Seedling Growth, Leaf Injury and Ion Uptake Response of Cold-Resistant Palm Species to Salinity[1]

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Abstract

Palms are becoming popular landscape plants in the upper desert region of the Southwest where water used for irrigation has elevated salinity. An experiment was conducted in a greenhouse to evaluate leaf damage and growth response of nine cold-resistant palm species to salinity. One-year-old potted seedlings were transplanted to 10-liter containers filled with loamy sand and irrigated with saline solutions containing 800, 2000, 5000, and 7500 mg/liter of predominantly NaCl salts. The corresponding electrical conductivity was 1.2, 4.4, 9.4, and 13.7 dS/m, respectively. Seedlings were irrigated at a leaching fraction of 30 to 35% for six months, and leaf growth, leaf injury, and leaf mineral contents measured. Under this irrigation regime, salinity of irrigation solutions approximately equals salinity of the soil saturation extract. Leaf growth and leaf injury were highly species-dependent. A significant growth reduction and leaf injury of *Sabal palmetto*, *Butia capitata*, and *Trachycarpus fortunei* appeared when irrigated with the 4.4 dS/m solution, those of *Trithrinax brasiliensis*, *Brahea armata*, and *Sabal minor* when grown with the 9.4 dS/m solution, and *Washingtonia filifera*, *Washingtonia robusta* and *Phoenix canariensis*, using the 13.7 dS/m solution. Injured leaves of poorly-tolerant species contained unusually large amounts of Na (10 to 70 g/kg) when irrigated with the 9.4 dS/m solution. *W. filifera*, *W. robusta*, and *P. canariensis* seem to be ideal species for saline areas.

Index words: salinity, palm species, salt tolerance, ion uptake, cold-resistance.

Species used in this study: Mexican blue fan palm (*Brahea armata S. Wats.*); Pindo palm (*Butia capitata* (*Mart.*) *Becc.*); Dwarf blue palmetto (*Sabal minor* (*Jacq.*) *Pers.*); Cabbage palm (*Sabal palmetto* (*Walt.*) *Lodd.*); Chinese windmill palm (*Trachycarpus fortunei* (*Hook*) *H. Wendl.*); Brazilian fan palm (*Trithrinax brasiliensis* (*Mart.*)); Canary Island date palm (*Phoenix canariensis Hort. ex Chabaud.*); California fan palm (*Washingtonia filifera* (*L. Linden*) *H. Wendl.*); Mexican fan palm (*Washingtonia robusta H. Wendl.*).

Significance to the Nursery Industry

Water available for maintaining urban landscapes in the desert Southwest is becoming increasingly salty. This study provides the information on salt tolerance of nine palm species considered to be cold-resistant enough to use in this region. The information presented should be useful for selecting and growing palms in saline areas.

Introduction

Palms have been used extensively as landscape and street trees in southern California and Arizona where winters are mild. They establish easily after transplanting in most soils and require minimal care. They produce little litter and require little space for growth. Many palm species are now planted in the upper desert region of the Southwest, and some have been damaged by freezes. Cold resistance of palms varies with species. Some species tolerate subfreezing temperatures (3), and certain species have root systems prone to freeze injury (6). The threshold cold temperature for palm species commonly planted in the Southwest (Table 1) came from the Cold Rating Database for Palm (2). Actual survival would depend on other factors, such as the nature of the cold spell, the duration of the exposure, age as well as health of the trees. Several popular garden books also provide general guidelines for selection of cold-resistant plant species (12).

