FORUM
Agricultural Water Pollution Control: an Interdisciplinary Approach

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ABSTRACT / Regulation and control of agricultural water pollution is unique and difficult to accomplish. Water quality standards are often proposed without adequate consideration of the overall economic impact on agricultural production. This article illustrates how economists and physical scientists can cooperate to develop appropriate control strategies for agricultural water pollution. Data provided by physical scientists and economists are used in a linear programming model to describe salt discharge as a function of water management, production levels, and an associated effluent charge. Four water management activities were chosen on the basis of different costs of production (including a parametrically varied effluent charge), water requirements, alfalfa yields, and levels of salt discharge. Results indicate that when the effluent charge is low (<$0.20/metric ton salt discharged), maximum production with maximum salt discharge is most profitable. As the effluent charge is increased ($0.20–$0.40/metric ton salt discharged), it becomes progressively less profitable to produce alfalfa at maximum levels of pollutant discharge. When the effluent charge is >$0.40/metric ton salt discharged, alfalfa production is no longer economically feasible. An important aspect of this approach is that it permits policy makers to identify explicitly the relationship between the environmental standard and the effect on agricultural production.

The problem of applying uniform water quality standards for control of pollution from irrigated agriculture has been an important concern to national water quality control agencies. To date, most measures have encouraged the use of standards and monitoring procedures. Emphasis has also been placed on the selection and use of “best management practices” appropriate for the special conditions imposed by climate, soils, topography, and farming practices of a particular land area (Stewart 1976, EPA 1973).

The effect has been twofold. First, various standards were considered with less than adequate physical data regarding the kinds and sources of pollutant loads carried by agricultural return flows to receiving waters (Miller and others 1978). Second, water quality standards were suggested without information concerning the overall economic impact of the restrictive level (Aleti and others 1974, Horner 1975 and 1977, Gossett and Whittlesey 1976).

Economists consider pollution as a primary example of a technical external diseconomy. Costs that do not directly affect the firm, such as pollution of downstream water, are not taken into consideration by the producer, so by-products are often freely discharged into the external environment. The economic solution to this problem is to integrate these external costs into the internal cost structure of the firm so that external pollution costs are part of the producer decision framework. Such a procedure is known as internalizing externalities.

Taxation can be used to discourage nonpoint pollution in one of two ways. Meade (1952) suggested that taxing the inputs in the production process can be economically efficient if there is an explicit relationship defined between inputs and the amount of pollution generated by the production process. Alternatively, Baumol and Oates (1971) have argued that an equally efficient approach is to tax the pollutants arising from the production process. If there is an explicit relationship between pollutant discharge and the inputs used in the production process, then either taxing the inputs or the effluent discharged is potentially an efficient means of pollution control (Pfeiffer and Whittlesey 1978).

This article presents an interdisciplinary approach as a method to analyze water pollution for agricultural water quality management. While a call for such an approach is not original (Kneese and Bowers 1968), application has been less than actively pursued and requires greater emphasis (Sobel 1965, Heady and Nicol 1975, Casler and Jacobs 1975, Revesz and Marks 1982). Given the immensity of water quality problem and present implementation of many unproven “best management practices” for control of agricultural discharges, an example of an interdisciplinary approach merits added discussion.

This study has three parts: (a) The physical scientist

KEY WORDS: Water quality; Agricultural discharge; Costs of pollution control
Table 1. Physical and economic input for simulated application.

Physical input
1) An initially saline soil \((E_{C_s} = 14 \text{ dSm}^{-1})\).
2) Irrigated water salinity \((E_{C_w})\) of \(<1 \text{ dSm}^{-1}\).
3) Crop consumptive use (alfalfa—northwestern Nevada, elevation 1515 m) of 1.35 ha-m/ha (Guitjens and others 1978).
4) Relationship \(E_{C_s}\) vs salt content (Table 2) in soil (Richards 1954).
5) Relationship \(E_{C_s}\) vs \% yield reduction (Table 3) of alfalfa (Ayers and Westcot 1976, FAO 1976).
6) Relationship salt discharge vs water applied (Table 4) to initially saline soil (Van Schilfgaard 1974).

Economic input
1) The producer is a price taker in both the product and factor markets.
2) Linear production activities sufficiently describe behavior of the producer over the relevant range of production.
3) Costs and return for the producer are known with certainty.
4) The producer wishes to maximize net returns.

\(\text{It was necessary to assume an initially saline condition in order to relate salt discharge directly to the amount of water applied. The assumption is not unreasonable in that agriculture is being forced to go to marginal lands in order to accommodate rural development.}\)
\(\text{EC}_s\) = electrical conductivity of soil saturation extract.
\(\text{EC}_w\) = electrical conductivity of the irrigation water.

Table 2. Relationship electrical conductivity \((E_{C_s})\) of saturation extract vs salt content in soil (Richards 1954).

<table>
<thead>
<tr>
<th>(E_{C_s}) (dSm(^{-1}))</th>
<th>Salt content(^a) (kg/ha)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2.0</td>
<td>7.0</td>
</tr>
<tr>
<td>4.0</td>
<td>20.0</td>
</tr>
<tr>
<td>6.0</td>
<td>26.0</td>
</tr>
<tr>
<td>8.0</td>
<td>32.0</td>
</tr>
<tr>
<td>10.0</td>
<td>39.0</td>
</tr>
<tr>
<td>12.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>

\(^a\%50\) saturation.
\(^b\%\) Salt in soil at a given \(E_{C_s}\) increases with soil saturation percentage.
\(^c\)Assume 2,240,000 kg/ha for an average ha-furrow slice.

Table 3. Relationship electrical conductivity \((E_{C_s})\) of saturation extract vs \% yield reduction for alfalfa (Ayers and Westcot 1976, FAO 1976).

<table>
<thead>
<tr>
<th>(E_{C_s}) (dSm(^{-1}))</th>
<th>Yield reduction(^c) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>3.4</td>
</tr>
<tr>
<td>4.0</td>
<td>5.4</td>
</tr>
<tr>
<td>6.0</td>
<td>8.8</td>
</tr>
<tr>
<td>8.0</td>
<td>15.5</td>
</tr>
</tbody>
</table>

\(^c\%\) Salt effects on plant growth (yield) increase with a decrease in saturation percentage.

\(\text{Methodology}\)

Producer management resulting in different levels of nonpoint pollutant discharge via irrigation return flow is described. An example relating salt discharge as a function of water management, production, and an associated effluent charge is presented through a linear programming framework. Table 1 identifies the physical and economic input information necessary for model application. Tables 2–4 represent the physical relationships derived by the physical scientist(s) in order to define quantitatively the problem of developing an explicit relationship between management activity and level of pollutant discharge. These data are used to generate, in Table 5, the relationship between total water application, salt discharged (leached), and level of production. Such data, once generated, are used by the economist(s) in defining producer behavior in response to an enforceable environment standard as reflected by an imposed effluent charge on total salt discharged. Rational producer behavior is described by the following mathematical presentation:

Maximize  \(Z = \sum_{i,j=1}^{4} (c_{ij}A_j) + c_5X_5 + c_6X_6\)  (1)

Subject to  \(\sum_{j=1}^{4} (a_{ij}A_j) \leq L\)  (2)

\(\sum_{j=1}^{4} (a_{2j}A_j) \leq W\)  (3)