United States Department of Agriculture

Science and Education Administration

Agricultural Research Western Region

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TO: Parties Interested in the Irrigation Water Quality in the South Delta

Enclosed please find a copy of the final report of the committee formed to evaluate the irrigation water quality requirements for agriculture in the South Delta. Following the preliminary report sent to you on November 3, 1981, we received comments and desires for additional information from the South Delta Water Agency and the Bureau of Reclamation. The committee has attempted to take these comments and requests into consideration in preparing this final report.

The committee assumes that its task is now complete and stands adjourned.

Sincerely,

Glenn J. Hoffman

GLENN J. HOFFMAN
Committee Member

Enclosure

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WATER QUALITY CONSIDERATIONS FOR THE SOUTH DELTA WATER AGENCY

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A mixture of soluble salts is present in all soils. If the concentration of these salts becomes excessive, crop yields will be reduced because of the decrease in osmotic potential of the soil water. To prevent harmful accumulation of salts, the soil profile must be leached periodically with an amount of water in excess of that used by evapotranspiration. Thus, where salinity is a hazard, the concept of efficient water use must be expanded to include an increment of water to meet the leaching requirement (L_r), defined as the minimum fraction of the total amount of applied water that must pass through the soil root zone to prevent a reduction in crop yield from an excess accumulation of salts. Leaching occurs whenever irrigation and rainfall exceed evapotranspiration.

Two quantities establish the leaching requirement: the salt concentration of the applied water and the salt tolerance of the crop. The average salt concentration of the applied water ($\bar{C}$) can be estimated from the mean salt concentration of the irrigation water (C_I) and the amount of rainfall (D_R) and irrigation (D_I) applied. Mathematically,

$$\bar{C} = \frac{C_I \; D_R}{D_I + D_R}$$

because rainfall has an insignificant salt concentration. The amount of water required by the major crops in South Delta, as estimated by both the Bureau of Reclamation and the Extension Service, is summarized in Table 1. Estimates of both evapotranspiration and the total amount of water that must be applied for each crop are in close agreement. We arbitrarily chose to use the average of the values of ET and $D_R + D_I$ in Table 1. Crop salt tolerance data were taken from Maas and Hoffman (1977). They reported salt tolerance by means of two parameters: the threshold (A) and the rate of yield decline as salinity increases beyond the threshold (B). The threshold value is the maximum average salt concentration in the root zone that does not reduce yield. The salt tolerance parameters for the crops of interest are given in Table 2. Relative crop yield (Y_r) as a function of these two parameters is given by

$$Y_r = 100 - B(EC_e - A)$$

where EC_e is the average electrical conductivity of a saturated soil extract from the crop root zone. For example, the relative yield of alfalfa would be 75% at a soil salinity of 5.4 dS/m ($Y_r = 100 - 7.3(5.4 - 2.0)$).

The fraction of the total amount of applied water ($D_R + D_I$) that passes through a crop root zone (D_D) is termed the leaching fraction (L) or

$$L = \frac{D_D}{D_R + D_I} .$$

Because L_r is the minimum leaching fraction needed to prevent yield reduction:

$$L_R = \frac{D_D^*}{D_R + D_I} ,$$

where the superscript * distinguishes required from actual values. Recently, Hoffman and van Genuchten (1981) provided a graphical solution to the relationship between a crop's salt tolerance threshold and the salinity of the applied water as a function of L_r. Such relationships are illustrated in

Fig. 1. As an example, the L_r for alfalfa (threshold value of 2 dS/m from Table 2) would be 0.15 if the salinity of the applied water was 1020 mg/ℓ of total dissolved salts. Fig. 1 presents the leaching requirement of the prominent crops in the South Delta as a function of the salinity of the irrigation water without rainfall. Fig. 2 gives the leaching requirement when rainfall is normal. The amount of rainfall that is effective in meeting each crop's water requirements is given in Table 1 as D_R. The curves in Fig. 2 are displaced to the right by the amount of dilution caused by D_R to the salt concentration of the total amount of water applied to each crop ($D_I + D_R$). This dilution factor is listed in Table 1 and is merely $(D_R + D_I)/D_I$.

