result in many differences in plant biomass, the *RY* of each species suggests that soil pH may play a role in competition. Cogongrass *RY* was significantly greater

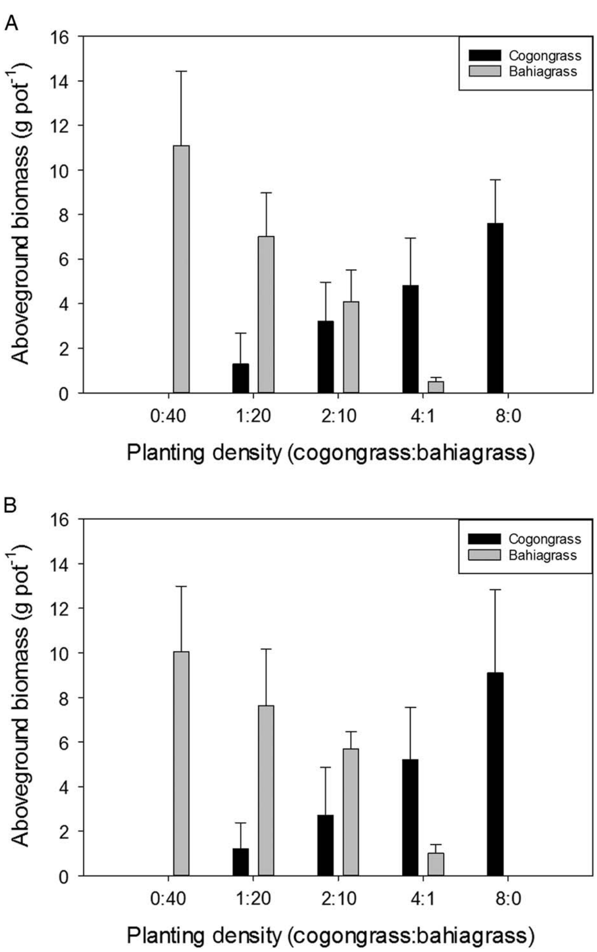

Figure 1. Aboveground biomass (g pot^{-1}) for cogongrass ramets and bahiagrass seedlings after 8 wk of competition as a function of (A) low soil pH (4.5) and (B) high soil pH (6.8). Error bars display 95% confidence intervals for eight replications of cogongrass and bahiagrass biomass at each planting density.

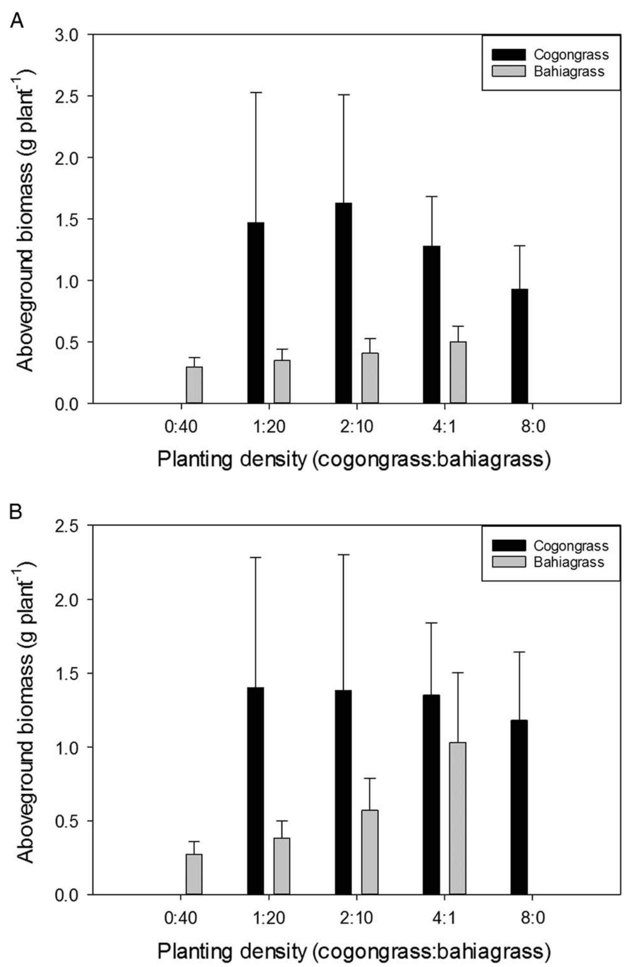

Figure 2. Aboveground biomass (g plant^{-1}) for cogongrass ramets and bahiagrass seedlings after 8 wk of competition as a function of (A) low soil pH (4.5) and (B) high soil pH (6.8). Error bars display 95% confidence intervals for eight replications of cogongrass and bahiagrass biomass at each planting density.

