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Saline Irrigation Affects *Belonolaimus longicaudatus* and *Hoplolaimus galeatus* on Seashore Paspalum[1]

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Abstract: Seashore paspalum (*Paspalum vaginatum*) has great potential for use in salt-affected turfgrass sites. Use of this grass on golf courses, athletic fields, and lawns in subtropical coastal areas may aid in conservation of freshwater resources. *Belonolaimus longicaudatus* and *Hoplolaimus galeatus* are considered among the most damaging root pathogens of turfgrasses in Florida. Glasshouse experiments were performed in 2002 and 2003 to examine the effects of increasing levels of irrigation salinity on *B. longicaudatus* and *H. galeatus*. Irrigation treatments were formulated by concentrating deionized water to six salinity levels (0, 5, 10, 15, 20, and 25 dS/m). Final population densities of *H. galeatus* followed a negative linear regression (r^2 = 0.92 and 0.83; $P \leq 0.01$) with increasing salinity levels. Final population densities of *B. longicaudatus* were quadratically (r^2 = 0.72 and 0.78; $P \leq 0.01$) related to increasing salinity levels from 0 to 25 dS/m. An increase in population densities of *B. longicaudatus* was observed at moderate salinity levels (10 and 15 dS/m) compared to 0 dS/m. Root-length comparisons revealed that *B. longicaudatus* caused root stunting at low salinity levels, 0 to 10 dS/m, but roots were not affected at 15 to 25 dS/m. These results indicate that the ability of *B. longicaudatus* to feed and stunt root growth was negatively affected at salinity levels of 15 dS/m and above.

Key words: *Belonolaimus longicaudatus, Hoplolaimus galeatus,* lance nematode, *Paspalum vaginatum,* salinity, seashore paspalum, sting nematode.

Salt-tolerant turfgrasses are becoming essential in many areas because of salt accumulation in soil, restrictions on groundwater use, and saltwater intrusion into groundwater (Carrow and Duncan, 1998; Parker, 1975). Seashore paspalum (*Paspalum vaginatum*) is a warm-season turfgrass adapted for saline conditions (Malcolm and Laing, 1969; Morton, 1973). Breeding for cultivars with fine leaf texture and tolerance to drought and high-salinity irrigation have allowed frequent use of seashore paspalum in highly managed turfgrass sites (Dudeck and Peacock, 1985; Duncan, 1999). One major limitation of cultivating turfgrasses in the sandy soils of the southeastern United States is the destruction of roots by phytoparasitic nematodes (Perry and Rhoades, 1982). The sting nematode (*Belonolaimus longicaudatus*) and the lance nematode (*Hoplolaimus galeatus*) are destructive pathogens on a variety of agronomic crops and turfgrasses (Ahmad and Chen, 1980; Perry and Rhoades, 1982; Perry et al., 1970; Smart and Nguyen, 1991).

Whereas *B. longicaudatus* is usually limited to the coastal plains of the southeastern United States (Christie, 1959; Holdeman, 1955; Robbins and Barker, 1974), *H. galeatus* has a much wider distribution (Williams, 1973). *Belonolaimus longicaudatus* damages lateral roots as soon as they are formed, causing stunted root growth, decreased water and nutrient uptake, and decreased rates of evapotranspiration (Busey et al., 1991; Johnson, 1970; Perry and Rhoades, 1982). *Hoplolaimus galeatus* enters the root cortex and may damage the roots by feeding and physical tunneling through the cell walls (Krusberg and Sasser, 1956; Williams, 1973). Both nematodes have been reported as important pathogens of turfgrasses in the southeastern United States (Christie et al., 1954; Kelsheimer and Overman, 1953; Perry and Rhoades, 1982). *Belonolaimus longicaudatus* and *H. galeatus* have been reported as pathogens of many bermudagrass (*Cynodon dactylon* and *Cynodon* spp. hybrids) and St. Augustinegrass (*Stenotaphrum secundatum*) cultivars (Busey et al., 1991; Giblin-Davis et al., 1992a,b; Perry et al., 1970). In more recent studies, root and shoot growth of diploid and polyploid St. Augustinegrasses were not affected by *H. galeatus,* even though the plants supported high population levels (Giblin-Davis et al., 1995; Henn and Dunn, 1989). Two populations of *B. longicaudatus* readily reproduced on 'Tifdwarf' bermudagrass (*C. dactylon* × *C. transvaalensis*) and caused extensive root damage (Giblin-Davis et al., 1992; Johnson, 1970). A forage grass study determined that there is differential host suitability and susceptibility to *B. longicaudatus* in *Digitaria* spp., *Paspalum* spp., and *Chloris* spp. introductions (Boyd and Perry, 1969).

Nematicides labeled for post-plant application to turfgrass are becoming limited and alternatives must be found to replace recently discontinued nematicides. Salinity had a detrimental effect on population densities of nematodes on some annual crops (Edongali et al., 1982; Heald and Heilman, 1971). Soil salinity has demonstrated negative effects on the hatching and infectivity of *Meloidogyne incognita, M. javanica,* and *M. arenaria* juveniles (Bird, 1977; Dropkin et al, 1958; Lal and Yadav, 1975; Maqbool et al., 1987). Khan and Khan (1990) found that after only 7 days of salinity exposure, *M. incognita* and *M. javanica* had reductions in hatching and increased mortality. Population levels of *Aphelenchus avenae, Pratylenchus thornei, Helicotylenchus* spp., and *Rotylenchulus reniformis* were found to be lower at in-

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creased salt concentrations compared to nonsaline treatments (Lal and Yadav, 1976). However, some species of root-knot nematodes (*M. spartinae*) and sting nematodes (*B. maritimus*) may be well adapted to high-salinity conditions (Rau, 1963; Rau and Fassuliotis, 1965). After personal communication with two turfgrass managers in south Florida, Morton (1973) hypothesized that low nematode counts may be associated with seashore paspalum irrigated with high-saline water. Further investigation is necessary to confirm this hypothesis.

