# LAND DRAINAGE AND SOIL SALINITY: SOME MEXICAN EXPERIENCES

R.J.Oosterbaan

During the month of July 1995, Ir R.J. Oosterbaan of ILRI was a guest researcher in the Irrigation and Drainage Division of the Mexican Institute for Water Technology/*IMTA* at Cuernavaca. IMTA functions under the aegis of the Mexican National Water Commission/*CNA*.

The purpose of Ir Oosterbaan's visit was to undertake joint research on agricultural land drainage for waterlogging and salinity control. A wealth of information was exchanged during the course of his stay. Some of the research results are summarized below.

## Extent of Waterlogging and Salinity

The extent of waterlogging and salinity in the major irrigation projects in Mexico is summarized in Table 1. Mexico has a large irrigated area (about 3 million ha in the major schemes alone), of which about 15 per cent is affected by salinity/sodicity and 9 per cent by waterlogging. About 50 per cent of the irrigated area is in the north-west. Of this area, 22 per cent is affected. Pre-

Table 1 Area affected by salinity/sodicity and waterlogging in Mexican irrigation schemes of more than 10 000 ha (by region).
Source: FAO/*Colegio de Postgraduados* 1990. (– = not recorded.)

| Region / Scheme | Scheme area (1000 ha) command | Scheme area (1000 ha) irrigated | Saline/sodic irrigated lands (%) | Waterlogged irrigated lands (%) |
|---|---|---|---|---|
| **North West** | | | | |
| Rio Colorado | 250 | 207 | 53 | <1 |
| Santo Domingo | 67 | 38 | 6 | – |
| Altar Pitiquito | 56 | 35 | 6 | – |
| Rio Mayo | 97 | 96 | 20 | 44 |
| Rio Yaqui | 229 | 220 | 11 | 17 |
| Colonias Yaquis | 28 | 19 | 26 | 12 |
| Costa de Herm. | 161 | 79 | 19 | 12 |
| Guaymas | 24 | 17 | 12 | – |
| Culiacán-Hum. | 272 | 265 | 20 | 3 |
| Mocorito | 45 | 41 | 8 | – |
| Guasave | 117 | 112 | 8 | 10 |
| Rio Fuerte | 257 | 236 | 32 | <1 |
| Valle Carrizo | 46 | 43 | 19 | 75 |
| EDO. de Nayarit | 54 | 48 | 13 | 46 |
| Subtotal | | 1456 | 22 | 11 |

Table 1 *Continued*

| Region / Scheme | Scheme area (1000 ha) command | Scheme area (1000 ha) irrigated | Saline/sodic irrigated lands (%) | Waterlogged irrigated lands (%) |
|---|---|---|---|---|
| **North** | | | | |
| Pabellón | 12 | 12 | 0 | – |
| EDO. de Zacatecas | 22 | 18 | <1 | – |
| EDO. de Durango | 21 | 21 | 30 | 17 |
| Río Lagunera | 86 | 86 | 0 | – |
| Palestina | 22 | 22 | 0 | – |
| Delicias | 92 | 68 | 14 | 9 |
| Juarez | 24 | 24 | 71 | 2 |
| El Carmen | 19 | 15 | 0 | – |
| B. Río Conchos | 10 | 10 | 4 | – |
| Río Florido | 10 | 10 | 0 | – |
| Subtotal | | 286 | 12 | 4 |
| **North East** | | | | |
| Don Martin | 30 | 30 | 12 | 10 |
| Río Panuco | 143 | 140 | 0 | – |
| B. Río Bravo | 256 | 202 | 17 | 20 |
| B. Río San Juan | 84 | 77 | 17 | 8 |
| Soto La Marina | 36 | 36 | 0 | 7 |
| Xicotencatl | 26 | 25 | 0 | – |
| La Antigua | 26 | 17 | 0 | 12 |
| Río Blanco | 17 | 14 | 0 | 7 |
| Subtotal | | 541 | 9 | 6 |
| **Centre** | | | | |
| EDO. de Colima | 32 | 24 | 0 | – |
| Alto Río Lerma | 112 | 112 | 5 | – |
| La Begoña | 11 | 11 | 1 | – |
| Amuco Cutzamala | 26 | 26 | 0 | – |
| Nexpa | 15 | 15 | 0 | – |
| Tula | 48 | 43 | 1 | <1 |
| Alfajayucán | 27 | 22 | 1 | <1 |
| EDO. de Jalisco | 72 | 60 | 0 | 2 |
| Tomatlán | 33 | 13 | – | – |
| Jalisco Sur | 13 | 13 | 13 | – |
| EDO. de México | 19 | 18 | 0 | – |
| Arroyo Zarco | 36 | 19 | 0 | – |
| Morelia | 20 | 20 | 25 | 15 |
| C. de Chalapa | 46 | 20 | 99 | 93 |
| Tuxpán | 24 | 16 | 0 | – |
| Zamora | 18 | 18 | 19 | – |
| Rosario-Mezq. | 51 | 49 | 0 | 3 |
| L. Cardenas | 85 | 46 | 0 | 31 |
| EDO. de Morelos | 35 | 35 | 0 | 7 |
| Valsequillo | 34 | 34 | 0 | – |
| S. Juan del Río | 11 | 11 | 0 | – |
| Subtotal | 818 | 625 | 7 | 8 |
| **South East** | | | | |
| San Gregorio | 14 | 11 | 0 | – |
| Tehuántepec | 52 | 23 | 16 | 13 |
| Subtotal | 66 | 34 | 11 | 9 |
| Grand Total | | 2942 | 15 | 9 |