After the leaching requirement has been established for a given crop and a given salinity of the irrigation water, the paramount question is whether or not the soil profile has sufficient permeability to pass the required amount of drainage water through and out of the crop root zone. The amount of water that must drain below the root zone (D_D) to prevent yield loss can be estimated from $D_D = L(D_R + D_I)$ when the value of L_R for the irrigation water quality in question is substituted for L. The value of D_D required to prevent yield loss as a function of irrigation water quality and crop is given in Fig. 3 for normal rainfall. For example, alfalfa with normal rainfall has a D_D value of 3.9 in. for a L_R of 0.07. Without rainfall, D_D must increase to account for the higher L_R caused by irrigation water of the same quality applied to compensate for no rainfall. L_R would increase to 0.096 without rainfall and D_D would become 5.3 in. For D_D to remain at 3.9 in. without rainfall, the quality of the irrigation water must improve to 480 mg/ℓ rather than 570 mg/ℓ with rainfall.

Few field measurements have been made of the leaching fractions achieved for various combinations of soils, crops, and water management. One such study was conducted by Jewell Meyer in the South Delta in 1976. His findings are summarized in Table 3. The leaching fractions measured varied from less than 0.05 to 0.25 with a mean of 0.15 for all 11 measurements with a standard deviation of 0.08. If these few measurements are representative then 16% of the soils have a leaching fraction less than 0.07 and 16% have L's above 0.23 with the remaining 68% of the L's between 0.07 and 0.23. A similar study was conducted in the Imperial Valley (Lonkerd et al., 1976). These data are summarized in Table 4. In the Imperial Valley the average L was 0.10 with a standard deviation of 0.09. Considering the fine texture of the soils in the Imperial Valley, these values are not unexpected and perhaps adds credence to the values reported for the South Delta.

With this basic information, the salt concentration of the irrigation water (with and without normal rainfall) that would cause various reductions in yield of the prominent crops in the South Delta are summarized in Table 5 for the mean leaching fraction reported for the South Delta, 0.15, and L's one standard deviation above and below the mean, namely 0.07 and 0.23. The amount of drainage required to prevent yield loss for the same three leaching fractions and crops considered in Table 5 is presented in Table 6.

In addition to the generalized salt tolerance of crops just described, some crops may be more sensitive during emergence than during later stages of growth. Dr. E. V. Maas of the Salinity Laboratory has compiled a list of crops comparing salt tolerance at emergence and for yield. His results for the crops of interest in the South Delta are presented in Table 7; bean is the only crop planted by seed that is lacking. Only sugar beet is more sensitive during emergence than at later growth stages. When comparing growth stages, it is important to separate effects that vary with stage of growth from those that reflect the duration of, or changes in, the saline condition. Plant response is directly related to duration of exposure to salinity. Some crops are salt sensitive at the early seedling stage. Data from the literature indicate that barley, corn, rice, and wheat are most sensitive between emergence and the four-leaf stage.

Another problem specific to crops planted on raised beds is the movement of soluble salts to the top center of the beds. Planting seeds in the center of a single-row, raised bed places the seeds exactly in the area where salts concentrate. Planting either a single or double row near the shoulder of the bed places the seeds away from the greatest salt accumulation. The magnitude of accumulation is site specific and related to soil characteristics, incoming water quality, evaporation rate, and the amount of water applied. Under normal conditions, the maximum salt concentration in the raised bed is no more than 2 to 4 times the average salt concentration of the surface soil.

Soils within the area of the South Delta Water Agency were formed from parent material including metasedimentary, granitic, and organic sources. As a result, the soils vary widely in physical characteristics. Soil textures, for example, range from coarse sand to clay, and in organic matter content, from less than 5% in most mineral soils to more than 50% in the muck soils.

A recent soil survey, conducted by the Soil Conservation Service and provided to us prior to publication, indicates 84 different soil series within the South Delta. A soil series is a group of soils that developed from a particular type of parent material and have soil horizons similar in physical characteristics and arrangement in the soil profile. The soils within a series are nearly homogeneous in all profile characteristics except texture near the surface and such featues as slope, stoniness, degree of erosion, topographic position, and depth to bedrock. Nevertheless, a substantial amount of variation can exist even within a defined soil series. Some fields contain several soil series that differ greatly in soil characteristics. The survey only considers variation on a scale of 10 acres or larger. Variations within a 10-acre block are not included in the survey. A typical soil series description follows.