Palms are generally regarded as salt tolerant, but some palm species seem to suffer from salt injury. Seed germination of cabbage palm (*Sabal palmetto*) and Canary Island date palm (*Phoenix canariensis*) decreased significantly when incubated, respectively, in saline solutions having the electrical conductivity (EC) of 1.6 and 4.9 dS/m (11). However, about 20% of *S. palmetto* and 40% of *P. canariensis* seed germinated in a saline solution with EC as high as 17 dS/m. According to a field survey in Egypt (5), yields of date palm (*Phoenix dactylifera*) declined by 72% when salinity of the soil saturation extract (EC_e) was elevated from 4.5 to 7.5 dS/m, and no fruit was formed at EC_e of 23 dS/m. An experiment conducted in a greenhouse in southern California has shown that growth of date palm seedlings declined by 30 to 35% when grown with irrigation water having EC of 11 dS/m, and by 30 to 55% at 20 dS/m (4). A comparable reduction in seedling growth of date palm was also reported in a similar greenhouse experiment involving different cultivars (1). Salt tolerance of ornamental palms is unknown.

The objective of this study was to evaluate growth, leaf injury, and ion uptake response of nine cold-resistant palm species (Table 1) when grown with saline water. *S. minor* and *P. canariensis* were represented by two cultivars each, thus making a total of 11 taxa for evaluation.

Materials and Methods

One-year-old seedlings grown from seed were purchased from wholesale nurseries in California. These seedlings were first planted in 3-liter plastic containers filled with calcareous Bluepoint loamy sand (Torripsamment, Entisol). They were grown for five months in a greenhouse, and 40 seedlings of an equal size were selected out of the original 80 seedlings per species or cultivar. These selected seedlings were transplanted to 10-liter plastic pots containing the loamy sand. Compost, made primary of wood chips of less than 1 cm in size, was added to the loamy sand at a volumetric ratio

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Table 1. **Palm species tested and their cold tolerance[z].**

Scientific name	Common name	Native habitat	Cold tolerance (C)
Sabal minor[y]	Dwarf blue palmetto	Southern US	–15.3
Sabal palmetto	Cabbage palm	Southern US	–12.2
Trachycarpus fortunei	Chinese Windmill palm	China	–11.9
Washingtonia filifera	California fan palm	Western US	–11.1
Brahea armata	Mexican blue fan palm	Mexico	–10.3
Butia capitata	Pindo palm	Brazil	–9.9
Phoenix canariensis[y]	Canary Island date palm	Canary Islands	–6.3
Washingtonia robusta	Mexican fan palm	Mexico	–5.6
Trithrinax brasiliensis	Brazilian fan palm	Brazil	–4.4

[z]Source: Cold rating database for palm, 2003.

[y]These species had two cultivars.

of 5 sand to 1 compost, mainly to improve aeration and drainage. Pots were placed in a greenhouse in which air temperatures ranged from 20 to 25C (70–80F), and were irrigated with tap water for one month of the establishment period. The greenhouse, constructed with aluminum frames and clear glass, was equipped with evaporative cooling panels.

Four saline solutions were prepared by adding NaCl, $MgSO_4$, and $CaCl_2$ to tap water (Table 2). The solution numbered as one is the local tap water and was used as a control. The pH of the solutions decreased slightly with increasing salinity, because of the reduction in H^+ activity. The ionic composition (but not concentration) of the saline solution numbered as two is similar to that of reclaimed municipal effluent and sodic irrigation water used in some areas of the middle Rio Grande Basin. The electrical conductivity (EC) of these saline solutions is comparatively high for the total dissolved salt content, because Na and Cl are the dominant ionic species.

Prior to imposing the saline water treatments, 20 plants out of the original 40 per species or cultivar were selected for testing based on their equal sizes. Seedling pots were arranged in a split plot initially in five replications with salinity of irrigation water as the main plot, and the species as subplots. Ammonium nitrate was added to the irrigation water once a month at a nitrogen level of 50 mg/liter. The salinity increase associated with fertilizer addition was ignored, as it was applied only once a month, and was very low as compared to salinity of the treatment solutions. The temperature of the greenhouse was kept at 20C (68F) at night, but increased to 30C (86F) during the day for the duration of the experiment. During summer months, exhaust fans were operated almost constantly during day-hours. A few observations have shown that soil temperature of the pots (measured at a depth of 2.5 cm (1 in)) was lower than the ambient temperature by a few degrees shortly after irrigation, and the temperature difference became smaller prior to the next irrigation. The photoperiod was the same as outdoors, and the incoming solar radiation was reduced during summer months by 25% with the use of shade cloth.