Seashore paspalum is known to be tolerant of high-salinity irrigation, but the effects of high-salinity irrigation on *B. longicaudatus* and *H. galeatus* parasitizing seashore paspalum is unknown. Therefore, the objectives of the experiment were to: (i) establish relationships between increasing irrigation salinity levels and population densities of *B. longicaudatus* and population densities of *H. galeatus* and (ii) compare the effects of high-salinity irrigation alone to the combined effects of high-salinity irrigation and *B. longicaudatus* on shoot and root growth.

Materials and Methods

Four separate experiments were performed, one with *B. longicaudatus* and one with *H. galeatus* in each of 2 years (2002, 2003). Experiments were conducted in 2002 from May through October and repeated in 2003 from April through September at the University of Florida Turfgrass Envirotron Glasshouse in Gainesville, Florida.

During the 2002 experiments, which lasted from 30 May 2002 to 10 October 2002, average monthly high and low air temperatures in the glasshouse ranged from 29 °C to 34 °C, and 21 °C to 26 °C, respectively. In 2003, the *B. longicaudatus* experiment began 8 April and ended 6 August, and the *H. galeatus* experiment began 23 May and ended 20 September. Average monthly low and high air temperatures ranged from 28 °C to 34 °C and 22 °C to 27 °C, respectively. An insecticide/miticide (Mavrik Aquaflow, Wellmark International, Schaumburg, IL) was applied at the labeled rate (0.14-ml a.i./liter of water) twice during the 2003 experiments for control of bermudagrass mites (*Eriophyes cynodoniensis*).

In preparation for these experiments, 'SeaIsle 1', a commercially available cultivar of seashore paspalum, was obtained from R. R. Duncan at the University of Georgia. Nematode-free plugs of grass were obtained by rooting aerial cuttings of stolons in tapered conetainers (cell depth = 14 cm; diam. = 3.8 cm; volume = 115 cm^3) (Ray Leach Single Cell Conetainer, Corvallis, OR) filled with 140 g of noninfested sand (100% U.S. Golf Association [USGA] sand [USGA Green Section Staff, 1993]). The soil texture was analyzed using the sieving method for testing a USGA root zone mix (Table 1). An absorbent cotton ball was placed at the bottom of each cell to prevent soil from escaping through the drain holes. The soil was then thoroughly wetted to allow for settling.

A depression was made in each cell, and two aerial stolons were planted on opposing sides of the depression. Stolons (5 to 8 cm long) were terminal cuttings with two or three nodes. During the winter months, the cells were placed on a glasshouse bench 1.25 m below an enclosed bay of 1,000-watt metal halide growth lamp (Hi-Tek Series, Lithonia Lighting, Conyers, GA) with a 12-hour daylength required for optimal growth. The grass was fertilized with a fertilizer solution (20%-20%-20% [N-P_2O_5-K_2O] plus trace elements) at a rate equivalent to 49.0 kg N/ha/month, 21.6 kg P/ha/month, and 40.7 kg K/ha/month. The root system was allowed to develop for 4 weeks.

Plugs of seashore paspalum obtained from the cells were transferred into 14.5 × 16-cm-diam. clay pots (1,500 cm^3) filled with 100% USGA specification sand. Roots were washed free of sand and trimmed to approximately 5 cm below the crown to promote fresh root growth. Two depressions were made in each pot on opposite sides, and two plugs of turfgrass were planted per pot. These experimental units were placed in an environmentally controlled glasshouse and irrigated with tap water as needed for 14 days to allow for adjustment to the new environment.

A population of *B. longicaudatus* originally from a field near Sanford, Florida, was obtained from R. M. Giblin-Davis and allowed to reproduce on 'FX 313' St.

Table 1. Particle size distribution of experimental soil compared to the U.S. Golf Association root zone mix specifications (USGA Green Section Staff, 1993).

Sand type	Particle size (mm)	Experimental soil[a]	USGA specifications
Fine gravel	2.0 to 3.4	0.1%	Not more than 10% of the total particles in this range, including a maximum of 3% fine gravel (preferably none)
Very coarse sand	1.0 to 2.0	3.7%	
Coarse sand	0.5 to 1.0	30.8%	Minimum of 60% of the particles must fall in this range
Medium sand	0.25 to 0.50	53.4%	
Fine sand	0.15 to 0.25	10.3%	Not more than 20%
Very fine sand	0.05 to 0.15	1.7%	Not more than 5%

[a] Data are means of five replicates.