vention and reclamation measures have been implemented (CNA-IMTA undated, and Pulido 1994b).

The results were available of a recent joint study conducted by IMTA, the Remote Sensing Laboratory of Weslaco, Texas, USA, and the irrigation district of Carrizo in north-west Mexico (Pulido and Sanvicente 1994). The purpose of the study was to identify the relation between wheat yield, soil salinity, and the reflections in the wave bands TM2 (green), TM3 (red), and TM4 (near-infrared) of the Landsat thematic mapper. The field data were taken from 49 points in a $60^2$ m grid. Soil salinities and sodicities were measured at depths of 0 to 30 and 30 to 60 cm. Grain yields were determined in 9 $dm^2$. They ranged from 2.0 to 9.3 T/ha, with an average of 5.8 T/ha. Results of the statistical analyses are given in Tables 2, 3, and 4 below.

Table 2 Summary of the results of regression analysis on the relations between wheat yield, soil salinity, and soil sodicity

1a. Yield (Y, t/ha) and salinity 0-30 cm expressed in electric conductivity of the extract of the saturated paste (EC1, dS/m):

| | | |
|---|---|---|
| $r^2 = 0.55$ | Y = 7.9 - 0.47 EC1 | 0.5 < EC1 < 12 |

1b. Yield and salinity 30-60 cm (EC2, dS/m):

| | | |
|---|---|---|
| $r^2 = 0.26$ | relation insignificant | 0.7 < EC2 < 18 |

1c. Salinity EC1 and salinity EC2:

| | |
|---|---|
| $r^2 = 0.51$ | EC1 = 1.1 + 0.58 EC2 |

1d. Yield and EC1, EC2:

| | |
|---|---|
| $r^2 = 0.55$ | Y = – 0.49 EC1 + 0.02 EC2 + 7.8 |

(the standard error of both coefficients is 0.09)

1e. Yield and sodicity 0-30 cm expressed in the Sodium Adsorption Ratio (SAR1):

| | | |
|---|---|---|
| $r^2 = 0.06$ | relation insignificant | 0.2 < SAR1 < 12 |

1f. Yield and sodicity 30-60 cm (SAR2):

| | | |
|---|---|---|
| $r^2 = 0.001$ | relation insignificant | 0.6 < SAR2 < 13 |

The conclusions from Table 2 are:

- The level of salinity EC1 exerts a strong influence on wheat yield; salinity level EC2 affects yield hardly at all. Measurement of EC2 can therefore be omitted to save time and effort;
- In the observed sodicity ranges, up to SAR = 13 no effect on crop yield can be detected. SAR = 13 is not a dangerously high level, and there is no major sodicity problem in the area surveyed.

Table 3 Results of regression analysis of the relations between wheat yield, soil salinity, and light reflection in the wave bands

| | | | |
|---|---|---|---|
| 2a. | Yield (t/ha) and reflection in the green light band (GRN, counts): | | |
| | $r^2 = 0.24$ | relation insignificant | $17 < GRN < 30$ |
| 2b. | Yield and red light reflection (RED, counts): | | |
| | $r^2 = 0.21$ | relation insignificant | $13 < RED < 35$ |
| 2c. | Yield and near infrared light reflection (NIR, counts): | | |
| | $r^2 = 0.31$ | relation insignificant | $50 < NIR < 115$ |
| 2d. | Salinity and GRN: | | |
| | $r^2 = 0.50$ | EC1 = 0.18 GRN – 13 | |
| 2e. | Salinity and RED: | | |
| | $r^2 = 0.46$ | EC1 = 0.40 RED – 3.6 | |
| 2f. | Salinity and NIR: | | |
| | $r^2 = 0.54$ | EC1 = –0.17 NIR + 18 | |
| 2g. | Salinity and GRN, RED, NIR: | | |
| | $r^2 = 0.62$ | EC1 = 0.84 GRN – 0.31 RED – 0.15 NIR | |
| 2h. | GRN and RED: | | |
| | $r^2 = 0.70$ | | |
| 2i. | GRN and NIR: | | |
| | $r^2 = 0.87$ | | |
| 2j. | RED and NIR: | | |
| | r2 = 0.70 | | |

