INFLUENCE OF SALTWATER ON WEED MANAGEMENT IN SEASHORE PASPALUM

By

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Greenhouse and field experiments were conducted in 2003 and 2004. Saltwater treatments consisting of 55 dS/m (1x = seawater), 41 dS/m (3/4x), 27 dS/m (1/2x), 13 dS/m (1/4x), and potable water (0x) were applied to established and newly sprigged seashore paspalum under greenhouse conditions. In the second study, 18 herbicides were applied to established seashore paspalum irrigated with saltwater treatments (1x, 3/4x, 1/2x, 1/4x and 0x) under greenhouse conditions. Saltwater treatments were applied 2 times per wk with 1 potable water treatment per wk for a total of 8 wk. Visual evaluations for turf quality were based on a scale of 0 (dead turf) to 9 (health turf). In a third study, 9 common turfgrass weeds were subjected to saltwater treatments (1x, 3/4x, 1/2x, 1/4x and 0x) applied 2 times per wk with 1 potable water treatment per wk. Visual evaluations for weed control were taken on a scale of 0 (no control) to 100 (complete control). Southern crabgrass and cocks-comb kyllinga susceptibility to saltwater was tested under field conditions in established 'Sea Isle 1' seashore paspalum. Plots were treated for 4 wk with a 1/4x or 1/2x concentration of salt applied as a liquid solution or as a granule and compared to a freshwater treatment.

Turfgrass quality was compromised (ratings < 7) at the 3/4x and 1x rates of saltwater applied to established seashore paspalum while all levels of salt caused unacceptable injury to newly sprigged seashore paspalum. Herbicides that caused a major reduction in the quality of seashore paspalum were atrazine and metribuzin. These herbicides will cause damage when seashore paspalum is irrigated with any concentration of saltwater and should not be applied to seashore paspalum. Minor reductions in quality were observed after the application of bromoxynil, 2,4-D + dicamba + mecoprop, and imazaquin. These herbicides should not be applied to seashore paspalum irrigated with saltwater concentrations > 1/2x. Florida pusley was controlled at all rates of saltwater while Virginia buttonweed was controlled at all rates except 1/4x. Crabgrass, goosegrass, and tropical signalgrass were adequately controlled (>70%) at the 3/4x and 1x rates of saltwater while the 1x rate was needed to provide control of purple nutsedge and dollarweed. Bermudagrass and torpedograss exhibited high levels of tolerance at all salt concentrations. In the field study, crabgrass was effectively controlled at 1/2x rate of saltwater applied as a solution or as granular salt. The 1/4x rate was also effective granularly applied, but not applied as a solution. Kyllinga was controlled at the 1/2x rate either as a granular or solution, but the 1/4x rate was not effective using either method. In both studies, the granular application method provided better control of crabgrass and kyllinga compared to salt applied in solution.

CHAPTER 1
INTRODUCTION

Characteristics of Seashore Paspalum

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial warm season turfgrass that is native to tropical and subtropical regions of the world (Duncan and Carrow, 2000). Although seashore paspalum has existed for many years, it has only been used commercially for the past few decades (Table 1.1). Seashore paspalum spreads by rhizomes and stolons that root at the nodes forming a deep fibrous root system (Duble, 2000). It is generally propagated vegetatively from sod or sprigs because seed production has not been reliable due to self-compatibility issues (Duncan and Carrow, 2000). Breeders have been able to overcome this obstacle and one seed produced cultivar, Seaspray, has recently been released (Hughes, 2005).

Seashore paspalum leaves are slightly coarser than those of common bermudagrass when mowed > 2.5 cm in height. When mowed < 2.5 cm, a finer textured dense turf is produced. Tiller production also increases as mowing height is decreased (Fry and Huang, 2004). Because of the increased tiller production, competition among plants is greater, resulting in a reduced leaf blade width response (Fry and Huang, 2004). A mowing height > 5 cm will cause the seashore paspalum turf to become spindly, increase thatch production, and shade itself out (Trenholm and Unruh, 2003).

Compared to bermudagrass (*Cynodon dactalon* [L.] Pers.), seashore paspalum does well under flooded conditions (Anonymous, 1998). Seashore paspalum also tolerates drought similar to centipedegrass (*Eremochloa ophiuroides* spp.) and better than bermudagrass (Duncan and Carrow, 2000). Seashore paspalum has cold tolerance similar to most hybrid bermudagrass (*Cynodon mageniggii*) cultivars (Duncan and Carrow, 2000). The fine-textured paspalums are often the last warm season turfgrasses to become dormant and generally require consecutive days with temperatures below freezing to reach full winter dormancy (Duncan and Carrow, 2000).

Like bermudagrass, seashore paspalum does not tolerate shade (Trenholm and Unruh, 2002). Areas with a dense tree canopy pose a problem when attempting to maintain seashore paspalum beneath them. However, when subjected to long periods of low light (cloudy, overcast/hazy/foggy, or monsoonal conditions), seashore paspalum grows well (Jiang et al., 2004). Jiang et al. (2004) concluded that seashore paspalum does well under low light conditions compared to hybrid bermudagrass. 'Sea Isle 1' seashore paspalum had the slowest rate of decline in quality (1 = dead turf to 9 = healthy turf) with 8.0 at full sunlight, 7.2 at 70% shade, and 6.9 at 90% shade compared to the best hybrid bermudagrass ('TifSport') with 7.7 at full sunlight, 6.3 at 70% shade, and 5.7 at 90% shade. Turf quality and photosynthetic rates of both turfgrass species declined as the duration of low light increased, but the seashore paspalum cultivars had a higher photosynthetic rate than the bermudagrass cultivars, suggesting the higher photosynthetic rates contribute to the tolerance of low light intensity in seashore paspalum (Jiang, 2004).

Fertility requirements of seashore paspalum appear to be lower than most warm season turfgrass species that are utilized on golf courses. However, in situations where saline water is used for irrigation and the soil is routinely flushed with water to prevent salt toxicity, fertility requirement will increase due to increased leaching (Duncan and Carrow, 2000).

The nitrogen requirement for seashore paspalum ranges from 97 to 390 kg ha^{-1} y^{-1} depending on the maintenance intensity of the turf (Duncan and Carrow, 2000). Turf mowed at greens height (< 0.5 cm) typically requires no more than 390 kg N ha^{-1} y^{-1} in tropical regions (Duncan and Carrow, 2000).

Phosphorus requirements for seashore paspalum are similar to bermudagrass and supplemental phosphorus is only needed when levels present in the soil are reported low on a soil test (Trenholm and Unruh, 2002; Duncan and Carrow, 2000).

Potassium must be supplied to seashore paspalum in salt affected areas because K^+ loss through leaching is increased with the presence of Na^+, Ca^{2+}, and Mg^{2+} (Duncan and Carrow, 2000). Potassium should to be applied at 1.5 to 2 times the rate of nitrogen (Duncan and Carrow, 2000). The application of potassium has been shown to improve wear tolerance, stress tolerance, and salinity tolerance of seashore paspalum (Duncan and Carrow, 2000).

Iron amendments can be applied in small amounts during the growing season to promote green up without promoting shoot growth (Trenholm and Unruh, 2003). Mn^{2+} and Zn^{2+} also aid in enhancing the ability of seashore paspalum to tolerate salinity by preventing cation and osmotic shock (Duncan, 2004). In high salinity situations where fresh water leaching is practiced, all micronutrients need to be monitored regularly for deficiencies due to excessive leaching of nutrients.

Saline soil is defined as a soil having a saturated extract with an electrical conductivity > 4 decisemens per meter (dS/m) (US Salinity Laboratory, 1969). Ocean water is equivalent to approximately 54 dS/m, or 34,500 ppm (Duncan, 2004). Sodium chloride (NaCl) is the predominant component contributing to salinity in soils (Jungklang et al., 2003). Salinity levels in soils are becoming increasingly problematic due to the use of alternative water (effluent or brackish) for irrigation. Duncan and Carrow (1998) have cited seven major contributors to increased soil salinity:

- increased use of wastewater on turfgrass;
- golf course construction in coastal sites;
- the placement of golf courses bordering environmentally sensitive wetlands or other similar areas;
- the use of high sand root zone mixes where sands can more readily become salinized than fine textured soils;
- the increasing emphasis on water conservation practices;
- saltwater intrusion in irrigation aquifers, especially within 16 km of sea coasts; and
- the construction of golf courses on sites with poor soil conditions, not normally suitable for crop production.

Salinity tolerance is a distinguishing physiological characteristic of seashore paspalum. Research on this physiological tolerance is limited because seashore paspalum has only been used commercially for the past decade.

There are three mechanisms plants use to tolerate salinity. The first mechanism is selective ion uptake by the roots (Colmer, 2000; Rose-Fricker and Wipff, 2001). Plants that use this mechanism are considered to be “salt excluders.” Even with a high concentration of Na^+ in the soil the plant is able to efficiently and selectively absorb essential ions.

The second mechanism is the accumulation of salt in specific vacuoles within plant cells, from which the salt is translocated back to the soil in small concentrations (Colmer, 2000; Rose-Fricker and Wipff, 2001). Other plants, such as inland saltgrass (*Distichlis spicata* (L.) Greene.) and bermudagrass, have special glands, called salt glands or bladders, on the leaf surface that excrete salt (Colmer, 2000; Rose-Fricker and Wipff, 2001). Plants that use this mechanism are considered to be “salt includers.”

The third mechanism is osmotic adjustment (Colmer, 2000; Fricker and Wipff, 2001; Marcum, 2004). The plants adjust their internal ion gradient to maintain turgor pressure, allowing it to continue water absorption in the presence of high salt concentrations.

All of these mechanisms operate in salt tolerant plants, while one or more of these mechanisms may be lacking in a salt sensitive plant (Colmer, 2000). Seashore paspalum has the ability to efficiently select ions absorbed by the roots, and it is also able to secrete salt through salt glands on the leaf surface (Marcum, 1999).

Salt injury to plants is exhibited as reduced growth, burning of leaf tips, and wilting (Colmer, 2000). Alternative, non-potable water sources may increase the salinity level of the soil over time and must be managed properly when establishing and maintaining a high quality turf. Soils high in Na^+ will have poor aeration and reduced water infiltration rates due to dispersal of soil particles in the soil profile (Mitra, 2000 and 2001). A form of soluble Ca^{2+} must be added to soils with a high exchangeable Na^+ percentage to replace the Na^+ on the cation exchange sites (Mitra, 2000 and 2001). Gypsum is the most common form of Ca^{2+} because it is water soluble and has little effect on soil pH (Mitra, 2001). Once the Na^+ is removed from the exchange site, it must be leached from the soil profile with deep, infrequent irrigation (Mitra, 2000 and 2001). An additional method of dealing with salinity problems is to use salt tolerant species and/or cultivars (Qian et al., 2001).

Several studies have been conducted testing the tolerance of seashore paspalum to various concentrations of saltwater. Noaman and El-Haddad (2000) exposed established seashore paspalum to three levels of salinity: 10 g/L (16 dS/m), 20 g/L (32 dS/m), and 40 g/L (64 dS/m). A reduction in plant height with increased salt concentration was apparent after 4 weeks (wk) and continued to decrease until the end of the experiment at 10 wk. Similarly, as salt concentration increased from 16 dS/m to 64 dS/m, plant biomass decreased by 70% (Noaman and El-Haddad, 2000).

Marcum and Murdoch (1994) subjected seashore paspalum and five other warm-season turfgrasses [manilagrass (*Zoisia matrella* (L.) Merr.), St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Ktze.), Tifway bermudagrass, Japanese lawngrass (*Zoisia japonica* Steud.), and centipedegrass] to five saltwater concentrations: 1 mM (1 dS/m), 100 mM (9 dS/m), 200 mM (17 dS/m), 300 mM (26 dS/m), and 400 mM (34 dS/m). Seashore paspalum growth rates were higher than the other turfgrass species at 34 dS/m. Seashore paspalum quality ratings were also higher than the other turfgrasses at all saltwater concentrations (Marcum and Murdoch, 1994).

Couillard and Wiecko (1998) evaluated saltwater tolerance on bermudagrass, and seashore paspalum. The turf was treated with ocean water at three concentrations: pure ocean water (54 dS/m), 2/3 ocean water (37 dS/m) + 1/3 potable water, and 1/3 ocean water (19 dS/m) + 2/3 potable water. The watering schedule was twice daily for two different periods: 3 days (d) or 6 d. Following the saltwater stress periods, potable irrigation was applied to evaluate the recovery potential of seashore paspalum and bermudagrass over a period of 32 d after the salt-stress treatments began. Injury was observed on all plant species tested at all three ocean water concentrations.

Bermudagrass and seashore paspalum both fully recovered from all treatments. The most injury occurred with pure ocean water after the 6 d salt-stress treatment.

Wiecko (2003) exposed seashore paspalum, bermudagrass, St. Augustinegrass, and centipedegrass to three different salinity levels (54, 37, and 19 dS/m) over two short term salt stress durations (3 and 6 d). Seashore paspalum showed excellent salinity tolerance compared to all other plants tested with the maximum injury of 18% at 54 dS/m after the 6 d salt stress duration. Bermudagrass injury was 30% at 54 dS/m after the 6 d salt stress duration and only minor injury at lower salt concentrations. St. Augustinegrass showed up to 60% injury under the 6 d duration of 54 dS/m and centipedegrass showed complete necrosis (Wiecko, 2003).