Augustinegrass. A population of *H. galeatus* was obtained from a 'Floradwarf' bermudagrass putting green at the G. C. Horn Turfgrass Field Laboratory in Gainesville, Florida. Inocula were extracted from soil using a modified Baermann funnel method (McSorley and Frederick, 1991). In 2002, the *H. galeatus* population was contaminated with other plant-parasitic nematodes; therefore, handpicking was necessary to obtain a noncontaminated population. One hundred *H. galeatus* of mixed life stages was inoculated into each pot of seashore paspalum. As the *B. longicaudatus* population was free of other plant-parasitic nematodes, handpicking was not necessary. A suspension of *B. longicaudatus* at various life stages and tap water was calibrated by counting nematodes from 1-ml aliquots on a grided counting slide (Hawksley and Sons Limited, Lancing, Sussex, UK) replicated 10 times. Approximate numbers of nematodes were measured with a pipet from water suspensions of inocula. A total of 111 ± 16 *B. longicaudatus* was added to each of the inoculated pots. In 2003, *H. galeatus* and *B. longicaudatus* were obtained from the previous year's experiment and, again, inocula was obtained using a modified Baermann funnel method (McSorley and Frederick, 1991). Solutions were made for each nematode, and a total of 243 ± 13 *B. longicaudatus*/pot and 238 ± 8 *H. galeatus*/pot was inoculated for two separate experiments. A higher level of nematodes was used in the second year to achieve higher reproduction. In both years, nematodes were suspended in 50 ml of tap water and equally distributed into four cavities formed in the soil near the base of the plant. After inoculation, the cavities were then closed with surrounding soil. Non-inoculated controls received 50 ml of tap water. Tap water was applied as needed for 2 weeks to allow nematodes to adjust to their new environment before experimental treatments were initiated. The 30 pots inoculated with each nematode were then separated into five randomized blocks and treated identically except for salt concentration in irrigation water. Separate experiments were performed for each nematode, with each experiment having six treatments with five replications.

Salinity irrigation treatments were formulated using Instant Ocean Synthetic Sea Salt (Aquarium Systems, Inc., Mentor, OH). Ionic composition of Instant Ocean is primarily Na^+ and Cl^- and designed to mimic closely that of seawater (Atkinson and Bingman, 1998; He and Cramer, 1992). Six 50-liter carboys were used to mix salinity treatments in 35 liters of deionized water. An electrical conductivity meter (YSI Incorporated, Yellow Springs, OH) equipped with a 14.6 × 1.3-cm-diam. dip-type plastic cell was used to test the accuracy of each treatment. The electrical conductivity meter was calibrated using a 10 dS/m standard solution and temperature chart. More salt or deionized water was added to adjust the electrical conductivity to the desired treatment level.

In 2002, irrigation treatments were deionized water concentrated to six salinity levels (0, 5, 10, 25, 40, and 55 dS/m). Irrigation treatments were adjusted in 2003, reflecting the results of the 2002 trials, and were formulated by concentrating deionized water to six salinity levels (0, 5, 10, 15, 20, and 25 dS/m). Each day, 150 ml of each irrigation treatment was applied to the appropriate pots, excluding days before and after leaching events. The experimental units were leached on a weekly (2002) or biweekly (2003) basis to prevent buildup of salts and to deliver fertilizer without changing treatment levels. Seashore paspalum was fertilized on a weekly basis with 20 ml of a solution consisting of 5,100 mg NH_4NO_3 (34% N), 6,354 mg KCl, 252 mg $Ca(H_2PO_4)_2$, 435 mg $CaSO_4$, 246 mg $MgSO_4$, 1.55 mg H_3BO_3, 0.34 mg $MnSO_4$, 0.58 mg $ZnSO_4$, 0.13 $CuSO_4$, and 3.5 mg $FeSO_4$ per 1 liter of deionized water. In 2003, 40 ml of the fertilizer solution was applied on a biweekly basis. Because salinity levels were lower in the 2003 experiment, leaching was done every 2 weeks as opposed to every week. Total N applied for the duration of the experiments was 624 mg/pot. Liquid fertilizer was added to 580 ml or 560 ml of deionized water, and varying amounts of artificial sea salt was added to concentrate the solution to each irrigation treatment. All 600 ml of solution was poured into each pot to flush out residual salts, and replaced with fertilizer solution.

After 120 days, the contents of each pot were emptied into individually labeled plastic bags and thoroughly hand-mixed. A 100-cm^3 soil sample was taken from each bag and processed using a modified centrifugal-sugar flotation technique (Jenkins, 1964). Nematodes were counted from the entire sample using an inverted light microscope at × 32 magnification. For the 2003 *B. longicaudatus* experiment, second-stage juveniles were counted separately from the other life stages. The two categories were summed to determine the total population of each soil sample. In addition to soil extraction, *H. galeatus* in roots from the 2003 experiment were stained and counted to determine number of nematodes per gram of root in fresh-weighed samples using a modified acid-fuchsin staining procedure (Byrd et al., 1983). Effects of salinity were evaluated by regressing log transformations of final nematode population densities on salinity irrigation levels.

In 2003, the sting nematode portion of the experiment was adjusted because *B. longicaudatus* was determined to stunt root growth in seashore paspalum. Effects of high-salinity irrigation alone were compared to the combined effect of high-salinity irrigation and *B. longicaudatus* on shoot and root growth. Thirty additional experimental units were irrigated with salinity treatments but not inoculated and served as controls. Using scissors (Fiskars Brand Inc., Madison, WI), the grass was trimmed biweekly to approximately 2 cm above the soil surface for all experiments. Tissue was placed in 15-cm × 23-cm catalog envelopes (Quality

Park Products, St. Paul, MN) using a spouted 2.84-liter sample pan (40.6 cm × 30.5 cm × 5 cm) (Seedburo, Chicago, IL) and dried at 75 °C for 48 hours to obtain cumulative shoot dry weight.

