Australian Journal of Crop Science
AJCS
AJCS 5(5):523-530 (2011) ISSN:1835-2707

Use of saline water for weed control in seashore Paspalum (*Paspalum vaginatum*)

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Abstract

Weeds are a serious problem in turfgrass establishment and management. Widespread use of herbicides to control weeds has resulted in environmental issues, and has led to the search for alternative control methods. Thus the use of sea water to control weeds was investigated. Glasshouse studies were conducted to determine responses of a number of local common weeds and the turfgrass species *Paspalum vaginatum* Swartz to five levels of salinity treatments. Twenty seven weed species comprising of nine broadleaved weeds, nine grasses and nine species of sedges, and *Paspalum vaginatum* were treated with distilled water as control, or seawater at salinities of 24, 48, 72, or 96 dSm^{-1}. Visual injury scores on weeds and turfgrass were recorded at day 3, 7, 14 and 21. Dry weights of shoots and roots per pot were recorded at the end of experiment. Results obtained showed that the response to salinity varied among species. Among the weeds tested *Tridax procumbens* L., *Hedyotis corymbosa* (L.) Lamk and *Borreria latifolia* (Aubl) K. Schum were the most sensitive and were completely killed at salinities of 24 dSm^{-1} or higher. Four broadleaved weeds [*Ageratum conyzoides* L., *Euphorbia prunifolia* (Jacq), *Desmodium triforum* (L.) DC, and *Lindernia crustacea* F. Muell], and two sedges [*Cyperus iria* L. and *Fimbristylis globulosa* (Retz.) Kunth] were less sensitive at 24 dSm^{-1}, but were severely injured at 48 dSm^{-1} salinity. Other weed species and *Paspalum vaginatum* were tolerant to all salt water treatments. The results indicate that sea water has excellent potential for sustainable control of several common broadleaved weeds and sedges in *Paspalum vaginatum* turf.

Keywords: weed control, sea water, turf grass, seashore paspalum.
Abbreviations: EC-Electrical Conductivity, LSD-Least Significance Difference DAT-Day After Treatment.

Introduction

Turfs are important in human activities from functional, recreational and ornamental standpoints (Beard, 1973), and are characterized by an attractive green colour and a uniform, consistent appearance (Emmons, 2000). Weeds in a turfgrass community, however, disrupt uniformity due to variability in leaf morphology, color, and growth habit. Weeds also compete for light, nutrients, water and physical space, and thus reduce the growth of turf, and can also be a host to other pests (Florkowski and Landry, 2002). Based on relative abundance indices, *Cyperus aromaticus* L., *Fimbristylis dichotoma* (L.) Vahl, *Desmodium triflorum* (L.) DC., *Chrysopogon aciculatus* (Retz.) Trin. and *Borreria repens* DC. were the more prevalent and abundant weed species of turfgrass in Peninsular Malaysia (Kamal Uddin et al., 2009). Various management methods such as hand weeding, chemical control, mechanical and cultural practices have been employed to control weeds, but each method has its limitations. Hand-weeding often does not remove below ground rhizomes and tubers, while herbicides are limited in their selectivity. Moreover, the misuse or excessive use of chemicals can cause acute toxicity to humans, contaminate soil and water, and lead to the development of herbicide resistance (Ross and Lembi, 1999). In view of this, alternative methods of weed control have received considerable attention and the possibility of using salt water as an alternative for herbicides has been attempted (Weicko, 2003). Visual observations on the effect of sea water sprays suggest that salt stress could give some control of salt-susceptible weeds in salt-tolerant turfgrasses (Wiecko, 2000). Growth of some weed species was suppressed when irrigated with salt water, while growth of seashore paspalum (*Paspalum vaginatum* Swartz.) was not affected (Duncan and Carrow 2000; Pool 2005). Raymer (2006) and Duncan and Carrow (1999) reported that seashore paspalum was the most salt tolerant warm-season turfgrass grown in Malaysia. Kamal Uddin et al. (2009) observed 50% shoot and root growth reductions in seashore paspalum at very high salinities of 39.8 and 49.4 $dSm^{-}1$, respectively. The high salinity tolerance of seashore paspalum, thus may allow the use of saltwater for weed control in place of post-emergence herbicides in seashore paspalum turf. Use of salt water as a substitute for herbicides would certainly be beneficial in terms of the impact on mankind and the environment. However, limited information was available on the responses of the local weed flora in Malaysia to saline water treatments. The present is study was therefore carried out to examine the sensitivity of local weed species commonly found in turfgrass to salinity stress under different salt concentrations.