Grangeville clay loam, drained (GC)

These are very deep, somewhat poorly drained soils, formed in flood plains derived from predominately granitic rock sources. Elevations are 10 to 50 feet, and slopes are 0 to 2 percent. Average annual rainfall is 14 to 16 inches; average annual air temperature is 60°F, and frost-free season is 260 to 280 days. In a typical profile the surface layer is grayish-brown neutral clay loam 16 inches thick. Where mixing with the subsoil and surrounding soils is more pronounced, the surface may be heavy loam or sand clay loam. The subsoil is stratified light grayish-brown mottled loam, fine sandy loam, and sandy loam. Reaction is neutral to mildly alkaline.

Included in this mapping unit are inclusions of other soils too small to delineate separately. About 2 percent of this unit consists of Grangeville fine sandy loam, drained, usually where deep cuts have brought the coarser subsurface material closer to the surface. About 4 percent consists of a similar soil that is underlain at about 40 inches by a clayey substratum, usually on the lower physiographic positions. Two percent consists of Dello loamy sand along old stream channels and there are 5 percent inclusions of Merritt silty clay loam, drained, located at random within the delineation. Two percent of this unit consists of a soil that has a grayish-brown silty clay loam or clay loam surface layer that is 20 to 30 inches thick, underlain by fine sandy loam and loam to 60 inches.

An important soil property in determining if a particular leaching fraction can be achieved is soil hydraulic conductivity, the ability to transmit water through a unit cross section of soil in unit time under specified temperature and hydraulic conditions. In the absence of precise measurements, soils may be placed into relative hydraulic conductivity or permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local experience. The 84 soil series in the South Delta were grouped into five permeability classes by the Soil Conservation Service based upon the percolation rate of the least permeable horizon in the profile. They are as follows:

	Permeability, in./hr
Slow	<0.2
Moderately slow	0.2 to 0.6
Moderate	0.6 to 2.0
Moderately rapid	2.0 to 6.0
Rapid	>6.0

To aid in visualizing how the permeability of soils varies, a generalized soil permeability map was made based on the previously stated soil series permeability ratings. The approximate percent of land in each rating, and the series which comprise each permeability rating are as follows:

Map Symbol	Soil Series
Slow (40%) - less than 0.2 inches per hour	
AD	Finrod clay loam
AO	Archerdale very fine sandy loam, overwash
AR	Archerdale clay loam
CL	Stockton clay
CP	Capay clay, 0 to 2 percent slopes
CPB	Capay clay, 2 to 5 percent slopes
CS	Capay clay, saline alkali
CW	Capay clay, wet
EG	Peltier mucky clay loam, drained
ES	Peltier mucky clay loam, organic substratum
PD	Pescadero clay loam, drained
RM	Rincon clay loam
RW	Rincon clay loam, wet
TC	Colusa variant clay loam, drained
WA	Willows clay, drained
XD	Hollenbeck silty clay
Moderately slow (34%) - 0.2 to 0.6 inches per hour	
BC	Blancho clay loam, drained
BR	Brentwood clay loam
BZ	Bronzan sandy clay loam, drained
CD	Eightmile variant clay loam
CH	Bronzan clay loam, drained
CI	Bronzan clay loam
EA	Egbert mucky clay loam, partially drained
EB	Egbert silty clay loam, partially drained
EF	Egbert silty clay loam, sandy substratum
KI	Kingile muck, drained
KL	Kingile-Ryde complex
LR	Los Robles gravelly clay loam
LS	Los Robles clay loam
ME	Merritt silty clay loam, partially drained
MF	Merritt silty clay loam, flooded
OD	Chualar variant coarse sandy loam
RH	Ryde clay loam, drained
RS	Ryde clay loam, organic substratum
SI	Shinkee muck, drained
VJ	Veritas silty clay loam, overwash
VL	Veritas sandy loam, saline-alkali
VM	Veritas variant sandy loam
VR	Vernalis clay loam
VW	Vernalis clay loam, wet
VY	Vina loam
VZ	Valdes silt loam, drained
WB	Webile muck, drained