Final destructive analysis also was adjusted from the previous years' experiments, with the inclusion of non-inoculated treatments in the *B. longicaudatus* experiment. Shoots were trimmed as close to the soil as possible and saved for cumulative shoot dry weight analysis. Using a stainless steel T-sampling tool, a root core (approximately 4-cm-diam. × 14-cm-deep) was taken from the center of each pot to compare root lengths at each salinity level with inoculated treatments. Root cores were washed free of soil on a sieve with 1.7-mm-pore openings nested within a sieve with 75-µm-pore openings. Roots were removed from any aboveground growth and placed into 50-ml disposable plastic centrifuge tubes containing 30 ml of tap water. The 75-µm-pore sieve was then submerged in 5 cm of tap water to allow the finer roots to float out and separate from the soil. These fine roots were collected using laboratory forceps and placed into the 50-ml plastic centrifuge tubes. Five drops (0.25 ml) of a 1% methylene blue mixture was added to the 30 ml of tap water to stain the roots. After a minimum of 24 hours in the solution, the roots were removed, placed on a 75-µm-pore sieve, and washed free of excess dye. Stained roots were placed in a glass-bottom tray and scanned using an HP ScanJet 2cx desktop scanner (Hewlett Packard, Boise, ID) to create a black-and-white bitmap image of the roots (Kaspar and Ewing, 1997; Pan and Bolton, 1991). The GSRoot (Louisiana State University, Baton Rouge, LA) software program was used to analyze the bitmap images. This program measures root lengths and surface areas from scanned images. Root-length data were recorded for seven diameter ranges (<0.05 mm, 0.05 to 0.10 mm, >0.10 to 0.20 mm, >0.20 to 0.30 mm, >0.30 to 0.40 mm, >0.40 to 0.50 mm, and >0.50 mm). The resulting values were summed to determine the total root length of each root sample.

In 2003, total root-length measurements and cumulative shoot dry weights from the sting nematode experiment were compared at each salinity level using an analysis of variance (ANOVA) procedure. Inoculated plants were compared to non-inoculated at each salinity level to determine if root and (or) shoot growth reduction occurred. Transformation by $\log_{10}$ x was performed to normalize nematode-count data and achieve a better trendline fit (Proctor and Marks, 1975). Using SAS software (SAS Institute, Cary, NC), the quadratic least-squares procedure was used to fit a linear or quadratic model to the data relating log-transformations of final nematode population levels to salinity irrigation treatment levels. Linear and quadratic regressions were drawn using Excel (Microsoft Corporation, Redmond, WA).

Results

Reproduction of *H. galeatus* and *B. longicaudatus* was affected by increasing salinity levels (Fig. 1, 2). Final populations of *H. galeatus* decreased linearly ($P \leq 0.01$) with increasing salinity irrigation treatments (Fig. 1). The high r^2-values, 0.92 (2002) and 0.83 (2003), indicate that the linear regression lines described the data well. Lower salinity treatments, 0, 5, and 10 dS/m, resulted in higher nematode reproduction than the higher-salinity irrigation treatments (Fig. 1). Final population densities were low at the treatment level of 25 dS/m in both years. Treatment levels of 40 and 55 dS/m were included in the first year of the study and resulted in population levels at or near zero. Final population means of *H. galeatus* were 1 ± 1 and 2 ± 1/100 cm^3 of soil for the 40- and 55-dS/m treatments, respectively. The ability of *H. galeatus* to enter the root cortex as migratory endoparasites also decreased as salinity levels increased. Final population densities within the root cortex were lower ($P \leq 0.05$) in the 15-, 20-, and 25-dS/m treatments (19 ± 14 *H. galeatus*/gram of root fresh weight) when compared to the 0-, 5-, and 10-dS/m treatments (167 ± 147 *H. galeatus*/gram of root fresh weight).

The relationship between final population densities of *B. longicaudatus* and increasing salinity treatment levels fit a quadratic regression curve ($P \leq 0.01$) in both years of the experiment (Fig 2). Non-transformed data also fit a quadratic model (data not shown), but log transformation improved r^2-values and goodness of fit. In 2002, final populations of *B. longicaudatus* demonstrated a quadratic relationship from 0 to 25 dS/m, with the 25-dS/m treatment supporting a lower popu-

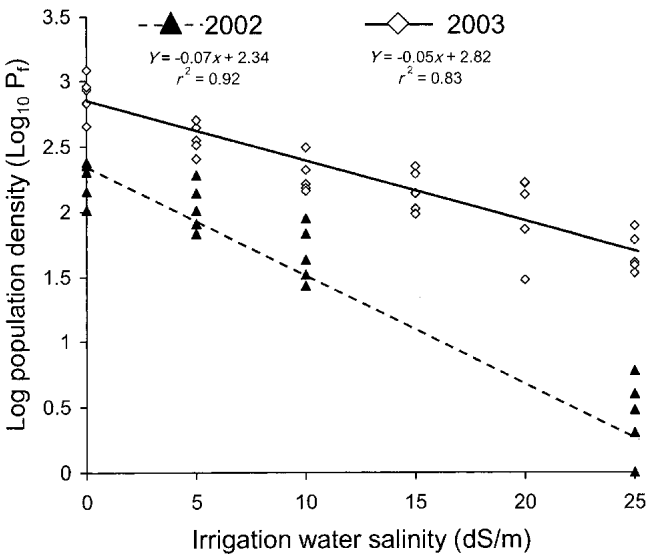

Fig. 1. Relationship between log transformation of final population densities (P_f) of *Hoplolaimus galeatus* (nematodes/100 cm^3 of soil) (*Y*) and salinity treatment (*x*) in 2002 and 2003 glasshouse experiments.