Materials and methods

Site description and planting materials

The experiment was conducted under glasshouse conditions at the Faculty of Agriculture, Universiti Putra Malaysia (UPM) in 2007/08. Nine grasses, nine sedges and nine

Table 1. Scientific and common names of weed species

Scientific name	Common name
Broadleaved	
Tridax procumbens L.	Coat buttons
Emilia sonchifolia (L.) DC. ex Wight	Red tassel flower
Ageratum conyzoides L.	Goat weed
Euphorbia prunifolia Jacq	Painted euphorbia
Phyllanthus amarus Schumach. & Thonn	Stonebreaker
Borreria latifolia (Aubl.) K. Schum	Broadleaf buttonweed
Hedyotis corymbosa (L.) Lamk.	Old world diamond flower
Desmodium triflorum (L.) DC.	Three flower beggarweed
Lindernia crustacea F. Muell.	Malaysian false pimpernel
Grasses	
Digitaria ciliaris (Retz.) Koel	Southern crabgrass
Isachne globosa (Thunb.) O.K.	Rounded Isachne
Eragrostis tenella (L.) Beauv. Ex R. & S.	Feathery lovegrass
Digitaria fuscescens (Presl) Henr.	Yellow crabgrass
Eragrostis atrovirens (Desv.) Trin.	Wiry eragrostis
Eleusine indica (L.) Gaertn.	Goosegrass
Chrysopogon aciculatus (Retz.)Trin	Pilipiliula
Sporobolus diander (Retz.) P. Beauv.	Common dropseed
Panicum repens L.	
Sedges	
Cyperus aromaticus L.	Greater kyllinga
Cyperus compressus L.	Annual sedge
Cyperus distans L.f.	Remote sedge
Cyperus eragrostis (non Lamk) Vahl	Lovegrass sedge
Cyperus iria L.	Rice flatsedge
Cyperus kyllingia Endl	White kyllinga
Cyperus rotundus L.	Purple nutsedge
Fimbristylis globulosa (Retz.) Kunth	Globe fimbristylis
Fimbristylis miliacea (L.)Vahl	Globe fringerush

Table 2. Injury rating scale

Scale	Injury (%)	Effects on weeds and turf
1	0	No effect (all foliage green and alive)
2	1-10	Very light symptoms
3	11-30	Light symptoms
4	31-49	Symptoms not reflected in yield
5	50	Medium
6	51-70	Fairly heavy damage
7	71-90	Heavy damage
8	91-99	Very heavy damage
9	100	Complete kill (dead)

broadleaved weeds were evaluated for salt water susceptibility. Mature plants of the selected twenty-seven weed species were transplanted from the field (Table 1). *Paspalum vaginatum* was used as control.

Planting material collection and establishment

Mature weeds were transplanted into 14 cm diameter by 15 cm deep pots filled with a mixture of sand and peat (9:1). The native soil around the turfgrass and weed roots were washed, and sods were transplanted into the plastic pots and grown for 8 weeks with non-saline irrigation water in order to achieve full establishment. The transplants were irrigated with fresh water to allow for rooting and recovery from transplanting shock. The weeds were then gradually thinned to a final density of 3 plants per pot. All pots were fertilized with a complete fertilizer (15 N: 15 P_2O_5: 15 K_2O) @ 50 kg N/ha/month applied fortnightly. Weeds were monitored weekly and aerial reproductive structures were removed to prevent the weeds from completing their life cycle.

Salt media preparation and salinity treatments

After full establishment, all weed species and turfgrass (seashore paspalum) were treated with the salt water solutions at salinities of 0, 24, 48, 72 or 96 dSm^{-1}. Sea water used in this experiment was obtained from the sea at Morib Beach, Selangor. The EC of the sea water was 48 dSm^{-1}. Common salt or sodium chloride (NaCl) was added to the sea water to prepare the higher salinity treatments with EC values of 72 and 96 dSm^{-1}. The sea water was 50% diluted with distilled water to prepare the treatment with the lower EC value of 24 dSm^{-1}. The treatment solutions were prepared and applied at a spray volume of 450 L/ha. The treatments were applied once using a 1 L capacity hand sprayer to wet whole plants as well as the soil media with the respective treatments.