These studies indicate seashore paspalum can tolerate saline irrigation, but long-term quality can be compromised when irrigated with high salt concentration water. When establishing seashore paspalum, saline conditions may negatively impact turfgrass growth rate (Duncan and Carrow, 1999). Before selecting a grass species for a specific site, water and soil samples should be collected to analyze quality (Duncan and Carrow, 2000). If saline soils are present, amendments should be added to manage the problem before turfgrass is established in the area (Duncan and Carrow, 2000). Long-term salinity problems will persist in the soil if poor quality irrigation water is used (Duncan and Carrow, 2000). Proper irrigation scheduling and duration will help alleviate the problem by leaching the salts through the soil profile (Duncan and Carrow, 2000).

Water Quality and Consumption on Golf Courses

Water management is one of the most important aspects of golf course maintenance. On average, a golf course occupies approximately 55 hectares (137 acres), of which 65% is irrigated on a regular basis (Marella, 1999). According to a survey by

Haydu and Hodges in 2002, golf courses in Florida use approximately 655 billion liters (173 billion gallons) of water per year. Recycled water accounts for 49% of the total water, while 29% comes from surface water and 21% from wells.

There are five Water Management Districts in the state of Florida that regulate the use of water. These districts have the power to issue water use permits, impose regulations, and establish permit fees. There are several types of water use permits that are issued by Florida's Water Management Districts. Consumptive use permits (CUPs) are the most commonly issued permit and are required if water is withdrawn from a well 15 mm (6 in) in diameter or greater, if the annual average water use is 378,500 liters (100,000 gal) per day or greater, and if a pump is used that has the capability to pump 3.8 million liters (1 million gal) per day or greater (SJRWMD 2002). Because CUPs determine the duration and amount of potable water available to golf courses, alternative water sources that have fewer restrictions are being used.

The United States Golf Association (USGA) lists several different irrigation water sources that are available to golf courses (Snow, 2004). Fresh water is the most common source of irrigation water and can be acquired from aquifers or retention ponds and lakes. Another source is tertiary treated effluent water. The turfgrass acts as a filter by extracting nutrients and breaking down chemicals in the effluent water that municipalities would otherwise discharge into nearby rivers or the ocean (Snow, 2004). Some areas in the southern U.S. including Arizona and Florida require the use of effluent water for turfgrass irrigation because of a limited supply of freshwater (Snow, 2004).

Brackish water (salt concentration between fresh water and ocean water) or ocean water is also used as an irrigation source on golf courses. Bermudagrass and seashore paspalum are tolerant to certain levels of saltwater (Snow, 2004). Precise application of saltwater is required to prevent injury to existing plant populations that have a low salt tolerance.

Reverse osmosis desalinization facilities can also be constructed on site to reduce the dissolved salt content of saline water to a usable level. Saline water (feedwater) is drawn from a source and pretreated by adjusting pH, removing suspended solids, and adding inhibitors to control scaling caused by calcium constituents (UNEP, 1997). The feedwater is then pressurized to the appropriate operating pressure for the water-permeable membrane (UNEP, 1997). The pressurized feedwater enters the membrane that inhibits dissolved salts from passing, while allowing the desalinized water to pass through (UNEP, 1997). Finally, the desalinized water is stabilized by degasification and adjustment of the pH (UNEP, 1997). These reverse osmosis desalinization plants are expensive, but are necessary in certain areas where freshwater is limited or too expensive to purchase in large quantities (Snow, 2004).

Weed Management on Golf Courses

Seashore paspalum exhibits exceptional salt tolerance, but is highly susceptible to injury from many postemergence herbicides (Wiecko, 2003). It may be possible to replace postemergence herbicides with saltwater to control some species of weeds (Wiecko, 2003).

Weeds compete with turfgrass for light, nutrients, water, and physical space (Florkowski and Landry, 2002) and weed management is a major cost for turfgrass managers. On golf courses in the Southeast, average expenditures for herbicides in 1998 were $11,690 per course (Florkowski and Landry, 2002).

Some of the more common weeds in turfgrass include dollarweed (*Hydrocotyle* spp.), Florida pusley (*Richardia scabra* L.), Virginia buttonweed (*Diodia virginiana* L.), goosegrass, southern crabgrass (*Digitaria ciliaris* (Retz.) Koel.), common bermudagrass, tropical signalgrass (*Urochloa subquadripara* [Trin.] R. Webster), torpedograss (*Panicum repens* L.), and purple nutsedge (*Cyperus rotundus* L.).

Dollarweed is a perennial broadleaf that reproduces by seed, rhizomes, and tubers. The leaves are long stalked with the petiole attached to the center of the leaf that resembles an umbrella. Dollarweed is most commonly found in areas with excessive moisture (Murphy et al., 1996).

Florida pusley is a summer annual broadleaf that reproduces by seed. The branched stem is hairy with thickened leaves that have an opposite arrangement. The white flowers are bunched at the end of the branches (Murphy et al., 1996).

Virginia buttonweed is a perennial broadleaf that reproduces by seed, roots, and stem fragments. The stem is branched and hairy with an opposite leaf arrangement. The flower is white with four lobes at each leaf axil (Murphy et al., 1996).

Goosegrass is a summer annual grass that reproduces by seed. The crown is generally white or silver in color and is usually found in areas with compacted soils. The leaves are smooth on both sides with a short-toothed membranous ligule (Murphy et al., 1996).

Southern crabgrass is a summer annual grass that reproduces by seed. Stems are branched and root at the nodes. The leaves are usually hairy on both sides and have a toothed membranous ligule (Murphy et al., 1996).

Common bermudagrass is a perennial grass that reproduces by stolons, rhizomes, and seed (Duble, 2004). The stolons and rhizomes root at the nodes to form a deep fibrous root system (Duble, 2004). The collar of the leaves have a fringe of short, white hairs (NewCROP, 1999).

Tropical signalgrass is a summer annual grass that reproduces by seed. The stem is branched with a blanket-like growth pattern. The leaves are glossy with a coarse texture (Busey 2000).

Torpedograss is a very persistent perennial grass that reproduces vegetatively or through rhizomes (Busey, 2002). The rhizome system is very robust with sharply pointed tips. The stems are stiff and erect with leaves that are folded or flat (Murphy et al., 1996).

Purple nutsedge is a perennial sedge that reproduces primarily by oblong tubers that are covered with hairs. The leaves taper abruptly to a point unlike yellow nutsedge that tapers gradually to a point. The seed head has a purplish color and is formed on a triangular stem (Murphy et al., 1996).

These weeds are a few of the most common weeds found in turfgrass in the Southeastern United States. Control of these weeds can be very difficult and expensive.

Weeds can be controlled using cultural practices to produce a healthy, competitive turfgrass, in combination with herbicides. Cultural practices can greatly reduce weed pressure on turfed areas. Using cultural methods can reduce chemical use, which can reduce herbicide costs for weed control. Often, the most cost effective method of weed control is to have a healthy, dense turf (Unruh and Elliott, 1999). The turf will naturally out-compete many weed species.

One important step in producing a healthy turf is proper fertility. Different turfgrasses have different fertility requirements. Nitrogen, phosphorus, and potassium are important nutrient requirements for enhanced shoot and root growth.

Aerification and verticutting are common cultural practices to control weeds and relieve turf stresses such as compaction and thatch on golf courses. Aerification consists of pulling soil core plugs 0.63 cm to 1.9 cm (0.25 to 0.75 in.) in diameter, ranging in depth of 5 to 10 cm (2 to 4 in.) (Unruh and Elliott, 1999). This process relieves soil compaction, improves surface drainage and water penetration, and reduces thatch (Unruh and Elliot, 1999).

Verticutting consists of vertical knives spaced close together on a horizontal shaft that slice into the turf (Unruh and Elliott, 1999). This practice removes the organic matter (thatch) layer allowing the turf to grow horizontally and allows for a smooth putting surface. Deep verticutting should be avoided when maintaining seashore paspalum greens because this increases the potential for scalping (Duncan and Carrow, 2002). Light verticutting enhances stolon-rhizome-shoot growth and allows topdressing sand to integrate into the thatch layer producing a more firm, smooth surface less susceptible to scalping (Duncan and Carrow, 2000, 2002). A good quality topdressing sand for seashore paspalum should integrate easily into the surface at light rates without verticutting (Duncan and Carrow, 2002).

Mowing is another very important cultural practice on a golf course. Improper mowing can weaken the turf reducing its density and quality (Unruh and Elliott, 1999), providing an opportunity for weeds to invade. Seashore paspalum does not tolerate scalping as well as bermudagrass or zoysiagrass and may take 4 to 6 wk to fully recover

(Duncan and Carrow, 2002). When reducing the mowing height on seashore paspalum tees and greens, it should be done in gradual increments of 0.05 to 0.08 cm (0.02 to 0.03 in.) over 2 to 3 d (Duncan and Carrow 2002). When the turf is mowed properly, very little stress is put on the plant, allowing it to recover very quickly. Frequent mowing increases shoot growth, producing a dense canopy that makes it more difficult for weeds to invade (Unruh and Elliott, 1999).

Finally, proper irrigation can be used to reduce weed pressure. Maintaining proper soil moisture levels is important for producing a healthy turf. Seashore paspalum is very responsive to irrigation duration and frequency and a shallow root system will result from frequent irrigation events of short durations (Duncan and Carrow, 2002). This also causes the turf to be more succulent, less drought tolerant, and more susceptible to scalping. Watering schedules should consist of long durations during applications with long intervals (1.25 to 2.5 cm of water every 4 to 7 days on a sand green) between applications to force the roots to grow deeper into the soil profile (Duncan, 2004; Duncan and Carrow, 2002). Various grass types require different moisture levels and weed species will also respond differently depending on moisture levels. For instance, dollarweed populations can be reduced in St. Augustinegrass turf by reducing irrigation levels (Busey, 2001).

Herbicides are regularly used for weed control on golf courses. Some important considerations when selecting a herbicide are effectiveness, turfgrass tolerance, speed of control, toxicity, and cost (Unruh and Elliott, 1999). There is no single herbicide that will control all weeds in a desired turf stand, so proper identification is essential (Unruh and Brecke, 1998). Seashore paspalum is sensitive to many herbicides commonly used on other turfgrasses (Trenholm and Unruh, 2003; and CTAHR, 1998). Herbicides that are noninjurous to seashore paspalum include bensulide, pronamide, benefin, DCPA, pendimethalin, ethofumesate, quinclorac, MCPP + 2,4-D + dicamba, dithiopyr, 2,4-D + dicamba + dicloprop, dicamba, halosulfuron, mecoprop, and bentazon (Duncan and Carrow, 2000). However, dithiopyr, halosulfuron, oxadiazon, and prodiamine are the only herbicides labeled for use on seashore paspalum (Unruh et al., 2005). These herbicides could possibly be used at reduced rates in conjunction with saltwater irrigation to control weeds in seashore paspalum (Duncan and Carrow, 2000).

Studies have been conducted to test the tolerance of seashore paspalum to several postemergence herbicides. In 1997, Johnson and Duncan tested the recommended rates and 3 times the recommended rates of diclofop, quinclorac, dicamba, imazaquin, halosulfuron, and 2,4-D + mecoprop + dicamba on four seashore paspalum accessions (AP 10, HI 25, PI 28960, and K-7).

Seashore paspalum accessions varied in their response to the herbicides evaluated. Quinclorac and halosulfuron were the only herbicides that did not reduce the quality of any accession at the recommended rates. When quinclorac and halosulfuron rates increased, quality of HI 25 and K-7 was reduced. All accessions recovered completely even from the high rates within 4 to 8 wk after initial treatment.

Dicamba had no effect on any of the accessions when applied at the labeled rate. Quality of the K-7 accession, however, was negatively affected by the increased rate of dicamba.

Diclofop, imazaquin, and 2,4-D + mecoprop + dicamba reduced the quality of all paspalum accessions regardless of application rate. Full recovery from diclofop and imazaquin required 4 to 8 wk. Recovery from the labeled rates of 2,4-D + mecoprop + dicamba took 4 to 8 wk for all accessions, and none of the accessions recovered from the high rate by 8 wk. The overall conclusion from this study was that quinclorac, dicamba, and halosulfuron were safe on all accessions, diclofop and imaziquin were marginal, and 2,4-D + mecoprop + dicamba were considered injurious.

A study was conducted by Unruh et al. (2005) testing the tolerance of 'Salam' seashore paspalum to postemergence herbicides for control of grass (clethodim, ethofumesate, metsulfuron, sethoxydim, and quinclorac), broadleaf (clopyralid, dicamba, and 2,4-D + mecoprop + dicamba), and sedge (bentazon, halosulfuron, imazapic, imazaquin, and trifloxysulfuron-sodium) species. Metsulfuron, quinclorac, clopyralid, dicamba, 2,4-D + mecoprop + dicamba, bentazon, halosulfuron, and imazaquin caused less than 15% injury at the recommended rates and are considered safe for seashore paspalum. Clethodim, sethoxydim, ethofumesate, imazapic, and trifloxysulfuron-sodium caused greater than the acceptable standard of 20% injury and are considered not safe for application to seashore paspalum.

The high level of salt tolerance may allow the use of saltwater for weed control in place of injurious postemergence herbicides (Wiecko, 2003). Couillard and Wiecko (1998) evaluated injury from saltwater on large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and mimosa-vine (*Mimosa pudica* Torr.). They treated both species with ocean water at three concentrations: pure ocean water (54 dS/m), 2/3 ocean water (37 dS/m) + 1/3 potable water, and 1/3 ocean water (19 dS/m) + 2/3 potable water. The weeds were watered twice daily for two different periods: 3 d or 6 d. Following the saltwater stress periods, potable irrigation was applied to evaluate the recovery potential over a period of

32 days after the salt-stress treatments began. Injury was observed on both plant species tested at all three ocean water concentrations.