Map Symbol	Soil Series
Moderate (17%) - 0.6 to 2.0 inches per hour	
FC	Fluvaquents
GC	Grangeville clay loam, drained
MN	Manteca sandy loam
RF	Ryde clay loam, sandy substratum
RI	Ryde-Peltier complex
SC	Timor loamy sand
SH	Shima muck, drained
XV	Galt clay
Moderately rapid (6%) - 2.0 to 6.0 inches per hour	
CB	Columbia fine sandy loam
CC	Columbia fine sandy loam, clayey substratum
CE	Columbia fine sandy loam, channelled
CF	Columbia fine sandy loam, flooded
CJ	Eightmile loam
CO	Eightmile fine sandy loam, overwash
CT	Cortina gravelly loam
DN	Escalon sandy loam
DV	Devries sandy loam, drained
GV	Grangeville fine sandy loam, drained
GS	Grangeville fine sandy loam, flooded
HA	Honcut fine sandy loam
HG	Escalon sandy loma
HL	Honcut gravelly sandy loam
RK	Reiff loam
VF, VG	Veritas fine sandy loam, very deep
VH	Veritas sandy loam
VK	Devries variant sandy loam
Rapid (3%) - greater than 6.0 inches per hour	
DB	Dello sandy loam, clay substratum
DC	Dello loamy sand, drained
DD	Dello clay loam, overwash
DE	Dello loamy sand, moderately wet
DF	Dello sand, flooded
DH	Delhi loamy coarse sand
RC	Rindge mucky silt loam, overwash
RN	Rindge muck, drained
TG	Tujunga gravelly loamy coarse sand
TS	Tinnin loamy coarse sand, drained
TT	Tinnin loamy coarse sand, loamy substratum
TW	Bisgani loamy coarse sand, partially drained
VC	Venice mucky silt loam, overwash
VE	Venice muck, drained

With this background information, it is hoped that the concerned parties can decide upon an adequate water quality standard for the South Delta. The biggest uncertainty in this information is the leaching fractions which can reasonably be achieved for the various combinations of soils, crops, and management options suitable for the South Delta. Therefore, this committee recommends that the concerned parties sponsor a more extensive field study of the leaching fractions being achieved in the South Delta. The leaching fraction for at least ten sites for soils having an SCS permeability rating of 0 to 0.2 inches per hour and ten for soils with a rating of 0.2 to 0.6 inches per hour should be determined by measuring the soil salinity at the bottom of the root zone in at least five locations at each site. A study of this magnitude would require several months and cost about $15,000.

eclamation		Extension Service			Average		Rainfall Dilution Factor for $\bar{C}$
ga- Water vered arm	Total Applied	Evapotrans-piration	Irriga-tion Water Delivered to Farm	Total Applied	Evapotrans-piration	Total Applied	
D_I n.	$D_R + D_I$ in.	ET in.	D_I in.	$D_R + D_I$ in.	ET in.	$D_R + D_I$ in.	$\frac{D_R + D_I}{D_I}$
.5	52.9	40.0	48.6	57.0	40.9	55.3	1.18
1.7	35.3	25.5	36.5	40.1	26.4	37.7	1.11
9.6	19.2	15.8	10.4	20.0	16.3	19.6	1.96
3.4	20.8	17.5	23.2	25.6	16.8	23.2	1.12
0.8	32.0	25.2	40.0	41.2	24.8	36.6	1.03
6.3	43.5	28.0	34.7	41.9	31.2	42.7	1.20
9.6	48.0	37.6	38.9	47.3	37.8	47.6	1.21
6.7	35.5	-	-	-	28.8	35.5	1.33
0.1	34.9	20.9	26.8	31.6	24.2	33.2	1.17

eff. = irrigation efficiency. USBR assumed an eff. of 0.75 for all crops; ES eff. varied from 0.60 to 0.75 depending on crop.

Table 2. Crop salt tolerance parameters (from Maas and Hoffman, 1977).

Crop		Alfalfa	Tomato	Wheat	Bean	Corn	Sugar Beet	Fruit & Nuts	Asparagus	Grape
Threshold, dS/m	(A)	2.0	2.5	6.0	1.0	1.7	7.0	1.5	10	1.5
% Yield decline per unit increase in salinity beyond threshold	(B)	7.3	9.9	7.1	19	12	5.9	20	-	9.6

Table 3. Leaching fractions achieved for various soil types in the South Delta (Meyer, unpublished report, 1976).

SCS Soil Permeability Class in/hr	Crop	No. of Sites Samples	Leaching Fraction Values	Leaching Fraction Mean
0 to 0.2	Alfalfa	2	0.03-0.05; <0.05	0.04
0.2 to 0.6	Alfalfa	2	0.15; 0.15	0.13
	Sugar Beet	1	0.10	
0.6 to 2.0	Walnut	1	0.15	0.18
	Corn	1	0.15	
	Alfalfa	1	0.25	
2.0 to 6.0	Tomato-Cabbage	1	0.25	0.25
	Tomato	1	0.25	
>6.0	-	0	-	-
			Overall Mean =	0.15
			Standard Deviation =	0.08

Table 4. Leaching fractions achieved for various soil types and crops in the Imperial Valley (Lonkerd, Ehlig, and Donovan, unpublished report, 1976).

