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DEL-SG-12-78

DOMESTICATION OF HALOPHYTES AS POTENTIAL CROPS FOR FOOD, FEED, OR MARSH IMPROVEMENT:

Summary of Progress--1974-1977

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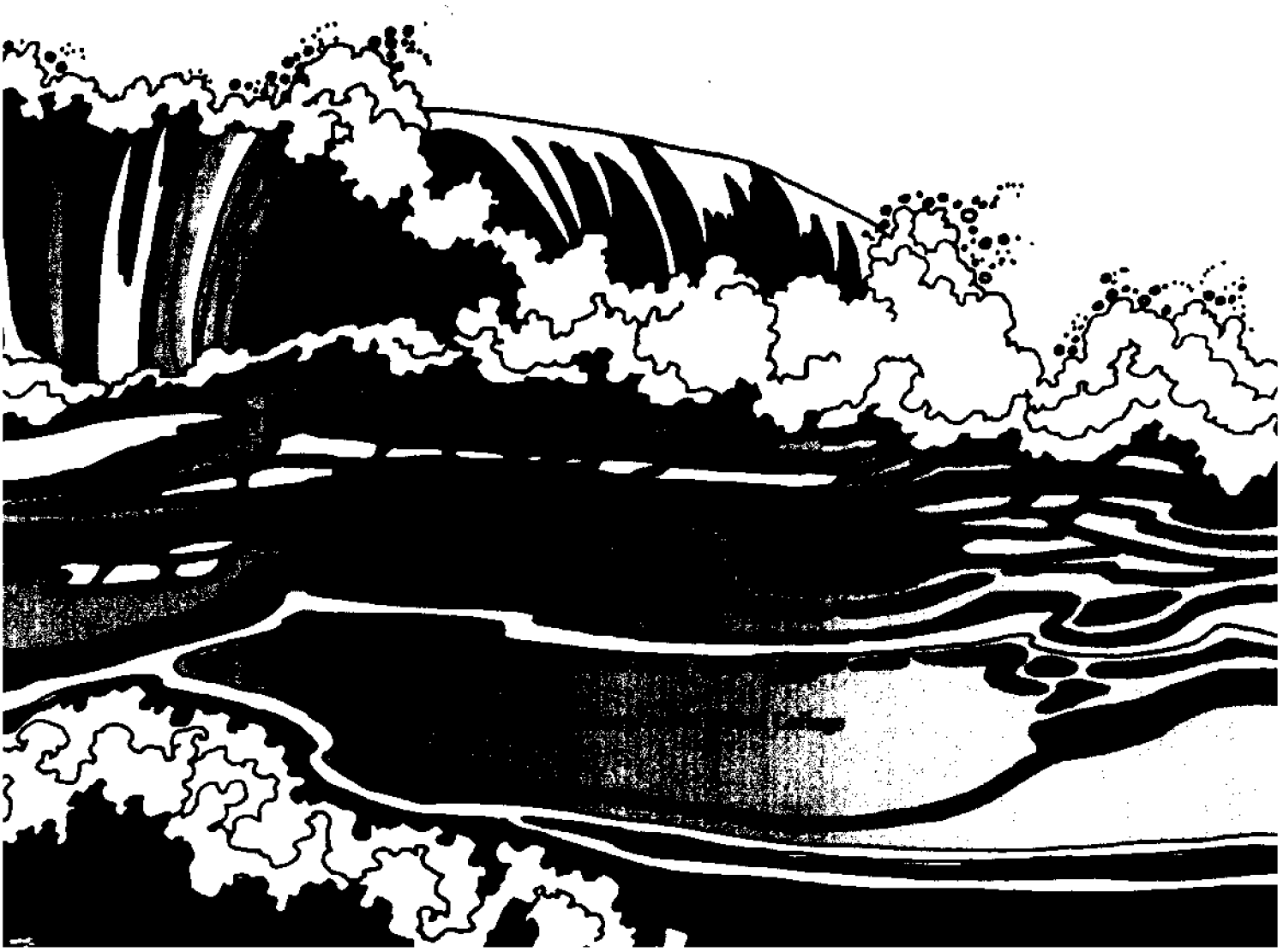

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DOMESTICATION OF HALOPHYTES AS POTENTIAL CROPS FOR FOOD, FEED, OR MARSH IMPROVEMENT:

Summary of Progress--1974-1977

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by

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INTRODUCTION

These investigations were undertaken in an effort to find salt-tolerant plants with potential as food crops for man or feed for domesticated animals, and to select superior plant lines for use in improving marshes. They were initiated September 1974 following a conference called to assess the desirability of further research in this field (Somers, 1975). The basic approach has been to assemble a collection of seeds from plants that grow in or near saline habitats and that appear to be potentially suitable as food or feed, either in the vegetative stage or as seed or fruit. Because coastal tide marshes and dunes were convenient to us, most of the species selected were from such habitats. However, seeds were obtained from a number of other sources as well; these were then evaluated for their capacity to germinate in the presence of a mixture of salts such as is found in sea water. Subsequent evaluation involved growth in the field and laboratory analyses. These basic criteria guided the selection of plants for further study (Somers, 1975):

1. Vigor of growth in saline habitats
2. Yield of fruit or other edible portion
3. General characteristics of edible portion, e.g., dry or fleshy, size
4. Quality of fruit or other edible portion
5. Potential for adapting to commercial production

A basic assumption has been that because of prolonged natural selection, plants that grow naturally in saline habitats have a greater intrinsic salt tolerance than crop plants, most of which display a very low tolerance for salinity in the soil or irrigation

water (Richards, 1954; Bernstein, 1964; and Maas and Hoffman, 1977). Barley is a notable exception to such a generalization (Boyko, 1966; Epstein, 1977; and Epstein and Norlyn, 1977). The natural occurrence of Hordeum jubatum in saline habitats suggests that this genus may be in some measure exceptional among conventional crop plants in possessing genetically determined salt tolerance. If this is a valid assumption, one then might be encouraged to look for other taxa with inherent salt tolerance. In natural populations salt-tolerant species are found in a number of plant families (Mudie, 1974). The cultivated beet (Beta vulgaris, Chenopodiaceae), in fact, displays a tolerance to rather high salinity (Boyko, 1966; Mudie et al., 1972). We were not particularly interested in exploiting this plant, however; we were more concerned about finding foods or feeds that offer a wider range of nutritional value, including proteins and vitamins. We have identified a limited number of species that show promise for meeting the overall objectives of this research. These will be described briefly in this publication and in more detail in later reports.

