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Reclamation of Saline Organic Soil

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Summary. Reclamation of saline, organic soils in the Sacramento-San Joaquin Delta of California was accomplished by both sprinkling and continuously ponding water on the soil surface. The reclamation data support the generalized guideline established for saline, organic soil.

A 70% reduction in the average root zone salinity required 3 months under ponding, compared to 4 months under sprinkling. Although accurate measures of water application on the ponded trials were not possible, the limited data indicate that the amount of water required is about the same per unit depth of soil reclaimed for both ponding and sprinkling. Reclamation proceeded more quickly under the second ponding trial than for sprinkling or the first ponding trial because of improved subsurface drainage. With sprinklers, 70% of the salt was removed from the soil profile to a depth of 1.2 m after 850 mm of leaching water entered the profile. Reclamation by ponding required about the same quantity of water but the water required for leaching could be reduced significantly by improved drainage.

Introduction

Saline, organic soils are an anomaly, usually being the consequence of man's manipulation of water resources. Saline soils normally occur in regions where fresh water is lacking while organic soils are formed in poorly drained soils where fresh water is abundant. The Sacramento-San Joaquin Delta of California is an important example of an agricultural area with organic soils that are threatened by salinity. As man's utilization and manipulation of the world's fresh water resources increases, the occurrences of saline, organic soils will surely increase.

Information on removing excess soluble salts from organic soils by reclamation procedures is limited. Beyce (1972), reclaiming peat soils in Turkey by continuous and intermittent ponding and by sprinkling intermittently, reported that a depth of about 1.5 m of water had to be leached through a 1-m deep profile to remove 70% of the soluble salts. Comparable values of water depth for mineral soils are 1.0 m for clay loam and 0.3 m for sandy loam (Hoffman 1980). The objective of this study was to determine the relative rates of reclamation for organic soil from ponding nonsaline water continuously on the soil surface and by sprinkling. Results of the study were compared with the simplified reclamation model proposed by Hoffman (1980).

Experimental Procedures

Reclamation by ponding water on the soil surface was studied on two areas that had been subirrigated with saline water for four years (1979–1982). Reclamation by sprinkling was evaluated on three areas that had been sprinkled for the same 4 year period with saline water. The areas studied (see Fig. 1) are indicated on a sketch of the experimental design for a previous salt tolerance trial during 1982. The amount and salinity of irrigation water and the amount of rainfall received by each of the areas during the 4 years prior to reclamation are given in Table 1. The electrical conductivity of the applied water during reclamation averaged 0.15 dS/m.

Reclamation by sprinkling began on November 23, 1982 and ended on February 3, 1983. The sprinkling system was operated from 1 to 6 hours on 26 days depending on rainfall and the amount of water that could be applied before

