Chapter 6
PLANT SELECTION FOR IFDM

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Chapter 6: Plant Selection for IFDM

I. Introduction

The use of saline drainage water for irrigation requires several changes from standard management practices including:

- Selection of appropriate crops — or perennial forages and halophytes for more saline waters.
- Improvements in water and soil management.
- More frequent water and soil sampling.
- Adoption of advanced irrigation technology.

Management is focused on:

- Salinity control within the root zone (maintaining a net downward flow of water and salt).
- Avoiding deterioration of soil physical conditions.
- Avoiding the accumulation of certain trace elements (e.g. B, Se, Mo) that may be problematic to plant production, or to wildlife, should they be present.

Selecting plants and the intensity of management required for an IFDM system depends on the salinity and composition of the drainage water, and whether good quality water also is available for irrigation.

Drainage water can be a resource and a constraint. Various drainage water constituents can have negative or positive impacts on plants, soil, water and different kinds of animals influenced by the system. A summary of these impacts with increases in various drainage water parameters are illustrated in Table 1. In the case of nitrate, there is a benefit for plants.

II. Considerations for Proper Plant Selection

When choosing plants, one should keep in mind the areas of the IFDM system where the plants will be grown, as well as the soil conditions and the purpose of that area. In Stage 1, which is irrigated only with fresh water, salts are leached out of the root zone and the soil is improved. This allows salt-sensitive plants to be grown. The larger the area within Stage 1, the greater is the profit potential. In subsequent stages, saline drainage water is applied to the plants and criteria such as salt and boron tolerance are paramount.

Prior to any plant selection, a representative water sample should be taken from a groundwater monitoring well; or preferably from a drain-

Table 1. Drainage water constituents having potential impacts on plants, soil structure, migratory waterfowl and wildlife, ruminant animals, and groundwater or surface water.

Drainage Water Parameter	Potential Negative (X) or Positive (+) Impacts On...†				
	Plants	Soil Structure	Migratory Waterfowl & Wildlife	Ruminant Animals	Groundwater or Surface Water
Salinity	X	+	X	+/X	X
Boron	X		X		X
SAR (sodicity)		X			
Selenium			X	+/X††	X
Molybdenum				X	
Nitrate	+			X	X

†Only significant & direct impacts are listed.
††Positive impact up to a given concentration, above which a mixed ration may be needed to avoid toxicity.

Table 2. Comparison of salinity tolerance and profit potential for various plants in an IFDM system.

Plants	Irrigation water salinity (EC) (fresh, mixed, or drainage)	Profit Potential
Salt-sensitive vegetables	below 2 dS/m †	high
Salt-tolerant vegetables & flowers	below 6 dS/m	medium
Field crops (cotton, wheat, canola)	below 8 dS/m	low
Salt-tolerant forages	8-15 dS/m††	low
Halophytes	Above 15 dS/m	none - low
Salt-tolerant trees	5-10 dS/m	none - low

†Most require irrigation water less than 2 dS/m. Optimal soil and water management is required to use waters from 2 to 4 dS/m.
††Over the short term, Jose Tall Wheatgrass, Paspalum, creeping wild rye and bermuda grass can be irrigated with water up to 20 dS/m.

age sump, if the drainage system has already been installed. The water analysis is the basis for plant selection.

Ideally, the water should be taken from several feet below the surface, rather than sampling immediately at the water surface.

The required characteristics for selected salt-tolerant plants (Stage 2 and higher) include:

- Salinity and boron tolerance;
- High water use (ET);
- Tolerance to frequent flooding-*if using flood irrigation;*
- Marketability of harvested biomass;
- Perennials or long–season annuals are preferred because they use water almost year-round;
- Frost tolerance;
- Are NOT an invasive plant; and
- Are NOT a host plant for insect vectors of plant viruses.

A. Determining Salt and Boron Tolerance

Salinity and boron tolerance are the main factors influencing plant selection in IFDM systems.

1. Salt

The Maas Hoffman tables (Maas & Grattan, 1999) provide salt tolerance rankings for many fiber, grain, forage, vegetable and woody crops. The tables are primarily for agronomic crops: halophytes are not listed, and only limited information is available for salt-tolerant forages. These tables can be found in the Appendix or at the USDA George E. Brown Salinity lab website, http://www.ussl.ars.usda.gov. They also are included in a very useful and reader friendly manual entitled "*Agricultural Salinity and Drainage*" by Hanson, Grattan, and Fulton, which after reprinting will be available for on-line purchase at http://anrcatalog.ucdavis.edu.

For each plant species listed, the Maas Hoffman tables give a threshold soil salinity (ECe in dS/m) above which a yield decrease is likely. The tables also list a "slope" value which is the expected yield reduction in percent for every unit (1 dS/m) increase above the threshold. The threshold values are based on the average root zone salinity. The slope value indicates how rapidly yield decreases once the threshold soil salinity has been passed. It is the combination of threshold and slope that determines the final tolerance ranking. Crops that are more tolerant to salinity have high threshold and low slope values.