MATERIALS AND METHODS

Laboratory Methods. Two kinds of facilities were used for germinating seeds and for growing plants in the laboratory. One was conventional, reach-in type growth chambers in which the duration and temperature of light and dark cycles could be controlled. Illumination was provided by a mixture of fluorescent and incandescent bulbs. The salinity of the germination or growing medium was adjusted as desired by the addition of a mixture of artificial sea salts ("Instant Ocean," Aquarium Systems, Inc., Eastlake, Ohio). The

initial salinity was a minimal value because of water losses resulting from evaporation and/or transpiration. The initial volume was routinely restored by adding water.

The other laboratory facility for growing plants consisted of six carts on each of which was mounted a stainless steel tray 0.91 m x 1.22 m 10 cm (Fig. 1). These were located in a room illuminated by 96 fluorescent lamps in two 1.22 m x 2.74 m banks that were mounted as close together as possible and that extended over all of the trays; the fluorescent lamps were supplemented some of the time by twelve 100-watt incandescent lamps. The surface of the trays was 1 m from the lamps and light intensity at that point was about 6500 lux.

The inside of each of the growing trays was coated with an asphalt mixture and each was lined with a sheet of plastic. Plants were grown in 5.7 cm deep peat pots filled with sand; a solution of the desired salinity was cycled through each tray. (See Fig. 1.) To initiate each cycle, the solution was siphoned from the upper storage tank (Fig. 1, B) until the pots were immersed. The solution was then allowed to siphon slowly into the lower tank (Fig. 1, A). Volume losses resulting from evaporation or transpiration were replenished by filling the lower tank with tap water at the end of each cycle. Cycling varied from two times daily to three times weekly, depending upon the experiment in progress. The solutions used were mostly half-strength Hoagland's supplemented with the mixture of artificial sea salts. The NO_3 and phosphate content of the solutions were monitored by colorimetric tests.

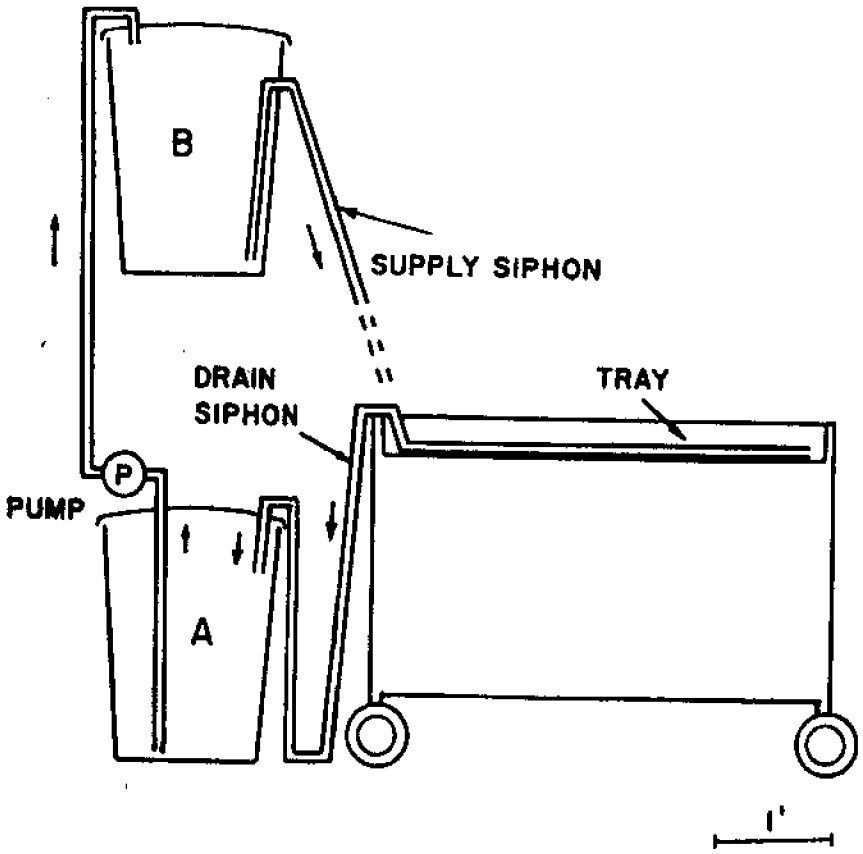

Fig. 1. Diagram of trays used for growing plants in the growing room and for providing recycled artificial sea water.
A = storage tank from which the solution is pumped, after adjusting the volume to provide the desired salinity, into tank B. A "fast" siphon, which is controlled by a clamp, delivers solution to the growing tray and a "slow" siphon returns it to tank A.

Seed was threshed by hand for the most part. In the case of Atriplex patula and Chenopodium album, the fruits were easily obtained by crushing the dried plants. Spartina alterniflora spikelets could usually be removed easily after the inflorescences had been stored in closed bags for a few weeks following harvest. In other cases, threshing was accomplished in a blender with its blades covered by plastic tubing and its speed controlled by means of a variable transformer. Winnowing of the seed from chaff, etc. was accomplished with screens and air currents for small lots of seed. For larger lots, winnowing was accomplished with a laboratory-size commercial seed cleaner ("Clipper" laboratory model, Ferrell-Ross, Saginaw, Michigan). Before being winnowed, fruits of Atriplex patula were milled to remove the bracts and fruits of Chenopodium album were milled to remove adhering calyces . Seeds of Spartina alterniflora for analysis and other laboratory studies except germination were removed from spikelets dried at 60C by milling in a blender as described above and winnowing with the seed cleaner.

Most of the cleaned seed was stored dry in closed containers at about 4C. Seeds of S. alterniflora were stored in 2/3 sea water and that of Zizania aquatica in about 1/3 sea water in closed containers at about 4C.

The germination capability of seed was determined using germination blotters moistened with the appropriate solution in plastic petri dishes. With S. alterniflora the seed (spikelets) were merely suspended in the solution. Germination was ususally carried out in reach-in growth chambers with diurnal cycling of light and temperature (Pihl, Grant, and Somers, 1978). Treating seed with

"Arasan" (thiram) controlled the growth of molds, which commonly occurred in the absence of such treatment and which was not controlled satisfactorily by treatment with NaOCl solutions.

In most cases, the freshly harvested seed was dormant. Germination could be effected by storage in the cold, by scarification, or by treating with concentrated H_2SO_4 (Pihl, Grant, and Somers, 1978). When continued growth of the seedlings was desired, the seedlings were transplanted from the petri dishes into pots filled with sand, in which they were grown in the trays described above with recycled nutrient solution containing a sea-salt mixture.

For small samples, the dry weight was determined by drying in a laboratory oven, usually at 60C. Large samples were allowed to dry at room temperature until the weight was constant. Subsamples were then dried at 60C (in some cases 105C) when dry weight at the higher temperature was desired.

Two instruments were used for salinity measurements: a salinity-conductance-temperature meter (Yellow Springs Instrument Co., Yellow Springs, Ohio, model 33) and a temperature-compensated refractometer (American Optical Co., Buffalo, New York) with salinity scale. Salinity of irrigation water in the field was measured mostly with the latter instrument.