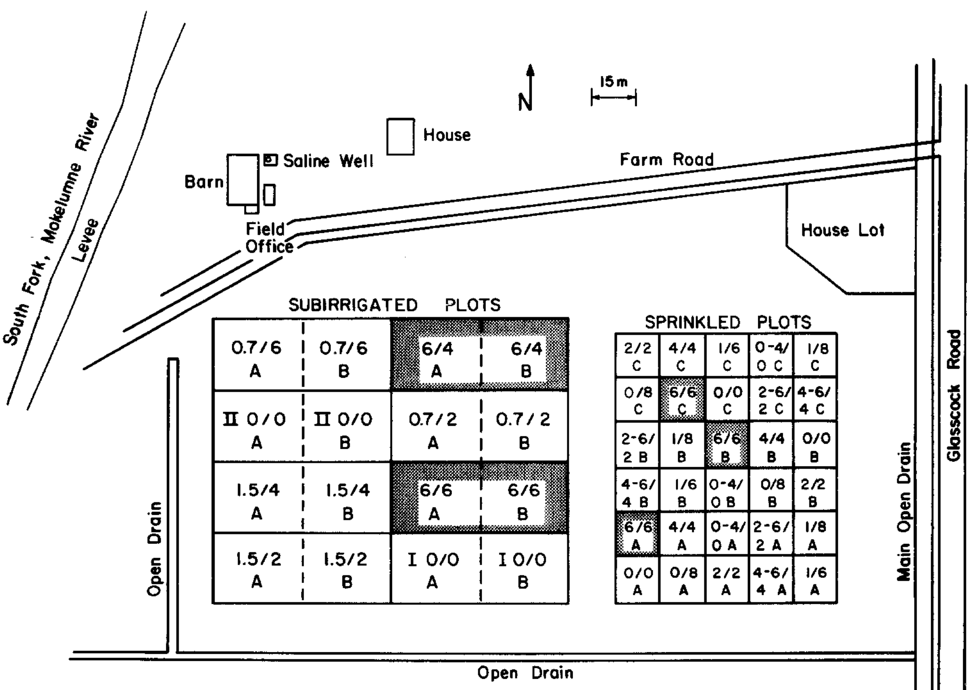

Fig. 1. Areas monitored during the reclamation experiment are shaded. Each plot studied was irrigated with waters having an electrical conductivity of 6 dS/m in 1982 and either 4 or 6 dS/m in 1980 and 1981

ponding began. The sprinkler application rate was 4.6 mm per hour. The distribution uniformity for the sprinkling system, expressed as the Christiansen coefficient of uniformity (Christiansen 1942), averaged 90%. Monitoring of rainfall and soil salinity continued until March 22. Drainage, in addition to that indicated in Fig. 1, was provided on February 23 by installing open ditch drains, each 0.3 m wide by 1.5 m deep, at intervals of 16 m throughout the sprinkled plots.

The first ponding experiment on subirrigated plots 6/6A and 6/6B began on November 11 and continued until December 31, 1982. The second ponding experiment on plots 6/4A and 6/4B started on January 17, 1983 and was discontinued on April 5. In both ponding experiments the center of each ponded area (5 m wide by 15 m long) was monitored for salinity reduction by isolating it from the perimeter area with waterproofed dikes. The central area was divided further into east, center, and west subareas to obtain replicated measurements. The amount of water applied to each subarea was metered in the first ponding experiment but not in the second. During both ponding experiments, water was ponded at depths ranging from 10 to 15 cm. To minimize the influence from horizontal movement of soil water, the perimeter area was ponded at the same depth as maintained in the subareas. An open drain ditch, 0.3 m wide by 1.0 m deep, was maintained around the perimeter of the experimental areas. Water level in the drain ditch was monitored throughout the experiment.

In each subarea of the ponded experiments and in each sprinkled plot, two sets of suction cups were installed at depths of 30, 45, 60, 75, 90, and 120 cm. The depth to the water table was monitored with shallow observation wells in the sprinkled plots.

Results

Reclamation by Sprinkling

The depth of water applied by sprinkling and rainfall during the sprinkling experiment is summarized in Table 2 along with the amount of evaporation from a Class

Table 1. Amount and electrical conductivity of irrigation water applied to the reclaimed areas during the 4 years prior to the study. Rain, measured from October to October, is also given

Year	Sprinkling		Ponding		Rain depth
	Depth [cm]	Salinity [dS/m]	Depth [cm]	Salinity [dS/m]	[cm]
1979	114	2	–[a]	2	–[a]
1980	140	6	106	6	54
1981	137	6	111	6	26
1982	111	6	77	4/6[b]	74

[a] Values were not measured

[b] One area received water having an electrical conductivity of 4 dS/m, the other area received 6 dS/m

Table 2. Depth of water applied, rainfall, pan evaporation, and the net depth of water entering the soil profile (D_w) for the reclamation study on saline, organic soil

