Estimating costs of quality changes in using WASTE WATER for irrigation

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AMONG CURRENT ISSUES in water management, perhaps none is more critical than evaluating the use of waste water in irrigation. Waste water includes return flow irrigation water, treated municipal effluent, and low quality waste water from other miscellaneous sources. Opinions range from those which view such use as completely impracticable to those which view reclaimed water as superior to present water supplies. At issue is the possible cost penalty from increased salts and nutrients in reclaimed water used to replace present water.

To measure the impact of waste water on crops, a method has been developed which uses the latest knowledge about salt tolerance in crops and the disposition of salts in the soil. The principal source of data was the U.S. Salinity Laboratory in Riverside, whose material was in turn utilized by the University of California's Committee of Consultants for the State Water Resources Control Board. This article presents the estimating formula in both written explanation and in mathematical notation.

Rationale

The rationale for the total dollar estimate is that the various impacts of changes in quality of irrigation water can be independently identified and measured. Once measured and converted to monetary units, these factors can be added to arrive at a total dollar impact. One caution is important to note: the formula treats only estimated percentage reductions in crop value. If the use of reclaimed water precludes present crop production and necessitates entirely different cropping patterns (because of differences in salt tolerance among crops), then the net impact of such a crop change must be calculated separately.

Formula

The formula estimates the net dollar impact per acre foot of irrigation water by adding together the following five variables: (1) **the reduction in gross crop value,** calculated by multiplying the estimated yield reduction associated with the increased salinity of the waste water by the expected crop value per acre previously expected and dividing by the acre feet of water applied; (2) **the cash costs of additional water applied to meet leaching requirements,** calculated by adding the cost of additional water to the cost of labor for applying it, then multiplying this sum by the consumptive use of water in acre ft, and finally multiplying the result by the difference in leaching requirements between the two types of water considered; (3) **the annual fixed costs (depreciation and interest on investment) of capital improvements required to distribute increased volumes of water necessitated by changes in water quality,** calculated by dividing such fixed costs per acre by the amount of water applied per acre; (4) **the net dollar impact of nutrients added by the changed water supply,** calculated by multiplying the value per lb of nitrogen by the increased nitrogen resulting from the difference in water quality applied, divided by the amount of water applied; (5) **the costs of any change in quantity of dilution water used to meet State Water Resources Control Board discharge requirements for drainage water,** calculated by first determining the differences in concentration between SWRCB objectives and undiluted discharge, divided by the difference between dilution water and SWRCB objectives, multiplied by the acre ft irrigated with undiluted discharge. Prices of different quality dilution water are then applied to quantities required, and divided by the quantity of water applied, to convert into cost per acre ft of application.

MATHEMATICAL FORMULATION

$$X = \frac{y}{W_2}\triangle + (C_W + C_L)(R_2 - R_1) + \frac{C_c}{W_2} - C_n (N_2 - N_1) + \frac{C_G (D_2 - D_1)}{W_2}$$

Note: subscript 1 = original water; subscript 2 = replacement water

X = Total impact \$/acre ft of water applied (positive sign = cost, negative sign = revenue)

y = Value of crop in \$/acre at farmgate using original water supply

w = Irrigation water applied in acre feet

$$w_1 = \frac{U / I}{1-R_1} \qquad w_2 = \frac{U / I}{1-R_2}$$

$\triangle$ = Estimated yield change due to increased salinity in irrigation water expressed as percentage

C = Cost per Unit:

- C_W = Cost difference between replacement and original water per acre ft
- C_L = Cost of labor per acre ft
- C_c = Cost of capital (annually) per acre to utilize replacement water
- C_n = Cost (or value) of nitrogen per lb
- C_G = Cost of dilution water per acre ft

U = Consumptive use of water

I = Irrigation efficiency (exclusive of leaching fraction)

R = Leaching requirement:

- R_1 = of original water as a fraction
- R_2 = of substitute water being evaluated as a fraction

N = Nitrogen in water:

- N_1 = nitrogen in original water, lbs per acre ft
- N_2 = nitrogen in substitute water, lbs per acre ft

D = Volume of dilution water required to meet SWRCB objectives, acre ft per ft of applied water:

- D_1 = dilution (acre ft) required with original water
- D_2 = dilution (acre ft) required with substitute water

Where $D = \frac{V (E_s - E_d)}{E_I - E_s}$

V = Acre feet of undiluted discharge per acre irrigated

E_s = Quality objectives of SWRCB for discharge water in mmhos

E_d = Quality of drainage water in mmhos

E_I = Quality of dilution water in mmhos

Example

To illustrate the formula, the following example is offered:

Assume that Delta-Mendota Canal water being used for irrigating field beans is to be replaced with water having a higher salinity. Present water has an EC of .3 mmhos, while the replacement water has an EC of 1.0 mmhos. Th district using the replacement water dis charges its drainage water into the Sa Joaquin, where the SWRCB requires a limit of EC = 1.5 mmhos on discharge Field beans are estimated to consume 3 acre ft of water per year, and irrigatio efficiency (not including a leaching frac tion) is 80%, so 3.75 acre ft of wate are applied annually. Irrigation labo costs are $2 per acre ft applied with th replacement water, requiring an addi tional cost of $2 per acre for leveling Present and replacement water have th same cost, but dilution water, with an EC of .1 mmhos, costs $10 per acre foot Present water contains 10 lbs of nitroge per acre ft while replacement water con tains 50 lbs per acre ft. Nitrogen i valued at 15¢ per lb. Beans have an ex pected value of $200 per acre, with an expected 10% reduction in yield at an EC of 1.0 mmhos.