The conclusions from Table 3 are:

- The relation between yield and the reflectance indices is weak;
- There is a definite relation between salinity and reflectance. The most indicative reflectance index is in the near-infrared band (NIR);
- Due to high correlations between the counts in the green (GRN), red (RED), and NIR bands, a multiple regression of salinity upon GRN, RED, and NIR gives only a slightly, but not significantly, better correlation than a regression on NIR alone. Future work on the use of reflectance for salinity detection may be limited to the NIR band to save time and effort;
- The NIR band is useful for surveying the extent and degree of areas under wheat that have salinity problems. It can reduce the field survey work. In combination with the use of Yield-EC1 relations, to be obtained from field surveys, it has

promising diagnostic and predictive applications, as shown below.

By using the reflection data for the whole Carrizo area, and extrapolating the previously obtained relations with soil salinity, the researchers estimated that some 7000 ha of the entire wheat area of 19 000 ha had saline soils.

Table 4 Results of regression analysis of the relation between wheat yield (Y, t/ha) and soil salinity in Carrizo (49 data), expressed in the electric conductivity of the saturated paste of the soil at 0-30 cm depth (EC1, dS/m), with a breakpoint at EC1 = 6

| Range | Regression equation | Average yield | Number of data |
|---|---|---|---|
| EC1 < 6 | Y = 6.9 | Yav = 6.9 | N = 33 |
| EC1 > 6 | Y = 6.9 - 1.1(EC1-6) | Yav = 3.4 | N = 16 |
| 2 < EC1 < 12 | r2 = 0.52 | (coefficient of explanation) | |

The inference from Table 4 is that the introduction of a breakpoint (EC1 = 6) in the relation between yield and salinity, whereby yield reduction occurs only at EC values higher than the breakpoint value, was successful for the Carrizo data. This is because $r^2$ = 0.52 is not significantly smaller than $r^2$ = 0.55, the value for all data, obtained without a breakpoint (Table 1).

When a reclamation program is able to reduce salinity to less than EC1 < 6 dS/m, one can estimate that the yield benefit per ha would be

$$B = (6.9 - 3.4) \times 16/49 = 1.1 \text{ T/ha/year}$$

Applying this ratio to the total saline area under wheat (7000 ha), one finds a total yield benefit of 7700 T/year. Conversely, one can say that the present salinity problems in Carrizo are causing production losses of 7700 T/year.

Similar research is now going on for cotton. It will include the much larger irrigation district of Yaqui, just to the north of Carrizo.

### Research on Surface Drainage

IMTA attaches much importance to surface drainage in the humid areas of Mexico (Namuche and Tiedeman 1994). To predict the discharge of surface drainage systems in these areas, Ir Oosterbaan developed and tested a simple rainfall-runoff model based on the concept of a non-linear reservoir. Compared with the more commonly used model of various parallel linear reservoirs, the non-linear reservoir offers the advantage of avoiding the difficulty of distributing the rainfall over different reservoirs.

The recharge-discharge relation of a linear reservoir is expressed mathematically as

$$Qt = Qi.\exp(-\alpha) + P[1-\exp(-\alpha)]$$

where

- Qt is the discharge rate at time t;
- Qi is the discharge rate at time i which is one time-step before t;
- P is the recharge rate during the time-step t-i;
- $\alpha$ is the reaction factor of the reservoir per time-step.

When P = 0, the previous equation reduces to

$$Qt = Qi.\exp(-\alpha) \quad \text{or} \quad \alpha = -\ln(Qt/Qi)$$

Hence, $\alpha$ can be determined from the discharge rates measured during periods without rainfall.

When the reservoir is non-linear, $\alpha$ is not a constant; it varies with the discharge rate. Often, the relation between $\alpha$ and Qi is linear

$$\alpha = a.Qi + b$$

This represents a reservoir with multiple outlets at different levels. Figure 1 illustrates the linear ($\alpha$,Q) relation.