Soil Series	Crop	No. of Sites Samples	Infiltration Rate, in/hr Range	Leaching Fraction Range	Leaching Fraction Median
Holtsville, stratified fine textures over loamy subsoils	Alfalfa	33	0.30 to 2.0	0.03-0.23	0.09
	Cotton	41		0.01-0.42	0.06
	Lettuce	56		0.02-0.76	0.27
	Sugar Beet	18		0.01-0.49	0.28
	Wheat	37		0.03-0.50	0.12
Imperial, variable surface soil texture but underlain by fine textured subsoil	Alfalfa	21	0.15 to 2.0	0.02-0.11	0.05
	Cotton	11		0.02-0.05	0.03
	Lettuce	26		0.01-0.44	0.07
	Sugar Beet	115		0.01-0.24	0.04
	Wheat	100		0.01-0.42	0.05
Indio, coarse texture over silty flow control subsoil	Alfalfa	71	>2.0	0.02-0.22	0.06
	Cotton	33		0.01-0.26	0.04
	Lettuce	74		0.01-1.00	0.28
	Sugar Beet	7		0.09-0.38	0.15
	Wheat	35		0.03-0.48	0.23
Meloland, coarse loamy surface soils over fine textured subsoils	Alfalfa	14	2.0 to 3.0	0.02-0.05	0.03
	Cotton	17		0.02-0.86	0.05
	Lettuce	10		0.02-0.18	0.04
	Sugar Beet	11		0.01-0.17	0.05
	Wheat	7		0.03-0.16	0.04

Overall Mean = 0.10

Standard Deviation = 0.09

Table 5. Salt concentration of irrigation water, reported as mg/ℓ of total dissolved salts that results in various reductions in crop yield as a function of leaching fraction and rainfall.

Leaching Fraction	No Rainfall: Relative Crop Yield 100%	90%	80%	70%	Normal Effective Rainfall: Relative Crop Yield 100%	90%	80%	70%
ALFALFA								
0.07	480	830	1170	1500	570	980	1380	1770
0.15	1060	1730	2430	3120	1250	2040	2870	3680
0.23	1880	3150			2220	3720		
TOMATO								
0.07	590	860	1110	1360	650	950	1230	1510
0.15	1290	1800	2320	2840	1430	2000	2580	3150
0.23	2310	3280			2560	3640		
WHEAT								
0.07	1430	1810			2800	3550		
0.15	3070	3790			6020	7430		
0.23								
BEAN								
0.07	250	380	510	640	280	430	570	720
0.15	520	790	1060	1330	580	880	1190	1490
0.23	940	1430	1910	2410	1050	1600	2140	2700
CORN								
0.07	420	630	830	1040	430	650	850	1070
0.15	880	1300	1730	2150	910	1340	1780	2210
0.23	1590	2360	3150		1640	2430	3240	
SUGAR BEET								
0.07	1660	2120			1990	2540		
0.15	3580				4300			
0.23								
FRUIT AND NUTS								
0.07	360	500	620	740	440	600	750	900
0.15	780	1040	1290	1550	940	1260	1560	1880
0.23	1400	1870	2340	2800	1690	2260	2830	3390
GRAPE								
0.07	360	630	880	1140	420	740	1030	1330
0.15	780	1310	1840	2370	910	1530	2150	2770
0.23	1400	2370	3340		1640	2770	3910	

Table 6. The amount of drainage required to prevent yield loss for the leaching fractions and crops considered in Table 5.

