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アメリカCoachella Valleyにおける畦中の塩類分布

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Salinity Distribution in Seedbed and Furrow Sections in the Coachella Valley, USA

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The hindrance of salinity to agricultural production is very well known, particularly, the hazard caused to crops by salt concentration in the root-zone. Thus, there is the need for clear mapping out of actual salinity distribution in seedbeds especially in areas where the salinity of irrigation water is known to be high. In this paper we present the results of a study conducted to determine salinity distribution in seedbeds in the direction of flow of furrow irrigation water. Soil sampling and experimentation were done shortly after the growing season in the Coachella Valley of USA in March 1991. The results from our study showed that salts move to and accumulate along the top of seedbeds and decrease in concentration with increasing depth. However, at the furrow sections, the salt concentration is lowest near the surface and increases with depth. The highest salinity of 96.9 dS/m was recorded at about mid-section of the seedbed (about 300 m long), which then decreased in both directions and the lowest value of 1.2 dS/m was recorded near the entrance of the irrigation water and in the furrow section. From the top of the seedbed, the salt concentration gradually decreased along the shoulders down to the furrows. We found also that the variations in soil moisture content was small and did not affect the salinity distribution along the seedbed. The soil in the study area was silt loam with an average CEC of about 30 cmol kg^{-1} soil. The ESP at some points in the seedbed was quite high (about 18%) inferring a sodic condition. There were high ion concentrations especially of soluble Na at the sections where high salinity was recorded and this confirmed the relationship between salinity and soil chemical properties

Key Words: Salinity distribution, Seedbed, Southern California, Coachella Valley, Soil properties, Salt concentration

1. Introduction

Soil salinity is a widespread limitation to agricultural production in semiarid and arid soils throughout the world (JANZEN, 1993). Saline and sodic soils occur naturally in arid and semiarid regions, and as water development brings more land into irrigation, the salinity problem expands (BACKLUND and HOPPES, 1984). Poor soil drainage, improper irrigation methods, poor water quality, insufficient water supply for adequate leaching, and insufficient disposal sites for water that leaches from the soil aggravate this condition.

One region that has seriously been plagued by salinity and drainage problems is the California region in the USA from the time irrigation was introduced in the second half of the nineteenth century (KELLEY and NYE, 1984). Even though, annual precipitation in this area is sporadic and limited to only about 80 mm, supply of water from the Colorado River, good climate, and alluvial soil have created ideal conditions for large scale production of many vegetables, fruit, and field crops. However, the Colorado River is highly saline ranging in average salinity from less than 50

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mg/L in the headwaters to 825 mg/L at the Imperial Dam, the last U. S. diversion point, and 950 mg/L in Mexico (HOLBURT, 1984). Continuously irrigating with the highly saline water from the river has worsened the salinity problem. Over-irrigation, which has caused the water table in the region to rise, has also created frequent flooding problems.

The Coachella Valley, where this study was undertaken is a desert area of Southern California, extending from Palm Springs to the Salton Sea. It receives a limited amount of rain, like the other areas, with average annual precipitation of 50 to 120 mm. The mean minimum winter temperature is 4.4° C and the mean maximum summer temperature is 38° C. The floor of the valley has deposited soils consisting of fine-textured sediments (Indio very fine sandy loam, wet), and near the mountains washed-down alluvium and weathered rock created coarse-textured soils (Salton silty clay loam), (KNECHT, 1974). Water from the Colorado River used to irrigate the Coachella Valley area has an average salinity of 1.25 dS/m (TDS of about 800 mg/L) (RHOADES *et al.*, 1989a). Almost all soils in the valley are slightly alkaline (pH 7.0 ~ 8.4).

More than thirty different kinds of crops are grown commercially in the Coachella Valley area. The growing season for most of the crops is from late January to early December. It is therefore an important agricultural area and the need for countermeasures to deal with the salinity problem that adversely affects agricultural production cannot be over-emphasized. Moreover, because plants vary in their tolerances to salts, it is important to avoid planting less tolerant young seedlings in portions of the seedbed with high salt concentrations. In order to be able to propose appropriate countermeasures, with regards to leaching requirements and crop selection, the process and trend of salt concentration along seedbed and furrow sections must first be well understood. This follows from the findings of BERNSTEIN *et al.* (1955), BERNSTEIN and FIREMAN (1957), who reported that salts tend to accumulate to excess levels in certain regions of the seedbed under furrow irrigation.

Soil properties also play an influential role in the way salts move and accumulate in the seedbed. Successful management of salinity therefore depends to a great extent on the nature and properties of the soil. Water movement through the soil is also dependent on properties such as texture, porosity, and hydraulic conductivity.

The purpose of the present study was to document the actual levels of salt accumulation in seedbed and furrow sections, and to use the results to promote better management of agricultural fields that are prone to salinity problems, and also to determine how salts accumulate in the seedbed after the harvest period when no crops are growing and there is little or no rainfall and irrigation water is no longer applied. Particularly, it is very important to ensure effective use of water in the California region where the water supply system is becoming stricter with time. This can be achieved by avoiding over-irrigation that leads to excessive salt accumulation, and requires the use of already scarce water for leaching out the excess salts.