Total nitrogen was determined by the micro-Kjeldahl method. The spectrum of amino acids of some seed lots was determined for us chromatographically by Siegelman and Alonzo of the Brookhaven National Laboratory, Upton, New York.

Methods for Field Plots. Field plots were in Lewes, Delaware, proximal to tidal streams. During the first summer (1975) they were

located adjacent to the Broadkill River (near Roosevelt Inlet) on an old sand dune which had been leveled. These plots were irrigated with water from the river by overhead sprinklers located close enough together to provide a substantial overlap in pattern. One-third of the plots were sprinkled with water from the river only, another third simultaneously with fresh water and river water, and the remainder with fresh water only. Beakers were located in the plots to sample the water from the sprinklers. Measurements of these samples provided data with respect to rates of application and salinity.

From 1976 on, plots were located near two additional tidal streams. One was the Lewes-Rehoboth Canal, near the Roosevelt Inlet, proximal to the mouth of the Delaware Bay, about 6 km from the Atlantic Ocean. The other stream was a small branch of Canary Creek which joins the Canal at Roosevelt Inlet. This stream drained a relatively small portion of Canary Creek marsh. Plots were established adjacent to the canal on soil which appeared to be largely old dredge spoil. The soil profile to a depth of 60 cm ranged from essentially sand to finer material containing brown to black organic matter.

Soil cores were taken at the old dredge-spoil site before plots were established. Many locations contained a band of material which was characteristically black in some cases and was very hard. The latter appeared to be the result of more or less cementing together of soil particles by iron oxide in the old spoil. This dark layer occupied up to 15 inches (38 cm) of the upper 24 inches (60 cm) of soil (Fig. 2). Sometimes it occurred as relatively thin (2.5 cm to 5 cm), dense bands. The pH of various zones of these soil cores was

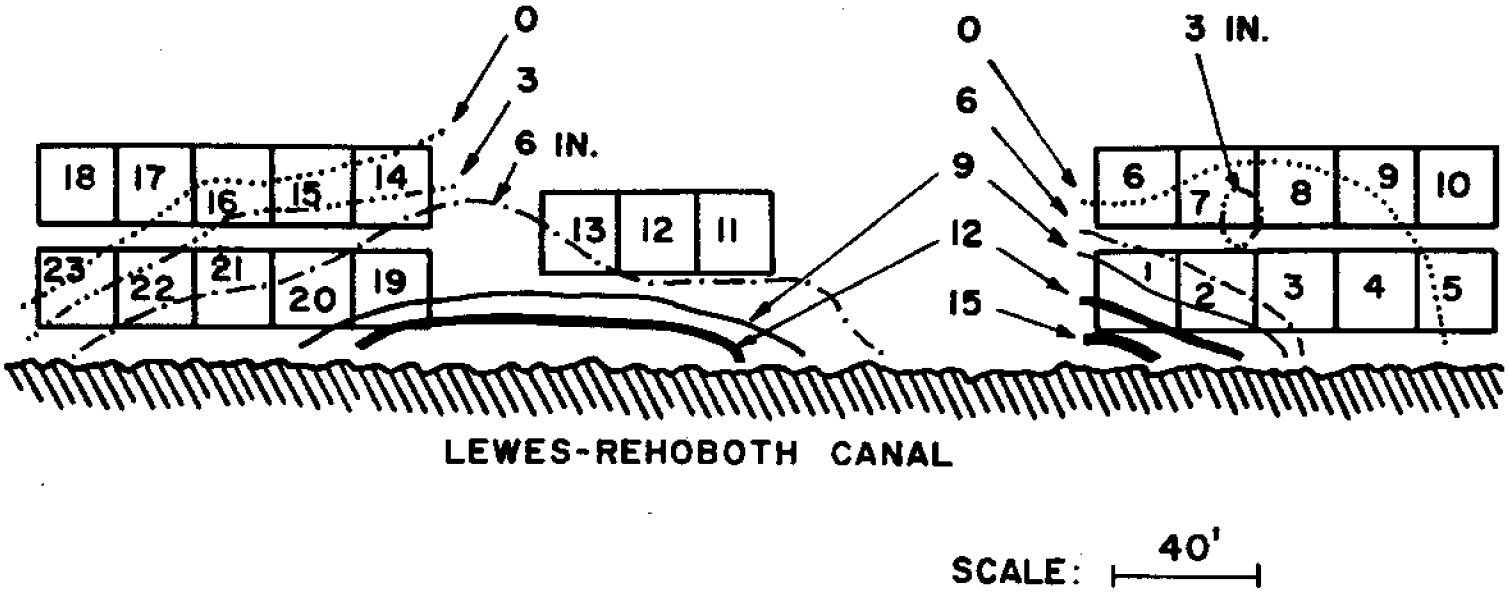

Fig. 2. Diagram of plots adjacent to Lewes-Rehoboth Canal. Contours of the depth of a brown-black, dense layer in the soil profile are shown. These occupied from none to 15 inches of the top 24 inches. The rest of the profile was sand.

measured after the cores were suspended in water. Concern was had for the possibility that they may have become very acid as a result of oxidation, a phenomenon observed commonly in dredge spoils. However, for the most part, the pH was between 6 and 8; of 56 samples the lowest pH was 4.0, the highest, 8.6, and the average, 7.0.

Plots located near the marsh stream were on soil mapped as Rumford loamy sand (Soil Survey of Sussex County, U.S. Dept. of Agr., Soil Cons. Service, and Delaware Agr. Expt. Station), which had been used formerly for growing farm crops, most recently soybeans.

These plots resembled small rice paddies. Each was approximately 6.7 m x 7.3 m and was bounded by a low earthen bank which was lined with polyethylene to 8 cm to 10 cm below the surface of the plot . The surface of the plots was leveled to flood uniformly. After the 1975 season, water for irrigation was pumped from the canal or from the marsh stream, depending on the plots in question, using pumps with fiberglass housings and plastic impellers. It was distributed through plastic pipes; flow to the plots was controlled by plastic valves and 3.8-cm-diameter plastic pipes coupled to the valves with flexible tubing (Fig. 3). The main distribution pipes were provided with drain plugs which were removed after each irrigation. This was done to minimize fouling. After being used for two seasons these pipes were free of fouling organisms. Flow to each plot was at such a rate to provide rapid, uniform flooding to a depth of about 5 cm. In this way all of the soil in each plot was saturated relatively uniformly three to five times weekly.