Special attention was given to the control of the leaching fraction (LF) within a target level of 30 to 35%. Three out of five pots per treatment per species were weighed bi-daily, and were irrigated within 24 hours when the soil water in the potted media depleted to half of the maximum storage. The remaining two pots per treatment were watered when two out of the three pots reached the targeted depletion level. The frequency of irrigation was mostly once a week, but in the control treatment with the lowest salinity, it reached 2 times a week during summer months. Since irrigation was made within a day after reaching the target depletion level, the salinity difference caused by the delay in irrigation should not be greater than approximately 15% in most cases, and in the case of control treatment, about 25%. These differences are small as compared to the differences in the saline treatments imposed. The quantity of irrigation needed was estimated by using a simple water balance formula (14), and the estimated quantity was adjusted at times against the actual measured drainage, as the water holding capacity of potted loamy sand varies slightly. This irrigation regime is supposed to yield salinity of drainage water approximately three times the salinity of irrigation water. The measured salinity of drainage water shown in Table 3 confirmed this estimate, and can also be considered the salinity of the soil solution prior to irrigation.

Foliar damage was recorded photographically every two months. Seedling heights were measured every two months,

Table 2. **The composition of saline solutions used in the experiment.**

No.	TDS	EC[z]	SAR[y]	pH	TDC[x]	Na	Ca	Mg	K	HCO_3	Cl	SO_4
	mg/L	dS/m			mmol (+)/L					mmol (–)/L		
1	800	1.2	5	8.2	9	6	1.9	0.7	0.3	2.2	5	2
2	2000	4.4	24	8.1	37	33	1.9	1.7	0.3	2.2	35	2
3	5000	9.4	38	8.1	92	83	4.6	4.6	0.3	2.2	88	4
4	7500	13.7	52	8.0	138	124	6.9	6.9	0.3	2.2	130	8

[z]EC = Electrical conductivity of irrigation water at 25C.

[y]SAR = Sodium adsorption ratio.

[x]TDC = Total dissolved cations.

Table 3. Salinity of irrigation and drainage water, and the estimated mean salinity of soil solutions.

Treatment	Salinity of irrigation water (ECi)	Salinity of drainage water (ECd)	Mean (ECi + ECd) / 2	Estimated extract salinity[z]	LF[y] %
	dS/m				
1 (control)	1.2	4 (0.9)[x]	3	1.3	35
2	4.4	12 (2.6)	8	4.1	34
3	9.4	29 (4.1)	19	9.5	33
4	13.7	41 (7.2)	27	13.6	34

[z]The saturation water content was assumed to be two times of the soil water storage.

[y]Leaching fraction = (ECi / ECd) × 100.

[x]Mean standard deviation of drainage water salinity.

and seedling growth was to be estimated by subtracting the initial height. This plan was modified as some of the leaves and whole seedlings grown under high salinity dried out due to salt damage. Instead, the length of 'green leaves' was measured at the end of six months from the crown to the tip of the green portion of the three longest leaflets, and was used as an indicator of growth. The mean length of 'green leaves' was then correlated to salinity of the irrigation solutions using the three plants, instead of the initial five plants per treatment per species or cultivar. As described earlier, salinity of the drainage water measured was three times the salinity of the irrigation solutions, as the leaching fraction was controlled at 30–35%. The mean salinity of the soil solution is then equal to twice the salinity of the irrigation solutions. Salinity of the saturation extract, an official measure of soil salinity, is usually about half of the salinity of the soil solutions (14), thus it would be approximately equal to the salinity of the irrigation solutions used at the specific leaching fraction employed in this experiment. The rate of growth reduction was determined through a regression against salinity of the irrigation solutions.