2. Materials and Experimental Methods

1) Field description and sampling

The study area was located in the Coachella Valley at Indio (about 110 km east of Riverside, where the US Salinity Laboratory is located) in Southern California State (see Fig. 1). The Salton Sea lies between the Coachella and Imperial Valleys and is 70 m below sea level. From the Colorado River in the east, runs the main Colorado River Aqueduct that conveys water to Los Angeles and its surroundings. The Coachella Valley Canal, also supplies water directly to the Indio region for irrigation and other purposes. Drainage water from the two valleys is discharged into the Salton Sea resulting in the subsequent rise in its water level thus, creating drainage water disposal problems.

We carried out the study on a seedbed on Site 5 located between Avenues 60 and 62 (Fig. 2). Furrow irrigation water is applied from the Ave. 60 section, and flows in the direction of Ave. 62. This site was selected for our study because there had previously been other studies on the same site. We did not anticipate any particular influence on this site by external factors due to its location. Irrigation water was applied evenly irrespective of position as a network of roads separated all plots from each other.

Soil samples were collected at the end of the harvest season from sections of the seedbed

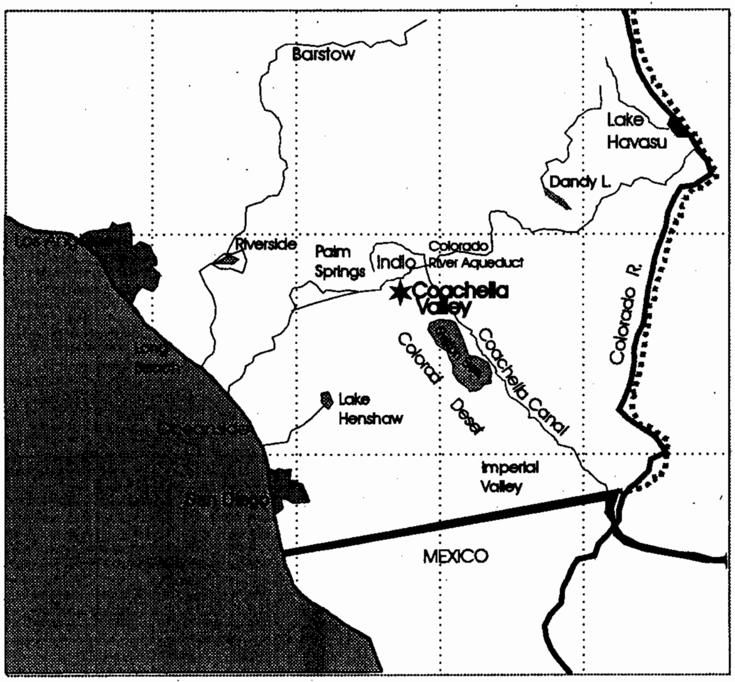

Fig. 1. Position of the Coachella Valley in South-western USA.

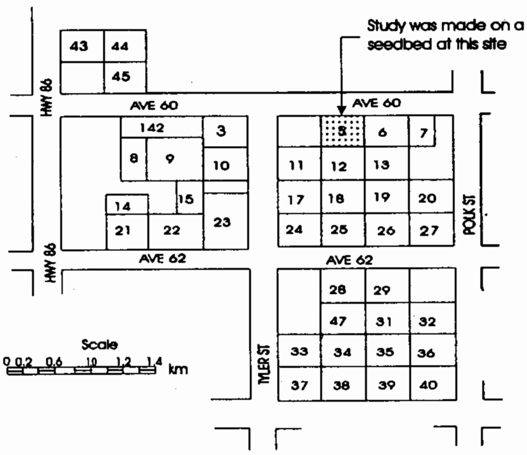

Fig. 2. Location of seedbed at site No.5 between Ave 60 and 62.

measuring about 300 m in length and 0.76 m in width between furrows (Fig. 3). A total of 140 samples were collected from 10 locations on the seedbed. At each location 14 samples were collected across the section of the seedbed and its adjoining furrows as shown in Fig. 3. To ensure that the samples were representative of each sampling point, soils were taken from three points at about 10 cm apart with a 1-inch diameter auger and thoroughly mixed together to form one sample. The samples were then placed in cups and tightly sealed. The first 3 sampling points were located at 15-m intervals starting from the entry point of the irrigation water, and the subsequent ones at 30-m intervals. Each sample was collected at depths of every 15 cm (see Fig. 4). All the other soil properties were determined from the samples collected at location No. 8. The results from the 4-electrode conductivity probe (RHOADES, 1994) indicated that this site had properties that were typical of the area (silty loam soil).