Salinity of the irrigation water was measured regularly, both by sampling the source and by measuring the salinity of the water on the

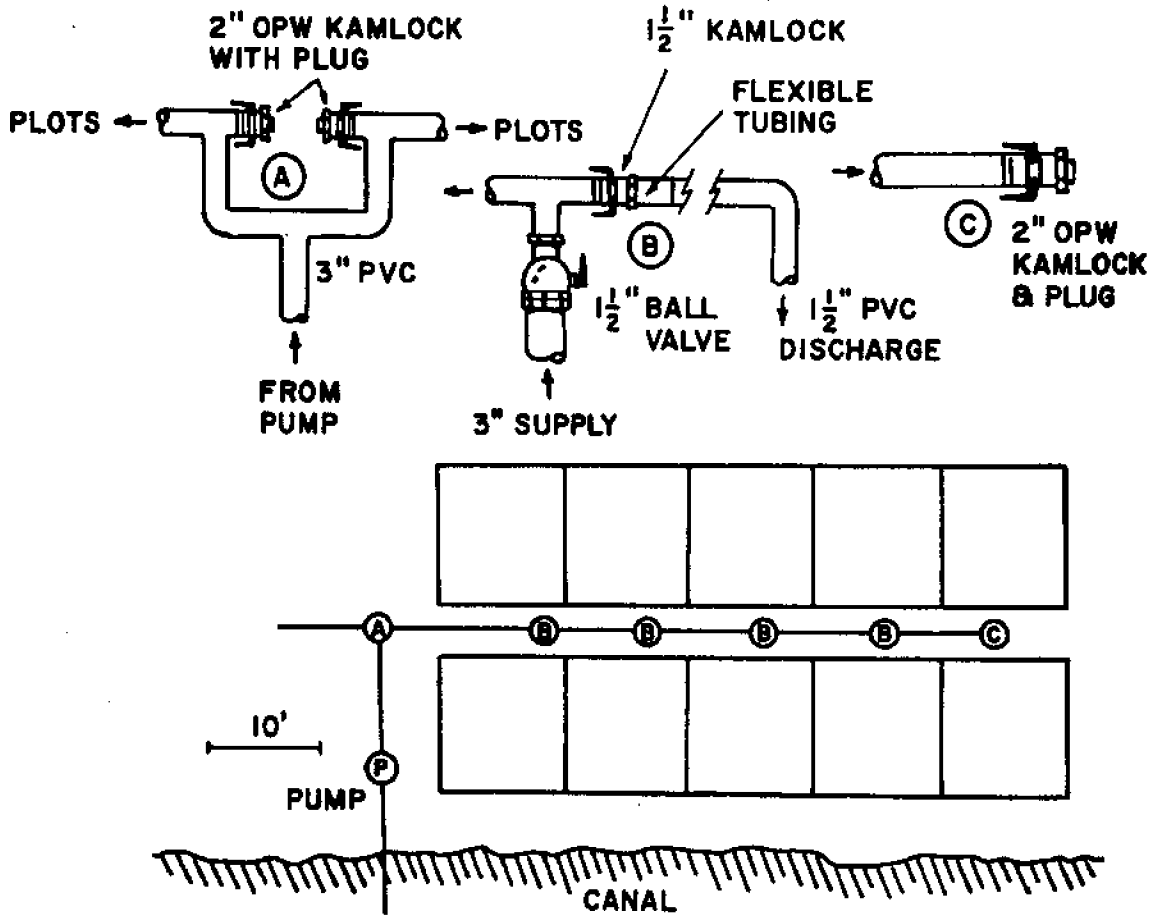

Fig. 3. Diagram of a portion of the irrigation distribution system for field plots. The main lines from the canal, to the pump and to the plots were 7.6 cm (3") PVC plastic. The major portions of each line could be drained by removing plugs, e.g. at A and C. Flow to each plot was controlled by a 3.8 cm (1-1/2") ball valve (B) coupled with flexible tubing to a 3.8 cm (1-1/2") PVC pipe. There was a ball valve and a drain plug at C. The energy of the stream onto the plots was reduced by discharging it into a plastic bucket.

plots. The latter was monitored both soon after irrigation and again just before irrigation in those cases where it had not all drained away. In many cases the rate of percolation into the soil was such that there was no free water on the surface of the soil at the time of irrigation. In some of the plots on the Rumford loamy sand soil the saline water from the marsh stream was blended with fresh water.

Periodically the rate of infiltration of water into the soil was estimated by measuring the decrease in level of water on the plots as a function of time (Table 1). No correction was made for evaporation. As a consequence, the observed values are higher than actual percolation, but they do give a measure of how soon free water disappeared from the surface of the soil. In those plots in which no water remained on the surface, the water content of the soil would be expected to decrease to field capacity and then the salinity should begin to increase as further drying occurred as a result of evaporation and transpiration. (The soils were always moist at the time of the next irrgiation.)

Accumulation of salts in the plot soil was tested for by preparing saturation extracts of cores (Richards, 1954). These extracts were prepared using the same water used for irrigation. This gave a measure of the degree to which any salts which had accumulated in the soil would increase the salinity of the applied water.

Preliminary tests of trickle irrigation were made during the summer of 1977 using drip irrigation and "Viaflo" tubing (courtesy E. I. du Pont de Nemours & Company, Inc., Wilmington, Delaware).

Plants grown in the laboratory in peat pots were transplanted into field plots following a conditioning period in the field. To

Table 1. Rate of percolation of water into the field plots for 1977 growing season.

Plot No.	Draining time hours[a]		Percolation rate liters x m^{-2} x hr^{-1}	
	Dredge spoil	Rumford loamy sand	Dredge spoil	Rumford loamy sand
1	104	22	0.48	2.3
2	100	43	0.50	1.2
3	90	37	0.56	1.4
4	70	31	0.71	1.6
5	38	17	1.3	3.0
6	27	11	1.9	4.8
7	39	11	1.3	4.6
8	29	6.6	1.7	7.5
9	40	7.1	1.3	7.0
10	34	6.2	1.5	3.1
11	24	7.8	2.1	6.4
12	13	7.1	3.9	7.0
13	16	8.6	3.1	5.8
14	c. 9	15	c. 5.6	3.3
15	17	7.1	2.9	7.0
16	20	-	2.5	-
17	17	25	2.9	2.0
18	20	(7.2)[b]	2.5	(6.9)[b]
19	25	7.7	2.0	6.5
20	19	-	2.6	-
21	20	-	2.5	-
22	19	7.5	2.6	6.7
23	20	21	2.5	2.4
24	-	23	-	2.2

[a]Hours required for the level to decrease by 5 cm.

[b]One value only.

minimize the shock of moving the plants from the low light intensity of the growing room to full sunlight in the field, plants were grown for one week or more under a shade which was gradually reduced to full sunlight.

Various quantitative measures of plant response were used, including fresh and dry weight of whole plants or parts thereof. In the case of Spartina alterniflora and other grasses in the field, the height of culms was measured to the tip of the uppermost leaf, extended upward for measurement. Counts of the number of stems were made and of the number, size, and dry weight of inflorescences.