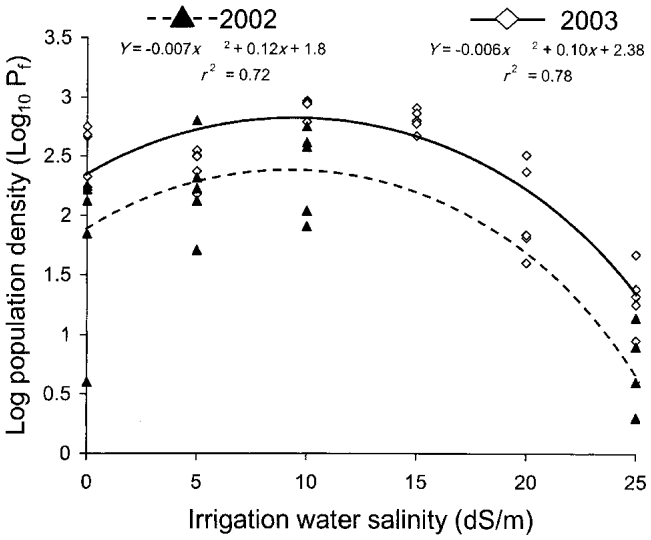

FIG. 2. Relationship between log transformation of final population densities (P_f) of *Belonolaimus longicaudatus* (nematodes/100 cm^3 of soil) (*Y*) and salinity treatment (*x*) in 2002 and 2003 glasshouse experiments.

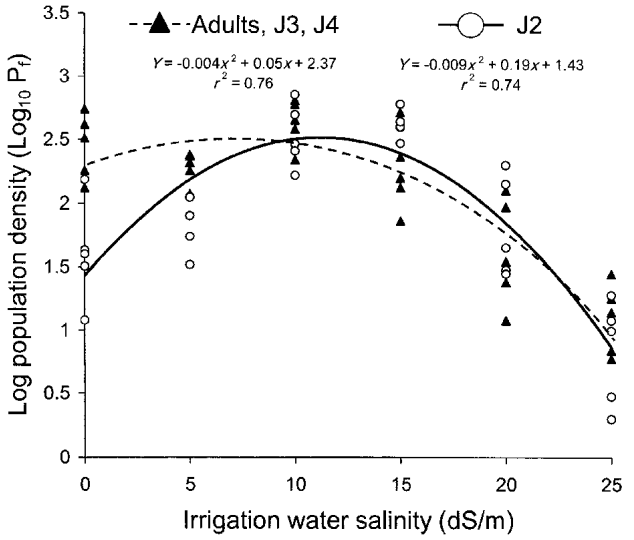

FIG. 3. Relationship between log transformation of J2 or adults, J3, and J4 final population densities (P_f) of *Belonolaimus longicaudatus* (nematodes/100 cm^3 of soil) (*Y*) and salinity treatment (*x*) in the 2003 glasshouse experiment.

lation level than the 5- and 10-dS/m treatments ($P \leq 0.01$). Treatment levels of 40 and 55 dS/m were included in the first year of the study and again resulted in population levels at or near zero. *Belonolaimus longicaudatus* final population means were 3 ± 4 and < 1/100 cm^3 of soil for the 40- and 55-dS/m treatments, respectively. In both years, the 10-dS/m treatment supported a higher population of *B. longicaudatus* than did the 0-dS/m treatment ($P \leq 0.05$) causing the regression lines to be quadratic (Fig. 2).

Final *B. longicaudatus* population densities were higher at 10 and 15 dS/m than 0 dS/m ($P \leq 0.05$) in the second year of the study (Fig. 2). At 15 and 20 dS/m, second-stage juveniles (J2) were the predominant portions of the overall population, making up an average of 68% and 60% of the total population, respectively (Fig. 3). At lower salinity levels (0, 5, and 10 dS/m), adults, third-stage juveniles (J3), and fourth-stage juveniles (J4) were the larger portions of the final population densities (Fig. 3).

Although shoot dry weights were lower at salinity levels greater than 10 dS/m, shoot growth was not affected by inoculation with *B. longicaudatus* (Fig. 4). Statistical analysis of root-length data showed an interaction between salinity treatments and inoculum levels, forcing analysis within salinity treatments. These root-length comparisons revealed that *B. longicaudatus* caused root reduction ($P \leq 0.05$) at low salinity levels, 0 to 10 dS/m (Fig. 5). However, at higher-salinity irrigation treatments, 15 to 25 dS/m, root lengths were not different between inoculated and non-inoculated plants (Fig. 5). These results indicate that the ability of *B. longicaudatus* to stunt root growth was negatively affected at salinity levels of 15 dS/m and higher.

DISCUSSION

Irrigation with poor-quality water is becoming more common as increasing water restrictions force turfgrass managers to obtain water from alternative sources. In our experiments, high-salinity irrigation affected these particular populations of the two nematodes differently. Moderate salinity levels (10 and 15 dS/m) caused an increase in *B. longicaudatus* reproduction, whereas

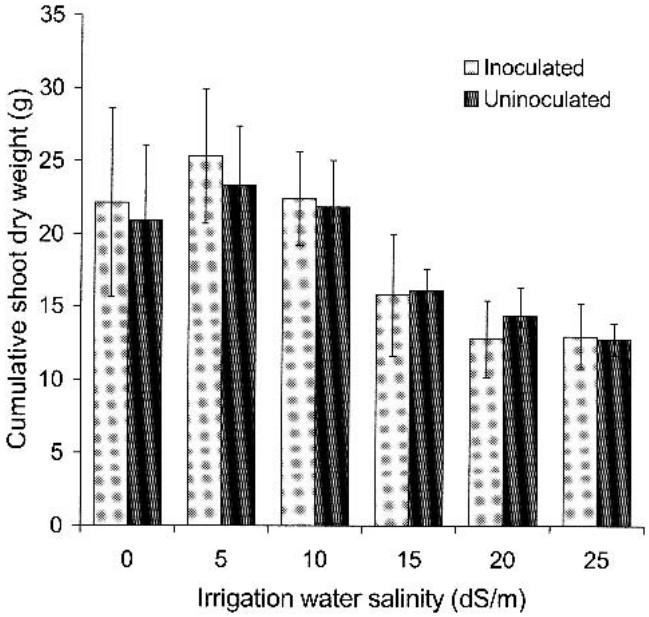

FIG. 4. Effects of *Belonolaimus longicaudatus* on shoot growth of 'SeaIsle 1' seashore paspalum (*Paspalum vaginatum*) at increasing salinity levels. Inoculated plants received 243 ± 13 *B. longicaudatus*, whereas non-inoculated plants received no nematodes. The bars show standard deviation of individual population means.