After six months of the saline treatments, leaf samples of both dead regions and uninjured portions were taken from the three plants per treatment per species or cultivar, and

Fig. 1. Growth and leaf injury of selected palm species grown with saline water for six months. The numbers in the photos indicate salinity in mg/liter, and the corresponding conductivity was 1.2, 4.4, 9.4, and 13.7 dS/m, respectively.

Table 4. Leaf growth, leaf injury and plant mortality after 6 months of the saline treatments.

Classification[z] Species	Leaf[y] length	Growth[x] reduction	Salinity for 25% & 50% reductions		Salinity for leaf injury: Recognizable		Salinity for leaf injury: Extensive		Plant mortality	
	cm	cm/(dS/m)	dS/m		g/L	(dS/m)	g/L	(dS/m)	g/L	(dS/m)
Moderately sensitive										
Sabal palmetto	26e	—[z]	<2.1	<4.2	2.0	(4.4)	5.0	(9.4)	5.0	(9.4)
Butia capitata	49b	–5.9[a]	2.1	4.2	2.0	(4.4)	5.0	(9.4)	5.0	(9.4)
Trachycarpus fortunei	45bc	–5.4[a]	2.1	4.2	2.0	(4.4)	5.0	(9.4)	5.0	(9.4)
Trithrinax brasiliensis	37d	–3.7b	2.5	5.0	5.0	(9.4)	7.5	(13.7)	>7.5	(13.7)
Moderately tolerant										
Brahea armata	<38d	–3.0c	3.2	6.3	5.0	(9.4)	7.5	(13.7)	>7.5	(13.7)
Sabal minor	42c	–3.0c	3.5	7.0	5.0	(9.4)	7.5	(13.7)	>7.5	(13.7)
Sabal minor ‘riverside’	40cd	–2.2d	4.5	9.0	5.0	(9.4)	7.5	(13.7)	>7.5	(13.7)
Tolerant to highly tolerant										
Washingtonia filifera	60a	–2.7c	5.5	11.1	7.5	(13.7)	>7.5	(13.7)		
Washingtonia robusta	59a	–2.2d	6.7	13.4	7.5	(13.7)	>7.5	(13.7)		
Phoenix canariensis	40c	–0.2e	>13.4	>13.4	7.5	(13.7)	>7.5	(13.7)		
Phoenix canariensis ‘Dwarf’	42c	–0.3e	>13.4	>13.4	7.5	(13.7)	>7.5	(13.7)		
LSD $_{.05}$	4.3	0.5								

[z]USSL classification based on a 50% growth reduction.

[y]Leaf growth at the lowest salinity.

[x]Leaf length reduction per unit increase in conductivity.

[w]Insufficient data to compute.

ground with a Wiley mill with a 40-mesh screen. Leaf chloride contents were analyzed by titrating the hot water extract with $AgNO_3$ (15). Cations (Na^+, Ca^{2+}, Mg^{2+} and K^+) were determined by an inductively coupled plasma unit (ICP) following dry ashing and digestion with 0.1-N HNO_3. These leaf ion concentrations were correlated against leaf growth and salinity of the irrigation solutions. The analysis of variance of the leaf ion concentration was made for a split plot by a method given in Little and Hills (10). The mean separation was made by using Duncan’s multiple range test.

Results and Discussion

Leaf growth and leaf injury. Palm seedlings photographed six-months after the designated saline treatments are shown in Fig. 1. The plants shown are representative of replicates. The length of ‘green leaves’ (measured from the crown to the tip of the green portion of three longest leaflets) decreased in a linear fashion with increasing salinity. The coefficient of correlation (r value) between ‘green leaf length’ and salinity of irrigation solutions exceeded 0.87 with a mean of 0.92,

Table 5. Leaf Na, Ca, Mg, K and Cl concentrations in nine palm species.