Some crops may perform differently than predicted by the Maas Hoffman salinity tolerance ranking if certain management practices to minimize salinity impacts are implemented, such as:

- A high leaching fraction or end-of-season reclamation;
- Planting position (shoulders of bed for furrow irrigated, and along the drip line for drip irrigated crops);
- Proper timing of the application of saline water ("cyclic" strategy).

Threshold soil salinities for individual crops are listed in the Maas Hoffman tables found in the Appendix. For most crops belonging to each

Pistachio

of the four tolerance categories, the thresholds are as listed in Table 3.

Table 3. Soil Salinity Threshold (Ece)

"S" (sensitive):	1.0 to 1.8 dS/m ECe.
"MS" (moderately sensitive):	1.5 to 2.8 dS/m ECe.
"MT" (moderately tolerant):	4.0 to 6.3 dS/m ECe.
"T" (tolerant):	6.8 to 10 dS/m ECe.

In systems such as IFDM that utilize "wastewaters," the starting point for plant selection is actually the applied water salinity (drainage or drainage blend), rather than the soil salinity. Unfortunately, comprehensive salt tolerance tables similar to the Maas Hoffman tables, but based on irrigation water salinity, are not available. The soil salinity (ECe) resulting from irrigation with water of a given salinity (ECi.w.) is difficult to predict because of the influences of texture, drainage, duration of saline irrigation, and leaching fraction. However, a reasonable but rough estimate is that:

Soil salinity (ECe) = 1.5 x irrigation water salinity (ECi.w.)

provided that a leaching fraction of 15-20 percent is achieved over the long term (Ayers and Westcot, 1985). Therefore based on this relationship, irrigation with drainage waters over 6.5 dS/m (i.e. ECe=9.8 dS/m) would exceed the limit (Maas Hoffman thresholds) for most salt-tolerant agronomic crops.

2. Boron

Maas and Hoffman also compiled boron tolerance tables that list threshold values for numerous agronomic crops based on the boron concentrations in the "soil water" (saturated paste extract). These tables were recently revised by Maas and Grattan (1999). Some salt-tolerant crops are also tolerant ("T") or moderately tolerant ("MT") to boron; for example, cotton, sugarbeets, asparagus, and red beet. Alfalfa is boron tolerant (T) and but is listed as moderately sensitive ("MS") to salinity. Nevertheless, there are new cultivars available that have higher salt tolerance. Tomato and garlic are also boron tolerant; but they are, respectively, moderately sensitive ("MS") and sensitive ("S") to salinity. These boron-tolerance tables do not contain listings for salt-tolerant forages or halophytes.

With soil boron concentrations of 4-8 ppm (mg/L) in the saturated paste extract or drainage waters of similar concentration, only boron-tolerant agronomic plants should be planted. For drainage waters of 10-15 ppm boron, blending could be utilized, as is done at AndrewsAg in southern Kern County. Boron toxicity was not observed in trials in the San Joaquin Valley in which annual crops were irrigated with saline-sodic drainage water containing 7 to 10 ppm (mg/L) boron. These included cotton, melon, sugarbeet, tomato and wheat (summarized in Grattan & Oster, 2003).

Pistachio trees were irrigated with drainage water containing 10 dS/m salinity for more than 8 years with no reported yield reductions (B. Sanden, UC Cooperative Extension, personal communication). However, in this study boron concentrations were low in the simulated drainage water. At Red Rock Ranch where young pistachio trees were irrigated with drainage water containing 18-24 ppm boron, severe foliar injury attributable to boron toxicity occured. The symptoms generally appeared in July and August when ET was highest, and the trees recovered each year following leaf fall. The impact of this foliar injury on nut yield was not determined, but it would not be advisable to irrigate pistachio with drainage water having boron concentrations greater than 3-4 ppm until more research is done with drainage water containing both high salinity and boron.

Table 4. Example of Maas Hoffman salinity tolerance coefficients and slopes for field crops and vegetables (Maas & Grattan, 1999).

	Maas Hoffman Salinity Tolerance Values		
	Threshold soil salinity (ECe) in dS/m	Maximum water salinity (ECiw in dS/m) that can be used without yield reduction*	Slope (% yield reduction per unit dS/m increase)
Salt-Tolerant Field Crops			
Cotton	7.7	5.1	5.2
Wheat	6.0	4.0	7.1
Barley	8.0	5.3	5.0
Sugarbeet	7.0	4.7	5.9
Canola (*B. napus*)	11.0	7.3	13
Canola (*B. campestris*)	9.7	6.5	14
Salt-Tolerant Vegetables			
Artichoke	6.1	4.1	11.5
Asparagus	4.1	2.7	2.0
Red beet	4.0	2.7	9.0
Zucchini squash	4.9	3.3	10.5
Purslane	6.3	4.2	9.6
Moderately Salt-Sensitive Vegetables			
Garlic	3.9	2.6	14.3
Pea	3.4	2.3	10.6
Broccoli	2.8	1.9	9.2
Tomato	2.5	1.7	9.9
Salt-Sensitive Vegetables			
Carrot	1.0	0.7	14.0
Onion	1.2	0.8	16.0
Bean	1.0	0.7	19.0

