# Salinity Damage to Irrigated Crops: Economic Measures from a Farm Survey in Pakistan

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**Abstract**: Dissolved salts (salinity) in irrigation water are a significant environmental problem in arid regions. Some of the most seriously impacted irrigated areas are found in Pakistan's Indus Basin. Economic damage measures are essential for evaluating salinity control programmes. Most damage estimates are derived from controlled experiments, which may not be applicable to actual field conditions. Data from two jointly conducted farm surveys—one dealing with farm inputs and production and the other with soil and water chemistry—are analyzed with statistical regression techniques. Damage measures for three winter crops are developed. While the dual survey method is expensive, the statistical analysis shows that less elaborate soil sampling procedures can provide sufficient information. The technique is judged to be a reliable approach to measuring salinity damage functions under actual field conditions.

## Introduction

Dissolved salts (salinity) in irrigation water are an important environmental problem in many arid agricultural production regions. The salts that occur naturally in small amounts in irrigation water are left behind in the soil as the water evaporates. If steps are not taken to dispose of excess salinity, crop yields are impaired and, eventually, production may become uneconomical. Some of the early irrigation-based civilizations are thought to have disappeared because they lacked the technology and institutions to deal with the salinity problem (Moore, 1972).

The Indus River in Pakistan irrigates over 40 million acres. That area is the largest contiguous irrigation system in the world. Increasingly, lands in the Indus Basin are being affected by accumulation of salts (White House-Interior Department Panel, 1962; Chaudhri *et al.*, 1978; and Johnson, 1982). Some estimates indicate that over 100,000 acres of productive land per year are being lost through salinization of soils. In a nation with an already high and growing ratio of population to arable land and with limited resources, the salinity problem looms as one of the most important and intractable public policy issues.

Economic analysis can aid in appraising investment and policy decisions regarding salinity control and abatement (Yaron, 1985). Estimates of economic damage from salinity provide the basis for measuring economic benefits of reductions in salinity. Yaron and his associates originated an approach to economic evaluation of salinity impacts on individual crops. Moore *et al.* (1974) developed a linear programming procedure for estimating economic damage for the multicrop farm. Their approach has since been elaborated upon and applied elsewhere in the Colorado River Basin in southwestern USA and in Mexico (Boster and Martin, 1979; and Oyarzabal and Young, 1978).

A major concern for salinity evaluation is to determine the effects of salinity on crop productivity under actual production conditions. The physical-biological relationships among irrigation water quality, soil moisture salinity, and crop productivity must be the foundation for salinity damage measurement. Some studies have drawn on controlled experiments to estimate the impact of salinity on crop productivity (e.g., Yaron and Olian, 1973). Many studies have adopted generalized crop damage relations based on judgmental summaries or statistical analyses of a variety of controlled experiments (e.g., Maas and Hoffman, 1977).

This paper takes an alternative approach, utilizing actual farm production data from a unique pair of surveys conducted in Pakistan. One survey identified inputs and production on a sample of farms, while the other obtained data on a number of chemical characteristics of irrigation water and soils on the same farms. Those data were generously made available to us by the Government of Pakistan and the World Bank. This paper reports measurements of salinity damage utilizing a part of that data set.

## Source and Nature of Data

The data used in the analysis came from two Indus Basin farm surveys of 61 randomly selected watercourses, carried out as a joint venture by the World Bank and the Water and Power Development Authority of Pakistan (WAPDA) in 1976/77.[2] The first survey, termed the Agro-Economic Survey (AES), included responses on inputs, costs, and returns from 179 farms in each of the major provinces. Three farms (head, middle, and tail) on each watercourse were selected through random sampling. The analysis reported here was confined to 140 farm observations from Punjab Province because production conditions in the other provinces differ from those in the Punjab, and few observations outside the Punjab were collected. The Soil Salinity Survey (SSS), also conducted on the same 61 watercourses in the same year, represents 1,268 records pertaining to measurement of the soil and water chemistry. Calcium and magnesium ratios (Ca/Mg) of the soil, electrical conductivity (EC) of the soil, sodium absorption ratio of the soil (SAR), each at five different depths, and EC, SAR, and residual sodium carbonate (RSC) of irrigation water were recorded. The survey was conducted at the start of the winter (*Rabi*) season of 1976/77. Farm records for both surveys were matched by computer search. The analysis is limited to the productivity of winter crops, which most closely corresponds to the time the soil survey was conducted.

## Statistical Procedure

The statistical analysis was conducted in three stages. First, crop production for each crop was regressed on all soil and water quality variables, controlled for land, fertilizer, and number of irrigations. Stepwise regression was utilized. Four functional forms were tested: linear, quadratic, log-linear, and Cobb-Douglas. Following the advice of Leamer (1983) (and also due to space limitations), the subsequent discussion is confined to the best fitting form, the Cobb-Douglas. The other forms yielded similar statistical results.