Week number	Water application I [mm]	Rain R [mm]	Pan evaporation E [mm]	D_w I+R−E [mm]	Accumulated D_w [mm]
Sprinkling experiment					
1	46	28	6	68	68
2	18	49	7	60	128
3	79	2	9	72	200
4	76	5	4	77	277
5	0	38	10	28	305
6	88	0	2	86	391
7	60	0	2	58	449
8	42	6	6	42	491
9	28	72	7	93	584
10	12	58	10	60	644
11	12	41	10	43	687
12	0	19	8	11	698
13	0	0	2	−2	696
14	0	53	20	33	729
15	0	48	12	36	765
16	0	55	12	43	808
17	0	21	6	15	823
Total	461	495	133	823	
First ponding experiment					
1	160[a]	13	6	167	167
2	6	69	5	70	237
3	0	28	6	22	259
4	0	49	7	42	301
5	18	2	9	11	312
6	5	5	4	6	318
7	7	38	10	35	353
Total	196	204	47	353	

[a] The initial depth of water was reduced by 150 mm to account for the depth of water ponded on the soil surface

A pan. The depth of water entering the soil profile (D_w) was taken as the sum of irrigation and rainfall minus pan evaporation and is given in column 5 of Table 2. Because the soil was maintained at a high water content, evaporation from the soil surface was assumed to equal pan evaporation. Surface runoff did not occur.

The change in soil salinity based on electrical conductivity measurements of soil water extracted from suction cups throughout the soil profile during reclamation is illustrated in Fig. 2. Each data point is the average for six locations at each depth (two locations in each of the three plots). As expected, by the end of 4 weeks the salinity at the 30-cm depth had been reduced significantly. During the second month, the salinity of the lower profile decreased drastically. The average salinity

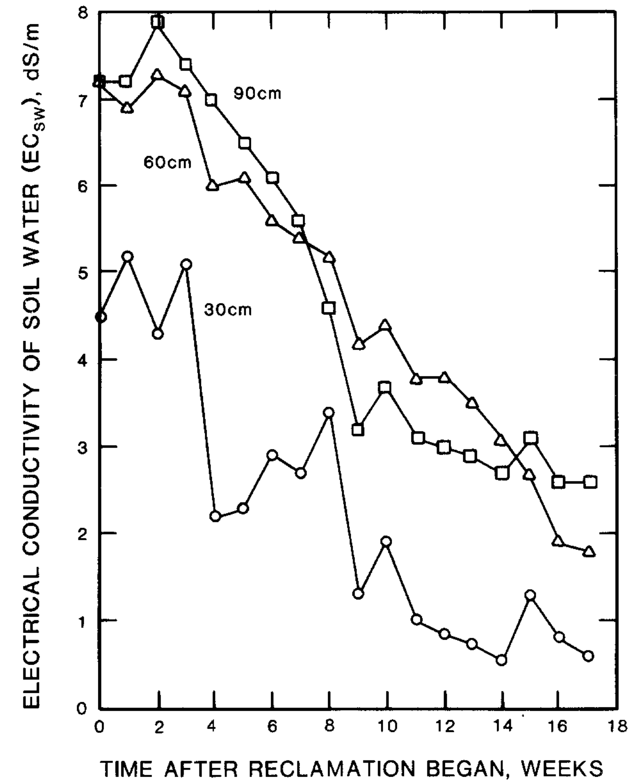

Fig. 2. Time course of reclamation at three soil depths for the sprinkling experiment

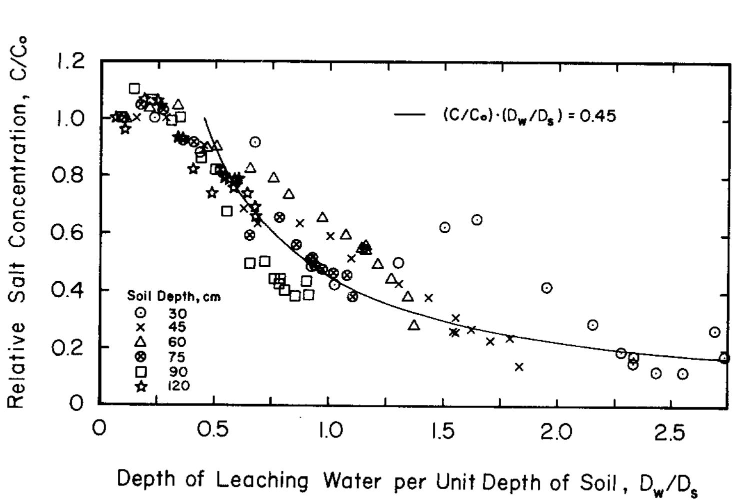

Fig. 3. Depth of leaching water per unit depth of soil required to reclaim a saline, organic soil by sprinkling