In addition, especially for plots of Spartina alterniflora, qualitative ratings were made by each of three independent evaluators. These ratings included composite evaluation of vigor, number of stems, color, and size.

Insect pests were controlled by spraying as needed with "Systox," a commercial formulation of demeton. Weeds were not a problem in most of the highly saline plots, except for Phragmites communis in some plots, plants of which were pulled when they appeared. In plots maintained at about 20 $^{0}/_{oo}$ salinity Panicum dichotomiflorum was a problem; it was controlled by pulling out the unwanted plants.

RESULTS

The salinity of the water used for irrigation of field plots during the 1977 growing season is summarized in Fig. 4 and Table 2. In the Canal, the water occasionally was only 20 to 22 $^{0}/_{oo}$ salinity during March, April, and May. Such low values followed spring rains and drainage of fresh water from nearby upland areas. However, during

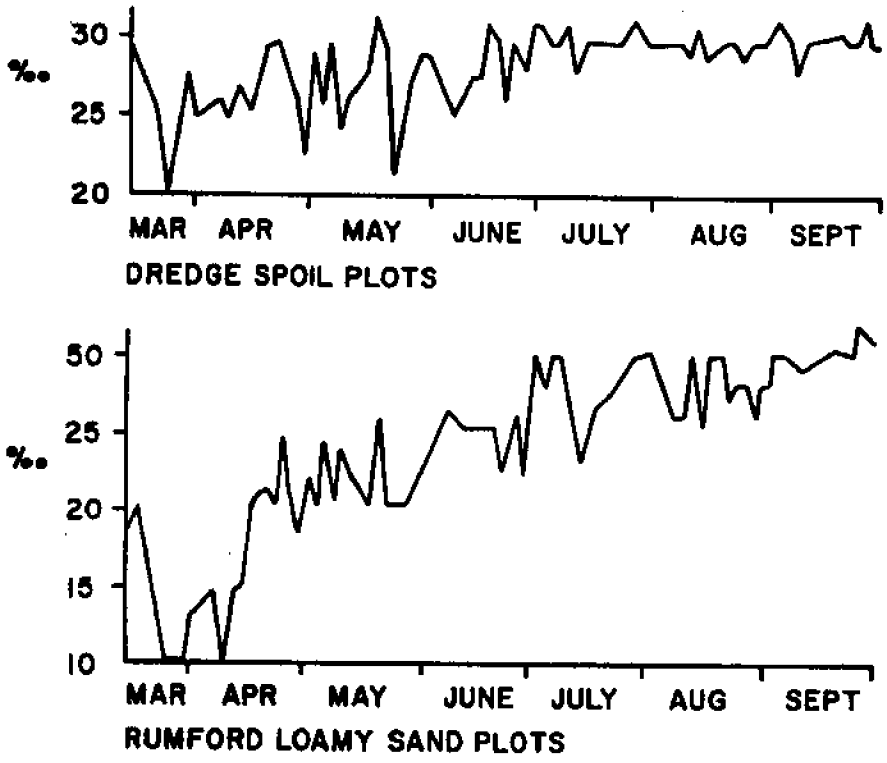

Fig. 4. Salinity of water used for irrigation during the 1977 growing season.

Table 2. Monthly averages for the salinity of water used for irrigation during the 1977 growing season.

	Rehoboth-Lewes Canal			Tidal Stream, Canary Creek Marsh		
	Mean	S.Dev.	n	Mean	S.Dev.	n
March	25.6	3.8	5	14.5	5.3	4
April	26.8	2.4	11	17.8	4.3	12
May	27.5	3.0	12	21.8	2.2	11
June	28.7	2.2	11	24.6	1.5	9
July	30.5	1.2	11	28.0	2.4	9
Aug.	30.0	0.9	10	27.6	1.8	11
Sept.	30.3	1.1	11	30.3	1.0	7
Oct.	*			*		
Nov.	24.6	1.5	5	17.8	5.1	4

*No observations

most of the growing season, the salinity of this water was 30 to 32 °/oo. The water used for the Rumford sandy loam plots was less saline, especially during the spring months; there were periods in March when it was only 10 °/oo. In April it increased to a value of generally > 20 °/oo; for most of June it was about 25 °/oo, and for the rest of the growing season was 25 to 30 °/oo. The salinity of both sources of water was rather consistently high from June through September. The salinity was lower in November. (No measurements were made in October.)

The pattern of salinity in the summer of 1976 was similar to that of 1977. The water used for irrigation in 1975 was similar to that from the Lewes-Rehoboth Canal.

The rate at which water percolated into the various plots varied considerably. One subjective measure of this was the observation that some plots still had water standing on them from the previous irrigation when they were flooded once again. Such observations were used to compute an "index of wetness":

$$\text{Index of wetness} = \frac{W}{W+D}$$

where W is the number of times the plot had water standing on it at the time of the next irrigation, and D is the number of times it was recorded as having no visible water at that time (Table 3). A more quantitative measure of the rate of percolation of water into the soil was obtained also (Table 1). Times for the water level to decrease from 5 cm (the level following irrigation) to 0 was projected from regression curves computed from measurements of the depth of the water

Table 3. Index of wetness.
See text for definition of this index.

Old Dredge Spoil Plots	9/27-10/16/76	5/6-6/16/77
1	1.0	1.0
2	1.0	1.0
3	1.0	1.0
4	1.0	1.0
5	1.0	0.75
6	0.67	0.63
7	0.83	0.75
8	0.83	0.75
9	0.83	0.75
10	0.67	0.63
12	0.50	0.16
Loamy sand plots		
1	0.83	0.48
2	0.83	0.93
3	0.83	0.79
4	0.83	0.79
5	0.50	0.52
6	0.33	0.28
7	0.33	0.28
8	0.33	0.25
9	0.33	0.22
10	0.17	0.24
11	0.20	0.19
12	0.50	0.08
13	0.50	0.15
14	0.33	0.22

in the plots at various intervals following irrigation. On some plots there was water continuously except, in some cases, after the three-day weekend. In other cases there was no water visible after a relatively few hours. However, the soil was still moist at the time of the next irrigation.

A few measures of percolation rate were obtained toward the end of the growing season of 1976. Those for the 1977 season (Table 1) show a wide range of values. The few values for 1976 were similar. It is clear that there were great differences among the plots in percolation rates. In those plots on the old dredge spoil there was a general correlation between a low percolation rate and the presence of the dark material in the top 60 cm of soil (Fig. 2). The absence of this layer was associated with rapid percolation. No observations were made for such a layer in the soil of the sandy loam plots. The soil survey description does not mention one. It should be noted that the plastic used to line the banks of the plots extended 8 cm to 10 cm below the surface. As a result, percolation through the dikes was precluded.