Parameters measured

Injury symptoms were visually evaluated on weeds and seashore paspalum at 3, 7, 14 and 21 days after salt water

Table 3. Effect of salt water treatments on broadleaved weeds at 3, 7, 14 and 21 days after treatment

Species	Treatment (dSm^{-1})	Visual injury (Scale)				Dry weight (g) pot^{-1}	
		Day 3	Day 7	Day 14	Day 21	Shoot	Root
Tridax procumbens	0	1.0d	1.0c	1.0d	1.0c	8.0a	2.0a
	24	1.5d	4.0b	5.5c	7.0b	7.0b	1.0b
	48	2.5c	4.5b	7.0b	9.0a	1.8c	1.0b
	72	7.8b	8.2a	9.0a	9.0a	1.7c	0.5b
	96	8.5a	8.7a	9.0a	9.0a	1.5c	0.5b
Emilia sonchifolia	0	1.0c	1.0d	1.0d	1.0d	0.7a	0.7a
	24	1.0c	1.2cd	1.4cd	1.4cd	0.5b	0.5ab
	48	1.5c	2.0c	2.0c	2.0c	0.4bc	0.5ab
	72	5.5b	6.3b	7.0b	5.0b	0.4bc	0.4ab
	96	6.5a	7.5a	8.7a	7.7a	0.3c	0.2b
Ageratum conyzoides	0	1.0c	1.0d	1.0d	1.0c	1.3a	0.75a
	24	2.5b	3.5c	4.0c	4.0b	0.8b	0.5b
	48	3.5b	4.7b	7.6b	8.7a	0.7b	0.4bc
	72	7.6a	8.0a	8.5ab	8.8a	0.8b	0.4bc
	96	8.0a	8.2a	8.8a	9.0a	0.6b	0.3c
Euphorbia prunifolia	0	1.0d	1.0d	1.0d	1.0d	0.9a	2.5a
	24	1.5d	1.5d	2.3c	2.5c	0.6b	1.5b
	48	3.2c	3.5c	4.5b	6.5b	0.5bc	1.4b
	72	5.1b	5.5b	6.3a	7.5ab	0.4c	1.4b
	96	7.7a	7.2a	7.2a	7.8a	0.2c	0.9c
Phyllanthus amarus	0	1.0c	1.0d	1.0e	1.0c	1.5a	0.8a
	24	1.0c	1.5cd	1.8d	2.0c	1.4a	0.6a
	48	1.0c	2.0c	3.0c	4.3b	0.8ab	0.4b
	72	2.2b	3.2b	4.3b	5.0b	0.5b	0.3b
	96	2.8a	5.5a	6.6a	7.5a	0.4b	0.3b
Borreria latifolia	0	1.0d	1.0d	1.0d	1.0c	2.2a	1.0a
	24	3.0c	6.0c	7.2c	8.0b	1.5b	0.5b
	48	6.5b	7.7b	8.0bc	8.8a	1.5b	0.5b
	72	7.0b	7.8ab	8.2ab	8.9a	1.5b	0.5b
	96	8.0a	8.3a	8.7a	8.9a	1.5b	0.4b
Hedyotis corymbosa	0	1.0d	1.0c	1.0c	1.0b	7.5a	2.0a
	24	2.8c	6.4b	7.7b	8.0a	2.0b	1.0ab
	48	6.0b	7.0ab	8.2ab	8.8a	1.0c	0.8ab
	72	7.2a	7.8a	8.8a	8.9a	1.0c	0.7ab
	96	7.4a	8.2a	8.8a	8.9a	1.0c	0.4b
Desmodium triflorum	0	1.0d	1.0c	1.0c	1.0c	2.7a	0.8a
	24	1.0d	1.0c	1.2c	1.8c	2.4b	0.7a
	48	7.6c	4.8b	6.8b	7.5b	1.5c	0.5b
	72	6.0b	7.5a	8.7a	8.9a	1.3d	0.3c
	96	7.2a	7.9a	8.7a	8.9a	1d	0.3c
Lindernia crustacea	0	1.0e	1.0d	1.0d	1.0d	3.8a	2.5a
	24	2.0d	2.2c	2.2c	2.2c	3.5ab	1.5b
	48	3.5c	3.2b	6.7b	7.8b	3.0b	1c
	72	5.5b	7.5a	8.3a	8.6a	2.5c	0.5d
	96	6.5a	7.9a	8.5a	8.9a	2.0d	0.5d