2) Experimental methods

Saturated soil-pastes were prepared from each of the 140 samples using standard methods described by RHOADES (1982). The electrical conductivity of the saturated soil-paste (EC_p) was measured in a calibrated "Bureau of Soils Cup" (RICHARDS, 1954: 7-33) using a conductivity meter. The measured EC_p was then converted to electrical conductivity of the saturated soil-paste extract (EC_e) using

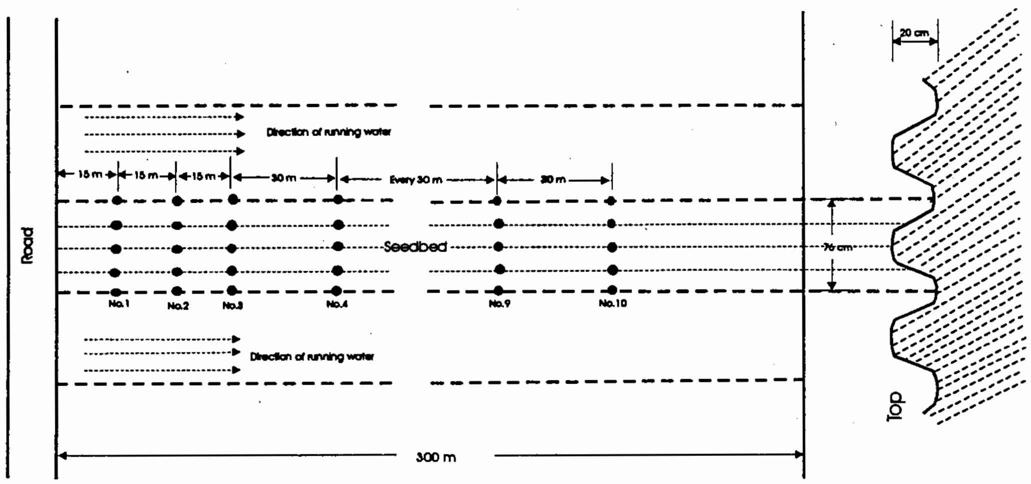

Fig. 3. Schematic drawing of the seedbed showing sampling points and end section.

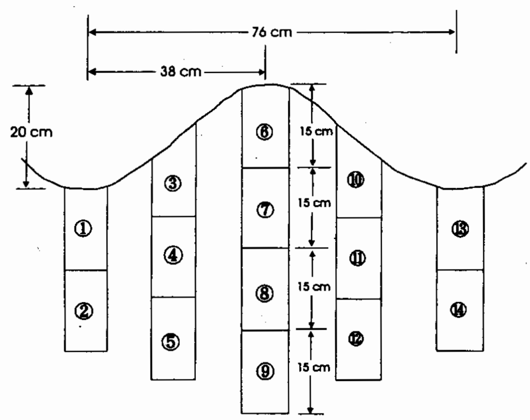

Fig. 4. Section of seedbed showing sampling points and depths.

equation (1) below, developed by RHOADES *et al.* (1989b),

$$EC_p = \{[(\theta_s+\theta_{ws})^2 EC_e EC_s]/[(\theta_s)EC_e+(\theta_{ws})EC_s]\} + (\theta_w-\theta_{ws})EC_e, \quad (1)$$

where EC_p and EC_e are as defined above, EC_s is the electrical conductivity of the solid phase of the soil (due primarily to exchangeable cations adsorbed on clay minerals and secondarily to metallic minerals), θ_s and θ_w are the volume fractions of the solid particles and total water in the paste respectively, and θ_{ws} is the volume fraction of water in the paste that is coupled with the solid phase to provide an electrical pathway through the paste (a series-coupled pathway). The difference ($\theta_w - \theta_{ws}$) is equal to θ_{wc}, which is the volume fraction of water in the paste that provides a continuous pathway for electrical current flow through the paste (a parallel pathway to the series-coupled pathway). EC_e is used in preference to EC_p because it is directly related to the field moisture range from field capacity to the permanent wilting point, which is a good parameter for evaluating the effect of soil salinity on plant growth (FOTH, 1990: 73-99).

We determined the moisture content by the standard gravimetric method with oven drying described by TOPP (1993). The results of moisture content were calculated and recorded as percent on mass basis. The particle size distribution was determined by a combination of the standard procedure of sieving the oven-dried soil and the hydrometer method.

The CO_3^{2-} and HCO_3^- were determined from the original saturation extract solution using the Standard Potentiograph E36 meter. Details of the method for the preparation of the saturation extract are described by RHOADES (1982). From this solution, a pH meter was also used to measure the pH. An Aminco Chloride Titrator was used to determine the Cl^-. The soluble ions Na^+, K^+, Ca^{2+}, Mg^{2+}, and SO_4^{2-} were measured by Inductively Coupled Plasma (ICP) Atomic Emission Spectrom-eter machine. For details of method of extraction of the ions see RHOADES (1982). The cation exchange capacity (CEC) was determined by the procedure described by POLEMIO and RHOADES (1977).

3) Exchangeable sodium percentage (ESP)

The ESP, a measure of soil sodicity, is the molar proportion of cation-exchange sites in a soil (CEC) occupied by exchangeable sodium (Na_{exch}). The ESP was calculated from equation (2) given below (JANZEN, 1993), to enable us determine the level of sodicity of the soil in the study area:

$$ESP = (Na_{exch})/CEC \times 100 \qquad (2)$$

Traditionally, sodic soils have been defined as having an *ESP* greater than 15 (RICHARDS, 1954).