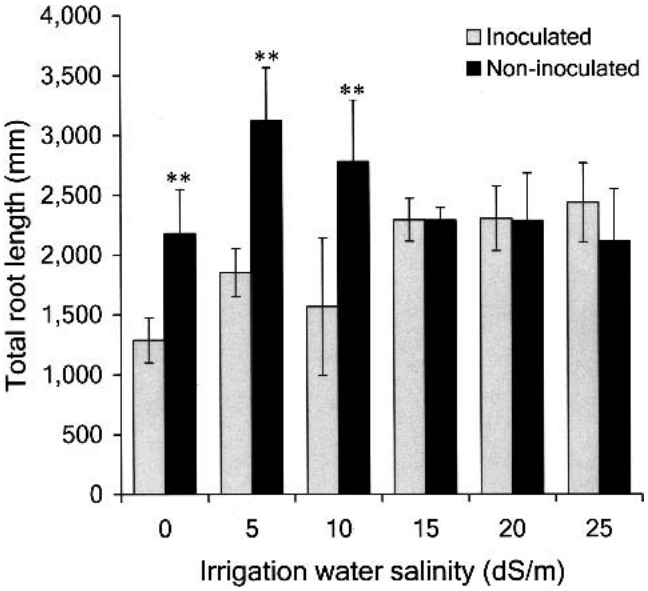

FIG. 5. Effects of *Belonolaimus longicaudatus* on root length of 'SeaIsle 1' seashore paspalum (*Paspalum vaginatum*) at increasing salinity levels. Inoculated plants received 243 ± 13 *B. longicaudatus*, whereas non-inoculated plants received no nematodes. The bars show standard deviation of individual population means. **Indicates difference from inoculated at $P \leq 0.01$, according to the ANOVA procedure.

the population of *H. galeatus* steadily decreased as salinity levels increased. Irrigation with low-salinity levels (5 and 10 dS/m) resulted in denser, more vigorous *P. vaginatum* root and shoot growth than did the 0 dS/m treatment. Irrigating with deionized water may have caused nutrient deficiencies and elevated evapotranspiration rates. With increased root growth, more feeding sites were available for *B. longicaudatus,* perhaps resulting in increased populations.

In 2003, J2 of *B. longicaudatus* comprised a majority of the population in the 15- and 20-dS/m treatments. The abundance of J2 at moderate salinity levels resulted in elevated total population numbers compared to lower salinity levels, causing the regression line to be quadratic. The nematodes counted as J2 had a clear body cavity, indicating they were probably unable to feed. Usually, J2 can be separated easily from other life stages by their dark color and stout body shape (Han, 2001). Root-length data in 2003 support this hypothesis, with root reduction not occurring at the 15-, 20-, or 25-dS/m treatments as opposed to the lower-salinity treatment levels. Reproduction and maturation of the nematodes at higher salinity treatments probably occurred early in the experiment, before the salinity was able to build up in the soil. Han (2001) stated that it is unknown whether or not feeding is necessary for J2 to develop into J3. However, J2 began molting into J3 3 to 5 days after hatching (Han, 2001).

Shoot growth was not affected by inoculations with *B. longicaudatus,* but, at salinity levels above 10 dS/m, shoot growth became less vigorous. In a previous study, shoot growth began to decline in response to soil electrical conductivity levels ≥8 dS/m, with shoot growth being reduced by 25% and 50% at 14 dS/m and 34 dS/m, respectively (Lee, 2000). Cumulative shoot dry weight data collected from previous susceptibility experiments also showed that inoculation with *B. longicaudatus* did not affect aboveground plant growth (Hixson et al., in press). Salinity treatment levels equaling 25 dS/m and above reduced *B. longicaudatus* populations to extremely low levels in 2002, but these high salinity levels had detrimental effects on the growth of the grass.

Hoplolaimus galeatus are classified as migratory endoparasites on turfgrasses. Their ability to enter the roots allows them to escape the effects of most nematicides (Giblin-Davis et al., 1995). In our experiment, both soil and root populations were reduced as salinity irrigation levels increased from 0 to 25 dS/m. The nematodes were probably not able to escape the effects of the salinity by entering the roots because the root cortex tissue does not exclude the elevated ion concentrations associated with saline water (Marcum and Murdoch, 1990). Published action thresholds that justify postplant nematicide treatment for *H. galeatus* on bermudagrass are 40/100 cm^3 of soil (Crow et al., 2003). Soil populations more than exceeded these numbers for both experiments at 15 dS/m and less. In previous experiments, *H. galeatus* had no effect on seashore paspalum growth even though soil counts exceeded 40/100 cm^3 of soil throughout the experiments (Hixson et al., 2004). Time course experiments (Giblin-Davis et al., 1995) with Floratam and FX-313 St. Augustinegrass also indicated that *H. galeatus* had no effect on plant growth.