value for the profile (30- to 120-cm depth) decreased at monthly intervals to 6.0, 4.3, 3.1, and 2.5 dS/m from an initial average value of 6.9 dS/m. The overall reduction was 67%. These data indicate that the average salinity of the profile was at the salt tolerance threshold for corn (3.7 dS/m from Hoffman et al. 1983) after about 9 weeks and a net application (D_w) of about 600 mm.

The initial delay in leaching after reclamation was begun is particularly important. Under these field conditions, soil salinity began to decrease significantly below the initial value for the three soil depths depicted in Fig. 2 after about 3 weeks. The amount of water applied during the first three weeks was required to increase the soil water content above field capacity and to initiate significant water movement through the soil profile. The initial increases in salinity are caused by the wetting front pushing the saline soil water ahead of it. The fluctuations in soil salinity during reclamation, particularly notable at the 30-cm depth, are probably caused by spatial variability and the intermittent applications of irrigation water and rainfall. The decrease in salinity from the third to the fourth month at the 60 cm soil depth (see Fig. 2) was caused in part by the additional drainage provided during the fourteenth week.

All of the reclamation data for the sprinkling trial were placed on the same relative basis by dividing the amount of water applied (D_w) by the soil depth (D_s) and plotting this relative water depth (D_w/D_s) versus the relative soil salinity (C/C_0). For example, the value of D_w/D_s would be 1.0 for the case where 0.9 m of water had been applied when considering the salinity at a soil depth of 0.9 m. Relative salinity was obtained by dividing the salinity measured at any time (C) by the initial soil salinity (C_0) at the depth in question. Thus, C/C_0 equals 0.5 when the initial salinity of 7.2 dS/m for the 90-cm depth has been reduced to 3.6. This procedure was followed in Fig. 3 to place the sprinkler data for the various soil depths on a common basis. Note that different symbols were used for each soil depth monitored so visual comparisons can be made. The procedure is an attempt to minimize the differences among soil depths and permits the formulation of a generalized reclamation equation for saline, organic soil. The generalized reclamation equation proposed by Hoffman (1980) based on the results of Beyce (1972) is

$$(C/C_0) \cdot (D_w/D_s) = 0.45 \text{ when } D_w/D_s > 0.45.$$

The curve in Fig. 3 is plotted from this equation. Although the equation is hyperbolic and goes to infinity as D_w/D_s approaches zero, the value of D_w/D_s when C/C_0 equals 1.0 indicates the amount of water that must be applied before reclamation begins. The equation predicts a D_w/D_s value of 0.45 when reclamation commences while the field data for sprinkling indicate an average value of 0.25. Based on the data in Fig. 3, between 1.3 and 1.8 m of water must be applied to reduce the salt concentration of a 1-m deep saline, organic profile to 0.3 of its original concentration. Despite considerable scatter among the data points, these results support the prediction of 1.5 m from the equation.

A more detailed analysis indicates that the value of D_w/D_s for a given salt reduction varies with soil depth. For example, the required value of D_w/D_s to remove 70% of the initial salts present varies from 2.1 at the 30-cm depth to 1.0 at the 90-cm depth. The average of these two values agrees with the predicted value of 1.5.

Reclamation by Ponding

The amount of water applied to reclaim the subirrigated plots is not known as accurately as for the sprinkled plots. Several times in the first ponding experiment the dikes were eroded by heavy rainfall or slumped because of the continuously saturated conditions. Although these problems reduced the accuracy of the measurement of applied water, corrections were estimated. The depth of water applied each week for the first ponding experiment given in Table 2 is based upon corrected water meter readings. The total net depth of water entering the soil was 353 mm.