Means within columns (within a species) with the same letters are not significantly different ($p \leq 0.05$, LSD test; Visual injury scale; 1 (0%) = no effect, 9 (100%) = completely kill, 6 (51-70%) = acceptable control)

Table 4. Effect of salt water treatments on grass weeds at 3, 7, 14 and 21 days after treatment

Species	Treatment (dSm^{-1})	Visual injury (Scale)				Dry weight (g) pot^{-1}	
		Day 3	Day 7	Day 14	Day 21	Shoot	Root
Digitaria ciliaris	0	1.0c	1.0d	1.0d	1.0d	6.8a	1.3a
	24	1.6c	2.2cd	4.0c	4.0c	7.8a	1.3a
	48	2.0c	3.8c	6.2b	6.2b	4.7ab	0.5b
	72	4.4b	4.8b	7.0ab	7.0ab	2.7b	0.4b
	96	6.6a	8.2a	8.0a	8.0a	2.2b	0.3b
Isachne globosa	0	1.0e	1.0e	1.0d	1.0d	2.6a	0.6a
	24	2.0d	2.4d	2.4c	2.4c	1.9ab	0.4ab
	48	5.8c	5.8c	6.8b	6.8b	1.5abc	0.3b
	72	6.8b	7.6b	8.6a	8.6a	1.0bc	0.2b
	96	8.6a	8.6a	8.6a	8.6a	0.5c	0.2b
Eragrostis tenella	0	1.0e	1.0e	1.0e	1.0e	6.0a	1.8a
	24	2.0d	2.6d	2.6d	2.6d	5.0a	1.3b
	48	5.2c	5.6c	6.2c	6.2c	4.8ab	1.1abc
	72	6.4b	6.6b	6.8b	6.8b	2.6b	0.7bc
	96	7.6a	8.6a	8.6a	8.6a	2.3b	0.4c
Digitaria fuscescens	0	1.0e	1.0d	1.0e	1.0e	8.1a	1.4a
	24	3.0c	3.0c	3.2d	3.2d	7.9a	1.3a
	48	4.0c	4.6b	4.8c	4.8c	4.8b	1.0ab
	72	5.6b	7.6a	7.6b	7.6b	4.7b	0.9ab
	96	7.6a	7.6a	8.2a	8.2a	2.2b	0.6b
Eragrostis atrovirens	0	1.0e	1.0e	1.0e	1.0e	2.1a	1.a
	24	2.0d	2.0d	2.0d	2.0d	2.0a	0.9ab
	48	3.2c	3.2c	3.2c	3.2c	0.9a	0.5bc
	72	4.2b	4.2b	5.2b	5.2b	0.9a	0.5bc
	96	5.0a	5.0a	5.8a	5.8a	0.9a	0.2c
Eleusine indica	0	1.0e	1.0e	1.0e	1.0e	5.8a	1.8a
	24	3.0d	3.0d	3.0d	3.0d	3.9ab	1.5ab
	48	3.6c	3.6c	3.6c	3.6c	2.1bc	1.0bc
	72	4.8b	4.8b	4.8b	4.8b	1.4c	0.7c
	96	6.0a	6.a	6.0a	6.0a	0.8c	0.4c
Chrysopogon Aciculatus	0	1.0e	1.0e	1.0e	1.0e	4.0a	1.9ab
	24	3.6d	3.6d	3.6d	3.6d	4.1a	1.9a
	48	5.0c	5.0c	5.0c	5.0c	2.1a	0.9b
	72	7.0b	7.0b	7.6b	7.6b	1.3a	0.6b
	96	8.0a	8.0a	8.8a	8.8a	1.3a	0.6b
Sporobolus diander	0	1.0e	1.0e	1.0e	1.0e	2.4a	0.9a
	24	2.0d	2.0d	2.0d	2.0d	2.3a	0.9a
	48	3.0c	3.0c	3.0c	3.0c	2.2a	0.7a
	72	3.4b	3.4b	4.4b	4.4b	1.3a	0.4a
	96	4.0a	4.0a	5.0a	5.0a	0.6a	0.3a
Panicum repens	0	1.0e	1.0e	1.0e	1.0e	7.9a	3.3a
	24	2.0d	2.0d	2.0d	2.0d	7.2a	3.6a
	48	3.2c	3.6c	3.6c	3.6c	5.8a	2.9a
	72	5.0b	5.0b	5.0b	5.0b	5.5a	2.5a
	96	6.0a	6.0a	6.0a	6.0a	4.5a	2.3a