Value of variables: $Y = \$200$; $\triangle = 10\%$; $C_{w_1} = C_{w_2}$
$C_L = \$2$; $C_c = \$2$; $C_n = \$0.15$; $C_G = \$10$; $U = 3$
$I = 80\%$; $N_1 = 10$; $N_2 = 50$.

$$R_1 = \frac{.3}{12} = \frac{.1}{4} = .025 \qquad R_2 = \frac{1.0}{12} = .083$$

$$w_1 = \frac{\frac{3.0}{.80}}{1-.025} = \frac{3.75}{.975} = 3.85$$

$$w_2 = \frac{\frac{3.0}{.80}}{1-.083} = \frac{3.75}{.917} = 4.09$$

(Leaching requirement formula and value for maximum concentration of salts for field beans (12) from table by Committee of Consultants "Crop Tolerance and Leaching Requirement Tables," 1-7-74.)

The total leachate volume is, therefore, .85 and 1.09 acre ft for w_1 and w_2 respectively.

Assuming no precipitation, or weathering, and further assuming that the salt balance is being maintained in the root zone, all of the salt contained in the original irrigation water must be contained in the leachate.

Therefore (for original water) $E_d = 3.85 \times .3 \div .85 = 1.36$ mmhos; and (for replacement water) $E_d = 4.09 \times 1.0 \div 1.09 = 3.75$ mmhos.

$$D_1 = .85 \frac{(1.5 - 1.36)}{.1 - 1.5} = -.085$$

$$D_2 = 1.09 \frac{(1.5 - 3.75)}{.1 - 1.5} = 1.75$$

$$X = \frac{200}{4.09}(.10) + (0 + 2)(.083 - .025) + \frac{2}{4.09} - .15\,(50 - 10) + 10\,\frac{[1.75 - (-.085)]}{4.09}$$

$X = 4.89 + 0.12 + 0.49 - 6.00 + 4.44$
$X = \$3.94$ = Cost due to increased salinity for each acre foot of replacement irrigation water applied.

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Maximum vs. Minimum TILLAGE EFFECTS *on barley and wheat in Imperial Valley*

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THE OPTIMUM PLANTING time for wheat and barley in Imperial Valley is between December 15th and January 15th, which makes them excellent crops to follow cotton and late-plantings of grain sorghum. The growing period (and production) of the cereal crops might be increased if the time between the harvest of cotton or grain sorghum and the planting of wheat and barley could be shortened, by eliminating some irrigation and tillage operations. These possibilities were investigated during an experiment designed to compare wheat (Siete Serros and Anza) and barley (CM 67) in the winters of 1971–72 and 1972–73 under maximum and minimum soil preparation following cotton and grain sorghum.

Tillage

The maximum and minimum tillage experiments following cotton were on heavier and more saline soils than those following grain sorghum in 1971–72, but the soils were similar in 1972–73. Maximum soil preparation after cotton and grain sorghum involved shredding of stalks, discing twice, bordering up for pre-irrigation, pre-irrigation, discing once, leveling, a broadcast application of 540 lbs per acre of ammonium nitrate (33⅓% N), planting (80 lbs of seed per acre), and irrigating up.

Minimum soil preparation operations after cotton and grain sorghum involved shredding of stalks, discing twice, leveling, bordering up for irrigation, and application of 540 lbs per acre of ammonium nitrate, planting (80 lbs per acre), and irrigating up.

A second minimum soil preparation after grain sorghum involved removing the sorghum stalks by cutting and baling, an operation practiced in the Imperial Valley, followed by the minimum soil preparation.

Wheat and barley were planted after cotton on December 10, 1971, and January 5, 1972. Sorghum was planted on December 18, 1971, and January 5, 1972. Seven replications were used for the tests following cotton and six following grain sorghum. Yields were determined by harvesting an 8 by 50 ft plot with a combine. No statistical comparisons could be made between the tests following cotton and grain sorghum because two separate locations were used. Growing barley with wheat which matured 14 to 22 days later may have had some effect on the yield of each crop. For this reason, it may be unfair to make rigid yield comparisons between the two crops.

Germination and early seedling growth of wheat and barley were excellent, and no differences due to tillage operations were observed. The slightly lower yields in wheat and barley following cotton may have resulted from the higher soil salinities in this area. Lower grain yields may have resulted from the barley receiving one irrigation too much and the wheat needing an additional irrigation.

After cotton

Compared with wheat, barley was 14 days earlier, slightly shorter in plant height, lower in bushel weight, and severely lodged. No significant differences