For comparison, the amount of water applied was estimated from infiltration measurements. Infiltration rates in the ponded experiments were low, probably averaging about 3.5 mm per day based on ring infiltrometer measurements started 3 weeks after the reclamation study began. Assuming a steady infiltration rate of 3.5 mm/day for the third and succeeding weeks of the experiment and assuming the infiltration rate during the first 2 weeks was equal to the measured application rates given in Table 2, the amount of water applied was estimated to be 362 mm for the first ponding trial. For the second ponding experiment, D_w was estimated from the measured infiltration rates because the volume of applied water was not measured. About 130 mm were applied during the first week of the second ponding experiment and 90 and 50 mm were assumed to be infiltrated during the second and third weeks of the trial. After the third week, the amount of water entering the soil was assumed to be equal to the infiltration rate of 3.5 mm per day. Thus, the accumulated value of D_w for the second ponding experiment was approximately 420 mm.

The reduction of soil salinity throughout the soil profile for both ponding experiments, as measured from soil water extracted from suction cups, is given in Fig. 4. In the relatively short first ponding trial, 7 weeks, only the salinity level at the 30-cm soil depth decreased significantly. Salinity was reduced at all depths during the second ponding trial, in part because of the improved drainage conditions provided by maintaining a lower water table in the open ditch surrounding the study area. The average depth to the water table immediately adjacent to the study area averaged 45 cm in the first and 90 cm in the second ponding experiment. The average salt concentration in the soil profile (30- to 120-cm depth) during the first ponding trial was reduced from 8.5 to 6.6 dS/m, a 22% reduction with a c.v. of 12%. After 7 weeks the average salt concentration was less than the salt tolerance threshold for corn (3.7 dS/m). Only six weeks were required in the second ponding trial to reduce the average salt concentration to the threshold value for corn. During the 9-week trial, the average salt concentration was decreased from 6.4 to 2.4 dS/m (c.v. = 15%), a 62% reduction.

In contrast to the delay in salinity reduction at the 30-cm soil depth in the sprinkler experiment, the salinity level at the 30-cm depth was reduced after 1 week in both ponding trials. This illustrates the difference in the reclamation rate under unsaturated flow conditions dictated by the slow application rate by sprinkling compared to saturated flow induced by immediately ponding water on the soil surface.

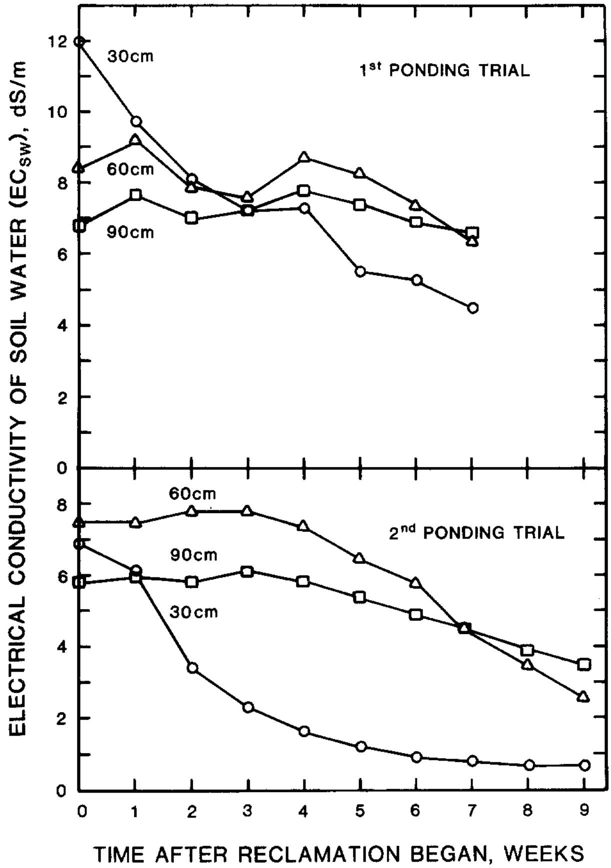

Fig. 4. Time course for reclamation at three soil depths for both ponding trials

The reclamation data for both ponding trials are presented in Fig. 5 on a relative basis. The curve in Fig. 5 is for the generalized reclamation equation. Despite the difficulties in measuring or estimating D_w, the agreement between the data and the model is acceptable. In general, data points for the first ponding trial lie above the curve while those for the second trial fall below the curve. The more rapid reclamation in the second ponding trial is probably the result of the additional drainage provided. The significant increases in soil salinity above the initial values for the deeper soil depths were caused by the high salt concentrations shallow in the profile initially being leached downward.