https://doi.org/10.1017/wet.2018.3 Published online by Cambridge University Press

under conditions of low soil pH at the density level of 2:10 (0.42 at pH 4.5 and 0.24 at pH 6.8), although differences were nonsignificant at other density levels (Figure 3). Similarly, bahiagrass had significantly greater *RY* under high pH conditions for only one density level, 4:1 (0.04 at pH 4.5 and 0.12 at pH 6.8). Relative yield of the two species was almost equal at the 2:10 planting density under low soil pH, indicating similar competitive ability under these conditions; conversely, the *RY* of cogongrass was half that of bahiagrass at this planting level when soil pH was 6.8.

Relative yield of cogongrass under low pH showed a nearly linear increase with increasing density. At a planting density of 2 ramets per pot, *RY* for cogongrass was 0.42, while that of bahiagrass was 0.39 (Figure 3A). Relative yield for bahiagrass showed a much steeper decline, with a *RY* of 0.04 at a density of 1 seedling per pot. In the higher pH treatment, an opposite trend was observed; bahiagrass exhibited a more linear increase in *RY* as planting density increased, while cogongrass *RY* increased more sharply with planting density (Figure 3B).

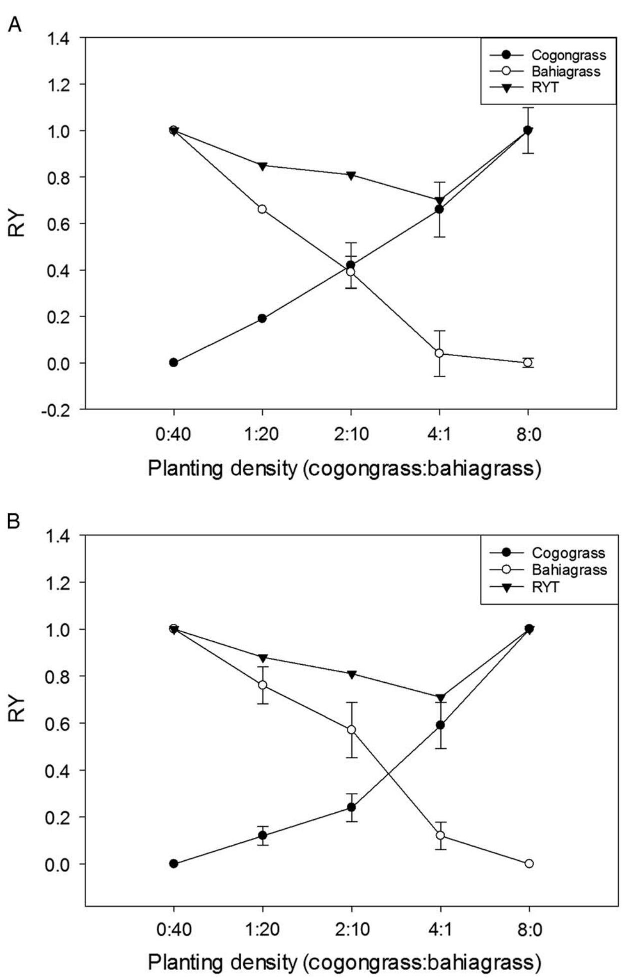

Figure 3. Relative yield (*RY*) of aboveground biomass for cogongrass ramets and bahiagrass seedlings, as well as relative yield total (*RYT*), after 8 wk of competition as a function of (A) low soil pH (4.5) and (B) high soil pH (6.8). Indices were generated using aboveground biomass per pot. *RY* was calculated using Equation 1, where X_{mix} and X_{mono}, refer to the yields of species *x* in mixture and monoculture, respectively. *RYT* was calculated using Equation 2, where RY_x and RY_y refer to the relative yields of species *x* and *y*, respectively. Error bars display 95% confidence intervals for eight replications of cogongrass and bahiagrass *RY* at each planting density.