Mimosa only recovered from the 1/3x ocean water treatment subjected to 3 d salt-stress. Complete crabgrass control was only achieved with pure ocean water under 6 d salt-stress.

Other studies were conducted by Wiecko (2003) with the addition of goosegrass, alyceclover (*Alysicarpus vaginalis* (L.) DC.), and yellow nutsedge (*Cyperus esculentus* L.) to the species previously evaluated. Mimosa-vine showed complete necrosis at 54 dS/m and 37 dS/m under both salt stress durations, respectively. Alyceclover showed >90% injury at 34,500 ppm under both salt stress durations, and >70% at 37 dS/m. Large crabgrass and goosegrass showed >90% injury at 54 dS/m. Yellow nutsedge had the greatest salt tolerance among the weeds with injury <40% at all salt concentrations (Wiecko, 2003).

Based on these studies, ocean water can be used as an alternative to herbicides to control weeds in certain turfgrasses (Couillard and Wiecko, 1998). Most annual grass and broadleaf weed species cannot tolerate continuous irrigation with saltwater or saltwater blends (wastewater) (Duncan and Carrow, 2000).

Summary

During early root growth and establishment, all plants are more sensitive to saline conditions causing desiccation of the plant and reducing water infiltration and aeration of the soil (Duncan and Carrow, 2000). Salinity will also cause nutrient deficiencies or imbalances resulting in toxicities that will influence plant growth and development (Duncan and Carrow, 2000). Genetic resistance to these stresses and toxicities is valuable for managing turf successfully on saline soils (Duncan and Carrow, 2000).

While considerable research has been conducted to determine the tolerance of established seashore paspalum to saltwater, little information is available concerning saltwater tolerance in newly sprigged seashore paspalum. Thus, research was conducted to compare salt tolerance of established with newly sprigged seashore paspalum.

Some research has been conducted to evaluate susceptibility of selected weed species to saltwater. However, additional information about the effectiveness of saltwater for control of additional weed species is needed. Research was conducted with eight weed species to determine the level of control that can be achieved with saltwater alone. This will help determine the contribution to overall weed management that can be expected from saltwater irrigation.

Tolerance of seashore paspalum to many postemergence herbicides has been determined over the past decade. However, herbicide response of seashore paspalum in salt-affected areas has not yet been determined and seashore paspalum may be more sensitive to injury as salt-stress increases. Susceptibility to herbicide injury under salt stress was also tested on seashore paspalum.

Table 1-1 Paspalum cultivars, leaf texture, and year of introduction.

Cultivar	Leaf texture	Year Introduced
Saltene	intermediate	1951
Salpus	intermediate	
Futurf	intermediate	1972
Adalayd (Excalibur)	intermediate	1975
Fidalayel	intermediate	
Tropic Shore	course	1991
Mauna Kea	intermediate	
Salam	fine (fairway/sports)	1998
Sea Isle 2000	fine (greens/tees)	1999 to present
Sea Isle 1	fine (fairway/tees/sports)	
Durban Country Club	fine (fairway/tees/roughs)	
Sea Dwarf	fine (greens/tees)	
Sea Green	fine (greens/tees)	
Seaway	fine (fairway/sports)	
Seaspray (seeded)	fine (fairway/sports)	

CHAPTER 2
TOLERANCE OF NEWLY SPRIGGED AND ESTABLISHED SEASHORE PASPALUM TO SALTWATER

Introduction

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial, warm season turfgrass that is native to tropical and subtropical regions of the world (Duncan and Carrow, 2000). Although seashore paspalum has existed for many years, it has only been used commercially for the past few decades. Seashore paspalum spreads by rhizomes and stolons that root at the nodes forming a deep fibrous root system (Duble, 2000). It is generally propagated vegetatively from sod or sprigs because seed production has not been reliable (Duncan and Carrow, 2000). Research into the self-incompatibility issues has led to the introduction of one seed produced cultivar, Seaspray (Hughes, 2005).

The leaves of seashore paspalum are slightly coarser than those of common bermudagrass when mowed > 2.5 cm in height. When mowed < 2.5 cm, a finer textured dense turf is produced. Tiller production will increase as mowing height is decreased and the width of the leaf blade is reduced as a result of competition among plants (Fry and Huang, 2004). A mowing height > 5 cm causes the seashore paspalum turf to become spindly, increase thatch production, and shade itself out (Trenholm and Unruh, 2003).

In flooded conditions seashore paspalum does well compared to bermudagrass (Anonymous, 1998). Seashore paspalum also tolerates drought similar to centipedegrass and better than bermudagrass (Duncan and Carrow, 2000). The cold tolerance of seashore paspalum is similar to most hybrid bermudagrass cultivars (Duncan and Carrow, 2000). The fine-textured paspalums are often the last warm season turfgrasses to go into full winter dormancy and generally require consecutive days with temperatures below freezing to reach full winter dormancy (Duncan and Carrow, 2000).

Like bermudagrass, seashore paspalum does not tolerate shade, however, when low light conditions (cloudy, overcast/hazy/foggy, and monsoonal conditions) are present, seashore paspalum does well under low light conditions compared to hybrid bermudagrass (Jiang et al., 2004; Trenholm and Unruh, 2002).

Fertility requirements of seashore paspalum appear to be lower than most warm season turfgrass species that are utilized on golf courses. However, in situations where saline water is used for irrigation and the soil is routinely flushed with water to prevent salt toxicity, fertility requirements will increase due to increased leaching and all micronutrients need to be monitored regularly for deficiencies. (Duncan and Carrow, 2000).

Salinity levels, predominantly sodium chloride (NaCl), in soils are becoming increasingly problematic due to the use of alternative water (effluent or brackish) for irrigation (Duncan and Carrow, 1998; Jungklang, 2003). There are three physiological mechanisms plants use to tolerate salinity. The first mechanism is selective ion uptake by the roots (Colmer, 2000; Rose-Fricker and Wipff, 2001). The plant is able to efficiently and selectively absorb needed ions even with a high concentration of Na^+ in the soil. The second mechanism is the accumulation of salt in specific vacuoles within plant cells, from which the salt is retranslocated back to the soil or excreted by salt glands on the leaf surface (Colmer, 2000; Rose-Fricker and Wipff, 2001). Finally, the plant uses osmotic adjustment to maintain turgor pressure allowing it to continue water absorption in the presence of high salt concentrations (Colmer, 2000; Fricker and Wipff, 2001; Marcum, 2004).

Salt injury to plants is exhibited as reduced growth, burning of leaf tips, and wilting (Colmer, 2000). Alternative, non-potable water sources may increase the salinity level of the soil over time and must be managed properly when establishing and maintaining a high quality turf. Soils high in Na^+ will have poor aeration and reduced water infiltration rates due to dispersal of soil particles in the soil profile (Mitra, 2000 and 2001). A form of soluble Ca^{2+} must be added to soils with a high exchangeable Na^+ percentage to replace the Na^+ on the cation exchange sites (Mitra, 2000 and 2001). Gypsum is the most common form of Ca^{2+} because it is water soluble and has little effect on soil pH (Mitra, 2001). Once the Na^+ is removed from the exchange site, it must be leached from the soil profile with deep, infrequent irrigation (Mitra, 2000 and 2001). An additional method of dealing with salinity problems is to use salt tolerant species and/or cultivars (Qian, 2001).

Several studies have been conducted testing the tolerance of seashore paspalum to various concentrations of saltwater. Noaman and El-Haddad (2000) exposed established seashore paspalum to three levels of salinity: 10 g/L (16 dS/m), 20 g/L (32 dS/m), and 40 g/L (64 dS/m). The plant height reduction with increased salt concentration was apparent after 4 wk and continued to decrease until the end of the experiment at 10 wk. Similarly, as salt concentration increased from 16 dS/m to 64 dS/m, plant biomass decreased by 70% (Noaman and El-Haddad, 2000).

Marcum and Murdoch (1994) subjected seashore paspalum and five other warm-season turfgrasses [manilagrass (*Zoisia matrella* (L.) Merr.), St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Ktze.), Tifway bermudagrass, Japanese lawngrass

(*Zoisia japonica* Steud.), and centipedegrass] to five saltwater concentrations: 1 mM (1 dS/m), 100 mM (9 dS/m), 200 mM (17 dS/m), 300 mM (26 dS/m), and 400 mM (34 dS/m). Seashore paspalum growth rates were higher than the other turfgrass species at 34 dS/m. Seashore paspalum quality ratings were also higher than the other turfgrasses at all saltwater concentrations (Marcum and Murdoch, 1994).

Couillard and Wiecko (1998) evaluated saltwater for tolerance on bermudagrass, and seashore paspalum. The turf was treated with ocean water at three concentrations: pure ocean water (54 dS/m), 2/3 ocean water (37 dS/m) + 1/3 potable water, and 1/3 ocean water (19 dS/m) + 2/3 potable water. The watering schedule was twice daily for two different periods: 3 d or 6 d. Following the saltwater stress periods, potable irrigation was applied to evaluate the recovery potential of seashore paspalum and bermudagrass over a period of 32 d after the salt-stress treatments began.

The most injury for bermudagrass and seashore paspalum occurred with pure ocean water after the 6 d salt-stress treatment. In all instances, bermudagrass and seashore paspalum both fully recovered from all treatments when watered with potable water.

Wiecko (2003) exposed seashore paspalum, bermudagrass, St. Augustinegrass, and centipedegrass to three different salinity levels (54, 37, and 19 dS/m) over two short term salt stress durations (3 and 6 d). Seashore paspalum showed excellent salinity tolerance compared to all other plants tested with the maximum injury of 18% at 54 dS/m after the 6 d salt stress duration. Bermudagrass injury was 30% at 54 dS/m after the 6 d salt stress duration and only minor injury at lower salt concentrations. St. Augustinegrass showed up to 60% injury under the 6 d duration of 54 dS/m and centipedegrass showed complete necrosis (Wiecko, 2003).

These studies indicate seashore paspalum can tolerate saline irrigation, but quality can be compromised long-term when irrigated with high salt concentration water. When establishing seashore paspalum, saline conditions may negatively impact turfgrass growth rate (Duncan and Carrow, 1999). The salinity tolerance during establishment of seashore paspalum has not yet been determined. The objective of this study was to determine the tolerance of both newly sprigged and established seashore paspalum to various concentrations of saltwater.

Methods and Materials

Studies were conducted under greenhouse conditions at the University of Florida in Gainesville in 2004. Strips of sod were cut with a sod cutter from a two year old stand of 'Sea Isle 1' seashore paspalum. Plugs were cut from the sod strips using a golf cup cutter 15 cm in diameter. The native soil was washed from the plugs and then plugs were transplanted into 15 cm in diameter by 17 cm deep (3,000 cm^3 volume) plastic pots containing a growing medium of USGA (1993) greens mix (80% sand and 20% organic matter). The intact seashore paspalum plugs were planted level with the rim of the pots.

After transplanting, the pots were placed in a greenhouse receiving full sun and maintained at a temperature range of 27^o to 32^o C. A slow release 18-9-18+Mn+Fe fertilizer was applied at a rate of 24.5 kg N ha^{-1} 1 wk after planting. The plugs were irrigated with potable water during a 3 wk rooting period.

Separate pots were planted with seashore paspalum sprigs. Plugs were harvested as described above and separated into sprigs. The sprigs were planted (200 ml/pot) in pots measuring 15 cm diameter by 17 cm deep containing USGA greens mix. A 2.5 cm layer of the greens mix was then applied, covering the sprigs to allow for good growing medium to stolon contact.

Saltwater applications were initiated immediately after sprigging (January 19 in 1st study and March 3rd in repeated study) and were applied to both sprigged and established seashore paspalum (transplanted 3 wk prior to initiation of saltwater treatment). Saltwater treatments were applied twice per week (Mon. and Wed.), with one potable water treatment per week (Fri.) applied to prevent salt accumulation on the growing medium surface.

The five saltwater (NaCl) concentrations utilized for this study were as follows: untreated (0X), 13 dS/m (1/4X), 27 dS/m (1/2X), 41 dS/m (3/4X), and 55 dS/m (1X). The 55 dS/m (1X) concentration is equivalent to ocean water and the untreated (0X) is potable water. Each irrigation event consisted of 200 ml of saltwater or potable water, which was equivalent to 1 cm of water (irrigation) per event, totaling the standard 3 cm of water (irrigation) recommended for seashore paspalum weekly (Duncan and Carrow, 2000). All pots were maintained at 2 cm using rechargeable grass shears. Chlorothalonil [2,4,5,6-tetrachloroisophthalonitrile] and chlorpyrifos [0,0-diothyl 0-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] were applied preventively at 14.5 kg ai ha^{-1} and 1 kg ai ha^{-1}, respectively, to control fungal disease and insects (Anonymous 2004a, 2004b).

Visual quality ratings were taken at 4 wk and 8 wk after initiation of saltwater applications with a range from 0 (dead turf) to 9 (green, healthy, ideal turf). The experimental design was a randomized complete block design with four replications. The sprigged and established seashore paspalum studies were evaluated separately. Data were analyzed in PROC GLM using an ANOVA to test all possible interactions of saltwater treatment, replication, and trial, and means were separated using least significant difference (LSD) at the 5% probability level (SAS, 2004). Regression analysis was utilized to show the response of both sprigged and established seashore paspalum quality to saltwater concentration.