Very high multicollinearity was found among the independent variables. Soil salinity variables at 6-72 inches were highly correlated; the correlation coefficients of EC of soil among the horizons being as high as 0.87. The correlation between SAR and Ca/Mg was also high. As a consequence, the mean value of the three soil chemistry measures (EC, SAR, and Ca/Mg) was calculated and stepwise regression again performed. The stepwise procedure selected EC of the soil first for all three crops. Further, the mean EC of soil was highly correlated with the means of the other soil chemistry measures (SAR and Ca/Mg), having correlations of 0.75 and 0.81, respectively. SAR and Ca/Mg of soil were therefore dropped from the subsequent analysis.

The final step was to fit Cobb-Douglas production functions to data for all three crops on a per-cropped-acre basis. The results are shown in Table 1. In the case of local wheat, only water salinity is not significantly different from zero and does not display the expected sign. The predictive power of the equation is very high. The expected negative production elasticity of soil salinity indicates that a 5 percent decrease in yield of local wheat is associated with a 1 percent increase in soil EC.

Turning to improved wheat, only phosphatic fertilizer and water salinity are not significantly different from zero. Soil salinity has a much more pronounced effect on this crop, showing a decrease in yield of 12 percent with a 1 percent increase in soil salinity. The production elasticity of water and nitrogen fertilizer were higher as compared to local wheat, which is consistent with other findings regarding improved Green Revolution varieties. However, local wheat showed a better response to phosphatic fertilizer.

Finally, the mustard crop equation also predicted a 5 percent yield decrease due to a 1 percent increase in soil electrical conductivity. The coefficients for irrigation water and seed were highly significant, but the fertilizer and water salinity coefficients were not significantly different from zero. The proportion of variation explained by the equation was also relatively high.

## Deriving Damage Measures

Finally, by taking the appropriate derivatives of the production functions, the marginal value product (MVP) of selected inputs and the marginal value of damage (MVD) due to soil salinity were obtained for each of the three crops. The MVP criterion demonstrates the allocative efficiency of a particular input when it is compared with the price of that input. An input ($X$) is being allocated efficiently when its MVP is equated with its price or opportunity cost. The opportunity cost of canal water is measured by the price of pumping groundwater in Punjab Province. Nitrogen and phosphate fertilizer prices were derived from government sources.

The results are presented in Table 2, with each independent variable evaluated at its mean. Fertilizer and irrigation water show marked scarcity. The interest here is primarily in the marginal salinity damages. Local wheat and mustard are found to be relatively tolerant to soil salinity, showing marginal damage of -18.00 and -14.00 rupees per acre. The Green Revolution wheat varieties are much more sensitive, with an estimated marginal damage of -63.00 rupees per acre at the mean.

**Table 1—Regression Results**

| | Local Wheat | Improved Wheat | Mustard |
|---|---|---|---|
| Constant | -0.132** | 0.021 | -0.022 |
| | (0.064) | (0.195) | (0.059) |
| Irrigation Water | 0.374*** | 0.532*** | 0.443*** |
| | (0.072) | (0.089) | (0.042) |
| Nitrogen Fertilizer | 0.186** | 0.214*** | -0.046 |
| | (0.084) | (0.084) | (0.069) |
| Phosphatic Fertilizer | 0.356*** | -0.021 | -0.191 |
| | (0.050) | (0.083) | (0.121) |
| Water Salinity | 0.051 | 0.045 | 0.016 |
| | (0.048) | (0.053) | (0.018) |
| Soil Salinity | -0.047** | -0.122* | -0.052** |
| | (0.035) | (0.083) | (0.029) |
| Seed | 0.366*** | 0.197*** | 1.085*** |
| | (0.040) | (0.080) | (0.073) |
| $R^2$ | 0.93 | 0.79 | 0.87 |

[*P < 0.10. **P < 0.05. ***P < 0.01. Note: Standard errors are in parentheses.]

**Table 2—Marginal Value Product, Opportunity Cost, and Marginal Value of Damage, in Rupees**

| | MVP | OC | MVD |
|---|---|---|---|
| *Local wheat:* | | | |
| Irrigation water (mean value of 5 irrigations per acre) | 32.00 | 12.00 | – |
| Nitrogen fertilizer (mean value of 3.6 kg per acre) | 27.52 | 3.25 | – |
| Phosphatic fertilizer (mean value of 52 pounds per acre) | 122.93 | 67.00 | – |
| Soil salinity (mean value 2.12 ergs of electrical conductivity) | – | – | -18.00 |
| *Improved wheat:* | | | |
| Irrigation water (mean value of 6 irrigations per acre) | 22.10 | 12.00 | – |
| Nitrogen fertilizer (mean value of 3.0 kg per acre) | 43.98 | 3.25 | – |
| Phosphatic fertilizer (mean value of 150 pounds per acre) | * | * | – |
| Soil salinity (mean value 2.12 ergs of electrical conductivity) | – | – | -63.00 |
| *Mustard:* | | | |
| Irrigation water (mean value of 3 irrigations per acre) | 59.06 | 12.00 | – |
| Nitrogen fertilizer (mean value of 2.5 kg per acre) | * | * | – |
| Phosphatic fertilizer (mean value of 1 pound per acre) | * | * | – |
| Soil salinity (mean value 2.12 ergs of electrical conductivity) | – | – | -14.00 |

[–Not applicable. *Not significant.]