These results suggest that bahiagrass is more competitive at pH 6.8 than it is at pH 4.5, because it achieved the same competitive ability as cogongrass with fewer plants under higher pH conditions. This is supported by the species contribution to *RYT*: cogongrass and bahiagrass contributed similarly to the *RYT* when soil pH was 4.5, while bahiagrass contributed more when soil pH was 6.8 (Figure 3). This suggests that high pH is more influential on competition between these two species than low pH. Overall, there were few differences in *RYT* as a function of soil pH, but the mixtures were antagonistic, suggesting an additional negative impact from one or both species.

An advantage of the de Wit experimental design is that it allows for manipulation of environmental variables; replacement series studies elucidate the competitive hierarchies among a set of species, which are often determined by resource gradients or other environmental conditions (Gao et al. 2005; Keddy 1990). Other replacement studies have shown shifts in *RY* of competing species under varying environmental conditions. Santos et al. (1998) demonstrated enhanced competitive ability of lettuce (*Lactuca sativa* L.) with increased phosphorus availability when grown in mixture with smooth pigweed (*Amaranthus hybridus* L.), as well as enhanced competitive ability of common purslane (*Portulaca oleracea* L.) in mixtures with lettuce. In addition, Griffin et al. (1989) found that water availability affected the competitive interactions of soybean (*Glycine max* (L.) Merr.) and Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.].

Relative Crowding Coefficient and Aggressivity

Bahiagrass had significantly greater *RCC* values under higher pH at the density levels of 2:10 and 4:1 (Table 1). An *RCC* of 1.00 indicates that the two species are equally competitive, and *RCC* increases with increasing competitive ability of a species. Relative crowding coefficient values for bahiagrass were greater than 1.00 for all density levels and pH treatments, while for cogongrass *RCC* was only greater than 1.00 at the density levels of 1:20 and 2:10 under low pH conditions.

Table 1. Cogongrass and bahiagrass as measured by relative crowding coefficient (*RCC*) and aggressivity (*A*). *RCC* was calculated using Equation 3, where X_{mix}, X_{mono}, Y_{mix}, and Y_{mono} refer to the yields of species *x* and *y* in mixture and monoculture, respectively. *A* was calculated using Equation 4. Data were based on aboveground biomass per pot and are represented as the mean of eight replications. Mean separation (indicated by letters) is only shown between soil pH treatments within each density level for *RCC* of cogongrass, *RCC* of bahiagrass, and *A* of cogongrass, respectively.

	RCC				*A*	
Density	Cogongrass		Bahiagrass		Cogongrass[a]	
Cogongrass: bahiagrass	pH 4.5	pH 6.8	pH 4.5	pH 6.8	pH 4.5	pH 6.8
0:40	0	0	–	–	−1	−1
1:20	1.23 a	0 a	1.25 a	2.55 a	0.06 a	−0.52 b
2:10	1.49 a	0.63 a	1.10 a	3.26 a	0.11 a	−1.31 b
4:1	0.91 a	0.53 a	1.44 a	4.71 a	−0.47 a	−3.52 b
8:0	–	–	0	0	1	1

[a]Bahiagrass aggressivity values are the same as for cogongrass, but with an inverse sign.

https://doi.org/10.1017/wet.2018.3 Published online by Cambridge University Press

This is supported by the aggressivity (A) values, which for cogongrass were negative under pH 6.8 for all density levels (excluding the 8:0 cogongrass monoculture) (Table 1). These negative values indicate that cogongrass was less competitive than bahiagrass under these conditions. Cogongrass had significantly greater A under pH 4.5, and positive values for two of the density levels (1:20 and 2:10). These are the same densities at which cogongrass had an RCC greater than 1.00, further suggesting that the species had greater competitive ability when soil pH was low and intraspecific competition was minimal. For bahiagrass, A values hold the same absolute value as for cogongrass, but with an inverse sign. Aggressivity of bahiagrass was greatest at pH 6.8.