Results and Discussion

There were no interactions between trials, therefore the data were pooled. There was an interaction between treatment and timing of visual evaluation. Therefore data are presented separately for the 4 wk and 8 wk evaluations.

Newly Sprigged Seashore Paspalum

Quality of newly sprigged seashore paspalum was affected by saltwater treatments. After 4 wk of treatment, quality ratings decreased as saltwater concentration increased. The sprigs had a quality rating of 6.5 when irrigated with potable water, but decreased to 2.5 when irrigated with 27 dS/m saltwater (Table 2.1). At 55 dS/m, the seashore paspalum sprigs were nearly dead 4 wk after initial treatment with quality rating of only 1.0 (Table 2.1). A similar trend was observed 8 wk after the initial saltwater treatments. The sprigs treated with potable water were well established by 8 wk with a quality rating of 7.5 (Table 2.1). Seashore paspalum quality declined to 2.0 at 27 dS/m and 0.5 at 55 dS/m (Figure 2.1 and Table 2.1). The regression model indicates the quality rating of seashore paspalum will decrease below 6.5 when irrigated with saltwater < 13 dS/m 8 wk after the initial saltwater treatments (Figure 2.1).

Alternative irrigation water with a salt concentration range between 27 dS/m to 55 dS/m will reduce the growth rate of even the most salt tolerant paspalum cultivar by 50% if the salts are not replaced and consistently moved through the soil (Duncan and Carrow, 2000). Due to the lack of tolerance to salinity, newly sprigged seashore paspalum should be irrigated with potable water during establishment to reduce stress and promote healthy growth.

Established Seashore Paspalum

Once established, seashore paspalum exhibited excellent salinity tolerance. Seashore paspalum quality ratings were acceptable (≥ 6.5) at 13 dS/m and 27 dS/m salt, but declined to 6.0 and 4.5 at 41 dS/m and 55 dS/m, respectively 4 wk after initial saltwater treatments (Table 2.1). Turfgrass quality increased over time with ratings of 8.0, 7.5, and 6.5 at 13 dS/m, 27 dS/m, and 41 dS/m, respectively 8 wk after saltwater irrigation initiation (Table 2.1). Quality was below the 6.5 minimum acceptable level only at 55 dS/m. The regression model indicates the quality rating of established seashore paspalum will decrease to 6.5 at 33 dS/m 8 wk after the initial saltwater treatment (Figure 2.1).

The largest reduction in quality was observed 4 wk after initiation of the saltwater treatments. The increase in quality over time may have been due to the ability of established seashore paspalum to physiologically adjust to the saline conditions for an extended period of time. Growth rate measurements were not taken, but a reduced growth rate was visually evident as saltwater concentration increased.

Newly sprigged seashore paspalum is sensitive to saltwater concentrations ≥ 13 dS/m. Growth rate is reduced and the time of establishment increases as saltwater concentration increases. Saltwater concentration > 27 dS/m will cause desiccation and eventual death of the sprigs. Established seashore paspalum exhibited a high tolerance to saltwater irrigation. Although seashore paspalum did not maintain acceptable quality when irrigated with pure ocean water (55 dS/m), it is able to tolerate irrigation with salinity levels up to 41 dS/m. This characteristic will allow turf managers, located near the coast or those who have water restrictions, to use alternative water sources (effluent and brackish) for irrigation with salt concentrations up to 41 dS/m.

Table 2-1 Saltwater effect on sprigged and established seashore paspalum.

	Seashore Paspalum quality rating[a]			
	Established		Sprigged	
Salt Concentration[b]	4 wks[c]	8 wks[c]	4 wks[c]	8 wks[c]
0	9.0	9.0	6.5	7.5
13	7.5	8.0	4.0	5.0
27	6.5	7.5	2.5	2.0
41	6.0	6.5	1.5	1.0
55	4.5	4.0	1.0	0.5
LSD (0.05)	2.0	2.0	2.5	3.0

[a] Quality ratings range from 0 (dead turf) to 9 (healthy turf).

[b] Salt Concentrations in decisemens per meter (dS/m).

[c] Weeks of exposure to saltwater concentrations.

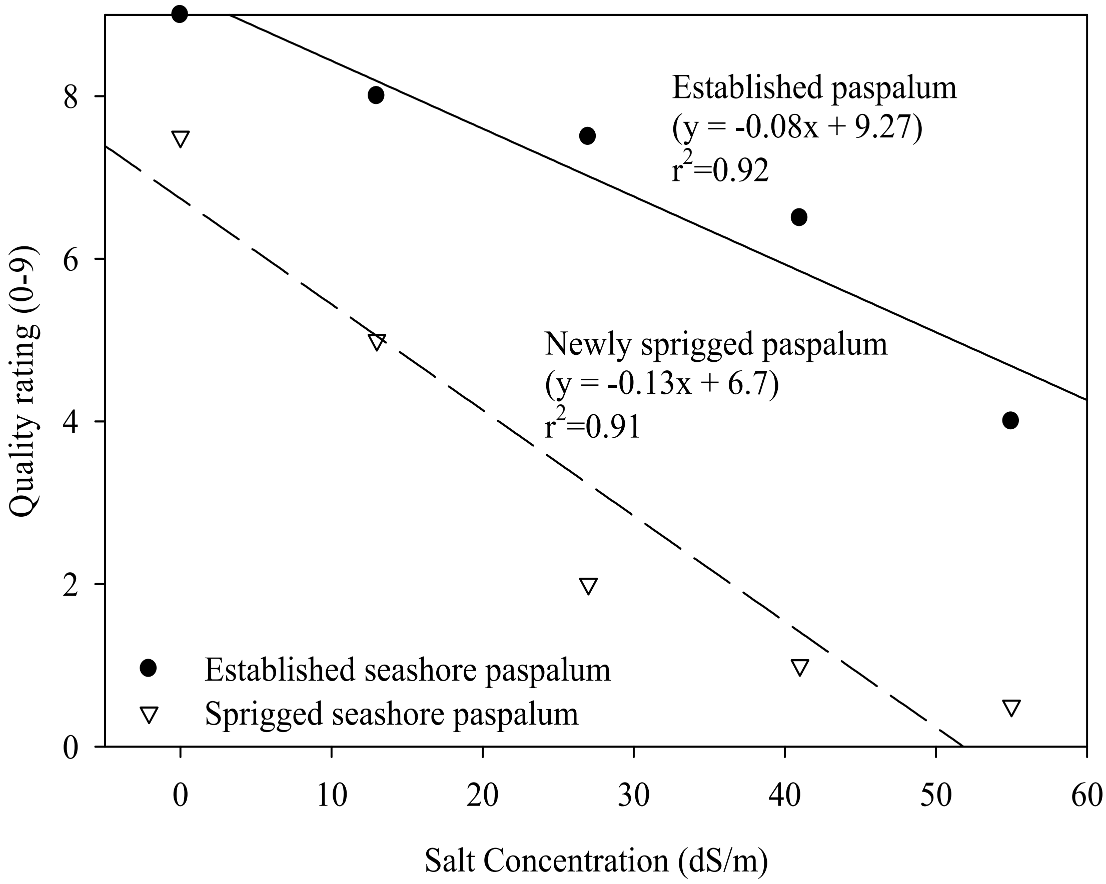

Figure 2-1 Effect of saltwater concentration on seashore paspalum quality ratings 8 wk after initial application of saltwater (data pooled over trials).

CHAPTER 3
SUCEPTIBILITY OF NINE TURFGRASS WEED SPECIES TO FIVE SALTWATER CONCENTRATIONS

Introduction

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial warm season turfgrass that is native to tropical and subtropical regions of the world (Duncan and Carrow, 2000). It has existed for years, but has only been used commercially for the past few decades. Seashore paspalum spreads by rhizomes and stolons that root at the nodes and forms a deep fibrous root system (Duble, 2000). It is generally propagated vegetatively, because seed produced have low viability (Trenholm and Unruh, 2002), although seeded varieties are under development. Seashore paspalum is a desirable turfgrass that has a high salt tolerance (Duncan and Carrow, 2000).

Weeds compete with turfgrass for light, nutrients, water, and physical space (Florkowski, 2002) and weed management is a major cost for turfgrass managers. On golf courses in the Southeast, the average expenditures for herbicides in 1998 were $11,690 (Florkowski, 2002).

Some of the more common weeds in turfgrass include dollarweed (*Hydrocotyle* spp.), Florida pusley (*Richardia scabra* L.), Virginia buttonweed (*Diodia virginiana* L.), goosegrass (*Eleusine indica* [L.] Gaertn.), southern crabgrass (*Digitaria ciliaris* [Retz.] Koel.), common bermudagrass (*Cynodon dactalon* [L.] Pers.), tropical signalgrass (*Urochloa subquadripara* [Trin.] R. Webster), torpedograss (*Panicum repens* L.), and purple nutsedge (*Cyperus rotundus* L.).

Dollarweed is a perennial broadleaf that reproduces by seed, rhizomes, and tubers. The leaves are long stalked with the petiole attached to the center of the leaf that resembles an umbrella. Dollarweed is most commonly found in areas with excessive moisture (Murphy et al., 1996).

Florida pusley is a summer annual broadleaf that reproduces by seed. The branched stem is hairy with thickened leaves that have an opposite arrangement. The white flowers are bunched at the end of the branches (Murphy et al., 1996).

Virginia Buttonweed is a perennial broadleaf that reproduces by seed, roots, and stem fragments. The stem is branched and hairy with an opposite leaf arrangement. The flower is white with four lobes at each leaf axil (Murphy et al., 1996).

Goosegrass is a summer annual grass that reproduces by seed. The crown is generally white or silver in color and is usually found in areas with compacted soils. The leaves are smooth on both sides with a short-toothed membranous ligule (Murphy et al., 1996).

Southern crabgrass is a summer annual grass that reproduces by seed. Stems are branched and root at the nodes. The leaves are usually hairy on both sides and have a toothed membranous ligule (Murphy et al., 1996).

Common bermudagrass is a perennial grass that reproduces by stolons, rhizomes, and seed (Duble, 2004). The stolons and rhizomes root at the nodes to form a deep fiberous perennial root system (Duble, 2004). Seeded varieties are currently being developed and tested (Evers and Davidson, 2004). The collar of the leaves have a fringe of short, white hairs (NewCROP, 1999).

Tropical signalgrass is a summer annual grass that reproduces by seed. The stem is branched with a blanket-like growth pattern. The leaves are glossy with a coarse texture (Busey 2000).

Torpedograss is a very persistent perennial grass that reproduces vegetatively or by soil transfer (Busey, 2002). The rhizome system is very robust with sharply pointed tips. The stems are stiff and erect with leaves that are folded or flat (Murphy, 1996).

Purple nutsedge is a perennial sedge that reproduces primarily by oblong tubers that are covered with hairs. The leaves taper abruptly to a point unlike yellow nutsedge that tapers gradually to a point. The seed head has a purplish color and is formed on a triangular stem (Murphy et al., 1996).

These weeds are a few of the most common and troublesome weeds found in turfgrass in the Southeastern United States (Webster, 2000). Control of these weeds can be very difficult and expensive. Weeds can be controlled using cultural practices to produce a healthy, competitive turfgrass, in combination with herbicides.

Aerification and verticutting are common cultural practices on golf courses to control weeds and relieve turf stresses such as compaction and thatch. Aerification consists of pulling soil core plugs 0.63 cm to 1.9 cm (0.25 to 0.75 in.) in diameter, ranging in depth of 5 to 10 cm (2 to 4 in.) (Unruh and Elliott, 1999). This process relieves soil compaction, improves surface drainage and water penetration, and reduces thatch (Unruh and Elliot, 1999).

Vertical mowing consists of vertical knives spaced close together on a horizontal shaft that slice into the turf (Unruh, and Elliott, 1999). This practice removes the organic matter (thatch) layer, allowing the turf to grow horizontally and allows for a smooth putting surface. When maintaining seashore paspalum greens, deep verticutting should be avoided (Duncan and Carrow, 2002). Light verticutting enhances stolon-rhizome-shoot growth and allows topdressing sand to integrate into the thatch layer, producing a more firm, smooth surface that is less susceptible to scalping (Duncan and Carrow, 2000 and 2002). A good quality topdressing sand should integrate easily into the surface at light rates without verticutting (Duncan and Carrow, 2002).

Mowing is a very important cultural practice on golf courses. Improper mowing can weaken the turf, which reduces the density and quality (Unruh and Elliott, 1999), allowing for weed invasion. Seashore paspalum does not tolerate scalping as well as bermudagrass or zoysiagrass and may take 4 to 6 wk to fully recover (Duncan and Carrow, 2002). When lowering the mowing height on seashore paspalum gradual increments of 0.05 to 0.08 cm (0.02 to 0.03 in.) over 2 to 3 d is best (Duncan and Carrow 2002). When the turf is mowed properly, very little stress is put on the plant, allowing it to recover very quickly. Frequent mowing increases shoot growth, producing a dense canopy that makes it more difficult for weeds to invade (Unruh and Elliott, 1999).