Means within columns (within a species) followed by the same letters are not significantly different ($p \leq 0.05$, LSD test; Visual injury scale; 1 (0%) = no effect, 9 (100%) = completely kill, 6 (51-70%) = acceptable control) exposure using the European Weed Control and Crop Injury Evaluation Scale (Table 2; Burrill et al., 1976). Plants were harvested at 21 days after treatment, shoots and roots of plants were separated, washed and dried in an oven at 70 ^{o}C for 3 days, and dry weights recorded.

Statistical analysis

The experimental design was a completely randomized design with five replications. Data were analyzed using the analysis of variance procedure in the SAS statistical software package, and means were tested using LSD at the 5% probability level (SAS, 2004).

Results and discussion

Effect of salt water treatments on visual injury of weeds

Broadleaved weeds

In all the broadleaved weed species, visual injury increased with increasing level of salt concentration. Injury levels were either constant or increased over time from 3 to 21 days after treatment (Table 3). The visual injury scores of salt-treated plants of all species at 24 dSm^{-1} salinity were significantly greater (P $\geq$ 0.05) than those of the control treatment (distilled water), except for *Phyllanthus amarus*, *Emilia sonchifolia* and *Desmodium triflorum*. At this level of salinity, *Tridax procumbens, Borreria latifolia* and *Hedyotis corymbosa*, were severely injured with injury scale ratings of 6.5, 8 and 8, respectively. At 48 dSm^{-1}, *Ageratum conyzoides*, *Euphorbia prunifolia*, *D. triflorum* and *Lindernia crustacea* showed complete necrosis or severe injury with ratings of 7 to 8.7, while *E. sonchifolia* and *P. amarus* showed relatively minor symptoms at this level. *Emilia sonchifolia* and *P. amarus* were rated as medium and severe injury at 72 and 96 dSm^{-1}, respectively. The sensitivity of broadleaved weeds to salt water irrigation, even at 24 dSm^{-1}, was supported by the fact that broadleaved plants and legume species are generally known to be more sensitive to salinity than grass species (Greub et al., 1985; Wiecko, 2003). Pool (2005) had also observed that broadleaved weed species were more sensitive to salt water treatments compared to grass weeds. The results of the present study showed that even the four least sensitive species (*A. conyzoides*, *E. prunifolia*, *D. triflorum* and *L. crustacean*) were severely injured damaged heavily or showed severe clorosis with sea water at an EC level of 48 dSm^{-1}. Pool (2005) had reported that *Hydrocotyle umbellate*, the least sensitive broadleaf species, was completely controlled by seawater at an EC level of 55 dSm^{1}. However, the two fairly tolerant species, *E. sonchifolia* and *P. amarus*, survived the salinity treatments presumably due to some adaptive mechanism enabling these plants to maintain water balance.

Grasses

Grass weeds showed significant differences in visual injury symptoms with salt water treatments. In general, visual injury symptoms gradually increased with increase in salinity levels. As for broadleaved weeds, injury levels either remained constant or increased over time from 3 to 21 days after treatment (Table 4). All grass species were alive and showed either green foliage or minor chlorosis or minor leaf curling with the 24 dSm^{-1} salinity treatment. When the salinity level was increased to 48 dSm^{-1} *Digitaria ciliaris*, *Isachne globosa* and *Eragrostis tenella* showed injury symptoms of between fairly severe to very severe. But, four other grass species, *Eragrostis atrovirens*, *Eluesine indica*, *Sporobolus diander* and *Panicum repens*, consistently showed light symptoms (with injury levels of between 3–3.6). These species showed only medium injury levels even with the higher salinity treatment at 72 dSm^{-1}. Injury symptoms were medium to fairly severe with a salinity treatment of 96 dSm^{-1}. However, *Digitaria fuscescens* and *Chrysopogon aciculatus* showed the worst injury symptoms with severe chlorosis to death with the 72 dSm^{-1} salinity treatment. The most salt tolerant species were *E. atrovirens*, *E. indica*, *S. diander* and *P. repens*. In general, most annual grass and broadleaved weed species do not tolerate continuous irrigation with saltwater (Duncan and Carrow 2000). Pool (2005) observed that *D. ciliaris* control increased from 25%, to 81%, with an increase in salinity from 13 dSm^{-1} to 41 dSm^{-1}. Complete mortality was observed in treatments with an EC of 55 dSm^{-1}. Wiecko (2003) exposed *D. ciliaris* to salt water twice daily for 3 and 6 days and observed more than 90% control with a salt water concentration of 55 dSm^{-1}, while at 18 dSm^{-1} the salt water provided little control. Sequential application of sodium chloride at 488 kg/ha provided 90% control of grass weeds in seashore paspalum (Brosnan et al, 2008). On the other hand, Pool (2005) observed that *P. repens* was tolerant at 55 dSm^{-1} salinity.