Leaching Fraction	No Rainfall: Salinity of Irrigation Water (mg/ℓ)	No Rainfall: Depth of Drainage (in.)	Normal Effective Rainfall: Salinity of Irrigation Water (mg/ℓ)	Normal Effective Rainfall: Depth of Drainage (in.)
		ALFALFA		
0.07	480	3.9	570	3.9
0.15	1060	8.3	1250	8.3
0.23	1880	12.7	2220	12.7
		TOMATO		
0.07	590	2.6	650	2.6
0.15	1290	5.7	1430	5.7
0.23	2310	8.7	2560	8.7
		WHEAT		
0.07	1430	1.4	2800	1.4
0.15	3070	2.9	6020	2.9
		BEAN		
0.07	250	1.6	280	1.6
0.15	520	3.5	580	3.5
0.23	940	5.3	1050	5.3
		CORN		
0.07	420	2.6	430	2.6
0.15	880	5.5	910	5.5
0.23	1590	8.4	1640	8.4
		SUGAR BEET		
0.07	1660	3.0	1990	3.0
0.15	3580	6.4	4300	6.4
		FRUIT AND NUTS		
0.07	360	3.3	440	3.3
0.15	780	7.1	940	7.1
0.23	1400	10.9	1690	10.9
		GRAPE		
0.07	360	2.3	420	2.3
0.15	780	5.0	910	5.0
0.23	1400	7.6	1640	7.6

Table 7. Relative salt tolerance of crops of interest in the South Delta at emergence and later growth of stages.

Crop	Electrical Conductivity of the Soil Saturation Extract (EC_e) that Causes a 50% Reduction in	
	Yield	Emergence
Alfalfa	8.9	8-13
Tomato	7.6	8
Wheat	13	14-16
Corn	5.9	21-24
Sugar Beet	16	6-12