3. Results and Discussion

1) Soil properties at location No. 8

The particle size distribution and other soil properties of samples at this location are presented in Table 1. The results showed that all the samples were silt loams. The soil in the area of our study has been reported to be uniformly silty loam (RHOADES, 1994). Leaching, which is the method used in reclaiming saline soils, is dependent upon the hydrodynamic permeability of the soil to water from the surface. The pores, which are also directly related to the texture as well as the structure, control the movement of the water. We were of the view that the silt loam soil, which was high in silt and low in sand, might not be suitable for effective leaching to reduce the accumulation of salts. Providing adequate drainage to reduce salt accumulation in the seedbed will avert this problem.

The pH results (see Table 1) confirmed the soils in the valley to be slightly alkaline with an average value of 7.4. The CEC, Ex-Na, and ESP are also shown in Table 1. The average CEC was about 30 cmol kg^{-1}. Thus, the amount of exchangeable cations adsorbed in the soil was high enough to allow exchange activity between sodium ions and other cations and cause salinization. The ESP values were much lower than the sodic soil limit of 15, except for one sample. As the ESP is directly related to the amounts of soluble Na^+, Ca^{2+} and Mg^{2+}, it follows that the ESP changes in accordance with changes in salt contents along the seedbed. However, as long as a large quantity of soluble salts remains in the soil, exchangeable sodium does not cause dispersion of colloids. The high concentration of ions in the soil solution will keep the colloids flocculated.

Results of soluble anions and cations representing the sampling points at location No. 8 are shown in Table 2. The moisture content, also presented in Table 2, was nearly the same at all the sampling points in contrast to the ion concentration, which had significant variations at the various points. Values for Cl^- ions were very low ranging from 1.1 ~ 2.1 cmol kg^{-1} and HCO_3^- ions were moderately low, ranging from 3.3 ~ 72.0 cmol kg^{-1} respectively, while those of SO_4^{2-} and NO_3^- (4.1 ~ 291.0 and 40.6 ~ 102.6 cmol kg^{-1} respectively) were high. Similarly, for the cations, the values for K^+ were very low (0.9 ~ 4.8 cmol kg^{-1}) compared with those for Na^+ (8.8 ~ 297.6 cmol kg^{-1}), Ca^{2+} (23.5 ~ 57.9 cmol kg^{-1}), and Mg^{2+} (8.5 ~ 84.4 cmol kg^{-1}) which were high. Sodium had the highest concentrations at the various sections in the seedbed. Thus, high concentrations of the sulfates and nitrates of sodium, calcium, and magnesium produced the saline condition in the soil. The total salt concentrations were consistent with the variations in the salinity levels at the sampling points. Both anion and cation concentrations were highest close to the top of the seedbed, where salinity was highest, and nearly equal at each sampling point. Thus, a condition of ion balance exists at the various

Table 1. Particle size distribution and other properties of selected points at location No. 8.

ID No.	Sand (%) 2mm ~ 50μm	Silt (%) 50mm ~ 2μm	Clay (%) < 2μm	Texture	CEC cmol kg^{-1}	EX-Na cmol kg^{-1}	ESP %	pH
①	15.3	61.3	23.4	silt loam	24.22	4.401	18.17	7.28
④	20.0	57.9	22.1	silt loam	24.81	2.389	9.63	7.46
⑥	17.4	59.2	23.4	silt loam	29.13	1.290	4.43	7.40
⑨	19.4	58.5	22.1	silt loam	33.16	0.862	2.60	7.56
⑪	20.1	57.8	22.1	silt loam	31.66	2.124	6.71	7.38
⑬	18.7	59.2	22.1	silt loam	30.33	0.233	0.77	7.36

CEC: Cation-exchange capacity, EX-Na: Exchangeable sodium, ESP: Exchangeable sodium percentage

Table 2. Water-soluble anions and cations measured at location No. 8.

Samp. No.	Cl	SO_4	NO_3	HCO_3	ΣA	Na	K	Ca	Mg	ΣC	SP^+	PW^{++}
	← A N I O N S →					← C A T I O N S →						
	← cmol kg^{-1} →					← cmol kg^{-1} →					%	%
①	2.1	8.7	74.6	—	85.4*	38.8	1.3	24.2	20.6	84.9	59.0	23.2
②	1.3	4.1	40.6	6.6	49.3	8.8	0.9	29.4	8.5	47.6	57.8	21.6
③	2.0	32.7	98.3	6.8	139.8	79.6	1.9	25.6	30.3	137.4	60.3	24.8
④	1.4	10.5	86.4	3.4	101.7	54.4	1.9	24.4	19.4	100.1	56.6	26.7
⑤	1.2	20.0	45.5	—	66.7*	22.7	1.9	36.1	18.6	79.0	56.7	24.4
⑥	1.6	291.0	89.0	72.0	453.6	297.6	4.8	57.9	84.4	444.7	56.2	24.4
⑦	1.3	111.8	101.0	25.9	240.0	158.5	3.4	33.9	41.1	236.9	56.3	25.4
⑧	1.2	113.4	92.6	23.9	231.1	140.3	2.8	33.7	47.7	224.5	57.1	27.4
⑨	1.1	68.5	102.6	11.8	184.0	112.0	2.3	29.2	38.6	182.1	61.1	25.1
⑩	1.3	63.4	96.5	12.3	173.5	105.8	2.3	29.2	37.7	175.0	58.8	28.9
⑪	1.2	57.7	96.9	—	155.8*	112.1	2.6	29.2	36.7	180.6	57.2	26.1
⑫	1.2	49.4	71.1	—	121.7*	90.1	2.4	34.4	28.1	155.0	55.8	26.3
⑬	1.4	20.0	94.7	—	116.1*	66.5	1.8	23.5	25.7	117.5	57.9	24.1
⑭	1.7	9.7	53.0	—	64.4*	22.7	1.3	27.9	14.0	65.9	57.2	30.0