Our data indicate that cogongrass ramets do not show overwhelmingly greater competitive ability than bahiagrass seedlings, a result that is inconsistent with previous research. In their 1990 study, Willard and Shilling evaluated the influence of propagule type on competition between the two species and showed that cogongrass was more competitive than bahiagrass seedlings regardless of planting density. Here, the competitive indices show that cogongrass was less competitive than bahiagrass under pH 6.8 for all density treatments, and even under one of the density levels under lower pH conditions (4:1). The authors of the previous research did not record the soil pH, however, and it is possible that soil conditions may partially account for this inconsistency.

We hypothesized that competitive ability of cogongrass and bahiagrass will be impacted by soil pH, with cogongrass showing stronger competitiveness when soil pH was low. Our results do not support this hypothesis. Cogongrass did not show more competitive ability at pH 4.5 than it did at pH 6.8, and it had a similar level of competitiveness to bahiagrass at the lower pH. Rather, it was bahiagrass competition that was influenced by soil pH: bahiagrass exhibited higher competitive ability at pH 6.8 than it did at pH 4.5. Soil pH has been shown to have differential effects on species in other contexts. In North American fescue prairies, invasive Kentucky bluegrass (*Poa pratensis* L.) is positively affected by the increased pH of disturbed grasslands, while the native plains rough fescue (*Festuca hallii* (Vasey) Piper) responds poorly to these conditions (Desserud and Naeth 2013). Another study found the growth of large crabgrass (*Digitaria sanguinalis* (L.) Scop.) to be negatively impacted by high soil pH and raised the possibility of using soil amendments as a management tool (Pierce et al. 1999).

Bahiagrass pastures can have open areas for a variety of reasons (e.g., periodic flooding, animal disturbance); these open areas are vulnerable to colonization by cogongrass. Low soil pH may exacerbate this vulnerability. While we used bahiagrass seedlings in this experiment, it is likely that mature plants would also show reduced health and competitive ability under acidic soil conditions; this weakness, coupled with the ability of cogongrass to thrive in conditions of low soil pH, may explain the recent cogongrass invasions into bahiagrass pastures. Although bahiagrass seedlings are generally considered weak competitors with cogongrass (Willard and Shilling 1990), this study has demonstrated that their competitive ability can be enhanced when they are grown under optimal environmental conditions. When combined with amendments to raise the soil pH, reseeding with bahiagrass may be a viable management tool to prevent invasion of cogongrass in Florida grazing lands.

Acknowledgements. The authors would like to acknowledge the Natural Resource Conservation Service for support of this research. They would also like to acknowledge the Center for Aquatic and Invasive Plants. Part of this research was conducted by Jingjing Wang while she was funded by the University of Florida. While every effort has been made to contact Jingjing Wang, she is no longer traceable.

References

Beard JB (1980) St. Augustine, zoysia and bahiagrass cultivar update. Grounds Maintenance 15:66–68

Brook RM (1989) Review of literature on *Imperata cylindrica* (L.) Raeuschel with particular reference to South East Asia. Trop Pest Manage 35: 12–25

Buchanan GA, Hoveland CS, Harris MC (1975) Response of weeds to soil pH. Weed Sci 23:473–477

Busey P, Myers BJ (1979) Growth rates of turfgrass propagated vegetatively. Agron J 71:817–821

Chambliss CG (1996) Bahiagrass (SS-AGR-36). Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences. 7 p

Cousens R, O'Neill M (1993) Density dependence of replacement series experiments. Oikos 66:347–352

de Wit CT (1960) On competiton. Verglagen Landvouw Kundige Onderzockingen 66:1–82

de Wit CT, Van den Bergh JP (1965) Competition between herbage plants. Neth J Agric Sci 13:212–221

Desserud P, Naeth MA (2013) Establishment of a native bunch grass and an invasive perennial on disturbed land using straw-amended soil. J Environ Manage 114:540–547

Eussen JHH (1979) Some competition experiments with alang-alang [*Imperata cylindrica* (L.) Beauv.] in replacement series. Oecologia 40: 351–356

Gaffney JF (1996) Ecophysiological and Technological Factors Influencing the Management of Cogongrass (*Imperata cylindrica*). Ph.D dissertation. Gainesville, FL: University of Florida. 113 p