* assumes 15-20% leaching fraction

III. Field Crops & Vegetables

Factors to consider when irrigating agronomic plants with drainage water:

- Species and varieties may have different salinity tolerances;
- Vegetables tend to be more sensitive to salinity than field crops;
- Plants may be more sensitive to saline water at different growth stage; and
- Establishment of crops must usually be done under non-saline conditions.

A. Field Crops

Cotton, barley and canola are among the most tolerant field crops. For example, because the soil salinity (ECe) threshold for cotton is 7.7 dS/m, the estimated limit for irrigation water salinity that could be applied to cotton over the long term without yield loss would be 5.1 dS/m (Table 4). If the average soil salinity in the root zone reached

Table 5. The maximum percent of saline water (4 to 10 dS/m) that can be mixed with non-saline irrigation water (0.8 dS/m) to achieve a yield potential of 100% and 80% for selected crops that vary in salt tolerance. Estimates assume a leaching fraction of 25% (Dinar and Letey, 1986).

EC of the Saline Irrigation Water (dS/m)					
		4	6	8	10
Crop	**Salt tolerance**[1]	**100 % yield**			
Lettuce	MS (1.3, 13)	2	2	1	1
Alfalfa	MS (2.0, 7.3)	14	9	6	5
Tomato	MS (2.5, 9.9	25	15	11	9
Zucchini	MT (4.7, 9.4)	62	38	28	22
Cotton	T (7.7, 5.2)	100	62	44	35
	80 % yield				
Lettuce	MS (1.3, 13)	37	23	17	13
Alfalfa	MS (2.0, 7.3)	80	52	39	31
Tomato	MS (2.5, 9.9	78	48	35	27
Zucchini	MT (4.7, 9.4)	100	84	68	58
Cotton	T (7.7, 5.2)	100	100	100	100

[1] The first number in parenthesis is the average root zone threshold salinity (A) in dS/m, and the second is the percent yield decline per unit increase in average root zone salinity (slope) (B). MS, MT and T refer to moderately sensitive, moderately tolerant and tolerant, respectively.

Vegetables growing under IFDM Stage 2 conditions.

8.7 dS/m under saline irrigation, there would be about a 5.2% reduction in crop yield. See Appendix for a complete listing of Maas Hoffman salinity tolerance rankings and a simple equation to calculate the relative yield predicted for a given crop and soil salinity (ECe).

Canola is even more salt tolerant than cotton, having a threshold salinity (ECe) of 11.0 dS/m (Table 4). Canola shows promise both as a selenium accumulator and as a biodiesel crop (G. Banuelos, USDA-WMRL, Parlier, CA, personal communication).

In an IFDM system where crops like cotton are being grown to "consume" drainage water, some yield loss due to salinity may be acceptable. Table 5 lists agronomic crops and compares the percentage of drainage water of different salinities that could be utilized if the yield goal was 80% rather than 100%. As shown in the lower half of the table, much higher percentages of drainage water can be used when the yield goal is lowered from 100% to 80% (Dinar & Letey, 1986).

Blending, however, requires additional management and irrigation equipment, e.g. to blend the drainage and fresh waters, and to monitor the salinity of the final blend. As proposed by Grattan and Oster (2003) and discussed in Chapter 5, with a blend of less than 25 percent drainage water one should consider whether or not blending is time and cost-effective.

B. Vegetables

Asparagus, artichokes, red beets and zucchini squash are among the most salt-tolerant vegetables; however, most drainage waters would need to be blended with fresh water to keep the salinity of the irrigation water low enough for these vegetables. Soil salinities in the root zone should ideally be kept at or below the threshold salinities listed in Table 5.

Swiss chard (*Beta* vulagaris var. flavescens), mustard greens (*Brassica juncea*), and kale (*Brassica oleracea* var (*Acephala* group) can be grown under irrigation with saline water (3-15 dS/m; 2220–10,120 ppm TDS) although at the higher irrigation water salinities, soil drainage must be very good and yield may be reduced as much as 50% (Shannon et al, 2000).

With leafy vegetables, plant size will be reduced by salinity. The potential yield reduction can be offset by denser plantings. If the greens are destined for packaged salad mixes, the smaller plant size may not be a detriment.

For non-leafy vegetables, saline water may reduce yield, but it may also improve quality; for example, it can increase soluble solids in tomato and sugar content in cantaloupe (Grattan & Oster, 2003).