In 2002, treatment levels of 40 and 55 dS/m caused near-complete mortality for both nematodes, but the shoot growth of the grass was stunted and yellowed. Even though *B. longicaudatus* and *H. galeatus* were effectively controlled, the turfgrass was not visually acceptable. Seashore paspalum can be irrigated with seawater (54 dS/m) in the field when soil conditions allow for sufficient leaching to occur and turfgrass managers fertilize, amend, and cultivate the soil properly (Carrow and Duncan, 1998). In our experiments, prolonged exposure to these high salinity levels was detrimental to turfgrass quality. In the glasshouse, we were unable to provide sufficient leaching, proper amendments, and cultivation of soil necessary for seashore paspalum survival at salinity levels near that of seawater.

Results from glasshouse experiments are difficult to extrapolate to field conditions, but we can conclude that salinity irrigation affected *B. longicaudatus* and *H. galeatus* nematode reproduction. The treatment salinity levels were at a continuous level throughout the experiment and never allowed the nematodes to recover from salinity stress. A discontinuous high-salinity irrigation situation would probably be more similar to irrigation with poor-quality water under field conditions where

rainfall can leach salt from the soil profile (Mashela et al., 1992). Irrigation with pure seawater or with seawater as a high percentage of the blended irrigation water may have potential as an effective option for control of *B. longicaudatus* and *H. galeatus*. This information may be vital to turfgrass managers currently maintaining seashore paspalum known to have a nematode problem. Further investigation is necessary to determine if frequency and timing of high-salinity irrigation, in addition to amount of salinity, can have an effect on nematode reproduction and feeding.

Literature Cited

Ahmad, M., and T. A. Chen. 1980. Effect of certain environmental factors and host plants on reproduction of *Hoplolaimus galeatus*. Plant Disease 64:479–480.

Atkinson, M. J., and C. Bingman. 1998. Elemental composition of commercial seasalts. Journal of Aquariculture and Aquatic Sciences 8:39–43.

Bird, A. F. 1977. The effect of various concentrations of sodium chloride on the host-parasite relationship of the root-knot nematode (*Meloidogyne javanica*) and (*Glycine max* var. Lee). Marcellia 40:167–175.

Boyd, F. T., and V. G. Perry. 1969. The effect of sting nematodes on the establishment, yield, and growth of forage grasses on Florida sandy soils. Soil and Crop Science Society of Florida Proceedings 29:288–300.

Busey, P., R. M. Giblin-Davis, C. W. Riger, and E. I. Zaenker. 1991. Susceptibility of diploid St. Augustinegrasses to *Belonolaimus longicaudatus*. Supplement to the Journal of Nematology 23:604–610.

Byrd, J., D. W., T. Kirkpatrick, and K. R. Barker. 1983. An improved technique for clearing and staining plant tissues for detection of nematodes. Journal of Nematology 15:142–143.

Carrow, R. N., and R. R. Duncan. 1998. Salt-affected turfgrass sites: Assessment and management. Chelsea, MI: Ann Arbor Press.

Christie, J. R. 1959. The sting and awl nematode. Pp. 126–135 *in* J. R. Christie, ed. Plant nematodes, their bionomics and control. Gainesville, FL: University of Florida Agricultural Experiment Station.

Christie, J. R., J. M. Good, and G. C. Nutter. 1954. Nematodes associated with injury to turf (*Belonolaimus gracilis*). Proceedings of the Soil and Crop Science Society of Florida 14:167–169.

Crow, W. T., J. W. Noling, J. R. Rich, R. A. Kinloch, and R. A. Dunn. 2003. Florida nematode management guide. University of Florida, Institute of Food and Agricultural Sciences. Gainesville, FL: University of Florida.

Dropkin, V. H., G. C. Martin, and R. W. Johnson. 1958. Effect of osmotic concentration on hatching of some plant-parasitic nematodes. Nematologica 3:115–126.

Dudeck, A. E., and C. H. Peacock. 1985. Effects of salinity on seashore paspalum turfgrasses. Agronomy Journal 77:47–50.

Duncan, R. R. 1999. Environmental compatibility of seashore paspalum (saltwater couch) for golf courses and other recreational uses. I. Breeding and genetics. International Turfgrass Society Research Journal 8:1208–1215.

Edongali, E. A., L. Duncan, and H. Ferris. 1982. Influence of salt concentration on infectivity and development of *Meloidogyne incognita* on tomato. Revue de Nématologie 5:111–117.

Giblin-Davis, R. M., P. Busey, and B. J. Center. 1992a. Dynamics of *Belonolaimus longicaudatus* parasitism on a susceptible St. Augustinegrass host. Journal of Nematology 24:432–437.

Giblin-Davis, R. M., P. Busey, and B. J. Center. 1995. Parasitism of *Hoplolaimus galeatus* on diploid and polyploid St. Augustinegrasses. Journal of Nematology 27:472–477.

Giblin-Davis, R. M., J. L. Cisar, F. G. Blitz, and K. E. Williams. 1992b. Host status of different bermudagrasses (*Cynodon* spp.) for the sting nematode, *Belonolaimus longicaudatus*. Journal of Nematology 24:749–756.

Han, H. R. 2001. Characterization of intraspecific variations of *Belonolaimus longicaudatus* by morphology, developmental biology, host specificity, and sequence analysis of ITS-1 rDNA. PhD dissertation. University of Florida. Gainesville, FL.

He, T., and G. R. Cramer. 1992. Growth and mineral nutrition of six rapid-cycling *Brassica* species in response to seawater salinity. Plant and Soil 139:285–294.

Heald, C. M., and M. D. Heilman. 1971. Interaction of *Rotylenchulus reniformis*, soil salinity, and cotton. Journal of Nematology 3:179–182.