The salinity of the water standing on the plots seldom was more than 1 to 2 $^{o}/_{oo}$ greater than that of the water used for irrigation. Hence, it seems likely that the water in the soil around the roots was similar in salinity to that applied in these cases. Such a conclusion is, of course, not warranted for plots on which the water did not stand continuously. As a result of continued evaporation and transpiration the salinity of the soil water may have increased markedly. It is noteworthy that Spartina alterniflora did not grow so well on these plots as it did on the ones which retained water on their surface (Somers, 1978).

An attempt to assess any accumulation of salt in the soil was made by preparing saturation extracts on October 6, 1977, of soil cores using water from the same sources as for irrigation. In most cases the salinity of these extracts was slightly higher than that of the irrigation water (Table 4), but there is no obvious correlation with the percolation rate. The highest value for the saturation extracts was 39 °/oo in dredge spoil as compared with 31 °/oo for the water used to prepare the abstract. It would appear that there has been a modest accumulation of salt in the upper layers of soil. This is a matter which requires further study.

A summary of many evaluations of various species for salt tolerance for three years is summarized in Table 5. For more details regarding germination responses see Pihl, Grant, and Somers (1978).

Analyses for total protein content of the seeds of some of these plants are summarized in Table 6. The spectrum of amino acids of these materials is given in Tables 7 and 8. Protein is assumed to be 6.25 x total N content. The amino acid content of the protein of Kosteletzkya virginica embryo (Table 7) is lower in lysine and methionine content than casein. The amounts of these amino acids are about 75% and 70% respectively that of casein. The protein of seeds of Chenopodium album and Atriplex patula contain only about 40% and 30% respectively as much methionine as casein. Otherwise, these materials compare rather well with casein in relative amounts of essential amino acids. By and large, the protein of the grass seeds (S. alterniflora and D. spicata) compare rather well in spectrum of essential amino acids with published values for wheat gluten (Table 7), except that they contain about 70% and 80% respectively as

Table 4. Salinity of saturation extracts prepared from soil cores taken from field plots.

	Excess Salinity (°/oo)[a]			
	Dredge spoil		Loamy sand	
Plot No.	0-5 cm	5-10 cm	0-5 cm	5-10 cm
1	6	3	9	10
2	7	4	8	
3	4		8	
4	6		7	
5	6		-	
6	4	6	6	8
7	4	4	7	
8	6		8	
9	8		-	
10	8		-	
11	5		-	
12	6		-	
13	4		-	
14	3	1	-	
15	0		6	
16	0		-	
17	0		8	
18	8		8	
19	6		2	
20	8		-	
21	4		-	
22	2		3	
23	0		6	
24	0		7	

[a]Extracts were prepared using irrigation water. Soil cores were for 0-5 cm and 5-10 cm and were measured separately in some cases. Where only one value is given it represents a 0-10 cm core. Salinity values are corrected for the salinity of the irrigation water (31 °/oo for dredge spoil; 23 °/oo for loamy sand).

Table 5. Evaluation of various species for salt tolerance.[a]

Species	1974-1975 Lab. Germ.	1974-1975 Lab. Grow	1974-1975 Field Germ.	1974-1975 Field Grow	1975-1976 Lab. Germ.	1975-1976 Lab. Grow	1975-1976 Field Germ.	1975-1976 Field Grow	1976-1977 Lab. Germ.	1976-1977 Lab. Grow	1976-1977 Field Germ.	1976-1977 Field Grow
Amaranthus cannabinus (L.) Sauer	+	10	-		-							
Ammophila breviligulata Fern	+		-		+				+			
Amorpha fruticosa L.	+		-	+			+	-				
Atriplex arenaria Nutt	+		25	25								
Atriplex canescens (Pursh.) Nutt	-		10									
Atriplex confertifolia (Torr. & Frem.) S. Wats	+	10	-									
Atriplex cuneata	+		-									
Atriplex patula var. *hastata* (L.) Gray	34	+	10	10	10	20	+	30			30	30
Bidens cernua L.											-	
Borrichia frutescens (L.) DC.					+						20	20
Bromus tectorum L.	17		-	10								
Cakile edentula (Bigel.) Hook	34[b]	+ 10	25	25			+	25				

Table 5 (continued)

Species	1974-1975 Lab. Germ.	1974-1975 Lab. Grow	1974-1975 Field Germ.	1974-1975 Field Grow	1975-1976 Lab. Germ.	1975-1976 Lab. Grow	1975-1976 Field Germ.	1975-1976 Field Grow	1976-1977 Lab. Germ.	1976-1977 Lab. Grow	1976-1977 Field Germ.	1976-1977 Field Grow
Chenopodium album L.				25	10	-	+	25	+	+	30	28
Chenopodium quinoa Willd.	+		10 25	+	22		+					
Distichlis spicata (L.) Greene	34			22	22	10		30			30	30
Distichlis stricta (Torr) Rydb.	+											
Echinochloa walteri (Pursh) Nash.		10			+	10	+	25				
Elymus mollis Trin.											+	20[e]
Elymus virginicus L.					+		+	15	+	15	+	20 [+]
Euphorbia polygonifolia L.	-[g]											
Geraea canescens Torr. & Gray	-		-		+							
Hibiscus pulustris L.	10	10	10				+	+				
Hudsonia tomentosa Nutt.	+											
Iris versicolor L.	+	+	-	10								
Kosteletzkya virginica (L.) Presl.	+		10 25[h]	+[i]	22	10 20	+	25	7 12	16	+	20[i]

Table 5 (continued)

Species	1974-1975 Lab. Germ.	1974-1975 Lab. Grow	1974-1975 Field Germ.	1974-1975 Field Grow	1975-1976 Lab. Germ.	1975-1976 Lab. Grow	1975-1976 Field Germ.	1975-1976 Field Grow	1976-1977 Lab. Germ.	1976-1977 Lab. Grow	1976-1977 Field Germ.	1976-1977 Field Grow
Lepidium virginicum L.	34										+	25[j]
Limonium sp.	34			25								
Opuntia compressa (Salisb.) Macbr.				25	+	20		25[k]				
Panicum amarulum Hitchc. and Chase			-	+ [10]	+	-						
Panicum dichotomiflorum Michx.											+	20
Panicum miliaceum L.	+		-	[10]	+	-						
Panicum virgatum L.						-[1]						
Peltandra virginica (L.) Kunth.	22	5	-	[4]								
Pennisetum ruppelianum	+	+	+									
Pennisetum typhoides	+	+	+									
Polygonum coccineum Muhl			-									
Prosopsis juliflora (Sw.) DC.	+		+	[10]								
Prunus maritima Marsh.	+		+	+			+	+				
Rosa rugosa Thunb.	-		-				+	-				

Table 5 (continued)