Two kind of statice (*Limonium spp*.) that can be sold as cut flowers thrive on saline waters. These flowers are being tested at the USDA Salinity Lab in Riverside (C. Grieve, personal communication). Early results indicate that salinity reduces stem length and that *L. sinuatum* is more tolerant than *L. perezii*.

IV. Salt-Tolerant Forages

Some salt-tolerant grass and legume forages are listed below, ranked in order of promise. For IFDM, the highest priority is given to salt and boron tolerance, productivity and water use (ET). Also considered are forage quality and the remaining factors previously discussed.

A. Tall Grasses

1. *'Jose'* Tall Wheatgrass (*Agropyron elongatum* or *Elytrigia elongata*)
2. Creeping Wild Rye var. '*Rio*' (also called Beardless Wild Rye) (*Leymus triticoides* or *Elymus triticoides*)
3. Tall Fescue (*Festuca arundinacea* vars. *'Alta'* and '*Goars'*)
4. Alkali sacaton (*Sporobolus airoides* var. '*solado'*)
5. Koleagrass, Perlagrass (*Phalaris tuberosa* var. '*Hirtiglumis'*)
6. Puccinellia (*Puccinellia ciliata*)

B. Turf Grasses

1. Paspalum (*Paspalum vaginatum* vars. *"Polo'*, '*PI 299042*', and *'Sealsle 1'*)
2. Bermuda grass (*Cynodon dactylum*, vars. '*Common*', *'Giant'* and *'Tifton'*)

C. Legumes

1. Salt-tolerant alfalfa (*Medicago sativum*)
   — cvs. '*Salado*' and '*Ameristand 801S*'.
   — cvs. '*SW9720*'
2. Narrowleaf trefoil (*Lotus glaber*)
3. Strawberry clover (*Trifolium fragiferum*)

The following forage characteristics should be considered:

- Salt and boron tolerance
- Biomass production

Jose Tall Wheatgrass

- Water use (ET)*
- Ion accumulation*; Se, S, NO_3, Mo, Cu, Mg, in particular. Also Na, Cl, K, Si
- Forage quality*
- Length of growing season
- Warm season vs. cool season
- Competitive ability (in the presence of invasive weeds)*
- Availability of seed or transplants
- Ease of establishment and maintenance
- Suitability for hay ("cut-and-carry") vs. grazing
- Grower and market acceptability

  **under saline conditions*

Table 6 compares the salt-tolerant forages using the criteria stated above.

Ideally, a forage production system should include both warm and cool season types and legumes along with the grasses. With the exception of adding in legumes, such as trefoil or clover, it is generally recommended that species be planted separately rather than inter-planting. The challenge is to manage the stand (i.e., cutting frequency and height) so as to maximize both the productivity (biomass accumulation) and the forage quality. Generally, as biomass accumulates (more time allowed between cuttings), forage quality decreases (Robinson, 2003).

Research thus far suggests that in general, salinity does not reduce forage quality (Robinson, 2003), but it can increase ash and nitrate, both of which are undesirable. Also, more frequent monitoring of elemental composition is required because if they should occur, excessive concentra-

Table 6. Comparison of salt-tolerant forages.

	Maximum Recommended[1] ECi.w. (dS/m)	Forage Quality[2]	Growing Season	Length of Growing Season	Suitability Hay vs. Grazing[4]	Seed or Transplant Availability[5]	Competitive Ability
Tall Grass forages							
'Jose' Tall Wheatgrass	8-15	High	Weakly cool[3]	Long	Grazing/ hay	Good (seed)	Good
Creeping Wild Rye var. *'Rio'*	8-13	Medium low	Weakly cool	Long grazing	Hay (plugs better)	Fair (seed)	Very Good
Tall fescue var. *'Alta'*	8-13	Medium high	Weakly cool	Medium long	Grazing/ hay	Good (seed)	Good
Alkali sacaton, var. *'Solado*	8-15	Low	Warm	Medium long	Grazing/ hay	Fair (seed; plugs better)	Good
Perlagrass	8-13	Medium	Cool	Medium	Grazing/ hay	Fair (seed; plugs better)	Poor
Puccinellia	8-13	Medium	Strictly cool	Short	Grazing/ hay	Fair (seed)	Average
Turf Grass or forages							
Bermuda grass	8-15	Medium high	Warm	Medium	Grazing/ hay	Good (seed)	Average to good
Paspalum	8-15	Medium high	Warm	Medium long	Grazing/ hay	Good (sod or stolons)	Average to good
Leguminous forages							
Salt-tolerant alfalfas (varieties listed on 6-6)	4-5	High	Warm	Long	Hay	Good (seed)	Average to good
Trefoil—narrow leaf	4-6	High	Weakly cool	Short	Grazing/ hay	Fair (seed)	Average