Henn, R. A., and R. A. Dunn. 1989. Reproduction of *Hoplolaimus galeatus* and growth of seven St. Augustinegrass (*Stenotaphrum secundatum*) cultivars. Nematropica 19:81–87.

Hixson, A. C., W. T. Crow, R. McSorley, and L. E. Trenholm. 2004. Host status of 'SeaIsle 1' seashore paspalum (*Paspalum vaginatum*) to *Belonolaimus longicaudatus* and *Hoplolaimus galeatus*. Journal of Nematology, 36:493–498.

Holdeman, Q. L. 1955. The present known distribution of the sting nematode, *Belonolaimus gracilis*, in the coastal plain of the southeastern United States. Plant Disease Reporter 39:5–8.

Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

Johnson, A. W. 1970. Pathogenicity and interactions of three nematode species on six bermudagrasses. Journal of Nematology 2:36–41.

Kaspar, T. C., and R. P. Ewing. 1997. ROOTEDGE: Software for measuring root length from desktop scanner images. Agronomy Journal 89:932–940.

Kelsheimer, E. G., and A. J. Overman. 1953. Notes on some ectoparasitic nematodes found attacking lawns in the Tampa Bay area. Proceedings of the Florida State Horticultural Society 66:301–303.

Khan, A. A., and M. W. Khan. 1990. Influence of salinity stresses on hatching and juvenile mortality of root-knot nematodes, *Meloidogyne incognita* (Race 2) and *Meloidogyne javanica*. Pakistan Journal of Nematology 8:107–111.

Krusberg, L. R., and J. N. Sasser. 1956. Host-parasite relationship of the lance nematode in cotton roots. Phytopathology 46:505–510.

Lal, A., and B. S. Yadav. 1975. Effect of leachates from saline soils on hatching of eggs of *Meloidogyne incognita*. Indian Journal of Nematology 5:228–229.

Lal, A., and B. S. Yadav. 1976. Effect of soil salinity on the occurrence of phytoparasitic nematodes. Indian Journal of Mycology and Plant Pathology 6:82–83.

Lee, G. 2000. Comparative salinity tolerance and salt tolerance mechanisms of seashore paspalum. PhD dissertation. University of Georgia. Athens, GA.

Malcolm, C. V., and I. A. F. Laing. 1969. *Paspalum vaginatum* for salty seepages and lawns. Journal of Agriculture, Western Australia 11:474–475.

Maqbool, M. A., P. Ghazala, and S. Begum. 1987. Influence of salts on the hatchability and infectivity of *Meloidogyne javanica* juveniles on tomato. Pakistan Journal of Nematology 5:99–102.

Marcum, K. B., and C. L. Murdoch. 1990. Growth responses, ion relations, and osmotic adaptation of eleven C4 turfgrasses to salinity. Agronomy Journal 82:892–896.

Mashela, P., L. W. Duncan, J. H. Graham, and R. McSorley. 1992. Leaching soluble salts increases population densities of *Tylenchulus semipenetrans*. Journal of Nematology 24:103–108.

McSorley, R., and J. J. Frederick. 1991. Extraction efficiency of *Belonolaimus longicaudatus* from sandy soil. Journal of Nematology 23: 511–518.

Morton, J. 1973. Salt-tolerant silt grass (*Paspalum vaginatum* Swartz). Proceedings of the Florida State Horticultural Society 86: 482–490.

Pan, W. L., and R. P. Bolton. 1991. Root quantification by edge discrimination using a desktop scanner. Agronomy Journal 83:1047–1052.

Parker, G. G. 1975. The hydrogeology and problems of peninsular Florida's water resources. Proceedings of the Florida Turfgrass Management Conference 22:13–36.

Perry, V. G., and H. Rhoades. 1982. The genus *Belonolaimus*. Pp. 144–149 *in* R. D. Riggs, ed. Nematology in the southern region of the

United States, Southern Cooperative Series Bulletin 276. Fayetteville, AR: Arkansas Agricultural Experiment Station, University of Arkansas.

Perry, V. G., G. C. Smart, and G. C. Horn. 1970. Nematode problems of turfgrasses in Florida and their control. Proceedings of the Florida State Horticultural Society 83:489–492.

Proctor, J. R, and C. F. Marks. 1975. The determination of normalizing transformations for nematode count data from soil samples and of efficient sampling schemes. Nematologica 20:395–406.

Rau, G. J. 1963. Three new species of *Belonolaimus* (Nematoda: Tylenchida) with additional data on *B. longicaudatus* and *B. gracilis*. Proceedings of the Helminthological Society of Washington 30:119–128.

Rau, G. J., and G. Fassuliotis. 1965. *Hysoperine spartinae* n. sp., a gall-forming nematode on the roots of smooth cordgrass. Proceedings of the Helminthological Society of Washington 32:159–162.

Robbins, R. T., and K. R. Barker. 1974. The effects of soil type, particle size, temperature, and moisture on reproduction of *Belonolaimus longicaudatus*. Journal of Nematology 6:1–6.

Smart, G. C., and K. B. Nguyen. 1991. Sting and awl nematodes: *Belonolaimus* spp. and *Dolichodorus* spp. Pp. 627–667 *in* W. R. Nickle, ed. Manual of agricultural nematology. New York: Marcel Dekker.

USGA Green Section Staff. 1993. USGA recommendation for a method of putting green construction: The 1993 revision. USGA Green Section Record 31:1–3.

Williams, K. J. O. 1973. *Hoplolaimus galeatus*. Commonwealth Institute of Helminthology descriptions of plant-parasitic nematodes 2:1–2.