Gao YZ, Wang SP, Han XG, Patton BD, Nyren PE (2005) Competition between *Artemisia frigida* and *Cleistogenes squarrosa* under different clipping intensities in replacement series mixtures at different nitrogen levels. Grass Forage Sci 60:119–127

Griffin BS, Shilling DG, Bennett JM, Currey WL (1989) The influence of water stress on the physiology and competition of soybean (*Glycine max*) and Florida beggarweed (*Desmodium tortuosum*). Weed Sci 37:544–551

Keddy PA (1990) Competitive hierarchies and centrifugal organization in plant communities. Pages 266–290 *in* Grace JB, Tilman D, eds. Perspectives on Plant Competition. San Diego, CA: Academic Press

Li B, Suzuki J-I, Hara T (1999) Competitive ability of two Brassica varieties in relation to biomass allocation and morphological plasticity under varying nutrient availability. Ecol Res 14:255–266

MacDonald GE (2004) Cogongrass (*Imperata cylindrica*) – biology, ecology, and management. Plant Sci 23:367–380

Mackowiak CL, Blount AR, Myer RO, Hanlon EA, Silveira ML (2008) Getting the Most out of Bahiagrass Fertilization (SL 249). Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences. 6 p

Magidow LC, DiTommaso A, Ketterings QM, Mohler CL, Milbrath LR (2013) Emergence and performance of two invasive swallowworts (*Vincetoxicum* spp.) in contrasting soil types and soil pH. Invas Plant Sci Manag 6: 281–291

McGilchrist CA, Trenbath BR (1971) A revised analysis of plant competition experiments. Biometrics 27:659–671

Nair VD, Nair PKR, Kalmbacher RS, Ezenwa IV (2007) Reducing nutrient loss from farms through silvopastoral practices in coarse-textured soils of Florida, USA. Ecol Eng 29:192–199

Newman Y, Vendramini J, Blount A (2010) Bahiagrass (*Paspalum notatum*): Overview and Management (SS-AGR-332). Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences. 8 p

Pierce GL, Warren SL, Mikkelsen RL, Linker HM (1999) Effects of soil calcium and pH on seed germination and subsequent growth of large crabgrass (*Digitaria sanguinalis*). Weed Technol 13:421–424

Radosevich SR, Holt JS, Ghersa CM (2007) Ecology of Weeds and Invasive Plants: Relationship to Agriculture and Natural Resource Management. 3rd edn. Hoboken, NJ: John Wiley & Sons, Inc. 454 p

Santos BM, Dusky JA, Stall WM, Shilling DG, Bewick TA (1998) Phosphorous effects on competitive interactions of smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) with lettuce (*Lactuca sativa*). Weed Sci 46:307–312

Shilling DG (1997) Ecology, Physiology, and Management of Cogongrass (*Imperata cylindrica* (L.) Beauv.). Bartow, FL: Florida Institute of Phosphate Research. 125 p

Silveira ML, Vendramini JMB, Rechcigl JE (2007) The Impacts of Soil Acidity on Bahiagrass Pasture Performance (SL 292). Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences. 4 p

Stephenson RJ, Rechcigl JE (1991) Effects of dolomite and gypsum on weeds. Commun Soil Sci Plant Anal 22:1569–1579

Swain HM, Boughton EH, Bohlen PJ, Lollis LO (2013) Trade-offs among ecosystem services and disservices on a Florida ranch. Rangelands 35:75–87

[USDA NASS] United States Department of Agriculture National Agricultural Statistics Service (2016) Florida Livestock, Dairy, and Poultry Summary – 2015. Maitland, FL: United States Department of Agriculture National Agricultural Statistics Service Florida Field Office. 66 p

Wilcut JW, Dute RD, Truelove B, Davis DE (1988) Factors limiting the distribution of cogongrass, *Imperata cylindrica*, and torpedograss, *Panicum repens*. Weed Sci 36:49–55

Willard TR, Shilling DG (1990) The influence of growth stage and mowing on competition between *Paspalum notatum* and *Imperata cylindrica*. Trop Grass 24:81–86