Classification Species	Salinity (dS/m) / Ion conc. (mmol(±)/L)	Na		K[y]		Ca[y]		Cl[x]	
	Salinity (dS/m)	1.2	4.4	9.4	1.2	9.4	1.2	9.4	1.2
	Ion conc. (mmol(±)/L)	6	33	83	0.3	0.3	1.9	4.6	5.0
		g/kg							
Moderately sensitive									
Sabal palmetto		4.9b[z]	5.8	9.6e	10.0d	16.0d	16.6a	7.8c	3.3b
Butia capitata		3.1d	5.5	11.0d	3.0f	12.0e	13.0c	5.0e	3.2b
Trachycarpus fortunei		4.2bc	3.5	41.7b	21.0a	22.0c	9.0e	6.0de	2.8c
Trithrinax brasiliensis		7.0a	3.4	76.4a	12.0c	39.0a	6.0f	16.0a	3.2b
Moderately tolerant									
Brahea armata		2.3d	3.5	37.0c	7.0e	10.0e	6.9f	6.0d	3.2b
Sabal minor		5.0b	6.2	74.3a	13.0c	31.0b	6.4f	7.5c	3.9b
Tolerant to highly tolerant									
Washingtonia robusta		4.2bc	4.3	10.0de	12.0c	33.0b	11.0d	10.0b	4.0b
Washingtonia filifera		2.4d	3.5	3.9g	15.0a	17.0d	15.0b	16.0a	2.9c
Phoenix canariensis		4.0c	4.8	6.7f	10.0d	22.0c	6.0f	5.0e	5.0a
LSD $_{.05}$		0.8	0.8	2.5	1.5	1.7	1.5	1.1	0.9

[z]Numbers in columns followed by the same letter are not significantly different at a 5% level.

[y]K and Ca values at 4.4 dS/m treatment are not shown as they did not significantly differ from those of the control treatment.

[x]Cl data at 9.4 dS m^{-1} are not available due to insufficient quantity of samples.

significant at less than a 5% confidence level. The rate of the growth reduction per unit increase in salinity is shown in Table 4, along with the estimate of salinity of irrigation solutions (or of the saturation extract) which causes 25 and 50% reductions in leaf length. The analysis of variance made for the split plot for the leaf length showed that both species and salt levels had significant effects on growth.

S. palmetto and *B. capitata* exhibited a sharp reduction in growth, (5.9 cm per unit reduction in salinity expressed in dS/m, Table 4), and recognizable leaf injury in all treatments, except for treatment 1. Seedlings of these species have died in two months when irrigated with solution 3 (5000 mg/liter and 9.4 dS/m). *T. fortunei* grew rapidly, but when grown with solution 2 (2000 mg/liter and 4.4 dS/m), its growth was also curtailed, and leaf injuries were recognizable. These three species, especially the first two seem to be most sensitive among the nine species tested.

The next three species, *T. brasiliensis*, *B. armata* and *S. minor* also exhibited severe growth reductions as well as leaf injury when grown with solutions 3 and 4. The two cultivars of *S. minor*, one is regular and another 'Riverside', were not significantly different in their growth and leaf injury.

The last three species, *W. filifera*, *W. robusta* and *P. canariensis* showed the least growth reduction, and the least leaf injury. However, the growth of both *W. robusta* and *W. filifera* decreased at the highest salt treatment (7500 mg/liter, 13.7 dS/m). *P. canariensis*, both regular and 'Dwarf', exhibited the least reduction in leaf length, and no visible leaf injury even at the highest salt level tested.