Discussion

The relative reduction of salinity for the entire soil profile (based on average electrical conductivity readings taken from 30 to 120 cm depths) as a function of the depth of water leaching through the profile (D_w) is given in Fig. 6. This presentation gives the relative salt concentration for the entire profile rather than for any soil depth monitored as in Figs. 3 and 5. Thus, Fig. 6 gives the average condition for the profile not the condition for individual soil depths. With

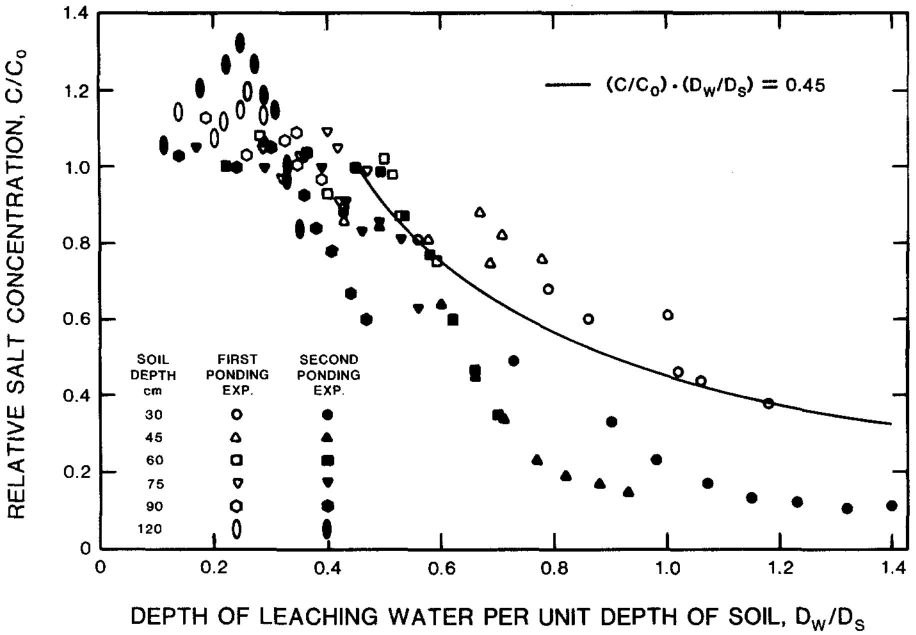

Fig. 5. Depth of leaching water per unit depth of soil required to reclaim a saline, organic soil by ponding