1 Can be irrigated with water of lower salinities, but then a forage or crop of lower salt tolerance and higher profitability, may be better. At the high end of the salinity range, productivity may be significantly reduced. Estimates are based on available scientific data and personal observation.
2 Rankings of forage quality are on a relative scale, which only compares the forages listed and only under conditions of saline irrigation.
3 "Weakly cool": forage grows best in the spring and fall. Does not go dormant in the summer, but growth is greatly reduced.
4 Listing before slash mark is the best use. Listing after slash mark is second in preference. Listings are best, current estimates: response to grazing has not been thoroughly tested for most of these forages.
5 "Good": commercial sources readily available and can supply large amounts. "Fair": commercial sources may not be available, but small amounts can be procured from the USDA Plant Materials Center (PMC) in Lockeford, CA, or from special purveyors. See Appendix.

tions of nitrate, molybdenum and sulfur could result in nutritional problems for animals that were fed forages irrigated with Westside drainage water (Grattan et al., 200X). In the case of selenium, modest enrichment could increase the value of the forage.

'Jose' tall wheatgrass is considered to be a top candidate because it has good productivity and forage quality under saline irrigation, a long growing season, and seed is readily available. It is sold locally in the San Joaquin Valley as "Westside wheatgrass." Under irrigation with saline drainage water from 10 to 14 dS/m and growing in very saline soils at Red Rock Ranch (17 and 20 dS/m ECe in the top 12 inches) produced approximately 9,000 kg/ha/yr in one field and only 4,700 kg DM/ha/yr of dry material in the other field. In addition to higher salinity and boron in the less productive field, the forage was irrigated less frequently; it had been cut shorter than the recommended level; and the physical soil conditions were more degraded. In both fields productivity has declined as the soil salinity has increased, but stable stands have been maintained. Forage quality of the tall wheatgrass was the highest of the grass forages growing at Red Rock Ranch for the two fields described in Table 7.

Table 7. Forage quality for Jose Tall Wheatgrass growing at Red Rock Ranch

	Field 1 17dS/m ECe	Field 2 20 dS/m ECe
Metabolizable energy (ME) (MJ/kg)	9.3	8.7 MJ/kg
Crude Protein (CP) (%)	8.5	12.2 %
Neutral detergent fiber (NDF) 52.2 (%)	64.0 %	
Acid detergent fiber (ADF) (%)	32.6	30.6%
Ash (%)	9.6	7.2 %

Creeping Wild Rye, irrigated with the same drainage water at Red Rock Ranch, but growing in less saline soil (11 to 13 dS/m ECe) accumulated much more biomass (11,500 to 13,000 kg DM/ha/yr), but forage quality was lower than for *'Jose'* Tall Wheatgrass. This grass has a more upright growth habit, which along with the lower soil salinity of the field, explains its higher

Creeping Wild Rye

productivity. The erect growth also makes Creeping Wild Rye suitable for haying, if forage quality is deemed acceptable.

Paspalum is also a top contender. It has good productivity and forage quality under saline irrigation and being a warm season grass, it complements the production of cool season grasses such as tall wheatgrass and Creeping Wild Rye. Paspalum has not been extensively tested in the field under irrigation with drainage water, but it was a top performer in sand tank studies where synthetic drainage water was applied (Robinson et al., 2003). Sod and chopped stolons are available commercially.

Bermuda grass has performed well in a beef cattle grazing study at Westlake Farms (S. Kaffka, UC Davis, personal communication) where it is growing under irrigation with saline drainage water with soil salinities averaging 13 dS/m ECe for the top 12 inches. Two seeded varieties, '*Common*' and '*Giant,*' were grown: '*Common'* is exclusively for grazing, and *'Giant'* is suitable for grazing or hay. Forage quality was considered to be acceptable for beef cattle: averages were CP = 16%, ADF = 29.4%, and ash = 13.1%. Forage productivity and quality also were good based on sand tank studies at the U.S. Salinity Laboratory (Robinson, et al., 2003). Some scientists do not consider Bermuda grass to be an invasive species, but there are different opinions on this issue.

Although most of the candidate forages are suitable for grazing, great caution will need to be taken if IFDM forage plantings are grazed. Rotational grazing will be essential to allow forage fields to dry out adequately prior to grazing. Grazing should not be done when soils are wet, as compaction will reduce water infiltration. This would further exacerbate the tendency toward reduced infiltration in soils irrigated with saline-sodic waters. Mixed forage plantings are generally not recommended for IFDM, optimizing the management for each species. However, in a grazing system there would be a nutritional benefit for the animals from mixed pastures. More research is needed to develop appropriate forage mixtures for IFDM grazing systems.

D. Establishment and Maintenance

Soil sampling and water analysis should be conducted prior to forage planting to determine if pre-plant leaching is required and/or soil amendments such as gypsum, sulfur or sulfuric acid should be applied to increase the soluble calcium fraction in the soil, which in turn will reduce sodicity and improve infiltration and drainage.