* Partial totals, + Saturation percentage, ++ Moisture content

sections of the seedbed and a relationship between the amount of soluble salts accumulated and salinity was established. We also observed gradual decreases in salt concentrations along the shoulders of the seedbed to the furrow sections.

2) Salinity distribution

Data for the soil salinity expressed as the electrical conductivity of the saturated soil paste extract (EC_e in dS/m) and the per cent moisture content are presented in Table 3. The results are presented at positions corresponding to the sampling points as shown in Fig.4. The EC_e levels at each sampling point of the 10 locations are presented in Fig. 5a. We grouped the salinity levels into five categories, which are represented diagrammatically (see Fig. 5a). The actual salinity values along the midsection of the seedbed are shown in Fig. 5b. The highest salinity was at the top of the seedbed and along its entire length ranging between 26.8 ~ 96.9 dS/m. From the top of the seedbed, salinity decreased consistently with depth to values ranging from 6.2 to 27.6 dS/m (see Fig. 5b).

Salinity on the shoulders also decreased with depth along the entire length of the seedbed ranging in values from 2.5 ~ 8.5 dS/m. The lowest concentrations of salts were at the furrow sections ranging from 1.2 ~ 16.2 dS/m, but unlike the other sections salinity increased with depth as shown in Fig. 5a. At the furrow sections, the salinities at 30-cm depths (1.7 ~ 25.7 dS/m) were about twice the values of the 15-cm depths (1.2 ~ 16.9 dS/m). This was probably due to the downward seepage of irrigation water in the furrows leaching the salts and reducing the salt concentration near the soil surface. Conversely, water moved to the top of the seedbeds and salt was deposited as the water evaporated. The lowest salinity value of 1.2 dS/m was recorded within the 15-cm depth of the furrow at the first sampling point. The highest value of 96.9 dS/m was recorded at the top of the seedbed at the sixth sampling point which was about halfway along the seedbed (see Table 3a).

From the entry point of irrigation water, salinity increased gradually along the seedbed and reached a peak value about midsection of the seedbed (Table 3a). From this point it decreased towards the end of the seedbed. We were of the view that this situation occurred because the volume of water running through the furrow was high from the entry point and hence a better leaching effect. Thus less salts accumulated in about the first 50 m of the seedbed. But as the volume of the water gradually decreased resulting in insufficient leaching, accumulation of salts increased. From this section of the seedbed

Table 3. Electrical conductivity, ECe and moisture content.

	(a) ECe (dS/m)					(b) Moisture content (%)				
			48.1					24.2		
		7.3	23.8	12.8			26.5	25.0	24.4	
No. 1	1.2	4.7	16.2	7.1	2.6	23.5	26.9	25.0	24.3	23.1
	3.4	4.3	11.4	6.2	5.0	25.7	23.1	29.0	27.0	25.1
			34.7					26.2		
		5.5	14.5	5.3			27.1	28.6	27.6	
No. 2	1.7	3.9	12.2	3.7	2.3	27.0	25.9	28.1	27.9	26.1
	1.7	2.8	8.1	2.5	2.2	25.5	28.4	30.7	29.2	26.3
			36.7					23.5		
		6.7	13.9	5.8			22.3	24.2	22.7	
No. 3	1.6	5.2	9.7	3.7	1.6	23.6	25.3	24.9	25.3	22.2
	1.6	5.2	9.7	3.7	1.6	23.6	25.3	24.9	25.3	22.2
	3.7	4.7	6.2	2.5	4.2	25.2	25.9	27.9	28.2	27.7
			82.3					23.7		
		22.4	42.6	38.5			23.1	22.6	28.1	
No. 4	5.8	16.5	34.6	20.0	6.8	22.9	24.9	26.3	24.8	24.5
	12.2	13.6	22.5	16.4	12.3	26.1	24.7	25.4	26.2	28.2
			89.8					23.4		
		12.2	32.7	18.4			23.7	25.9	27.5	
No. 5	6.6	9.2	27.6	14.7	5.4	23.9	24.6	25.0	25.4	26.0
	13.4	8.6	20.2	11.1	13.0	25.3	29.1	23.8	24.3	24.4
			96.9					24.6		
		29.0	50.2	19.1			31.9	28.9	24.1	
No. 6	5.9	22.4	28.0	13.7	6.9	25.8	22.3	31.4	28.6	26.5
	13.6	14.5	23.7	13.2	16.2	22.0	23.6	25.2	22.9	24.1
			26.8					23.0		
		13.4	22.4	11.2			22.2	24.7	20.1	
No. 7	3.7	8.9	16.8	9.7	4.7	21.2	24.2	26.5	28.6	22.2
	7.8	8.4	10.9	5.1	11.1	26.5	26.3	29.5	31.4	28.2
			36.9					24.4		
		10.8	18.9	14.6			24.8	25.4	28.9	
No. 8	3.7	7.8	18.7	14.2	5.2	23.2	26.7	27.4	26.1	24.1
	6.6	6.5	14.6	13.1	9.5	21.6	24.4	25.1	26.3	30.0
			79.8					23.2		
		26.8	57.1	27.8			22.7	23.3	23.4	
No. 9	7.9	25.7	28.8	25.8	16.9	26.8	23.1	25.6	24.7	20.9
	15.8	18.4	27.5	22.5	25.7	25.5	26.6	29.6	28.5	26.4
			38.1					26.8		
		14.9	36.9	25.7			24.6	27.5	27.1	
No. 10	4.4	10.2	24.8	25.0	6.5	22.7	26.3	26.7	26.1	23.7
	11.0	9.3	23.8	16.5	14.4	25.9	28.9	32.3	29.2	26.4