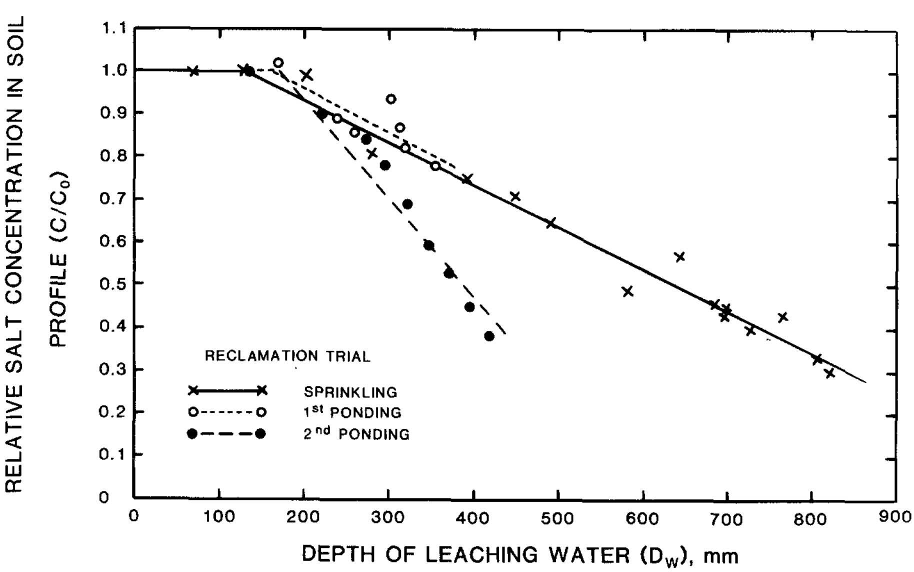

Fig. 6. Reduction in salinity for the soil profile (30 to 120 cm depth) as a function of applied water for three reclamation experiments on organic soil

sprinkling, about 130 mm of leaching water had to be applied before the salt content of the profile was reduced. For D_w greater than 130 mm, soil salinity for the profile was reduced at a steady rate of 10% per each 100 mm of applied leaching water. About 850 mm of leaching water had to be applied to this saline soil profile to remove 70% of the salts present originally. Under these field conditions about 2 weeks were required to apply 130 mm of leaching water by sprinkling (Table 2). The values given in Fig. 6 are for comparisons among the leaching trials. The results for an entire profile (30- to 120-cm depth) should not be confused with the relative rates of reclamation given in Figs. 3 and 5 for individual relative soil depths.

A check on the rate of reclamation given in Fig. 6 is the amount of reclamation that occurred from the end of the irrigation season (mid-September) until the sprinkling experiment began. On September 22, the salinity of the soil profile averaged 7.7 dS/m. At the beginning of the reclamation trial, the salinity averaged 6.9 dS/m, a 10% reduction. Over the same time period, 190 mm of rainfall were recorded. Volumetric soil water content averaged 67% for the profile at the end of the irrigation season. Saturation averages 74% for this profile (Hoffman et al. 1983). Thus, only 60 mm of water were required to saturate the profile. Subtracting 60 mm from the depth of rainfall gives the maximum amount of rain (130 mm) that should have leached through the profile if no surface runoff occurred. By using Fig. 3 and adding 130 mm to the threshold values of 130 mm for D_w a predicted salt reduction of 13% was obtained. This agrees reasonably well with the measured reduction of 10%.

The relationship in Fig. 6 for the first ponding experiment is similar to the sprinkling experiment. The best-fit linear relationship indicates a slightly higher threshold value, 160 mm compared to 130 mm, but the same slope, 10% salt reduction per 100 mm of D_w. This difference in the threshold is probably caused by a lower soil water content at the beginning of the first ponding experiment. The soil water content of the 30- to 120-cm deep profile was 35 mm less than that of the sprinkling experiment. Unfortunately, the experiment was not continued long enough to obtain large reductions in soil salinity for the entire profile.

Reclamation in the second ponding experiment was more efficient than the other two trials; i.e., less water was required to achieve the same degree of reclamation after soil water content exceeded field capacity. The rate of salt removal was 23% per 100 mm of D_w for the second ponding experiment after D_w exceeded 170 mm. This improved reclamation efficiency was caused in part by the improved drainage provided during the second ponding experiment.

References

Beyce O (1972) Experiences in the reclamation of saline and alkali soils and irrigation water qualities in Turkey. FAO Irrigation and Drainage Paper No. 16, Rome, p 63–84

Christiansen JE (1942) Irrigation by sprinkling. University of California Agricultural Experiment Station Bulletin 670, 124 p

Hoffman GJ (1980) Guidelines for reclamation of salt-affected soils. Proceedings Inter-America Salinity and Water Management Technical Conference, Juarez, Mexico. December 11–12, 1980, pp 49–64

Hoffman GJ, Maas EV, Prichard TL, Meyer JL (1983) Salt tolerance of corn in the Sacramento-San Joaquin Delta of California. Irrig Sci 4:31–44