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# THE INFLUENCE OF STOCHASTIC WEATHER, POLLUTION PREDICTIONS AND PRICES ON THE COST OF NITRATE LEACHING REDUCTION

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## INTRODUCTION

Considerable effort has been directed toward empirical investigation of least cost pollution abatement from agricultural non-point sources.

The main hypotheses of this paper is that non-stochastic specification of uncertain coefficients in such economic models can lead to erroneous conclusions about effectiveness or cost of agricultural pollution control policies. This study examines the impacts on pollution control cost of three sorts of uncertainty regarding coefficients driving economic models of agricultural pollution control: 1) product price variability, 2) weather variability, 3) uncertainty regarding the validity of computer pollution process simulations[1].

The implications of these uncertainties are examined in the context of an economic model of policies to reduce nitrate leaching to groundwater in an irrigated crop production setting.

## EMPIRICAL SETTING

The area of investigation is the Treasure Valley of eastern Oregon. The semi-arid setting is representative of many older public irrigation projects in the West. The relatively heavy soils and flat topography are well suited to gravity irrigation. For the purposes of this analysis, a farm representative of farms on class I soil in the area is modelled. These highly productive bottomlands constitute about 20% of the total irrigated area (Soil Conservation Service). The deep, well drained soils place few limits on crop rotation and senior water rights guarantee relatively non-limiting water supply.

Recently, the area was proclaimed one of two critical groundwater areas in Oregon because nitrate concentrations exceeding the EPA 10 ppm standard were found in 15 of 20 test wells.

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[1] Interesting discussions of uncertainty regarding coefficients and biophysical relationships which drive popular pollution process models are contained in Antle and Capalbo; and Phipps and Fletcher.

## METHODOLOGY

This analysis involves three parts: 1) quantification of the distribution of uncertain coefficients which enter into bio-physical simulation and economic analysis; 2) biophysical simulation to generate estimates of nitrate leaching for given crop, irrigation and fertility management strategies and weather conditions, and 3) farm level programming analysis to assess optimal irrigation, fertilizer and crop rotation choices given resource constraints and policy constraints and stochastic prices, weather and nitrate leaching prediction error.

### Stochastic Coefficient Specification

Examining the effects of coefficient uncertainty on nitrate leaching control policies requires quantification of these uncertainties. The methods of quantification are discussed for three sorts of uncertainty in turn.

1) Errors in computer pollution process model predictions - Several important parameters which drive pollution process models being used in much current research are associated with considerable uncertainty though they are usually specified deterministically.

As steps in a complex chain of interactions that result in nitrate leaching are combined in simulation code, the uncertainty may be compounded. However, because coefficients and/or data are entered into the process simulation as non-stochastic terms, the true nature of uncertainty in a particular problem is obscured.

Table 1 reports magnitudes of uncertainty associated with significant nitrogen additions and subtractions modelled in typical agricultural nitrate leaching models.

**To quantify prediction error distribution resulting from this uncertainty most appropriately would require a model which calculates outcome prediction uncertainty on the basis of component determinant distributions and their correlations. While such stochastic models do exist for some sorts of water pollution processes (see for example Burn and McBean) no stochastic model of the agricultural nitrate leaching process could be found.**

TABLE 1: UNCERTAINTY OF NITROGEN ADDITIONS AND SUBTRACTIONS

| NITROGEN ADDITIONS, SUBTRACTIONS | UNCERTAINTY [2] |
|---|---|
| (+) FERTILIZER ADDITIONS | +/- 5 TO 10 % |
| (+) MANURE ADDITIONS | +/- 30 TO 50 % |
| (+) LEGUME CREDITS | +/- 20 TO 40 % |
| (+) ORGANIC N MINERALIZATION | +/- 25 TO 50 % |
| (-) CROP N REMOVAL | +/- 15 TO 25 % |
| (-) AMMONIA VOLITIZATION | +/- 20 TO 50 % |
| (-) DENITRIFICATION | +/- 20 TO 50 % |

Thus in this study variance of prediction is based on best available extraneous information. Specifically, it is derived from nitrate leaching prediction errors reported in a series of field trial validations reported by Bouma. The value of root mean square error of predicted versus observed leaching averaged 40% of mean leached nitrate value for these validations. It is assumed that nitrate leaching is distributed N ~ [ $\mu, \sigma_2$ ] where $\mu$ is the value of nitrate leaching predicted with the CERES biophysical simulation and $\sigma = 0.4\mu$.