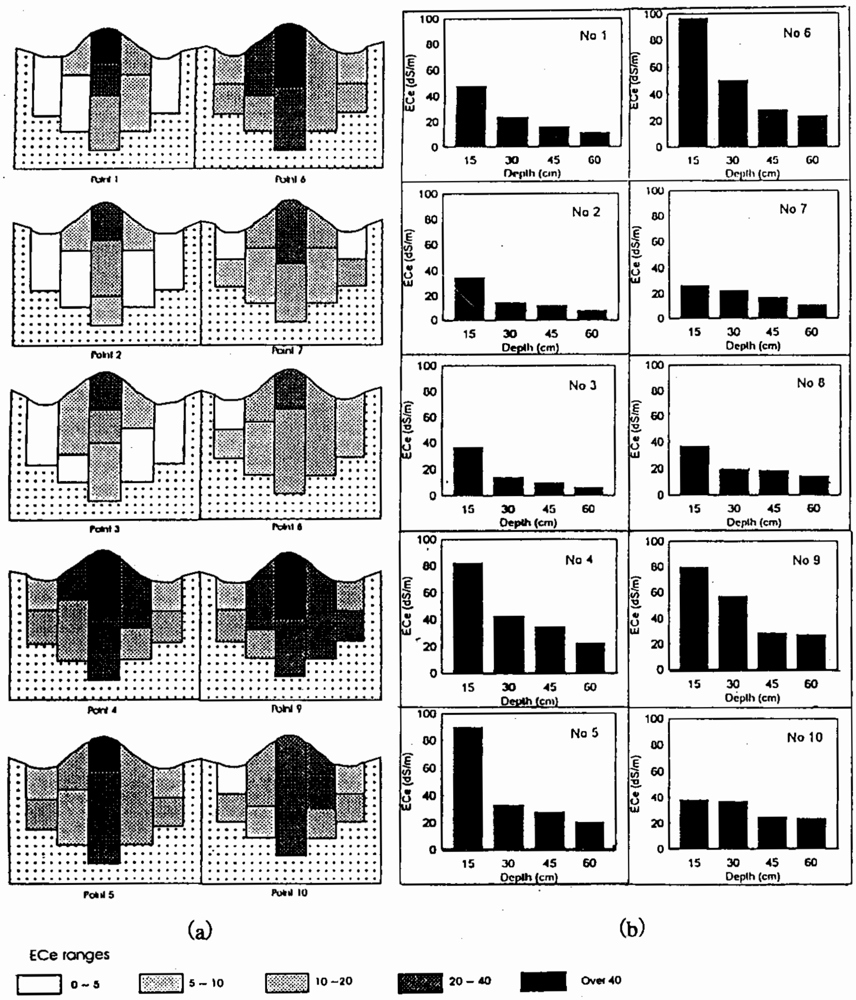

Fig. 5. Salinity distribution.
(a) along the entire seedbed
(b) along the mid-section of seedbed

further reduction in irrigation water (less salts) may have caused the decrease in salinity towards the tail end of the irrigation water.

The EC_e as calculated from equation (1) and presented in Table 3 produced values, some of which were quite high. We were, however, convinced that the accuracies of the experimental procedure and the formula used to obtain the salinity values were high. This study was done at the end of the harvest season and there was nearly zero rainfall to provide water during this period for leaching out some of the salts which probably was responsible for the extremely high accumulations of salts in parts of the seedbed. Moreover, mean salinity values that were quite high, in some instances >26 dS/m in the 0～15-cm depth have been reported for the Coachella Valley (RHOADES, 1994). However, these high salinity values do not pose much danger to crops because leaching is normally carried out before the next planting begins.