Finally, proper irrigation can be used to reduce weed pressure. Maintaining proper soil moisture levels is important for producing a healthy turf. Seashore paspalum is very responsive to irrigation duration and frequency and a shallow root system will result from frequent irrigation events of short durations (Duncan and Carrow, 2002). This also causes the turf to be more succulent, less drought tolerant, and more susceptible to scalping. Watering schedules should consist of long durations during applications with long intervals (1.25 to 2.5 cm of water every 4 to 7 d on a sand-based green) between applications to encourage the roots to grow deeper into the soil profile (Duncan, 2000;

Duncan and Carrow, 2002). Various grass types require different moisture levels and weed species are also dependent on moisture levels. For instance, dollarweed populations can be reduced in St. Augustinegrass turf by reducing irrigation levels (Busey, 2001).

Seashore paspalum exhibits exceptional salt tolerance, but is susceptible to injury from many postemergence herbicides (Wiecko, 2003). Dithiopyr, halosulfuron, oxadiazon, and prodiamine are the only herbicides labeled for use on seashore paspalum (Unruh et al., 2005). Dithiopyr, oxadiazon, and prodiamine are herbicides commonly used preemergence for annual grass control. Halosulfuron is commonly used postemergence for sedge control.

Seashore paspalum's high level of salt tolerance may allow the use of saltwater for weed control in place of injurious postemergence herbicides (Wiecko, 2003). Couillard and Wiecko (1998) evaluated saltwater for control/tolerance on crabgrass, and mimosa. They treated these species with ocean water at three concentrations: pure ocean water (54 dS/m), 2/3 ocean water (37 dS/m), and 1/3 ocean water (19 dS/m). The weeds were watered twice daily for two different periods: 3 d or 6 d. Following the saltwater stress periods, potable water irrigation was applied to evaluate recovery potential over a period of 32 d after the salt-stress treatments began. Mimosa only recovered from the 1/3x ocean water treatment subjected to 3 d salt stress. Complete crabgrass control was only achieved with pure ocean water under 6 d salt stress.

Similar studies were conducted by Wiecko in 1999 and 2000 with the additional species goosegrass, alyceclover (*Alysicarpus vaginalis* (L.) DC.), and yellow nutsedge (*Cyperus esculentus* L.). Alyceclover injury was similar to mimosa injury, and goosegrass injury was similar to crabgrass injury. Yellow nutsedge was the most tolerant to salt stress, fully recovering from all treatments.

Based on these studies, ocean water can be used as an alternative to herbicides to control weeds in certain turfgrasses (Couillard and Wiecko, 1998). Most annual grass and broadleaf weed species cannot tolerate continuous irrigation with saltwater or saltwater blends (wastewater) (Duncan and Carrow, 2000).

Few golf courses have the capabilities to use saltwater for irrigation, but it is becoming more common in coastal environments (Duncan and Carrow, 2000). Weeds are a common problem when trying to maintain a high quality turf. Since many golf courses border environmentally sensitive areas chemical control of weeds is not always feasible. The susceptibility of many turfgrass weeds to saltwater has not been determined. The objective of this study was to determine the potential of using saltwater for control of selected common turfgrass weeds.

Methods and Materials

Greenhouse Studies

Two greenhouse studies were conducted at the University of Florida, West Florida Research and Education Center (WFREC) near Jay during 2003 and 2004. Nine turfgrass weeds (torpedograss, dollarweed, Virginia buttonweed, large crabgrass, common bermudagrass, purple nutsedge, goosegrass, Florida pusley, and tropical signalgrass) were evaluated for saltwater susceptibility.

Weeds listed in Tables 3.1, 3.2, and 3.3 were transplanted as mature plants from the field, with the exception of crabgrass and tropical signalgrass, which were established from seed. The weeds were planted in 15 cm in diameter by 16.5 cm deep (3,000 cm^3 volume) pots that were filled with a United States Golf Association (USGA, 1993) greens mix (80% sand and 20% sphagnum peat moss). The weeds were placed in a greenhouse receiving full sun maintained at a temperature range of 27^{o} to 32^{o} C. The transplanted weeds were irrigated with freshwater for 3 wk to allow for rooting and recovery from transplanting. The seeded weeds were allowed to establish with potable water irrigation for 5 wk. Plants were gradually thinned to a final density of 3 plants per pot.

Saltwater treatments were initiated (July 30 in 2003 and August 2 in 2004) after establishment and continued for 8 wk in 2003 and 4 wk in 2004. Saltwater treatments were applied twice per wk (Mon. and Wed.), with one potable water treatment per wk (Fri.) applied to prevent salt accumulation on the growing medium surface. The saltwater ($Na^{+}Cl^{-}$) concentrations were as follows: untreated (0X), 13 dS/m (1/4X), 27 dS/m (1/2X), 41 dS/m (3/4X), and 55 dS/m (1X). The 55 dS/m (1X) concentration is equivalent to ocean water and the untreated (0X) is potable water. Each irrigation event consisted of 200 ml per pot of saltwater or potable water equivalent to 1 cm of water (irrigation) per event totaling the standard 3 cm of water (irrigation) weekly for seashore paspalum (Duncan and Carrow, 2000). The aerial reproductive structures of the annual weeds were removed weekly to prevent the weeds from completing their life cycle.

Weed control was visually evaluated at 8 wk in 2003 and 4 wk in 2004 after initial saltwater exposure using a scale of 0 (no control) to 100 (complete control). The experimental design was a randomized complete block with four replications. Data were analyzed in PROC GLM using an ANOVA to test all possible interactions of saltwater treatment, replication, and year, and means were separated using least significant difference (LSD) at the 5% probability level (SAS, 2004). Regression analysis was utilized to model the response of weed control to saltwater concentration.

Field Studies

Field studies were also conducted in the summer of 2004 at the University of Florida, WFREC near Jay, Florida to support results found in the greenhouse experiments. Southern crabgrass and cocks-comb kyllinga (*Kyllinga squamulata* Thonn. ex. Vahl.) control with NaCl were tested in separate studies in a 2 yr old stand of 'Sea Isle 1' seashore paspalum. Individual plot size was 1.5 m by 1.5 m. Crabgrass was seeded at a rate of 480 kg ha^{-1} in early May and allowed to establish until treatments were initiated in early June. An existing uniform area of cocks-comb kyllinga infested seashore paspalum was selected in a separate area and treatments were initiated in early July.

Saltwater treatments were applied twice per wk (Tues. and Thurs.). Plots were treated for 4 wk with either a liquid solution of NaCl at 13 dS/m (1/4 ocean water) or 27 dS/m (1/2 ocean water) concentration of salt or an equivalent amount of NaCl applied to each plot as granules. Granular NaCl applications were watered in with 30 L of water per plot. Potable water applications were dependent on the daily afternoon rainfall events that normally occur during the summer in the Southeast coastal region of the United States (Appendix A).

Visual evaluations of percent turfgrass injury on a scale of 0 (no injury) to 100 (dead turf) or percent weed control on a scale of 0 (no control) to 100 (complete control) were taken 4 wk after initial treatment. The experimental design was a randomized complete block with four replications. Data were analyzed in PROC GLM using an ANOVA to test all possible interactions and means were separated using least significant difference (LSD) at the 5% probability level (SAS, 2004).

Results and Discussion

Greenhouse Studies

There were no interactions between studies or between 4 wk and 8 wk evaluations, therefore weed control data were pooled over studies and evaluations.

Broadleaf species

Florida pusley and Virginia buttonweed were the most sensitive broadleaf species to saltwater treatments. All saltwater concentrations killed Florida pusley and all but the lowest concentration controlled Virginia buttonweed (Table 3.1). The data for Florida pusley and Virginia buttonweed were fit to exponential rise to max regression models with r^2 values of 1.00 and 0.96, respectively (Figure 3.1).

Dollarweed was the least sensitive broadleaf species with complete control achieved only at 55 dS/m salt concentration (Table 3.1). Dollarweed control increased as salt concentration of the irrigation water increased fitting a linear regression model (r^2 = 0.99) (Figure 3.1).

The sensitivity of Florida pusley and Virginia buttonweed to saltwater irrigation was expected because broadleaf and legume species are generally more sensitive to salinity than grassy species (Wiecko, 2003; Greub et al., 1985). The tolerance of dollarweed to high concentrations of saltwater irrigation could be due to extensive rhizome and tuber systems allowing the plant to regrow after each potable water soil flushing treatement.

Grass and sedge species

Goosegrass and southern crabgrass control with saltwater was similar. At 13 dS/m, goosegrass and southern crabgrass control was 39 and 25%, respectively, increasing to 53 and 51% at 27 dS/m, respectively, and to 74 and 81%, respectively, at 41 dS/m (Table

3.2). Complete mortality was observed at 55 dS/m for both species (Table 3.2). Control of goosegrass and southern crabgrass corresponded with a linear regression model with r^2 values of 0.97 and 0.99, respectively (Figure 4.2). Wiecko (2003) exposed goosegrass and crabgrass to saltwater twice daily for 3 and 6 d durations and observed similar results. Both weed species were controlled > 90% with a saltwater concentration of 55 dS/m, while 18 dS/m saltwater concentration provided little control (Wiecko, 2003).

Tropical signalgrass control with saltwater was similar to that observed with goosegrass and southern crabgrass (Table 3.3 vs. Table 3.2). Control at 13 dS/m was 33%, increased to 73% at 41 dS/m and 100% control at 55 dS/m. Tropical signalgrass control corresponded to a linear regression model ($r^2 = 0.98$) as saltwater concentration increased resulting in complete mortality at 55 dS/m (Table 3.3 and Figure 3.3).

Bermudagrass tolerance to saltwater irrigation was similar to seashore paspalum tolerance (Chapter 2), and injury symptoms were mostly stunting of the bermudagrass with some yellowing of the leaf tissue at the highest saltwater concentrations. Bermudagrass injury at saltwater concentrations of 13 dS/m and 27 dS/m was only 9 and 24%, respectively (Table 3.3). However, injury increased to 43 and 66% as saltwater concentrations increased to 41 dS/m and 55 dS/m, respectively (Table 3.3). This injury corresponded to a linear regression model with an r^2 value of 0.98 (Figure 4.3). Similar results were found where bermudagrass quality was not compromised with saltwater concentrations < 20 dS/m, but quality was reduced at 40 dS/m 4 WAT (Munshaw, 2004).

Torpedograss was tolerant to all concentrations of saltwater irrigation showing a reduction in growth as the only injury symptom. Less than 20% control was observed at 13 dS/m, 27 dS/m, and 41 dS/m, while control at 55 dS/m was only 35% (Table 3.3).

The data was consistant to a linear regression model with an r^2 value of 0.96 (Figure 3.3). Torpedograss is a rhizomatous perennial that is found along shorelines, canals, and poorly drained soils and can form dense floating mats in water up to 6 ft deep (USDA, 2003). The tolerance shown by torpedograss in this study could be attributed to the growth habit and ability for the plant to adapt to stressful environments allowing the plant to survive long periods of time under salinity stress (USDA, 2003). Further testing of torpedograss is necessary to determine the long-term effects of saline irrigation.

Purple nutsedge control was minimal at 13 dS/m (15% control). As saltwater concentration increased to 27 dS/m, control increased to 41% and 81% control at 55 dS/m (Table 3.3). Control was modeled using linear regression with an r^2 value of 0.99 (Figure 3.3). Purple nutsedge is a difficult weed to control and few herbicides have been effective in the past (Grey et al., 2003). Imazapic will provide > 90% control of purple nutsedge and halosulfuron combined with the right adjurvant will provide 100% control (McDaniel, 2001). Other herbicides, such as sulfentrazone, diclosulam, and flumioxazin, will provide < 70% control (Grey et al., 2003). Irrigation with a salt concentration of 41 dS/m will provide up to 60% control which is equivalent to some herbicides.

Seashore paspalum will maintain health and quality with saline irrigation up to 41 dS/m (Chapter 2). These studies indicate saline irrigation could be used as an alternative to herbicides for control of specific weeds. Successful control of Florida pusley was accomplished at 13 dS/m and Virginia buttonweed at 27 dS/m saltwater. Goosegrass, southern crabgrass, and tropical signalgrass were controlled at 41 dS/m. Saline irrigation as a single approach will control these weeds while maintaining a quality seashore paspalum turf. Additional measures, such as cultural practices or integrating reduced-rate herbicides, need to be utilized to control dollarweed, common bermudagrass, torpedograss, and purple nutsedge at saltwater concentrations up to 41 dS/m.

Field Studies

In the field study, southern crabgrass was controlled only 35 to 65% at 13 dS/m but control increased to greater than 85% at 27 dS/m when salt was either applied as a solution or as a granular (Table 3.4). At 13 dS/m, cocks-comb kyllinga control was no more than 60% using either granular or solution, but control improved to greater than 70% at 27 dS/m with either application method (Table 3.4).

In both studies, the granular application method provided better control of southern crabgrass and cocks-comb kyllinga compared to salt applied in solution. The reduced control from the solution may be due to salt leaching through the root zone more quickly than the granular applied salt.

There were no interactions between studies for seashore paspalum quality. Therefore, turf quality data were pooled over both studies. Seashore paspalum was injured < 20% for all treatments (Table 3.5). Salt applied as a granular increased turf injury by 5% over that observed with the solution at both concentrations due to localized foliar burn (Table 3.5). An uneven application of the granular salt caused the leaf tissue to burn in areas where the salt was concentrated on the surface and not completely moved into the root zone.

Results from these studies indicate that saltwater can provide effective control for weed species such as southern crabgrass, goosegrass, tropical signalgrass, Florida pusley, and Virginia buttonweed but not dollarweed, common bermudagrass, torpedograss, or purple nutsedge. Inland areas that do not have access to saline water may still be able to utilize the ability of seashore paspalum to tolerate salinity by applying specific rates of granular salt to control some weed species. Precautions must be taken to effectively move the granular salt into the root zone by means of potable water irrigation. Further research should be conducted to link specific concentrations with the control of specific weed species.