Plant salt tolerance has traditionally been expressed using salinity of the soil saturation extract EC_e, instead of salinity of irrigation water (15). As mentioned earlier, the leaching fraction in our experiment was controlled in such a way that salinity of the irrigation water would be approximately equal to EC_e. We then classified the tested species using a 50% reduction in leaf growth, following the scheme proposed by the US Salinity Laboratory (8) for ornamental plants: sensitive (<3 dS/m), moderately sensitive (3–6 dS/m), moderately tolerant (6–8 dS/m), tolerant (8–10 dS/m), and highly tolerant (>10 dS/m). The first four species tested can be classified as moderately sensitive (3–6 dS/m); the next two species, moderately tolerant (6–8 dS/m); and the last three species, tolerant to highly tolerant (>8 dS/m). *Trithrinax brasiliensis* is at the borderline and can be placed under moderately tolerant category. For production of palms, however, a maximum 25% reduction in growth may be more appropriate. If this performance index is used, the first four species can be classified as sensitive (<3 dS/m), the next three species moderately sensitive (3–6 dS/m), and the last two species either moderately tolerant (6–8 dS/m) or highly tolerant (>10 dS/m).

The analysis of variance indicated that mineral contents of leaf samples were affected significantly by the saline treatments and by the species tested, except for Mg concentrations, which were independent of the saline treatments. Leaf Na concentrations increased with increasing Na concentration of the irrigation solutions, whereas leaf Ca concentrations were unchanged or decreased, depending on the species tested (Table 5). The Na concentrations of leaf samples from the first and the second treatments had no significant correlation with salt tolerance or the leaf growth shown in Table 4, and were in the same range as those reported with date palms (5). However, leaf Na concentrations of low-tolerant species grown with the third solution were very high, some reaching 70 g/kg or 7% by wt. These unusually high Na concentrations are likely to be a result of break down of Na uptake regulation, and could have led to plant mortality. The Na concentrations of the moderately sensitive species; *S. palmetto* and *B. capitata* were, however, at the same level as those of the salt tolerant species. These plants have died before there was sufficient time to accumulate Na, and/or Na ions were leached from dead plant tissue. Sodium uptake into leaves carries a time lag, as Na is usually retained in the roots first (7).

The concentration of K observed in leaf tissue ranged from 7 to 21 g/kg when irrigated with 800 mg/liter water, and was in the same range as those reported for date palms (5). The K values for the 4.4 dS/m solution are not shown, as they were mostly similar to those of the control. It is interesting that leaf K concentrations were equal or greater when irrigated with water of higher salinity. Potassium deficiency induced by high Na concentrations does not seem to apply to palms, much like the case of mangrove (*Avicennia marina Forsk*. Vierh.) reported by Rains and Epstein (13). Leaf Ca concentrations decreased in most cases with increasing salinity, and this trend is consistent with the well-known reduction in Ca uptake with increasing Na (9). However, there was no consistent relationship between leaf Ca concentrations and salt tolerance. It is unclear if Ca deficiency is involved in the observed growth reduction. Leaf Cl concentrations when irrigated with tap water ranged from 2.9 to 5 g/kg, but there was no correlation with salt tolerance.

The salt tolerance data obtained here seem to indicate that salt tolerance of palms may simply be a reflection of habitat characteristics. Canary Island date palm (*P. canariensis*) is, for example, native to the sea coast, and it is not surprising that it is highly salt tolerant. *W. filifera* and *W. robusta* are native to the lower desert region of southern California and Sonora, Mexico, and presumably tolerate heat and salts. All other species tested came from humid and sub-humid habitats, which are likely to be nonsaline. It is a matter of conjuncture if certain physiological mechanisms such as Na exclusion and preferential absorption of K have evolved from the saline nature of habitats or made it possible to adapt to the saline environments.

Judging from the data obtained, *W. robusta*, *W. filifera*, and *P. canariensis* seem to be good choices for saline areas. If the soil is permeable enough to allow for a leaching fraction of at least 30%, these species can be grown with water containing 5000 mg/liter of dissolved salts or that has electrical conductivity of 10 dS/m or less. At the same time, *S. palmetto*, *B. capitata*, and *T. fortunei* may not be successful in saline areas. The other species tested can be grown adequately with water up to 2000 mg/liter (4.4 dS/m), if the soil is highly permeable to allow for a high level of leaching.

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