Out of the total 140 samples analyzed, we observed that only 10% recorded salinity values lower than 4.0 dS/m, the figure set as the tolerant limit beyond which the yields of most very salt-sensitive crops are affected (BERNSTEIN and FIREMAN, 1957). Salinity decreased from the top to the furrow sections of the seedbed. This agrees with the findings of RHOADES and LOVEDAY (1990) who reported that under moderately saline conditions, most of the salt is carried into the center of the seedbed, leaving the shoulders free for seedling establishment. At nearly all the sampling points the highest EC_e values on the shoulders were smaller than or nearly equal to the lowest values at the center of the seedbed (Table 3a). This further confirms the assertion that salts accumulate less on the shoulders of the seedbed.

We deduced from these results that the shape of the seedbed is important in determining the degree of salt accumulation in the various sections. A slightly flat-topped seedbed is more desirable for preventing excessive salt accumulation near the root zone of young seedlings than a round-topped seedbed (RHOADES *et al.*, 1992). Also, double row planting on flat-topped seedbeds or planting on the shoulders of sloping beds can be effective in preventing excessive salt accumulation near the root zones of young seedlings (RHOADES and LOVEDAY, 1990).

The soil moisture content at all the sampling points fell among 20 and 32% (see Table 3b). The difference between the highest and the lowest moisture contents was small which greatly contrasted the corresponding salinities of 1.2 and 96.9 dS/m. The moisture content at the point of lowest salinity was nearly the same as that at the highest salinity (23.5 and 24.6% respectively). We were, therefore, of the view that salinity levels were insensitive to the small variations in moisture content. This is consistent with the findings of RHOADES *et al.*, (1989b), who reported that the relatively small deviations from field capacity water content do not seriously interfere with salinity diagnosis, because the salt concentration of the soil water increases as the volume of soil water decreases with evapotranspiration and the content of dissolved electrolyte (current carrying capacity) remains essentially constant. There were slight increases in moisture content with depth at some of the sampling points. This was probably due to loss of water near the soil surface through evaporation.

Graphical representations of the values in Table 3 for variations in salinity levels and moisture content are shown in Fig. 6. The patterns of salinity at corresponding points along the seedbed (Fig. 4) can be recognized as against the moisture content, which showed no clear patterns. The most significant pattern in the salinity variations is that it generally decreased slightly from the entry point of the irrigation water and then increased towards the midsection of the seedbed. The variations in salinity were much higher for the end of the seedbed than for the entry point of irrigation water. Fluctuations in salinity were more pronounced around the midsection of the seedbed. There was no pattern in the moisture content variations as the graphs in Fig. 6 show.

The larger standard deviations (SD) among the salinity values were a clear indication of the difference in salt concentration at the different points. For instance, the SD's for the center of the seedbed were 7.6 ~ 26.9 and for the furrows it was 2.3 ~ 6.8. The shoulders, had SD's between 8.6 ~ 10.0 for the left and 4.9 ~ 8.5 for the right side. These results showed that unlike the center of the seedbed, the other sections produced no big differences between salinities at corresponding sampling points. However, the SD's for the moisture contents along the entire seedbed ranged among 1.3 and 3.0. This further reveals that only slight changes in moisture content occurred which further emphasized the difference in the salinity variations.

The most significant pattern, however, was along the center of the seedbed (Fig. 5). There was also some pattern in the variation of salt concentration along the entire length of the seedbed as corresponding points in Fig. 6 show. Salt accumulation in seedbeds under other forms of irrigation may be different from the results we obtained for furrow irrigation.

4. Conclusions

From the studies we arrived at the following conclusions. However, it must be pointed out that our results were basically consistent with the findings of other researchers.

1. The highest salinity is along the top of the seedbed (96.9 dS/m) and generally decreases with increasing depth. The shoulders of the seedbed and the furrows have lower levels of salt concentration. It is presumed that during irrigation salinity in the furrow sections was much lower than the recorded values due to leaching effects. It was also observed that salinity increases in the direction of