Table 3-1. Control of selected broadleaf weeds with saltwater in the greenhouse pooled data over years and evaluations.

	Weed Control [a]		
Salt Concentration	HYDSP[b]	RICSC[b]	DIOVI[b]
	---------------------	%	----------------------
13 dS/m	26	100	49
27 dS/m	52	100	100
41 dS/m	66	100	100
55 dS/m	100	100	100
LSD (0.05)	18	0	20

[a]Percent control compared to untreated check.
[b]HYDSP=dollarweed, RICSC=Florida pusley, DIOVI=Virginia buttonweed

Table 3-2. Control of selected annual grass weeds with saltwater in the greenhouse pooled data over years and evaluations.

	Weed Control [a]	
Salt Concentration	ELEIN[b]	DIGSA[b]
	-------------- %	---------------
13 dS/m	39	25
27 dS/m	53	51
41 dS/m	74	81
55 dS/m	96	100
LSD (0.05)	21	19

[a]Percent control compared to untreated check.
[b]ELEIN=goosegrass, DIGSA=large crabgrass

Table 3-3. Control of selected perennial grass and sedge weeds with saltwater in the greenhouse pooled data over years and evaluations.

	Weed Control [a]			
Salt Concentration	UROSU [b]	CYNDA[b]	PANRE[b]	CYPRO[b]
	--------------------------	%	--------------------------	
13 dS/m	33	9	4	15
27 dS/m	60	24	16	41
41 dS/m	73	43	19	60
55 dS/m	100	66	35	81
LSD (0.05)	6	9	14	14

[a]Percent control compared to untreated check.
[b]UROSU=tropical signalgrass, CYNDA=common bermudagrass, PANRE=torpedograss, CYPRO=purple nutsedge

Table 3-4. Control of southern crabgrass and cocks-comb kyllinga with two salt concentrations applied as a solution or granular in the field.

Treatment[a]	DIGSA[b]	KYLZZ[b]
	------- % Control -------	
Freshwater	0	0
13 Solution	35	45
13 Granular	65	60
27 Solution	85	70
27 Granular	90	80
LSD (0.05)	7	12

[a] Concentrations are decisemens per meter (dS/m).

[b] DIGSA=southern crabgrass, KYLZZ=cocks-comb kyllinga

Table 3-5. Seashore paspalum quality as affected by saltwater in the field.

Treatment[a]	Seashore paspalum
	% Injury
Freshwater	0
13 Solution	5
13 Granular	15
27 Solution	10
27 Granular	20
LSD (0.05)	4

[a] Concentrations are decisemens per meter (dS/m).

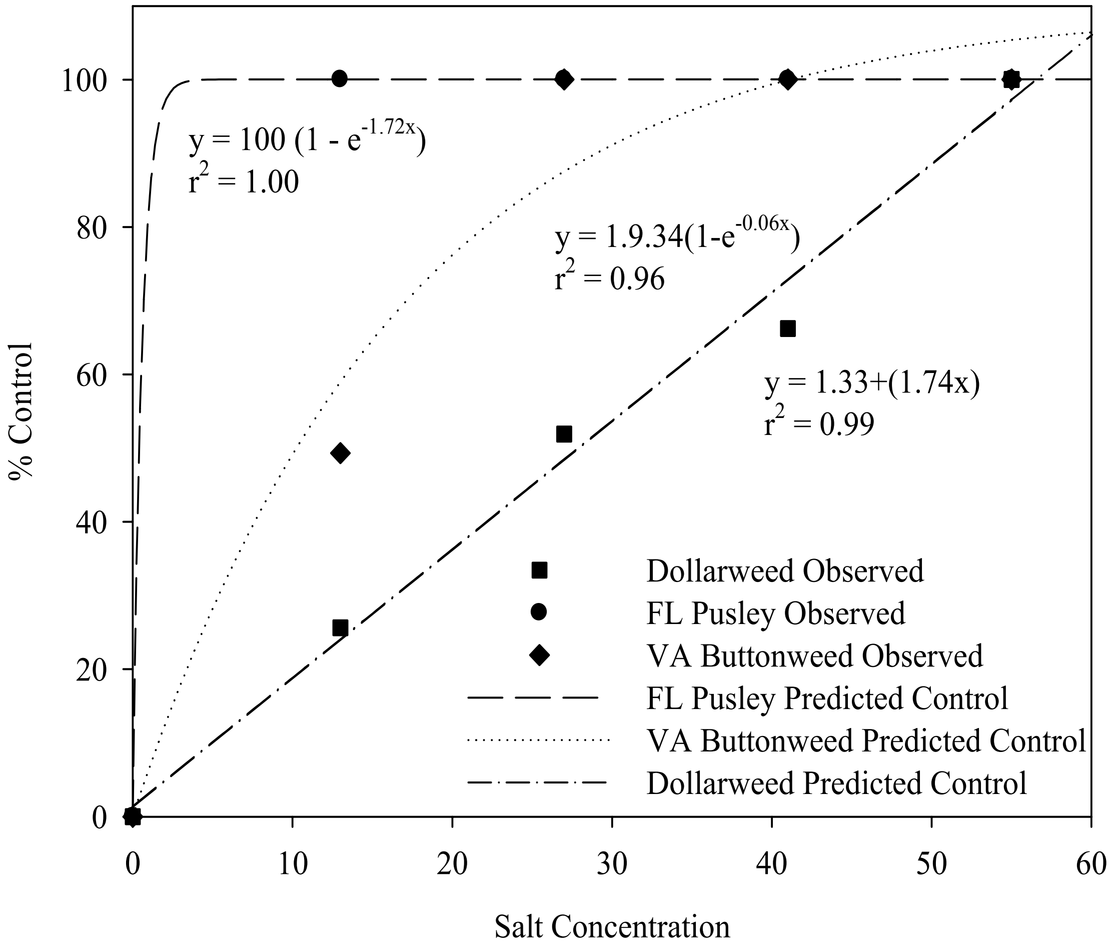

Figure 3-1 Saltwater concentration effect on broadleaf weed control pooled over years and evaluations. Dollarweed data were fit to a linear regression model y = a + (mx) while Florida pusley and Virginia buttonweed data were fit to an exponential rise to max regression model $y = a*(1 - e^{-b*x})$ to predict control at a specific concentration.

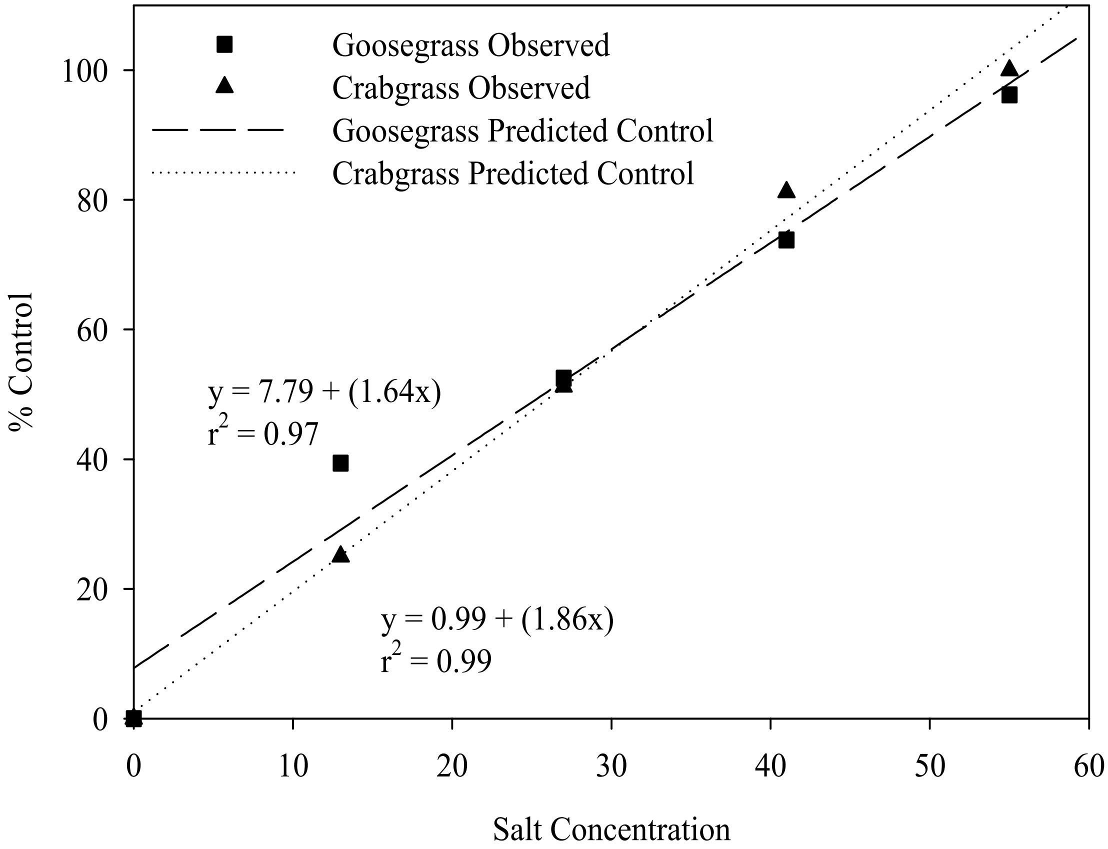

Figure 3-2 Saltwater concentration effect on annual grass control pooled over years and evaluation. Data were fit to a linear regression model y = a + (mx) to predict control at a specific concentration.

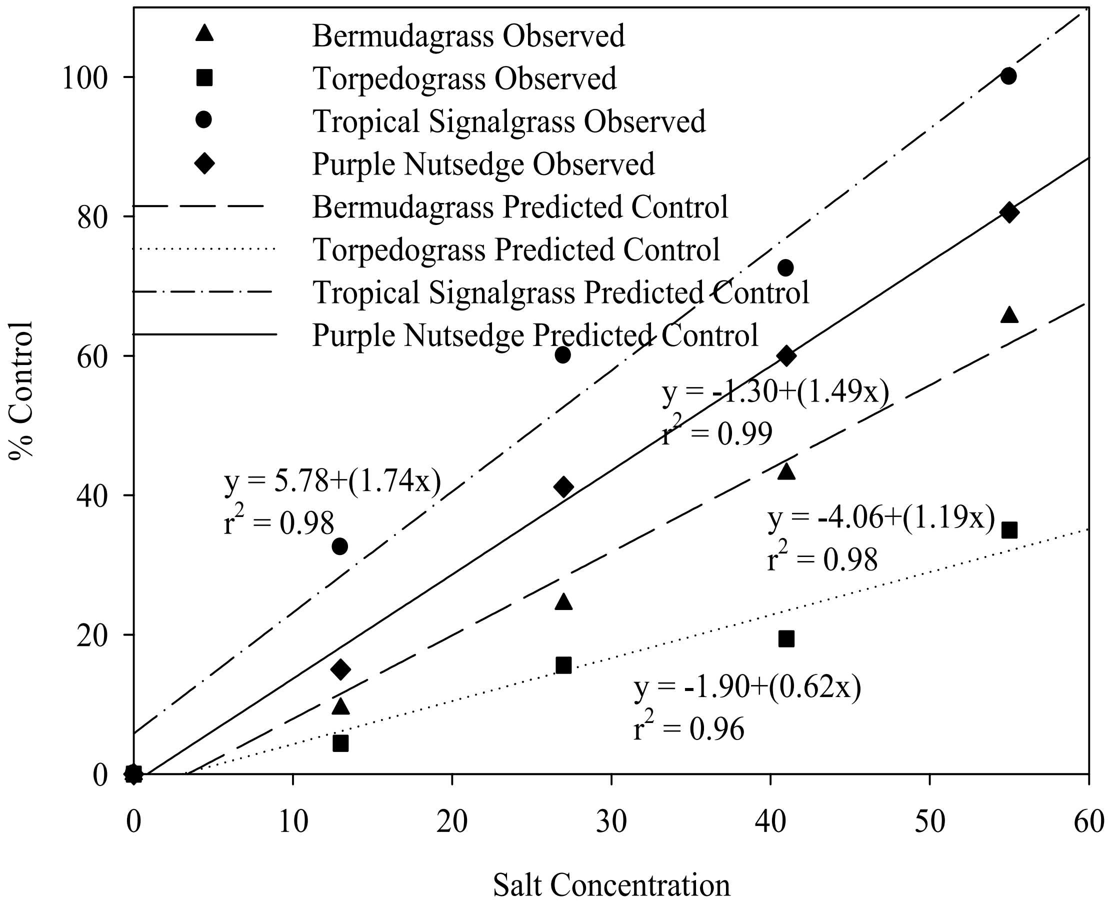

Figure 3-3 Saltwater concentration effect on perennial grass and sedge control pooled over years and evaluation. Data were fit to a linear regression model y = a + (mx) to predict control at a specific concentration.

CHAPTER 4
THE TOLERANCE OF SEASHORE PASPALUM TO HERBICIDES WHEN IRRIGATED WITH SALTWATER

Introduction

Seashore paspalum (*Paspalum vaginatum* O. Swartz) is a perennial warm season turfgrass that is native to tropical and subtropical regions of the world (Duncan and Carrow, 2000). Although seashore paspalum has existed for many years, it has only been used commercially for the past few decades. Seashore paspalum spreads by rhizomes and stolons that root at the nodes forming a deep fibrous root system (Duble, 2000). It is generally propagated vegetatively from sod or sprigs because seed production has not been reliable (Duncan and Carrow, 2000), though one seeded cultivar has been developed (Hughes, 2005).