As indicated in Table 6, many of the salt-tolerant forages can be seeded. Seeding is generally more successful for large-seeded forages such as tall wheatgrass. For small-seeded forages like alkali sacaton, a good firm moist seedbed is essential. Good land preparation may be difficult, however, on heavy clay soils that have poor structure due to sodium-induced clay dispersion. Using plugs or other container-grown material is more expensive, but they generally have a higher success rate. Fall is the best time to establish the cool season grasses. Warm season grasses should be established in the spring. It is best to establish the salt-tolerant forages with fresh water, ideally for the entire first year.

Proper cutting heights vary from forage to forage, but should not be too low for the perennial bunch grasses. In particular, tall wheatgrass should not be cut below a 6-inch height. Once the stand is established, cutting should be frequent enough to maintain vigorous growth (maximum ET) and provide acceptable forage quality.

More details on forage establishment and maintenance can be found in the Appendix.

V. Halophytes

Halophytes are largely undomesticated plants that are native to saline coastal marshes or inland salt flats. “Halo” means “salt” in Latin. These plants are truly salt-requiring; in fact, most do not grow well under non-saline conditions. Some halophytes can be irrigated with water as saline as seawater. Halophytes are suitable for irrigation with highly saline water (> 15 dS/m; 12,000 ppm TDS) and/or for highly saline soils (ECe ≥ 20 dS/m; 16,000 ppm TDS). Salicornia and Allenrolfea are the most salt-tolerant plants, thriving in soils with ECe of 50-60 dS/m in the top 12 inches. All of the halophytes are warm season plants. They include:

Allenrolfea (Iodine Bush)

- Saltgrass (*Distichlis spicata* var. ‘*stricta’*)
- Iodine bush (*Allenrolfea occidentalis*)
- Pickleweed Samphire (*Salicornia bigelovii*)
- Saltbush (*Atriplex lentiformis* and *A. numularia*)
- Cordgrass (*Spartina gracilis, S. alterniflor,* and *S. patens*)

At present these halophytes have limited economic value, but for Salicornia and saltgrass, breeding and selection is underway to improve their agronomic traits and develop new agricultural uses and products. Even if no revenue is generated from halophyte cultivation, the value of these plants in an IFDM system is their suitability for irrigation with concentrated drainage water, thereby allowing further volume reduction prior to discharge of the final effluent into a solar evaporation system. Profit is instead gained by an increase in the fresh water irrigated area of the IFDM with high value crops. Therefore, halophytes may serve the purpose as sacrificial

Table 8. Comparison of halophytes

	Suitable ECi.w. [1] (dS/m)	Establishment (ease/time)[2]	Maintenance[3]	Competitive ability	Availability seeds or transplants[4]	Water use (ET)	Economic potential	Selenium uptake	Comments
Annual									
Salicornia bigelovii	≥15	More difficult*/ few months	Medium	Fair	Low (seed, by agreement)	High	Medium	Very High	*not well-adapted to hard surface crust, best sown onto wet soils in late fall/winter.
Perennials									
Saltgrass	≥15	Average/ one year*	None*	Very Good	Good (rhizomes or clumps from native stands, or commercial)	Lower	Low	Medium	*new shoots must form on rhizome. Plugs from seed faster. "Nypa" does not produce seed
Allenrolfea	≥15	Average/ one year*	Low	Good	Fair (sprigs from native stands and seeds)	(No data)	Very Low	High	*new shoots must form on sprig. Seeding not tested.
Atriplex spp.	≥15	Average/ few months	Medium*	Very Good	Good (seed, or rooted cuttings — native stands or commercial)	Medium	Very Low	Low	*Shrubs get very large, best to cut every year or two.
Cordgrass	≥15	Average/ few months if plugs are used	Low*	Good	Good (clumps rooted in containers— native stands or commercial	No data	Low	Medium	*Cutting not required but may increase ET.

[1] *ECi.w = electrical conductivity of the irrigation water in dS/m.*
[2] *Establishment details can be found in the Appendix. Scale is relative. The success rate for establishing vegetation in saline areas is generally lower than for standard argronomic plantings on non-saline sites.*
[3] *Maintenance scale: Low = little care; Medium = may require re-seeding (Salicornia) or trimming (Atriplex); High = frequent trimming or re-seeding required.*
[4] *Availability: Good = commercial sources readily available and can supply large amounts; Fair = commercial sources may not be available, but plant material can be collected from native stands or small amounts requested from the USDA Plant Materials Center (PMC) in Lockeford, CA. Low = special purveyors and/or formal agreements may be required (Salicornia and "Nypa Forage" saltgrass).*

to reduce the volume of drainage water and thereby expand the area that is not affected by high saline water tables.

For IFDM, the following halophyte characteristics should be considered.