Species	1974-1975 Lab. Germ.	1974-1975 Lab. Grow	1974-1975 Field Germ.	1974-1975 Field Grow	1975-1976 Lab. Germ.	1975-1976 Lab. Grow	1975-1976 Field Germ.	1975-1976 Field Grow	1976-1977 Lab. Germ.	1976-1977 Lab. Grow	1976-1977 Field Germ.	1976-1977 Field Grow
Rumex crispus L.							+	25[m]				
Salicornia bigelovii Torr.	+	10	10	25								
Salicornia europaea L.	34	10	10									25
Scirpus americanus Pers.	+											
Scirpus robustus Pursh.	+	[5]	10	10	22	10		[25]			-	[25]
Setaria geniculata (Lam.) Beauv.					+	-						
Setaria magna Griseb.	+		-	[10]	+							
Spartina alterniflora Loisel.	+		10	25	22			30	34	40	30	30
Spartina cynosuroides (L.) Roth.	+		-									
Spartina patens (Ait) Muhl.			-	25				30				30
Spergularia marina (L.) Griseb.				25			+	25				
Strophostyles helvola (L.) Ell.	10		10	+ [10]	10	10 [20]	+	[25]				

Table 5 (continued)

Species	1974-1975 Lab. Germ.	1974-1975 Lab. Grow	1974-1975 Field Germ.	1974-1975 Field Grow	1975-1976 Lab. Germ.	1975-1976 Lab. Grow	1975-1976 Field Germ.	1975-1976 Field Grow	1976-1977 Lab. Germ.	1976-1977 Lab. Grow	1976-1977 Field Germ.	1976-1977 Field Grow
Strophostyles umbellata (Muhl.) Britt.	-		10	+								
Suaeda fruticosa (L.) Forsk.	+		-	10								
Suaeda maritima (L.) Dum.		+	10	25			+	25				
Tripsacum dactyloides (L.) L.	+		10	+			+					
Uniola latifolia Michx.	+		-	[10]								
Uniola paniculata L.	+											
Zizania aquatica L.	10	3 [10]	-	[10]								[25]
Zostera marina L.	-											

[a] - = unsuccessful attempt made to germinate or grow in fresh water; + = germination or growth in fresh water was successful; numbers = highest salinity (°/oo) at which germination or growth occurred; [numbers] = germination or growth attempted at this salinity (°/oo), but not successful.

[b] Cakile edentula: 1974-75, Proximal seed removed from pericarp germinated at 34 °/oo. Distal seed removed from pericarp germinated at 17 °/oo.

[c] Chenopodium quinoa: 1974-75, Seeds may have germinated because of a 2-1/2" rainfall rather than have germinated at 25 °/oo.

[d] Chenopodium quinoa: Seeds germinated at 10 °/oo, but plants never more than 4 cm tall.

Table 5 (continued)

[e]*Elymus mollis*: Plants survived in 20 °/oo, but grew very poorly.

[f]*Elymus virginicus*: 1976-77, Grew well at 0 °/oo, but when salinity increased to 20 °/oo plants died.

[g]*Euphorbia polygonifolia*: 1974-75, 10% germination in H_2O after 21 days in one test of several at temperature cycle of 12-35°C and with white layer over seed coat removed.

[h]*Kosteletzkya virginica*: 1974-75, Seeds may have germinated because of a 2-1/2" rainfall rather than have germinated at 25 °/oo.

[i]*Kosteletzkya virginica*: Seeds germinated at 10 °/oo, but seedlings never got out of cotyledon stage. Plants grew in 20 °/oo, unless saline water wet the leaves.

[j]*Lepidium virginicum*: 1976-77, Appeared in field plots as a result of seeding from nearby plants or as seed from previous years.

[k]*Opuntia compressa* (Salisb.) Macbr.: 1975-76, Established, wild colony grew well at 25 °/oo, but transplants did not survive at 25 °/oo. Specimens also agree with description for *O. humifusa* Raf.

[l]*Panicum virgatum*: 1975-76, 5% germination in H_2O in only one test of several.

[m]*Rumex crispus*: 1975-76, Seems to grow at 25 °/oo as long as the salt water stays off the leaves.

Table 6. Protein content.

	Portion Analyzed	(N x 6.25) Protein
Acnida cannabis	whole seeds	23.5
Atriplex patula	small seeds	14.2
Atriplex patula	large seeds	16.2
Borrichia frutescens	whole seeds	14.6
Chenopodium album	whole seeds	16.7
Distichlis spicata	whole seeds	13.9
Echinochloa walteri	"endosperm"	16.5
Elymus mollis	whole seeds	19.5
Elymus virginicus	whole seeds	23.8
Kosteletzkya virginica	embryo	33.6
Rumex crispus	whole seeds	13.3
Scirpus robustus	whole seeds	8.0
Spartina alterniflora	whole seeds	15.0
Strophostyles helvola	whole seeds	22.5

Table 7. Spectrum of amino acids in proteins of seeds.

(g Amino acid/100 g protein)

	Kost. virg.[a]	Atr. pat.	Chen. alb.	Spar. alt.	Dist. spic.
Alanine	6.2	2.5	2.7	3.9	4.6
Arginine	17.9	5.4	6.9	4.2	2.5
Aspartic acid	13.9	5.2	6.0	5.7	3.6
Cystine[b]	3.6	1.1	1.2	0.8	1.3
Glutamic acid	27.5	8.4	11.8	22.3	21.3
Glycine	7.1	3.1	4.6	2.7	1.9
Histidine	4.2	1.5	2.0	1.4	1.6
Isoleucine[c]	5.4	2.4	2.7	2.7	3.1
Leucine[c]	9.8	3.6	4.2	5.3	6.0
Lysine[c]	5.9	2.9	3.3	2.4	1.4
Methionine[c]	2.1	0.9	1.3	0.9	1.0
Methionine SO_2[d]	2.4	1.0	1.5	1.3	1.8
Phenylalanine[b]	7.7	2.6	2.9	3.0	3.5
Proline	5.2	2.1	2.6	2.9	3.6
Serine	6.9	2.6	2.9	2.7	2.9
Threonine[c]	4.9	2.1	2.3	2.1	2.5
Tyrosine	1.12	2.0	2.2	2.5	2.6
Valine[c]	7.4	2.9	3.4	3.9	4.1

[a] Kost. virg. = Kosteletzkya virginica, Atr. pat. = Atriplex patula, Chen. alb. = Chenopodium album, Spar. alt. = Spartina alterniflora, Dist. spic. = Distichlis spicata.

[b] Cysteic acid by performic acid analysis; computed as cystine.

[c] Required by man.

[d] Methionine SO_2 by performic acid analysis; computed as methionine.

These analyses were performed by Siegelman and Alonzo, Brookhaven National Laboratory, Upton, New York.