## Conclusion

The survey approach has both advantages and disadvantages compared to controlled experiments for measuring yield impacts of salinity. One advantage is in the use of data representing actual farm experiences. The disadvantages stem largely from the cost side. The dual survey is relatively expensive. The approach reported here involved detailed measures of soil and water chemistry, requiring both field and laboratory activities. However, the analysis indicates that soil data are more important than water chemistry measures, and one macro measure of salinity can probably capture most of the observed salinity effect, so that multiple observations on several measures are not needed.

## Notes

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[2]See Water and Power Development Authority (1979) for details of the sampling and survey procedures.

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## Discussion Opening–*Norman Rask*

A common theme of the three papers is the performance of the agricultural sector in meeting domestic food demands. All countries examined can be broadly classified as middle income countries, and most of their economies have experienced some form of energy related stimulation (oil revenues or alcohol based import substitution). The impacts of the energy programmes are viewed as neutral to negative in their effects on meeting food needs, particularly in reference to import/export ratios. Government policies, especially as they relate to expenditure patterns based on the increased revenue, are seen as contributing to the neglect of agriculture.

Conditions particular to middle income countries in tropical and subtropical climates lead to consumption patterns favouring substantial agricultural imports as incomes rise. Middle income countries experience a significant change in diet to more livestock products as higher per capita incomes are achieved. Since livestock are much less efficient in the conversion of plant material to food, the demands on crop agriculture can quickly outpace "normal" growth rates in the production of agricultural products, especially in countries with limited agricultural frontiers. Furthermore, feed grain production is typically more efficient (with higher yield and lower per unit cost) in temperate climates. Thus, the needs for and supply of agricultural commodities (at least at the margin) often do not reside in the same country, especially during periods of rapidly rising income.

Unexpectedly large oil revenues in the 1970s and early 1980s accelerated income growth and hence diet induced consumption changes in some countries, while at the same time providing the foreign exchange to purchase livestock products or feed grain inputs. While that allowed some neglect of the agricultural sector, we should not assume that agricultural imports would not have risen in the absence of the oil revenue windfall.

A broader issue in terms of consumption, production, and trade in agricultural products as more countries of the world enter and pass through the economic development process is that per capita consumption of food is stabilizing in developed countries, while technology continues to add to agricultural productivity, resulting in rising surpluses of livestock products and grains. As more developing countries raise dietary levels, the demand for livestock products and feed grains will rise. Trade can be stimulated if developing countries have commodities to export to developed countries. Oil has proven to be one alternative; alcohol, an agricultural product, can be another.

## General Discussion–*J.R. Wildgoose*, Rapporteur

The discussion centred around specific aspects of the country studies presented in the three papers. On the Ferreira and Tourinho paper, some general comments were made on the substitution effect in production between sugarcane and cotton and its implication for world efficiency. In the Nigerian case, in the context of the Scherr paper, reference was made to the exchange rate policy dilemma; i.e., currency devaluation would lead to adverse effects such as reduced oil revenues and decreased imports, at least in the short term, while the longer term benefits appeared less tangible. Inflation in food prices in Nigeria was attributed to factors on both the demand and supply sides, the significance of rural infrastructure being emphasized. Reference was also made to the increased direct agricultural production activities by the state and to the lack of success of such activities. More generally, questions were addressed to Scherr on the evidence of capital investment in the country studies, together with the types of government policies that had been pursued specifically in Mexico. On the Hussain and Young paper, comments were made on the difficulties of analyzing a problem such as salinity where some of the technical issues are not well understood. The importance of certain historical developments was also stressed, and due to some of those, coupled with certain current practices, the salinity problem may well become more widespread.

The authors responded that the salinity losses were potentially very high, with some 10 million acres being affected; some of the problems of current practises were due to institutional and administrative difficulties rather than lack of knowledge; the short-term dilemma facing the Nigerian exchange rate policy was well recognized, although the need for adjustment in the longer term also had to be borne in mind; state activity in production had been widespread in the countries examined and almost universally had not been successful due to lack of expertise; reference was made to very large capital investment programmes, particularly for education and roads; and in Mexico, massive rural welfare spending occurred, specifically on education and the development of rural markets.

Participants in the discussion included J. Akinwumi, K Azam, S W. Hiemstra, F Idachaba, M. Mielke, and L. Moore