- Water use (ET)
- Tolerance to water-logging and to soils with poor aeration and hard surface crusts
- Length of growing season
- Perennial vs. annual
- Ease of establishment and maintenance
- Availability of seed or transplants
- Competitive ability (in the presence of invasive weeds)
- Biomass production and amount of vegetative cover over soil surface
- Economic potential (as forage, animal feed supplement, seed oil, biomass, other)
- Ion accumulation; in particular Se, B, NO_3, S, Mo, Cu
- Grower and market acceptability

Salt and boron tolerance is not included because all are highly tolerant.

Table 8 compares the halophytes using many of the criteria listed above.

Thus far, saltgrass, Allenrolfea and Salicornia are the most promising halophytes. Saltgrass ranks high because once established, maintenance is minimal, and it provides a very dense vegetative cover which reduces evaporation and excess salt accumulation at the soil surface. The fibrous root system of the grass may also improve infiltration and drainage (Oster, et al., 1996). This is critical because the loss of soil permeability to water is a major problem in IFDM halophyte fields.

Allenrolfea has performed exceptionally well in the IFDM system at AndrewsAg. A 20-acre stand was established using cuttings taken from native stands surrounding the farm and after one year, a nearly full stand of 2-to-3-foot tall bushes was established. Allenrolfea stands at both AndrewsAg and Red Rock Ranch have competed well with invading halophytes and selenium accumulation is high.

Salicornia is the halophyte with the greatest potential for economic return. The "green tips" can be sold profitably as a gourmet addition to salad; however, when irrigated with drainage water, it is unlikely that a fresh market product could be sold. Salicornia also has promise as a cooking oil crop and as a selenium supplement for animals. It has very high selenium accumulation (>10ppm (mg/kg). Salicornia establishment can be difficult in fine-textured soils that form a tough surface crust. It grew exceptionally well at the Mendota agroforestry site, but it has not grown as well at Red Rock Ranch. Surface applications of gypsum at 3-tons/acre appear to be improving stand establishment in the spring.

IFDM Stage 3 halophytes at AndrewsAg.

Atriplex also grows very well under irrigation with saline drainage water and in the tough soil conditions normally encountered in IFDM halophyte plots. At present, however, Atriplex plantings are not allowed by the California Department of Food and Agriculture (CDFA) and the county agricultural commissioners due to concerns that it may harbor the Sugarbeet Yellows virus. It has been suggested that Atriplex is no more likely to harbor the virus than would other native vegetation, but the restriction is being maintained.

A. Soil Management

With long-term application of saline-sodic drainage water to IFDM halophyte plots, infiltration and soil permeability to water will decline appreciably. All of the halophytes listed above have demonstrated tolerance to water-logged soil conditions. Surface applications of gypsum, soil sulfur, or sulfuric acid are likely to be required and at rates higher than those used in conventional agriculture. Organic amendments also may have potential to mediate the negative effects of sodic irrigation waters; however, this has not been demonstrated.

B. Establishment and Maintenance

Halophytes can be established with fresh or saline water. The best time for seeding or transplanting is generally in the fall. The application of gypsum or soil sulfur prior to planting is advisable. Salicornia is generally more difficult to establish due to its inability to emerge through a tough surface crust. Atriplex does not appear to have this problem. Saltgrass and Allenrolfea are usually slower to establish, taking about one year because new shoots must form from the transplanted material. In the case of Allenrolfea, some seedlings may arise from seed dropped from transplanted sprigs. Other than soil amendment application, halophyte fields generally do not require much maintenance, especially if the plants are not being harvested for agricultural products. Saltgrass does not require cutting so it is maintenance free. Larger shrubs such as Allenrolfea may require cutting to restrict plant size and to reduce woody growth and maximize ET. Salicornia generally re-seeds itself and new plants emerge through last year's skeletons; however, weak stands will require over-seeding.

More details on halophyte establishment and maintenance can be found in the Appendix.

VI. Trees

Trees tend to be more sensitive to salinity and boron than field crops or forages. Therefore, drainage water is applied to salt-tolerant crops, forages and halophytes, and only occasionally to selected trees that show some tolerance to salinity and boron. Exceptions may be when drainage flows are very high or when drainage water salinities are low (5-8 dS/m). For example, drainage water could be used to irrigate Pistachio or Eucalyptus, though ideally with blending and with a subsurface drain line under the tree block. In the San Joaquin River Water Quality Improvement Project (SJRIP) that is managed by Panoche Drainage District, 10 acres of Pistachio have been established under irrigation with fresh water (300 ppm TDS = 0.5 dS/m) from the Delta Mendota Canal. The district may begin blending with sump water in Spring 2004 when the trees will be in their third year. Once the trees are mature the salinity of the blended water will range from 600 to 4000 ppm TDS (= 0.81 to 5.4 dS/m) with boron concentrations between 0.75 and 5 ppm. The orchard has subsurface drainage lines (Chase Hurley, Panoche Drainage District, personal communication).