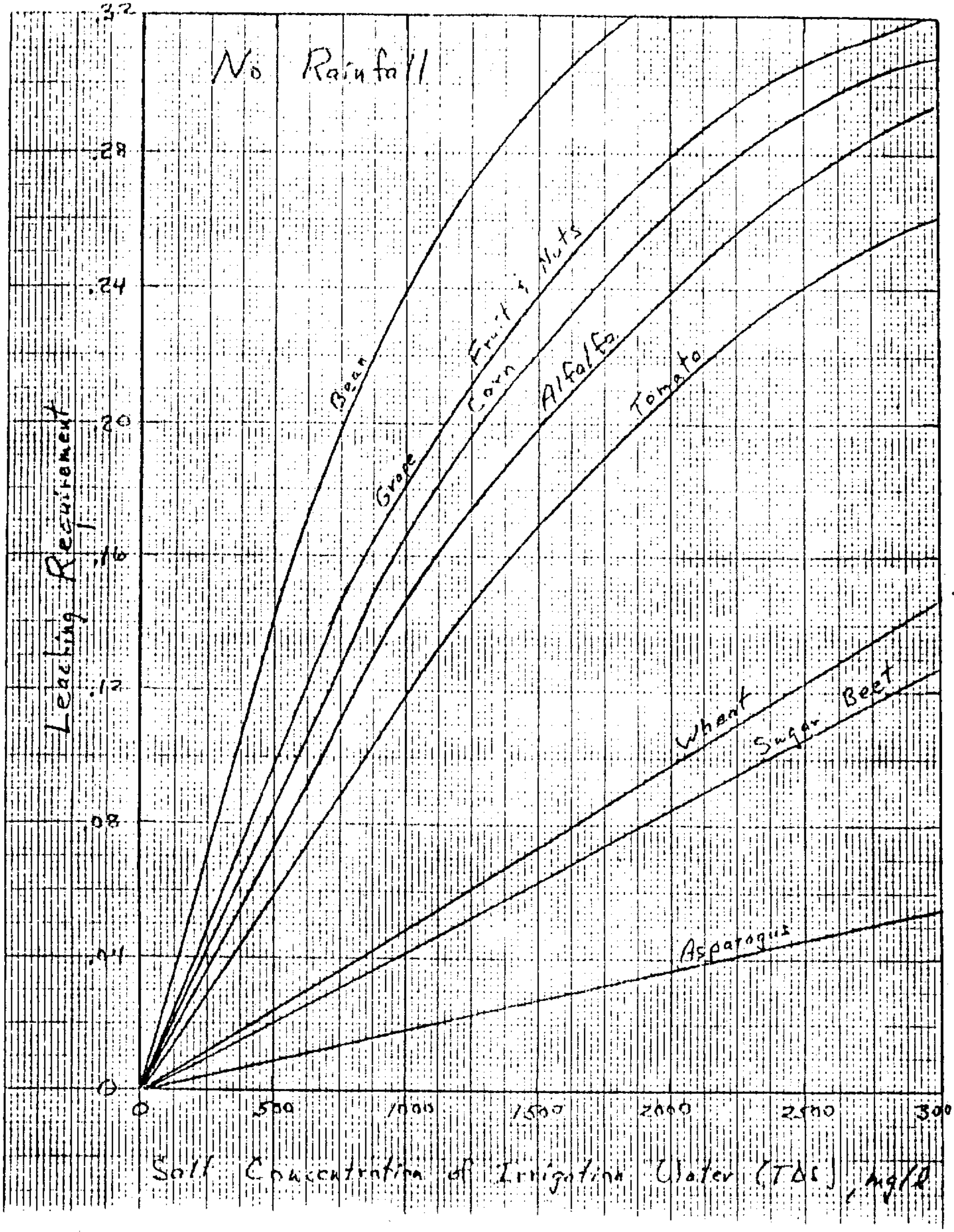

Fig. 1. Leaching requirement of the prominent crops in the South Delta as a function of the salinity of the irrigation water without rainfall.

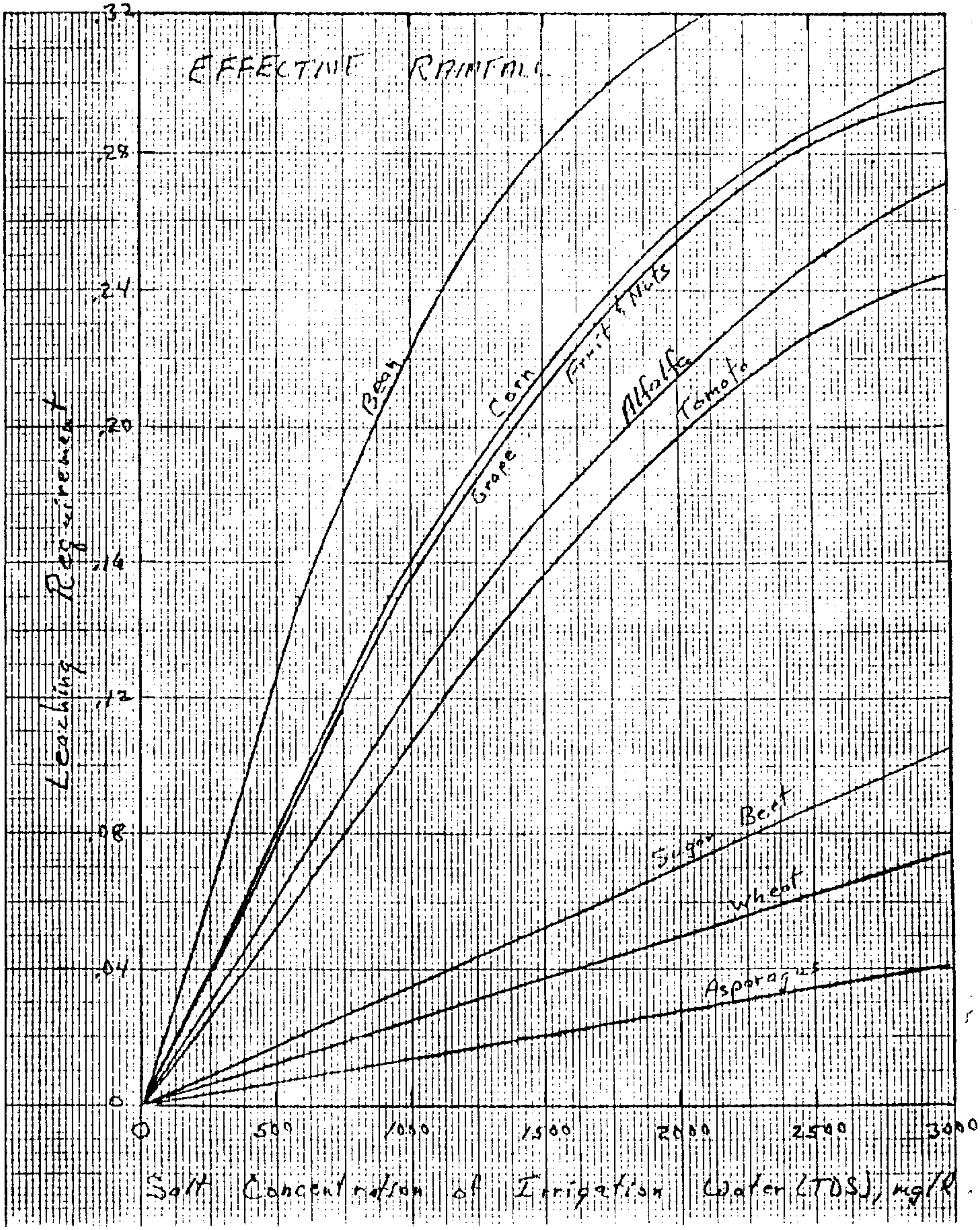

Fig. 2. Leaching requirement of the prominent crops in the South Delta as a function of the salinity of the irrigation water with effective normal rainfall.