Sedges

The common sedge species *Cyperus compressus*, *Cyperus iria* and *Fimbristylis globulosa* showed injury levels of between 4–5.2 with treatments at an EC level of 24 dSm^{-1} (Table 5). With increasing salinity levels higher injury symptoms with reduced plant growth including leaf tip burn, wrinkled leaf and inflorescence with yellow to brown colour symptoms were observed. The highest level of salt water treatment (96 dSm^{-1}) resulted in the highest visual injury (9.0) with very severe injury to complete kill of *F. globulosa* and *C. iria* at 21 days after treatment. *Cyperus distans*, *Cyperus kyllingia*, *Cyperus rotundus* and *Fimbristylis miliacea* showed light to medium symptom at EC 48 dSm^{-1}. An increase in salinity to 72 dSm^{-1} or higher resulted in very severe damage or complete kill. Salinity treatments at 24 dSm^{-1} did not produce any injury in *Cyperus aromaticus* and *Cyperus eragrostis*. These two species showed only medium symptoms (i.e. moderate chlorosis and/or moderate leaf curling), with a salinity treatment of 96 dSm^{-1}. Wiecko (2003) also observed similar minimal responses in *Cyperus esculentus* to salt stress, where treatments with an EC value of up to 55 dSm^{-1} produced maximum injury of only 35%. Pool (2005), however, reported slightly better weed control (60%) with salt stress treatments with an EC of 41 dSm^{-1}.

Effect of salt water on weed dry matter production

In most broadleaved weed species, shoot and root dry weight responses were inversely related to their visual injury ratings (Table 3). Both shoot and root dry weights decreased with increase in salinity. Most grass weeds also showed a similar trend to broadleaved weeds in that the shoot and root dry weights decreased with increase in the salinity level. Generally, increased levels of salinity would cause depletion of energy needed for growth, less turgor pressure and reduction in photosynthesis, resulting in reduced growth and ultimately less shoot and root dry matter. Moreover, accumulation of salts in cell walls, as a consequence of high salinity, would effectively reduce cell turgor pressure and

Table 5. Effect of salt water treatments on sedges at 3, 7, 14 and 21 days after treatment