Three methods of planting trees to reduce water-logging and ameliorate saline conditions on cropland are as follows:

- Interceptors are planted across regional subsurface flows to lower water tables (e.g. from 1 to 6 feet) in the immediate vicinity of the planting;
- Trees can also be used in a manner similar to a relief tile system by planting at a designed spacing to lower the water table; and
- Tree plantations for the reuse of low salinity drainage water (5 - 10 dSm). A subsurface drain line under the trees collects the concentrated drainage which can then be applied to salt-tolerant forages or halophytes.

Trees that are most promising for IFDM systems include:

- Athel (*Tamarisk aphylla*)
- Eucalyptus (*Eucalyptus camaldulensis*, "River Red Gum," clones 4573, 4543, 4544)
- Pistachio (*Pistacia vera*), e.g. var. "*Kerman*" on rootstock "*Pioneer gold*"
- Casuarina (*Casuarina cumminghamiana*)

Among this group, Athel is the most tolerant to salinity and boron, while Pistachio is less tolerant. Eucalyptus appears to be intermediate between the two. Pistachio has shown foliar injury when exposed to saline-sodic water containing high levels of boron, but no tolerance thresholds have been established. Casuarina has not been adequately tested under irrigation with saline drainage water.

Important considerations for using trees in IFDM systems include:

- Soil type, climate and salinity of the water will affect the water use (ET) of the trees. ET is reduced at higher salinities.
- Concerns include insufficient tolerance to water-logging, frost and high boron concentrations in the drainage water.
- Without drainage and adequate leaching in the tree blocks, the trees may also be injured by excess salt accumulation in the root zone.

A. Soil and Irrigation Water Quality Conditions

Soil conditions and the quality of irrigation water are the most important elements to consider when establishing trees. Soil sampling should be done to determine levels of salinity, boron and SAR before an area is planted. Soil salinity should not exceed 12 dS/m, boron should not exceed 12 ppm (3-4 ppm for pistachio and perhaps higher), and SAR should not be greater than 25. If these limits are exceeded, a drainage system is needed to leach out the elements before planting. Soil amendments such as gypsum, sulfur or sulfuric acid can be added to replace sodium which then must be leached below the root zone. Both the irrigation water and the shallow groundwater have to be tested for water quality: water salinity should be less than 8 dS/m, boron less than 10 ppm, and SAR less than 20 ppm. Pistachio, being the least boron tolerant, may require water of lower boron concentrations. As the most salt tolerant, Athel may withstand irrigation water or soil salinities higher than those listed.

B. Planting and Irrigation

The best time to plant trees in the San Joaquin Valley is the beginning of April to the end of June. Planting from July to the end of September is not recommended because of high summer temperatures.

Water must be available for irrigation immediately after planting. Water with a salinity of less then EC 3 dS/m is preferred for the first year of establishment on all plantings. Once established, eucalyptus trees and salt-tolerant grasses can be successfully irrigated with drainage water of about EC 8 to 12 dS/m. A sufficient volume of this saline water is required for salt leaching and a drainage system is required. Otherwise the salt load in the soil would increase to levels above ECe 20 dS/m, which is fatal to the trees.

Irrigation scheduling must provide for periods of soil drying and aeration. Gypsum applications have been shown to improve aeration and thus eucalyptus performance in soils with high clay content, according to studies at the Tulare Lake Drainage District (Oster, et al., 1999).

Over-irrigation and water ponding will damage the trees. The interceptor and relief plantings should be irrigated at least twice after the first year, once in May and then in September. These water applications will leach down some of the salts near the feeder roots. A good irrigation schedule for drainage water reuse plantations depends upon the soil and climatic conditions. The soil needs to dry out sufficiently between irrigations to reduce water-logging problems and anaerobic soil conditions.

C. Weed Control

Weed control is necessary to reduce competition with trees and habitat for rodents that damage trees. Weeds may also create environmental problems if they increase visitation or nesting by shore birds.

Undesirable weeds can be controlled by hoeing, disking and mowing or by applying a pre-emergent herbicide before planting and during the first two years of establishment. The first herbicide application should be made in March or April for summer annuals and September or October for winter annuals.

D. Grazing

Grazing can also be used once the trees are established and are over 10 feet tall. Good times for grazing are around April, and then again in July and October. Do not graze when soils are wet, as compaction will increase bulk density and reduce aeration and water infiltration. Mineral blocks can be set out to reduce damage by livestock girdling the base of trees. Blocks should be set out every two to five acres being grazed.

A cropping system that includes a combination of wider belts of salt-tolerant crops/grasses and rows of trees can also be considered. In this case, the irrigation water is mainly applied to crops/grasses but the trees also use it. This system is easy to manage as separate management can be employed for the crops/forages.

VII. Conclusion

Over the past decade, research and informal testing by university, government and resource agency personnel have identified a large number of salt-tolerant agronomic crops, forages, halophytes and trees that can be used in IFDM plantings. The final choice of species used within each of these groupings will depend on local soil and irrigation water salinities and boron concentrations, design of the particular IFDM system and intensity of management, and on grower preferences.