2) Product price uncertainty - Input and output prices influence the relative profitability of alternative production practices. Consequently, the cost of forgone farm income associated with a given production modification to reduce nitrate leaching is also influenced by price. For this preliminary analysis, only the influence of product prices is considered. Crop price distribution is quantified as follows. An index of prices is constructed for

[2] All numbers from Meisinger and Randall except the uncertainty associated with organic N mineralization which is reported by Schepers and Mosier.

the four crops analyzed using County price data from the years 1980 to 1989 (Oregon State University, Extension Economic Information Office). This involves: normalizing the all prices by mean prices; multiplying each normalized prices by a weight corresponding to its mean share of total revenue ; summing the share weighted normalized prices of the four commodities in each year.

Finally the ten price years are ordered according to the statistical deviation of the price index in a given year from the mean price index value.

3) Weather Uncertainty - Rainfall events which create random pulses of pollution occur stochastically. This effect can be a major determinant of nitrate leaching when winter rainfall is heavy or when soils have a low water holding capacity (see Johnson, Adams and Perry). Additionally, weather effects the recharge of the area reservoirs supplying irrigation water and consequently seasonal irrigation water allocations. Distributions of rainfall and irrigation water allocations are taken from historical data for the years 1982 to 1989 (Us Climatological Data and US Bureau of Reclamation).

<u>Biophysical Model</u>

The CERES biophysical simulator (Ritchie, Godwin, and Otter-Nacke; Hodges et. al.; Jones and Kiniry) is used to simulate crop growth, water and nitrogen balance over the course of a growing season. The crop yield routine is basically a Von Leibig or law-of-the-minimum type response function. Maximum potential photosynthesis in this model is determined by weather and genetics. Predicted yield declines from potential with nitrogen or water stress. The water and nitrogen balance routines model movement of water and nitrogen among soil horizons for given weather, plant uptake and soil nitrogen processes. These routines predict leaching of nitrogen below the root zone and soil residual nitrogen levels after the growing season.

Application of the CERES models to gravity irrigated fields required modification of the original CERES irrigation management routine. The expected uniformity of specific gravity irrigation management practices were predicted using the SCS model of furrow irrigation, (USDA Soil Conservation Service). Routines were added to CERES to allow for subfields with distinct water application depths but the same management soils and weather otherwise. Because an adequate model for onions was not available, yield and leaching coefficients for this crop were based on results from empirical experiments (Brown et. al., Oregon State University).

Economic Optimization

A mathematical programming model was developed to investigate the economics of groundwater pollution abatement. The model simulates the choice of crop rotation, irrigation and nitrogen management choices a profit maximizing producer would be expected to make when faced with specified resource and policy constraints. The activities in the model, $Q_{z,i,f}$, represent an acre of crop z grown with irrigation practice i and nitrogen management practice f. Where cropping choices (z) include onions, potatoes, corn and wheat; irrigation choices (i) include current gravity irrigation practices, improved gravity irrigation technology, solid set sprinkler technology, and each choice can be implemented with current rule of thumb scheduling practices or with scientifically base irrigation scheduling; nitrogen fertilizer management options (f) include applying all nitrogen at planting, applying part of nitrogen in fall preceding planting and part at planting, and applying part at planting and part in one or several sidedressings depending upon soil and plant tissue nitrogen test results.

Land and rotational requirements are the only factors assumed to limit cropping choices. This is not unrealistic when highly profitable crops such as onions and potatoes drive rotation decisions. In such instances farmers are motivated to structure farm capital to minimize production restrictions (Johnson, Adams and Perry; El-Nazar and McCarl). Two sets of rotational constraints are incorporated into the model. One set restricts the frequency of potatoes and onions to one year in four. The second set of restrictions forces onions and potatoes to be followed by wheat or corn. A set of transfer activities associate each production activity $Q_{z,i,f}$ with a nitrogen application level, a water application level and a nitrate leaching level.

Stochastic leaching, crop price and water allocation coefficients are expressed as certainty equivalents to allow preservation of linearity in the programming model. Given the distributions of nitrate leaching $NL_{z,i,f}$, the probability that nitrate leaching does not exceed a specified level $\underline{\underline{NL}}_{z,i,f}$ can be expressed as $\text{Prob}[NL_{z,i,f} \leq \underline{\underline{NL}}_{z,i,f}] = \alpha$. Thus a vector of nitrate leaching certainty equivalents can be expressed as $\underline{\underline{NL}}_{z,i,f}(\alpha)$. Certainty equivalents for water allocation and crop price are expressed in a like manner as $\underline{\underline{TW}}(\alpha)$ and $P_z(\alpha)$.