Species	Treatment (dSm^{-1})	Visual injury (Scale)				Dry weight (g) pot^{-1}	
		Day 3	Day 7	Day 14	Day 21	Shoot	Root
Cyperus aromaticus	0	1.0d	1.0d	1.0d	1.0d	17.1a	7.1a
	24	2.0c	2.0c	2.0c	1.0d	13.5bc	6.1ab
	48	2.0c	2.0c	2.0c	2.0c	14.2b	5.1b
	72	3.0b	3.0b	3.0b	3.0b	11.2c	4.7bc
	96	4.4a	4.4a	4.4a	4.4a	11.5c	3.4c
Cyperus compressus	0	1.0d	1.0e	1.0e	1.0d	1.8a	2.2a
	24	3.8c	3.2d	4.0d	5.2c	1.3b	1.2b
	48	5.6b	4.2c	5.6c	6.4b	1.3b	1.1bc
	72	7.4a	6.6b	7.8b	8.4a	1.0c	0.8cd
	96	7.2a	7.8a	8.6a	8.8a	0.7d	0.6d
Cyperus distans	0	1.0d	1.0c	1.0d	1.0d	9.4a	8.4a
	24	1.8cd	2.4b	2.6c	2.8d	5.7b	6.1b
	48	2.6c	3.2b	3.2c	3.6c	5.9b	4.7bc
	72	3.8b	4.4a	4.6b	6.8b	4.3c	3.8cd
	96	5.0a	5.0a	5.6a	7.6a	2.7d	2.8d
Cyperus eragrostis	0	1.0e	1.0e	1.0e	1.0e	4.3a	2.5a
	24	2.0d	2.0d	2.4d	2.6d	3.9b	1.8b
	48	2.6c	3.4c	3.6c	3.8c	3.8b	1.8b
	72	3.8b	4.4b	4.6b	4.6b	3.6b	1.3c
	96	4.4a	5.4a	5.4a	5.4a	3.1c	0.8d
Cyperus iria	0	1.0d	1.0d	1.0e	1.0d	2.3a	1.1a
	24	3.0c	3.0c	3.4d	4.0c	1.8b	0.9b
	48	5.0b	5.4b	6.0c	7.8b	1.6bc	0.8b
	72	7.4a	6.4b	8.0b	8.6a	1.3cd	0.7bc
	96	7.8a	8.0a	8.8a	9.0a	0.9d	0.6c
Cyperus kyllingia	0	1.0e	1.0e	1.0e	1.0e	11.2a	6.2a
	24	2.2d	2.4d	2.4d	2.2d	8.5b	4.9b
	48	3.6c	3.4c	3.8c	3.8c	7.1b	3.6c
	72	5.0b	4.6b	5.6b	6.2b	5.3c	2.8cd
	96	6.8a	6.8a	8.0a	8.8a	4.2c	2.1d
Cyperus rotundus	0	1.0d	1.0d	1.0d	1.0e	9.5a	11.2a
	24	2.2c	2.2c	2.4c	2.4d	6.4b	6.7b
	48	3.0b	3.0b	3.2c	3.4c	5.4bc	5.7bc
	72	5.4a	3.6b	5.0b	5.8b	4.3cd	3.9cd
	96	5.6a	5.8a	6.4a	7.0a	2.9d	2.5d
Fimbristylis globulosa	0	1.0e	1.0e	1.0e	1.0d	1.4a	0.9ab
	24	3.2d	3.2d	3.8d	4.4c	1.1ab	0.7abc
	48	5.0c	4.2c	5.6c	7.4b	0.8bc	0.9a
	72	7.0b	6.4b	7.8b	8.8a	0.6cd	0.5bc
	96	8.4a	7.8a	9.0a	9.0a	0.4d	0.3c
Fimbristylis miliacea	0	1.0e	1.0d	1.0e	1.0d	5.1a	1.9a
	24	3.0d	3.4c	3.4d	3.2c	3.9b	1.7a
	48	4.8c	4.2c	5.2c	5.2b	2.8c	1.4b
	72	7.4b	6.6b	7.8b	8.4a	2.8c	1.2b
	96	8.4a	8.2a	8.8a	8.8a	1.8d	0.6c

Means within columns (within a species) followed by the same letters are not significantly different ($p \leq 0.05$, LSD test; Visual injury scale; 1 (0%) = no effect, 9 (100%) = completely kill, 6 (51-70%) = acceptable control)

Table 6. Effect of salt water treatments on *Paspalum vaginatum* at 3, 7, 14 and 21 days after treatment

Treatment (dSm^{-1})	Visual injury (Scale)				Dry weight (g)	
	Day 3	Day 7	Day 14	Day 21	Shoot	Root
0	1.0d	1d	1.0b	1.0b	11.8a	2.9a
24	1.5cd	1.5cd	1.2b	1.0b	10.3ab	2.7ab
48	2.0c	2.0bc	1.5b	1.3b	9.4ab	2.5ab
72	4.0b	3.0b	2.0ab	1.5ab	8.1b	2.2bc
96	5.5a	4.0a	3.1a	2.0a	8.2b	1.9c