Table 8. Amino acid content of seeds.
(g Amino acid/100 g seed)

	Kost. virg.[a]	Atr. pat.	Chen. alb.	Spar. alt.	Dist. spic.
Alanine	1.06	0.35	0.46	0.58	0.64
Arginine	3.04	0.75	1.18	0.63	0.35
Aspartic acid	2.36	0.73	1.02	0.86	0.51
Cystine[b]	0.62	0.16	0.20	0.12	0.18
Glutamic acid	4.68	1.18	2.01	3.34	2.98
Glycine	1.20	0.44	0.78	0.40	0.26
Histidine	0.71	0.21	0.34	0.21	0.23
Isoleucine[c]	0.91	0.33	0.46	0.40	0.43
Leucine[c]	1.67	0.51	0.71	0.79	0.84
Lysine[c]	1.01	0.41	0.56	0.36	0.20
Methionine[c]	0.36	0.12	0.22	0.13	0.14
Methionine SO_2[d]	0.40	0.14	0.25	0.20	0.25
Phenylalanine[c]	1.31	0.37	0.50	0.45	0.49
Proline	0.88	0.30	0.44	0.44	0.50
Serine	1.17	0.37	0.50	0.41	0.41
Threonine[c]	0.84	0.30	0.39	0.31	0.35
Tyrosine	0.19	0.28	0.37	0.38	0.37
Valine[c]	1.25	0.41	0.58	0.59	0.58

[a]Kost. virg. = Kosteletzkya virginica, Atr. pat. = Atriplex patula, Chen. alb. = Chenopodium album, Spar. alt. = Spartina alterniflora, Dist. spic. = Distichlis spicata.

[b]Cysteic acid by performic acid analysis; computed as cystine.

[c]Required by man.

[d]Methionine SO_2 by performic acid analysis; computed as methionine.

much phenylalanine, and about 60% and 70% respectively as much methionine. In lysine content S. alterniflora exceeds wheat gluten and D. spicata contains about 80% as much.

Atriplex patula var. hastata grew rather well in the field. In one case (loamy sand soil) the seeds were left on the ground in the fall. They germinated in the spring of 1977 under natural rainfall and beginning about 4 weeks later (late April) they were subjected to flooding three times weekly with water from the tidal ditch (Fig. 4). In another case, seed was planted into a dredge spoil plot and irrigated three times weekly with water from the canal (salinity 30 to 32 $^{o}/oo$). Seed from at least one source germinated and grew reasonably well. The plants were smaller than those in the other test, but they were planted several weeks later and were subjected at all times to water of higher, sometimes much higher, salinity.

DISCUSSION AND CONCLUSIONS

Of the 60 species listed in Table 5, only these few have responded readily to efforts to germinate or grow them in saline water:

Atriplex arenaria

**Atriplex patula* var. *hastata*

Cakile edentula

**Chenopodium album*

**Distichlis spicata*

**Kosteletzkya virginica*

Lepidium virginicum

**Panicum dichotomiflorum*

Salicornia bigelovii

Salicornia europaea

**Spartina alterniflora*

**Spartina patens*

Suaeda fruticosa

Suaeda maritima

Opuntia compressa also grows well when irrigated with highly saline water, but the growth is very slow, even with fresh water.

Of those tested so far, the ones which appear most promising for further investigation, considering other characteristics in addition to salt tolerance, are indicated with an asterisk in the above list. *Atriplex patula* L. (*sensu* Gleason, 1952) is a highly variable taxon and, in fact, probably should be considered more than one (Taschereau, 1972). It has responded very well to tests both in the laboratory and

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*Selected for further investigation

in the field. Dry-matter yields equivalent to 12.1 to 13.7 tonnes/hectare (5.4 to 6.1 tons/acre) and seed yields equivalent to 470 to 503 kg/hectare (1040 to 1110 lbs/acre) were obtained in 1977 from plants which germinated in fresh water but grew most of the season in water of 25 to 30 ^{o}/oo. Many selections of this species are available for further selection. This plant can be eaten as a salad green or potherb when it is young. Further evaluation of its nutritive qualities should be undertaken before it is recommended for general dietary use.

Obviously this plant has substantial potential as a food crop for man and animals. The seeds are dimorphic and small. The larger ones are about 2.0 mm in diameter; the small ones 1.0 mm. As is the case with most wild plants, the seeds shatter badly. To obtain the yields reported above, care had to be taken to recover seeds that had fallen to the ground. Hopefully, lines that shatter less readily might be selected. This species merits substantial further testing.

Chenopodium album seedlings grew well; they were transplanted into loamy sand soil and grown throughout the season (1977) with flooding three times weekly with water which was mostly 25 to 30 ^{o}/oo salinity. When mature, the seeds amounted to 30% of the total dry weight of the plants. Obviously it produces tremendous quantities of seeds, but they are small (1.0 mm). The plant is commonly used as a potherb. As a forage for sheep it compares favorably with oats in palatability and with high-quality alfalfa in nutrient composition and digestibility (Marten and Andersen, 1975). This plant also merits serious consideration in further studies.

Distichlis spicata has not been evaluated very extensively. Some seed planted into the dredge-spoil plots germinated in the presence of water of about 30 $^{o}/_{oo}$ salinity. The plant grows slowly and appears to prefer soils which do not remain waterlogged. It is dioecious, which could pose a problem for seed production. Another closely related species, D. stricta (some authors consider these two as varieties of a single taxon), grows in inland saline areas. It was observed being grazed upon by cattle and horses in Sonora, Mexico, in the Colorado River delta region. Seed production appears to be good. The seed are about 1.3 mm x 2.4 mm.

While it is not so salt tolerant as the three species described above, Kosteletzkya virginica merits serious consideration. The seeds are relatively large, 4 mm, do not shatter badly, and are produced in what appear to be good quantities. The seeds contain large amounts of a gum or mucilage which might have useful properties. However, this plant has not proved to be winter hardy in Delaware. Nearly all plants died during the winter months of 1977-78. Hopefully, selection might provide more tolerant lines.

Panicum dichotomiflorum is an annual which grows abundantly in water of at least 20 $^{o}/_{oo}$ salinity. It produces copious quantities of small seeds. It appears to merit further consideration, but very little has been done with it.

Spartina alterniflora is the major grass of the tidemarshes of eastern United States. We have given this species substantial attention and will report more fully in another publication. It is clear that plants from seeds collected from different sources differ significantly in growth characteristics. Selection to take advantage

of this variability should prove useful. The value of the plant as a forage needs to be determined.

Spartina patens has been used as a forage for a long time. Such use is common practice in various places in the eastern United States and Canada. This plant is also very variable. Seedlings from a single source produced plants that differed markedly in color and growth characteristics. Natural populations differ greatly in growth habit.

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