Sodium chloride (NaCl) is the predominant component contributing to soil salinity (Jungklang, 2003). Saline levels in soils are becoming increasingly problematic due to the use of alternative water (effluent or brackish) for irrigation.

Salinity tolerance is a distinguishing physiological characteristic of seashore paspalum. There are three mechanisms plants use to tolerate salinity: selective of ion uptake by the roots, accumulation of salt in specific vacuoles within plant cells then retranslocated back to the soil or excreted by salt glands on the leaf surface, and osmotic adjustment (Colmer, 2000; Rose-Fricker and Wipff, 2001; Marcum, 2004). Seashore paspalum has the ability to efficiently select ions absorbed by the roots, and it is also able to secrete salt through salt glands on the leaf surface (Marcum, 1999).

Salt injury to plants is exhibited as reduced growth, burning of leaf tips, and wilting (Colmer, 2000). Alternative, non-potable water sources may increase the salinity level of the soil over time and must be managed properly to establish and maintain a high quality turf. Studies have been conducted testing the tolerance of seashore paspalum to various concentrations of saltwater. Seashore paspalum exhibits exceptional salt tolerance, but is highly susceptible to injury from postemergence herbicides (Wiecko, 2003).

The high level of salt tolerance may allow saltwater to be used as an alternative to herbicides or in combination with reduced-rate herbicides to control weeds in certain turfgrasses (Couillard and Wiecko, 1998). Few golf courses have the capabilities to use saltwater for irrigation, but it is becoming more common in coastal environments (Duncan and Carrow, 2000).

Herbicides are regularly used for weed control on golf courses. Some important considerations when selecting an herbicide are effectiveness, turfgrass tolerance, speed of control, toxicity, and cost (Unruh and Elliott, 1999). There is no single herbicide that will control all weeds in a desired turf stand, so proper identification is essential (Unruh and Brecke, 1998).

Seashore paspalum is sensitive to many herbicides commonly used on other turfgrasses (Trenholm and Unruh, 2002, 2003; and CTAHR, 1998). Herbicides that are noninjurous to seashore paspalum are bensulide, pronamide, benefin, DCPA, pendimethalin, ethofumesate, quinclorac, MCPP + 2,4-D + dicamba, dithiopyr, 2,4-D + dicamba + dicloprop, dicamba, halosulfuron, mecoprop, and bentazon (Duncan and Carrow, 2000). However, dithiopyr, halosulfuron, oxadiazon, and prodiamine are the only herbicides labeled for use on seashore paspalum (Unruh et al., 2005). These herbicides could possibly be used at reduced rates in conjunction with saltwater irrigation to control weeds in seashore paspalum (Duncan and Carrow, 2000).

In 1997, Johnson and Duncan tested the recommended rates and 3 times the recommended rates of diclofop, quinclorac, dicamba, imazaquin, halosulfuron, and 2,4-D + mecoprop + dicamba on four seashore paspalum accessions (AP 10, HI 25, PI 28960, and K-7).

Seashore paspalum accessions varied in their response to the herbicides evaluated. Quinclorac and halosulfuron were the only herbicides that did not reduce the quality of any accession at the recommended rates. When quinclorac and halosulfuron rates increased, quality of HI 25 and K-7 was reduced. All accessions recovered completely even from the high rates within 4 to 8 wk after initial treatment.

Dicamba had no effect on any of the accessions when applied at the labeled rate. Quality of the K-7 accession, however, was affected by the increased rate of dicamba.

Diclofop, imazaquin, and 2,4-D + mecoprop + dicamba reduced the quality of all paspalum accessions regardless of application rate. Full recovery from diclofop and imazaquin required 4 to 8 wk. Recovery from the labeled rates of 2,4-D + mecoprop + dicamba took 4 to 8 wk for all accessions, and none of the accessions recovered from the high rate by 8 wk. The overall conclusion from this study was that quinclorac, dicamba, and halosulfuron were safe on all accessions, diclofop and imaziquin were marginal, and 2,4-D + mecoprop + dicamba were considered injurious.

A study was conducted by Unruh et al. (2005) testing the tolerance of 'Salam' seashore paspalum to postemergence herbicides for control of grass (clethodim, ethofumesate, metsulfuron, sethoxydim, and quinclorac), broadleaf (clopyralid, dicamba, and 2,4-D + mecoprop + dicamba), and sedge (bentazon, halosulfuron, imazapic, imazaquin, and trifloxysulfuron-sodium) species. Metsulfuron, quinclorac, clopyralid, dicamba, 2,4-D + mecoprop + dicamba, bentazon, halosulfuron, and imazaquin caused less than 15% injury at the recommended rates and are considered safe for seashore paspalum. Clethodim, sethoxydim, ethofumesate, imazapic, and trifloxysulfuron-sodium caused greater than the acceptable standard of 20% injury and are considered not safe for application to seashore paspalum.

Growth of many weed species is suppressed when irrigated with saltwater while growth of seashore paspalum is not affected (Duncan and Carrow, 2000). Tolerance of seashore paspalum to preemergence and postemergence herbicides has not been determined when irrigated with saltwater and the turfgrass is potentially more sensitive to injury as salt-stress increases. The objective of this study was to determine the tolerance of seashore paspalum to commonly used turfgrass herbicides when irrigated with multiple concentrations of saltwater.

Methods and Materials

Two greenhouse studies were conducted at the University of Florida, West Florida Research and Education Center (WFREC) near Jay in the summer of 2004. Strips of sod were cut with a sod cutter from a two year old stand of ‘Sea Isle 1’ seashore paspalum. Plugs were cut from the sod strips using a golf cup cutter 15 cm in diameter. The native soil was washed from the plugs and then plugs were transplanted into 15 cm in diameter by 17 cm deep (3000 cm^3 volume) plastic pots containing a growing medium of USGA greens mix (80% sand and 20% organic matter). The intact seashore paspalum plugs were planted level with the rim of the pots.

After transplanting, the pots were placed in a greenhouse receiving full sun and were maintained at a temperature range of 27° to 32° C. A slow release 19-8-15 fertilizer was applied at a rate of 24.5 kg N ha^{-1} 1 wk after planting. The plugs were irrigated with potable water during a 3 wk rooting period.

A randomized complete block arranged in a split-plot experimental design with three replications was used. This was because the main plot was blocked while the sub-plot and replications were random in each block. Main plot factor consisted of five saltwater concentrations: 1) potable water (0x), 2) 13 dS/m (1/4x), 3) 27 dS/m (1/2x), 4) 41 dS/m (3/4x), and 5) 55 dS/m (1x). The 55 dS/m concentration is equivalent to ocean water. Sub-plot factor was 18 herbicide treatments with an untreated check and are listed in Table 4.1.

Saltwater treatments were initiated July 17, 2004 for the initial study and July 22, 2004 for repeated study after establishment and continued for the duration of the study. Saltwater treatments were applied twice per week (Mon. and Wed.), with one potable water treatment per week (Fri.) applied to prevent salt accumulation on the growing medium surface. Each irrigation event consisted of 200 ml of saltwater or potable water equivalent to 1 cm of water (irrigation) per event totaling the standard 3 cm of water (irrigation) recommended for seashore paspalum weekly (Duncan and Carrow, 2004). All pots were maintained at 2 cm (0.75 in) using rechargeable grass shears. Chlorothalonil [2,4,5,6-tetrachloroisophthalonitrile] and chlorpyrifos [0,0-diothyl 0-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] were applied preventively at 14.5 kg ai ha^{-1} and 1 kg ai ha^{-1}, respectively, to control fungal disease and insects (Anonymous

2004a, 2004b). After 2 wk of saltwater irrigation, herbicide treatments were applied at the recommended labeled rate to each saltwater concentration (Table 4.1).

Data collected included visual quality ratings 4 wk after herbicide application on a scale from 0 (dead turf) to 9 (healthy turf). Data were subjected to ANOVA using PROC MIXED to test all possible fixed effects and interactions of saltwater concentration, herbicide treatment, and trial (SAS, 2004). PROC MIXED was used to allow replication to be tested as a random effect. Means were separated using least significant difference (LSD) at the 5% probability level.

Results and Discussion

There was an interaction between trials, so data are presented separately. In both trials, there was an interaction between saltwater concentrations and herbicide treatments. In general, the quality of seashore paspalum decreased as saltwater concentration increased regardless of herbicide application.

Prodiamine, pendimethalin, oxadiazon, metolachlor, and dithiopyr are herbicides commonly used preemergence for summer annual grass control. In both trials, the herbicides alone without saltwater irrigation caused some reduction in turfgrass quality but ratings were 7.3 or higher, well above the minimum acceptable level of 6.5 (Table 4.2). Quality declined with increasing saltwater concentrations but reduction was no greater than for saltwater alone without herbicide (Table 4.2). These results indicate that salt stress did not impact seashore paspalum tolerance for prodiamine, pendimethalin, oxadiazon, metolachlor, or dithiopyr.

Fenarimol is labeled as a fungicide, but like pronamide, is also an effective preemergence for controlling winter annual grasses. Pronamide did not affect seashore paspalum quality with potable water and fenarimol only reduced quality in trial 1 to 8.3, well above the minimum of 6.5. As with the preemergence treatments for summer grasses, there was a reduction in quality with increasing salt concentration, but no greater than for salt alone except for salt of 55 dS/m. At the highest salt concentration, quality declined from 6.7 for the untreated to 5.3 with both fenarimol and pronamide (Table 4.2). As with the summer annual grass control herbicides, seashore paspalum tolerance to pronamide or fenarimol was not affected by saltwater irrigation.

Isoxaben and atrazine are applied preemergence to control many broadleaf weed species. Quality was lower with the use of isoxaben in some instances compared to the herbicide untreated in both trials, however, there was no consistent effect of saltwater on quality of turf treated with isoxaben (Table 4.2).

The application of atrazine reduced the quality of seashore paspalum compared to the herbicide untreated at all saltwater concentrations in both trials. Atrazine reduced quality in both trials to unacceptable levels (5 or less). There was some indication that quality improved with saltwater treatment in trial 2 (Table 4.2) suggesting that the saltwater may be interfering with atrazine activity and that the efficacy of atrazine may have been slightly reduced when saltwater irrigation is applied.

For annual and perennial grasses, quinclorac, metsulfuron, and metribuzin are herbicides often used as postemergence control. Quality was not different from the herbicide untreated when quinclorac or metsulfuron was applied in either trial 1 or trial 2 at salt concentrations of 27 dS/m or less (Table 4.3). Turf quality with both herbicides declined with increasing saltwater concentration, however the decline was similar to the saltwater alone treatment. Metribuzin reduced turf quality to ≤ 5 regardless of saltwater treatment in both trial 1 and 2 (Table 4.3). These results indicate that seashore paspalum remains tolerant to quinclorac and metsulfuron regardless of salt concentration while metribuzin is not tolerated, even when irrigated with potable water.

Clopyralid, bromoxynil, bentazon, and 2,4-D + dicamba + mecoprop applied postemergence will control many broadleaf weed species. Clopyralid did not reduce turf quality when using potable irrigation water. Quality did decline as saltwater concentration increased, but turf quality was not different from the herbicide untreated in either trial (Table 4.3). Bentazon caused a reduction in quality without saltwater (0 ppm) in trial 1 and at 13 dS/m in trial 2 but quality remained 7.7 or greater (Table 4.3). Bentazon caused turf quality to decline more than the herbicide untreated as salt concentration increased ≥ 41 dS/m in trial 1 and ≥ 27 dS/m in trial 2 (Table 4.3). Bentazon may be interacting with the saltwater at high salt concentrations, reducing the quality of seashore paspalum to unacceptable levels.

Bromoxynil and the 3-way mixture of 2,4-D + dicamba + mecoprop caused a reduction in seashore paspalum quality compared to the herbicide untreated at all saltwater concentrations in both trials. Quality declined to the minimum acceptable level of 6.5 or less at 13 dS/m saltwater concentration and continued to decline with increasing saltwater concentration (Table 4.3). Both bromoxynil and the 3-way mixture of 2,4-D + dicamba + mecoprop will injure seashore paspalum when irrigated with potable water, and should be used with caution when saltwater irrigation is utilized.

Halosulfuron and imazaquin are herbicides used as postemergence for control of sedges. The quality of seashore paspalum declined as saltwater concentration increased and when halosulfuron was applied, quality was not affected compared to the herbicide untreated. Imazaquin reduced turfgrass quality at all saltwater concentrations compared to the herbicide untreated. Quality was reduced below the 6.5 minimum at 27 dS/m and should also be used with caution on seashore paspalum irrigated with saltwater (Table 4.3).

When irrigated with saltwater concentrations of 41 dS/m and 55 dS/m, quality and growth rate of seashore paspalum is significantly reduced (Chapter 2). If the turf is further damaged by an herbicide application, the recovery time is increased due to the reduction in growth. Herbicides that caused a major reduction in the quality of seashore paspalum in this experiment were atrazine and metribuzin. These herbicides will cause damage when irrigated with potable water and any concentration of saltwater and should not be applied to seashore paspalum. Minor reductions in quality were observed after the application of bromoxynil, 2,4-D + dicamba + mecoprop, and imazaquin. These herbicides should not be applied to seashore paspalum irrigated with saltwater concentrations $\geq$ 27 dS/m.