Means within columns followed by the same letters are not significantly different ($p \leq 0.05$, LSD test; Visual injury scale; 1 (0%) = no effect, 9 (100%) = completely kill, 6 (51-70%) = acceptable control)

ultimately reduce growth (Flowers and Yeo, 1986). *Sporobolus diander* and *P. repens* showed poor tolerance to salinity stress in terms of shoot and root dry weights, although they had salt injury scores of around five. In *E. atrovirens* only the shoot dry weight remained constant at all salinity levels including control. Similar results were also observed in several other weed species viz. 'Garison' creeping meadow foxtail, common perennial ryegrass, redtop, and rough stalk bluegrass which had salt injury scores of five or above, and apparently were able to accumulate a normal amount of shoot growth (Greub et al., 1985). This response can be attributed to the capacity of these species to withstand saline environments. Shoot and root dry weights of sedges were highest in the control treatment and lowest in the highest salinity treatments. For most of the species, trends in shoot and root dry weights followed their visual injury scale. However, in the salt tolerant species, *C. aromaticus* and *C. eragrostis*, shoot dry weights of 67 and 72% of control respectively, were observed at the highest salinity level (96 dSm^{-1}). These values reflect a high level of tolerance when compared to the standard 50% tolerance criteria commonly used in salinity studies (Mass, 1986).

Effect of salt water on injury and dry matter production of seashore paspalum

Paspalum vaginatum showed very light injury symptoms with 24, 48, 72 and 96 dSm^{-1} salt water treatments (Table 6). Some injury symptoms were evident at 3 days after treatment, especially at the two highest salinity levels (72 and 96 dSm^{-1}). However the plants quickly recovered to an injury scale of between 1 and 2 at 21 days after treatment. The recovery over time may be attributed to the ability of seashore paspalum to physiologically adjust to the saline conditions over an extended period of time. Salinity treatments of up to 72 dSm^{-1} did not show any significant injury compared to the control on day 14. Although the injury level was significantly higher than the control at the highest EC treatment of 96 dSm^{-1}, the injury rating was only "very light symptoms". These results are in agreement with the findings of Duncan and Carrow (1998) and Duncan (2000). Shoot growth (Marcum and Murdoch 1990) and root mass (Marcum 1999) are important criteria used to determining salinity tolerance in turfgrass. Significant differences in shoot and root dry weight reductions were observed in *P. vaginatum* irrigated with saline water at EC 72 and 96 dSm^{-1} (Table 6). Shoot dry weight reductions compared to the control were 31.3 and 30.5% in treatments with an EC of 72 and 96 dSm^{-1}, respectively. In the case of root dry weight, maximum reduction of 34.4% (compared to control) was recorded for the highest salinity treatment (96 dSm^{-1}), which was not significantly different to the reduction of 24.1% when treated at 72 dSm^{-1}. Reduced shoot and root growth due to salinity stress is a consequence of leaf injuries like necrosis, leaf firing, and wrinkled leaf which reduce photosynthesis resulting in less shoot and root dry matter production. Detrimental effects of high salinity levels on shoot and root growth of different turfgrass species including seashore paspalum have been reported (Dean et al., 1996; Qian et al., 2001). Pool (2005) observed that seashore paspalum was able to tolerate irrigation at salinity levels of upto 41 dSm^{-1}, while irrigation with pure seawater at 55 dSm^{-1} reduced its quality to an unacceptable level. In the present study, seashore paspalum maintained good health and quality which was comparable to the control even in treatments with a salt level equivalent to that of seawater used in the study (48 dSm^{-1}).

Conclusion

Seashore paspalum was tolerant to irrigation at salinity levels of up to 48 dSm^{-1} (*i.e.* EC of pure sea water). Three broadleaved weeds (*T. procumbens*, *H. corymbosa* and *B. latifolia*) were successfully controlled with the lowest salinity treatment at 24 dSm^{-1}. The number of weeds effectively controlled increased by another four broadleaved weeds (*A. conyzoides, E. prunifolia, D. triflorum* and *L. crustacea*) and two sedges (*C. iria* and *F. globulosa*) when the salinity level was increased to EC 48 dSm^{-1}. Saline irrigation treatments can thus be used as single applications to control these weeds while maintaining the quality of seashore paspalum turf. These results suggest that saline irrigation is an effective alternative to herbicides for controlling several weed species in seashore paspalum and other salt tolerant turfgrass species. This option would be particularly attractive to managers of turf located near coastal areas where brackish or sea water can be readily made available for irrigation. However, additional measures would be needed to control other weed species, especially grasses.

Acknowledgments

This research was funded by the Science Fund (05-01-04-SF0302) with support from University Putra Malaysia.

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