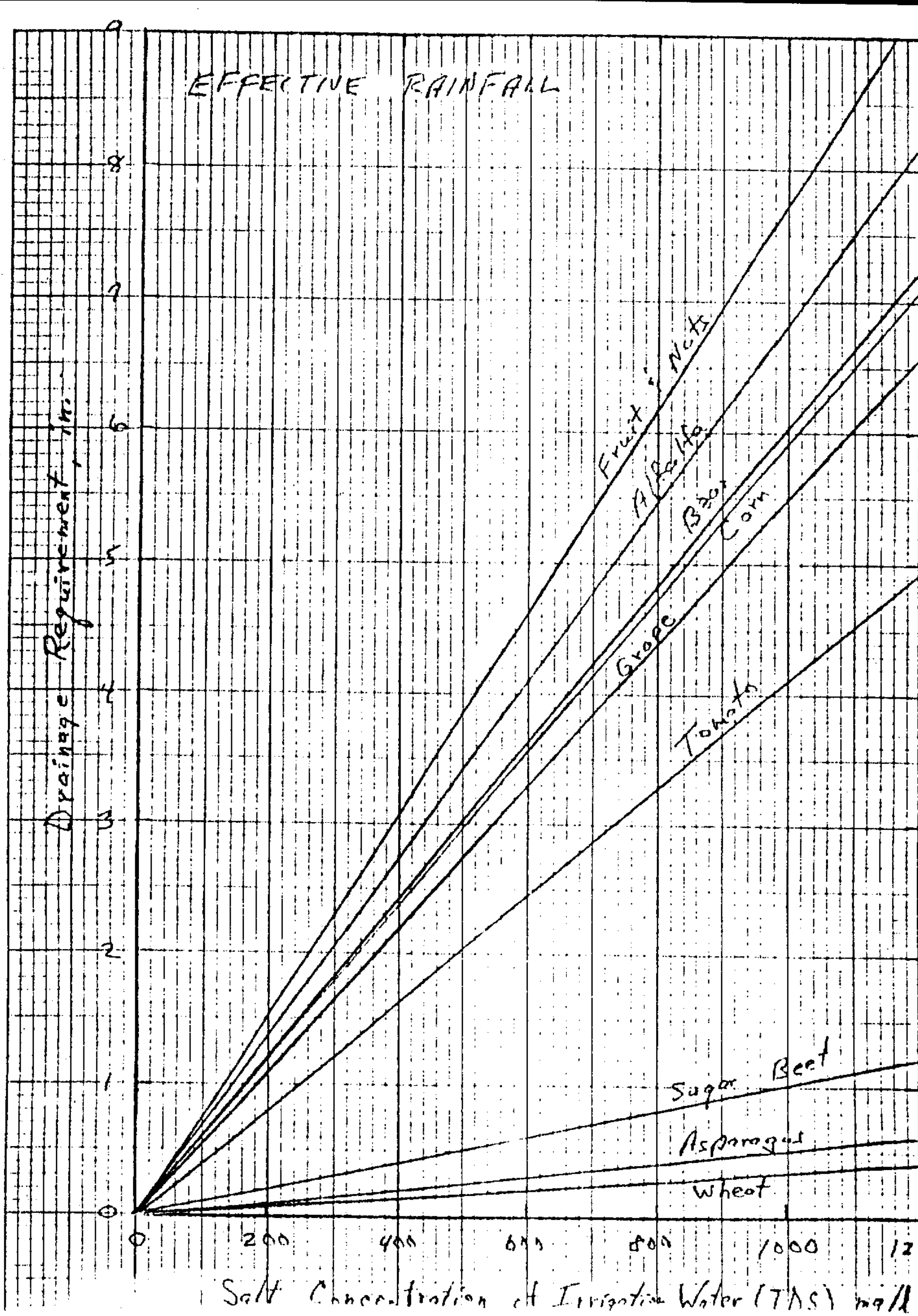

Fig. 3. The amount of drainage required to prevent yield loss as a function of irrigation water quality and crop when rainfall is normal.