Table 4-1 List of herbicides tested on seashore paspalum under salinity stress.

Common name	Chemical name	Application rate
	PREEMERGENCE	
Prodiamine	[2,4-dinitro-N^3,N^3-dipropyl-6-(trifluoromethyl)-1,3-benzediamine]	1.1 kg ai ha^{-1}
Pendimethalin	[N-(1-ethylpropyl)-3,4-demethyl- 2,6-dinitrobenzenamine]	2.0 kg ai ha^{-1}
Oxadiazon	[2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ-1, 3, 4-oxadiazolin-5-one]	2.9 kg ai ha^{-1}
Dithiopyr	[3,5-pyridinedicarbothioic acid, 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-S,S-dimethyl ester]	0.3 kg ai ha^{-1}
Metolachlor	[2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methtlethyl)acetamide	2.1 kg ai ha^{-1}
Isoxaben	[N-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide and isomers	0.8 kg ai ha^{-1}
Pronamide	[3,5-dichloro-N-(1,1-dimethyl-2-propynyl) benzamide	1.1 kg ai ha^{-1}
Fenarimol	[a-(2-chlorophenyl)-a-(4-chlorophenyl)-5-pyrimidinemethanol]	0.8 kg ai ha^{-1}
	POSTEMERGENCE	
Grass		
Quinclorac	[3,7-dichloro-8-quinolinecarboxylic acid]	0.8 kg ai ha^{-1}
Metsulfuron	[Methyl Methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino]carbonyl]amino]sulfony] benzoate]	0.3 kg ai ha^{-1}
Metribuzin	[4-Amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one]	3.4 kg ai ha^{-1}
Broadleaf		
Clopyralid	(3,6-dichloro-2-pyridinecarboxylic acid, monoethanolamine salt)	0.3 kg ai ha^{-1}
Bromoxynil	(3,5-dibromo-4-hydroxybezonitrile)	0.6 kg ai ha^{-1}
Atrazine	(2-chloro-4-ethylamino-6-isopropylamino-s-triazine)	1.7 kg ai ha^{-1}
Bentazon	[3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide]	1.1 kg ai ha^{-1}
2,4-D	[(2,4-dichlorophenoxy)acetic acid]	0.09 kg ai ha^{-1}
Dicamba	(3,6-dichloro-2-methoxybenzoic acid)	0.4 kg ai ha^{-1}
Mecoprop	[2-(4-chloro-2-methylphenoxy) propionic acid]	0.4 kg ai ha^{-1}
Sedge		
Halosulfuron	[methyl [[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonylaminosulfonyl]-3-chloro-1-methyl-1-H-pyrazole-4-carboxylate]	0.07 kg ai ha^{-1}
Imazaquin	[2-4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl-3-quinolinecarboxylic acid]	0.5 kg ai ha^{-1}

Table 4-2 The effect of preemergence herbicides and salt concentrations on seashore paspalum quality 4 wk after herbicide application.

Preemergence Herbicides	Seashore paspalum[c]									
	0[a]		13[a]		27[a]		41[a]		55[a]	
	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]
Untreated	9.0	9.0	9.0	8.3	7.7	7.0	7.0	6.7	7.0	6.7
Dithiopyr	9.0	8.0	9.0	8.1	8.0	7.0	7.0	6.7	7.0	6.0
Pronamide	8.7	8.7	8.7	8.0	8.0	6.7	6.7	6.0	7.0	5.3
Metolachlor	8.7	7.7	8.7	7.8	8.0	6.0	6.7	6.3	6.3	5.7
Isoxaben	8.7	7.7	8.0	7.8	7.3	6.3	6.7	6.3	6.3	5.7
Fenarimol	8.3	8.7	9.0	8.1	7.7	6.7	6.7	6.7	6.7	5.3
Pendimethalin	8.3	8.0	9.0	8.1	7.7	6.7	6.7	6.3	6.7	5.7
Oxadiazon	8.3	7.7	8.3	7.6	7.7	7.0	7.0	6.3	7.0	5.7
Prodiamine	8.3	7.3	9.0	7.9	8.0	6.7	7.0	6.7	7.0	5.7
Atrazine	4.7	3.0	4.7	4.9	5.0	4.3	4.7	4.0	5.0	3.7

[a] Salt Concentrations in decisemens per meter (dS/m).
[b] T1 = Trial 1 and T2 = Trial 2
[c] Quality ratings range from 0 (dead turf) to 9 (healthy turf).
$LSD_{0.05}$ = 0.55 (T1) and 0.80 (T2) for mean comparison of herbicide within a given salt concentration or salt concentration within a given herbicide.

Table 4-3 The effect of postemergence herbicides and salt concentrations on seashore paspalum quality 4 wk after herbicide application.

Postemergence Herbicides	Seashore paspalum[c]									
	0[a]		13[a]		27[a]		41[a]		55[a]	
	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]	T1[b]	T2[b]
Untreated	9.0	9.0	9.0	8.3	7.7	7.0	7.0	6.7	7.0	6.7
Halosulfuron	9.0	8.7	9.0	7.9	7.7	7.0	6.3	6.7	7.0	5.3
Clopyralid	9.0	8.7	8.7	8.0	8.0	6.0	7.0	6.0	6.7	4.0
Quinclorac	8.3	8.7	9.0	8.1	7.7	6.3	7.0	5.7	6.7	6.0
Metsulfuron	8.3	8.3	8.7	7.8	7.0	7.0	6.7	6.3	6.3	6.0
Bentazon	8.0	8.7	9.0	7.8	7.7	5.7	6.3	6.3	6.0	4.3
Imazaquin	7.7	7.3	7.0	6.7	6.3	5.3	6.0	6.0	6.0	5.3
2,4-D/Dicamba/Mecoprop	7.7	7.0	7.0	6.5	6.3	5.0	5.3	6.0	4.3	4.3
Bromoxynil	7.3	7.7	7.7	6.6	6.0	6.0	5.3	5.7	5.7	5.7
Metribuzin	5.0	1.7	5.0	4.0	4.7	2.3	5.0	3.0	4.3	2.7

[a] Salt Concentrations in decisemens per meter (dS/m).
[b] T1 = Trial 1 and T2 = Trial 2
[c] Quality ratings range from 0 (dead turf) to 9 (healthy turf).
$LSD_{0.05}$ = 0.55 (T1) and 0.80 (T2) for mean comparison of herbicide within a given salt concentration or salt concentration within a given herbicide.

CHAPTER 5
CONCLUSIONS

Seashore paspalum is a warm-season turfgrass that is replacing traditional turfgrasses in salt-affected areas due to its ability to tolerate saline conditions. Salinity levels in soils are becoming increasingly problematic due to the use of alternative water (effluent or brackish) for irrigation. When establishing seashore paspalum, saline conditions may negatively impact turfgrass growth rate (Duncan and Carrow, 1999). Studies were conducted to determine the tolerance of newly sprigged and established seashore paspalum to various saltwater concentrations.

Decreasing growth rates of seashore paspalum sprigs were observed with all saltwater concentrations and death of the sprigs occurred at 8 wk with 55 dS/m saltwater. Newly sprigged seashore paspalum is sensitive to saltwater concentrations ≥ 13 dS/m and the time to full establishment will increase as saltwater concentration increases. Saltwater concentration > 27 dS/m will cause desiccation and eventual death of the sprigs. Due to the lack of tolerance to salinity, newly sprigged seashore paspalum should be irrigated with potable water during establishment to reduce stress and promote healthy growth.

Established seashore paspalum exhibited a high tolerance to saltwater irrigation. Although seashore paspalum did not maintain an acceptable quality when irrigated with pure ocean water (55 dS/m), quality levels ≥ 6.5 were observed when irrigated with salinity levels up to 41 dS/m. This characteristic will allow turf managers located near the coast or those who have water restrictions to use alternative water sources (effluent and brackish) for irrigation that have salt concentrations up to 41 dS/m.

Because seashore paspalum will maintain health and quality with saline irrigation up to 41 dS/m, saline irrigation may be used as an alternative to herbicides to control specific weeds. Successful control of Florida pusley was accomplished at 13 dS/m and Virginia buttonweed at 27 dS/m saltwater. Goosegrass, southern crabgrass, and tropical signalgrass were controlled at 41 dS/m. Saline irrigation as a single approach will control these weeds while maintaining a quality seashore paspalum turf. Additional measures, such as cultural practices or integrating reduced-rate herbicides, need to be utilized to control dollarweed, common bermudagrass, torpedograss, and purple nutsedge at saltwater concentrations up to 41 dS/m.

In a field study, salt was applied as a granule and as a solution to seashore paspalum with a uniform population of southern crabgrass or cocks-comb kyllinga. The granular application method provided better control of southern crabgrass and cocks-comb kyllinga compared to salt applied in solution, but both methods provided > 70% control at 27 dS/m. The reduced control from the solution may be due to salt leaching through the root zone more quickly than the granular applied salt. Seashore paspalum injury was < 20% for all treatments. Salt applied as a granular increased turf injury by 5% over that observed with the solution at both concentrations due to localized foliar burn.

Inland areas that do not have access to saline water may still be able to utilize the ability of seashore paspalum to tolerate salinity by applying specific rates of granular salt to control some weed species. Precautions must be taken to effectively move the granular salt into the root zone by means of potable water irrigation to prevent burning of the leaf tissue. Further research should be conducted to link specific concentrations with the control of specific weed species.

Many weeds are suppressed in saline conditions, but salt tolerant weeds will require other means of control. Seashore paspalum is sensitive to many herbicides commonly used on other turfgrasses. Herbicide response of seashore paspalum in salt-affected areas has not yet been determined and may be more sensitive to injury as salt-stress increases. When irrigated with saltwater concentrations of 41 dS/m and 55 dS/m, quality and growth rate of seashore paspalum is significantly reduced. If the turf is further damaged by an herbicide application, the recovery time is increased due to the reduction in growth.

Herbicides that caused a major reduction in the quality of seashore paspalum in this experiment were atrazine and metribuzin. After atrazine was applied, there was some indication that quality improved with saltwater treatment in trial 2, although quality remained ≤ 5, suggesting that the saltwater may be interfering with atrazine activity and that the efficacy of atrazine may have been slightly reduced when saltwater irrigation is applied. Metribuzin, however, reduced quality < 5 at all saltwater concentrations. These herbicides will cause damage when seashore paspalum is irrigated with potable water and any concentration of saltwater and should not be applied to seashore paspalum.

Minor reductions in quality were observed after the application of bromoxynil, 2,4-D + dicamba + mecoprop, and imazaquin. Quality declined to < 6.5 at 27 dS/m saltwater and continued declining with increasing saltwater concentration. These herbicides should not be applied to seashore paspalum irrigated with saltwater concentrations ≥ 27 dS/m.

Bentazon did not reduce seashore paspalum quality with irrigation up to 27 dS/m in trial 1 and 13 dS/m in trial 2, but as saltwater irrigation increased, quality was reduced more than the herbicide untreated. At high saltwater concentrations, bentazon may be interacting with the saltwater causing a greater reduction in the quality of seashore paspalum.

Salt stress did not impact seashore paspalum tolerance for prodiamine, pendimethalin, oxadiazon, metolachlor, isoxaben, dithiopyr, pronamide, fenarimol, clopyralid, or halosulfuron. Quality was reduced as saltwater concentration increased, but the reduction was not different from the herbicide untreated.

APPENDIX A
2004 RAINFALL

Daily rainfall (cm) for the summer of 2004 at the WFREC near Jay, Florida.

Day	**June**	**July**	**August**
01	5.50	0.67	0.00
02	0.60	5.40	0.00
03	0.63	0.10	0.00
04	0.00	0.00	0.00
05	0.00	0.00	0.00
06	0.57	0.03	0.00
07	0.00	0.03	0.00
08	0.00	0.00	0.00
09	0.00	0.00	3.05
10	0.00	0.00	1.45
11	0.00	0.00	3.03
12	0.00	0.00	0.63
13	0.25	0.03	0.00
14	5.30	0.00	0.00
15	1.60	0.30	0.00
16	0.05	5.07	0.00
17	0.00	0.47	0.00
18	1.90	0.00	0.00
19	0.25	0.00	0.00
20	1.93	0.00	3.33
21	0.00	0.00	0.25
22	2.40	0.00	3.40
23	1.76	0.00	0.20
24	2.43	0.00	0.03
25	0.80	2.43	0.03
26	0.33	0.00	0.70
27	0.03	0.05	0.00
28	0.25	0.03	4.55
29	0.40	1.27	0.10
30	0.00	4.05	0.00
31	--	2.10	0.05

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BIOGRAPHICAL SKETCH

Nicholas Bradley Pool is the son of Gene Pool and Susan Owens. He was born on January 29, 1979, and raised on a corn and soybean family farm in Avon, Illinois. Nick graduated from Avon High School in 1997 and attended Spoon River College where he received his Associate of Science degree. In the Fall of 1999, he attended one semester majoring in recreation, parks, and tourism at Western Illinois University. In January of 2000 he was accepted to the University of Florida where he graduated in the summer of 2003 with his Bachelor of Science degree in environmental horticulture with an emphasis in turfgrass science. He immediately began his graduate career under the direction of Dr. Barry Brecke and Dr. Bryan Unruh and is currently a candidate for a Master of Science degree in agronomy with an emphasis in weed science.

After graduation, Nick is planning to enter the work force in the golf course industry.