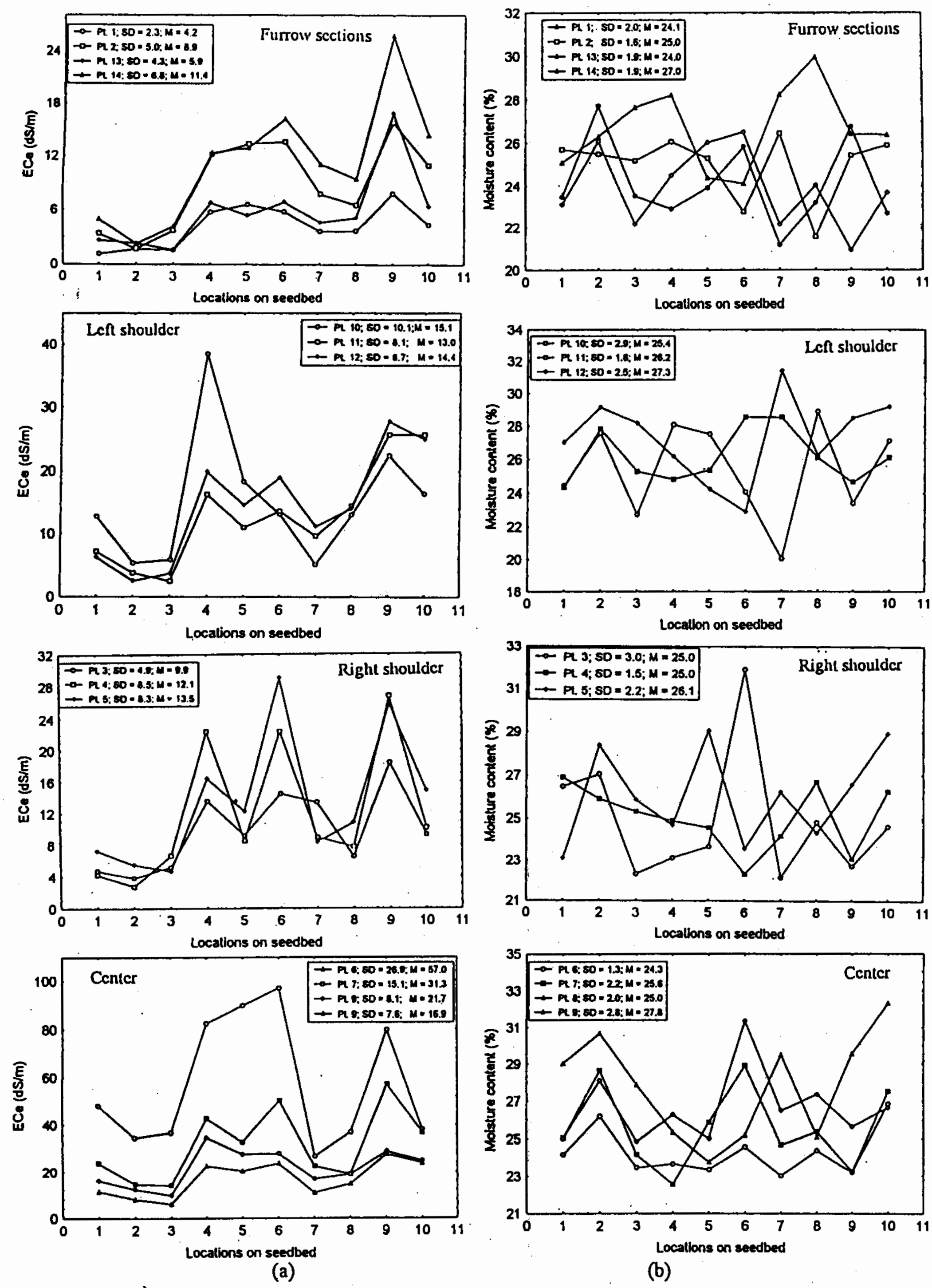

Fig. 6. Salinity (a) and moisture content (b) variations along seedbed.

flow of water up to a point and then decreases towards the tail end of the water. In direct contrast to the salinity in sections of the seedbed, salt accumulation in the furrows increased with increasing depth.

2. The shape of the seedbed is very important in determining the level of salt accumulation at the various sections. A slightly flat-topped seedbed is probably the best to ensure that salts do not accumulate to excessive levels near the root zones of young seedlings.

3. As the salinity increased in the direction of the running water, we were of the view that a reduction in the length of the seedbed could lower the salt accumulation in the sections of the seedbed.

4. Salinity was insensitive to variations in moisture content, which were within a narrow range and along the entire seedbed. This result was consistent with the findings of other researchers.

5. Salinity distribution in seedbeds is related to soil chemical properties. Properties such as pH and soluble salts affect the process of salt accumulation in the seedbed. High salinity values were recorded at points where the accumulation of soluble cations and anions was also high.

6. Due to the scarcity of irrigation water in the study area, strict management practices are required to avoid salt accumulation in the seedbed because salt accumulation requires the use of the already scarce water for leaching.

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アメリカ Coachella Valley における畦中の塩類分布

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この研究は，乾燥気候のアメリカ・カリフォルニア州東南部に位置するCoachella Valleyのビート畑地帯において，塩類の集積実態を迅速に把握する方法の確立を目指して行われたものの一部である．本地域では厳しい農業用水供給量の削減が続いており，コロラド川の渇水状況によっては灌漑不能の圃場が放棄され荒廃し，一種の沙漠化現象さえ発生する事態に至っている．調査は，収穫後の畦間灌漑圃場地域において，事前調査から平均的と判断された長さ約300mの1本の畦を対象に実施した．すなわち，流下方向に大体30m間隔で10個所の畦断面から，それぞれ14個の土壌試料を採取し，平衡状態での塩濃度分布状況を測定した．その結果，各断面中では畦の上部から畦間に向かい次第に塩濃度が減少すること，1本の畦では中央部分で最大となり，その上下流で塩濃度が減少することなどが明らかとなった．これらのデータは，畦間を流下する灌漑水による除塩管理に役立つ．

また，調査断面の代表的な位置と判定した土壌による物理・化学性の精密測定から，土性は均質なSilt Loamであること，CECは30前後で相当に活性であり，一部のESP値からはソーダ質化の危険性があると判断された．このことは，水溶性陽イオンに占めるナトリウム比の高さからもうかがわれ，灌漑水の組成によっては十分な注意が必要とされる．

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