When $\alpha$ has been determined, one can calculate the discharge rate for any sequence of recharge rates. When the recharge rate is not the same as the rainfall intensity, another reservoir, preceding the non-linear reservoir, can be introduced. The first reservoir is linear,

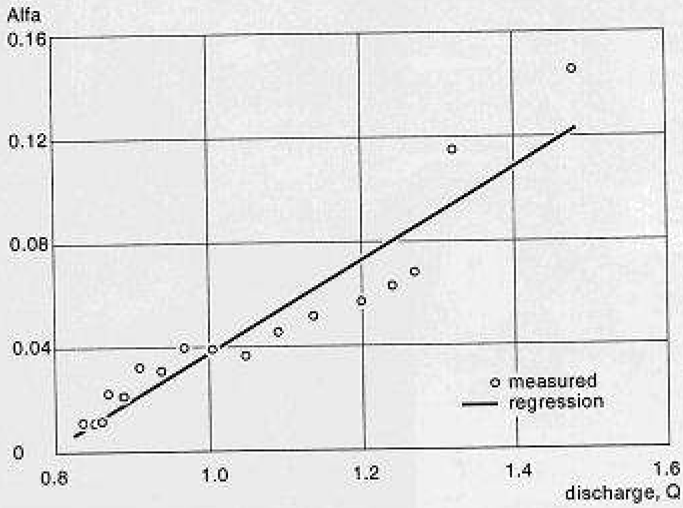


*Figure 1 Comparison of a with measured and calculated discharge values*

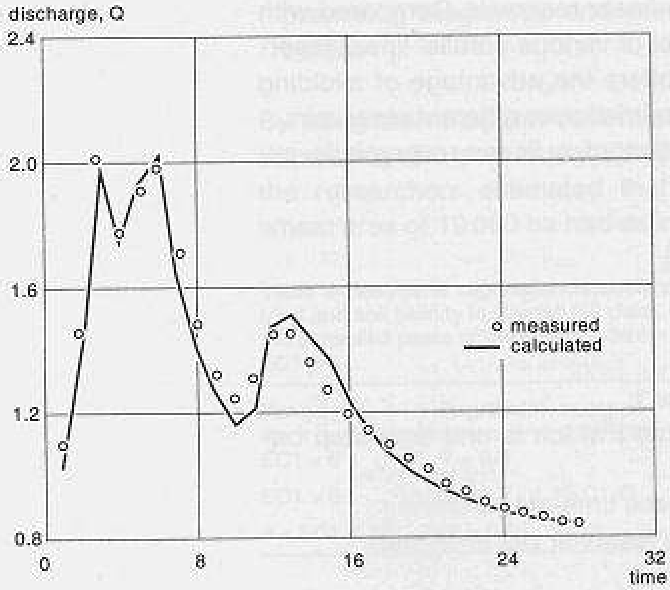


*Figure 2 Comparative values of measured and calculated discharge*

with evaporation as discharge. It has a maximum storage capacity and an overflow that empties into the second reservoir, which provides the recharge.

Figure 2 illustrates measured and calculated discharge rates.

IMTA is working with farmers' organizations in the humid areas of Mexico to conduct pilot area research on surface drainage in farmers' fields. A ditcher with rotary blades is being used for excavation, as it spreads the spoil away from the drainage ditch. The ditcher is attached to a tractor (Photo 1). The equipment is similar to that used by Dutch engineers for the preparation of soils in new polders reclaimed from the North Sea. Ditches are also being excavated manually. The results from the pilot areas are promising, and the rotary-blade ditcher has proved to be effective and efficient.

*Photo 1 Tractor-drawn rotary-blade ditcher at work. (By courtesy of Impex International, Spartanburg, South Carolina, USA)*

### Research on Subsurface Drainage

IMTA is collaborating with irrigation districts and farmers' organizations to establish pilot areas with subsurface drainage in waterlogged and saline farmers' fields in semi-arid zones (Namuche and Tiedeman 1994). To install shallow drains, the research team is using a drainage machine that is pulled by a tractor on wheels (Photo 2). Deeper drains are being installed by drainage machines that run on caterpillar tracks. Additional efforts are being made to introduce mole drains. Ir Oosterbaan has established contacts between IMTA and Professor Gordon Spoor of Silsoe College, England, who is an expert on mole drainage.

Studies of the effectiveness and efficiency of shallow drains and mole drains in reclaiming saline lands are certainly worth the effort. Shallow systems can be installed by farmers' organizations or local contractors more easily than the more common deep systems. If these trials are successful, they could lead to a wider application of shallow drainage around the world. This, in turn, would reduce the risk of excessive drainage by deep systems.

SALTMOD, a computer program developed by Ir Oosterbaan, was used to predict the effects of the reclamation efforts in the

*Photo 2 Tractor-drawn drainage machine with chain box*

pilot areas. The program uses readily available data and has a user-friendly menu, so the project officers had no trouble learning to run it. Initial results indicate a close match between observed and predicted water and salinity levels.

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