Modelling effects of coefficient uncertainty

The programming model used for this research can be represented as follows:

$$\text{Maximize} \quad \Sigma_{z,i,f} \; (\underline{\underline{P}}_z - C_{z,i,f}) * Q_{z,i,f}$$

S.T.

$$1) \quad Q_{z,i,f} \in R$$

$$2) \quad \Sigma_{z,i,f} \; \underline{\underline{NL}}_{z,i,f}(\alpha) * Q_{z,i,f} \leq TNL$$

$$3) \quad \Sigma_{z,i,f} \; W_{z,i} * Q_{z,i,f} \leq \underline{\underline{TW}}(\alpha)$$

where model variables are defined as follows:

$Q_{z,i,f}$ acre of crop z grown with irrigation management i, fertilizer management f

$\underline{\underline{P}}_z(\alpha)$ stochastically specified crop prices

$C_{z,i,f}$ cost of production

$\underline{\underline{NL}}_{z,i,f}(\alpha)$ stochastically specified nitrate leaching prediction

TNL total nitrate leaching standard

$W_{z,i}$ water requirement

$\underline{\underline{TW}}(\alpha)$ stochastically specified irrigation water allocation

Restriction 1 represents resource and rotation constraints. Restriction 2 constrains total nitrate leaching at certainty equivalence level $\alpha$ to not exceed a fixed level TNL. Restriction 3 constrains The sum of water used in all production activities to not exceed the stochastically specified water allocation.

The impact of coefficient uncertainty on nitrate leaching abatement cost is assessed by varying the values of stochastically specified coefficients as well as the level of allowable nitrate leaching parametrically.

## RESULTS

The cost abatement frontiers in figure 1 were generated by multiple runs of the chance constrained programming models with successively tighter restrictions on total average nitrate leaching and weather years representing approximately average rainfall, one standard deviation drier than normal and one standard deviation wetter than normal.

The middle cost abatement frontier depicted in figure 2 represent cost of abatement if mean nitrate leaching prediction values generated with the CERES nitrate leaching process model are accurate. The upper and lower lines represent costs of abatement if the predictions over or under estimate leaching by one standard deviation respectively.

The cost abatement frontiers in figure 3 were generated in a like manner except that the middle, upper and lower lines represent a mean product price expectation year, a year with product price expectation one standard deviation above the and below the mean respectively.

In interpreting these results the policy implications of the sort of maximum allowable nitrate leaching standard specified here must be considered. These results can be interpreted as representing a lower bound on cost of abatement. In general 'feasible' policies will be more expensive due to monitoring, enforcement and administrative costs. None-the-less, this analysis does render information about the nature of 'best management' production choices which can most economically reduce nitrate leaching.

The upper and lower bounds on the three sorts of uncertainties presented here render information about the sensitivity of pollution abatement cost to economic, environmental and informational uncertainties.

One conclusion that can be drawn from these research results is that abatement cost is relatively low for small to moderate nitrate leaching reductions. Furthermore, this result appears to be robust with respect to assumptions about uncertainty. The reason for this result is that initial increments of nitrate leaching reduction can be obtained with relatively inexpensive fertilizer and water information service purchases, timing and management changes. Furthermore, until these possibilities are exhausted, the cost of a 'safety margin' to deal with uncertainty is relatively low. Figure 4 illustrates these conclusions. The figure depicts the level of selected production activities which obtain a nitrate leaching levels of 40 lbs/ac (30% reduction from the mean base prediction of 57 lbs/ac) in a least cost fashion.

To achieve higher levels of nitrate leaching reduction is costly. Greater nitrate leaching reductions involve costly investments in irrigation capital and crop rotation changes with high opportunity costs (note the high level of irrigation capital investment activities associated with the 80% nitrate leaching reduction depicted in figure 5). These cost are significantly influenced by uncertainty in weather and accuracy of pollution process model. To buy insurance against prediction error or stochastic weather effects involves further increments of irrigation capital purchase (see figure 5) and more expensive crop rotation changes (not depicted).

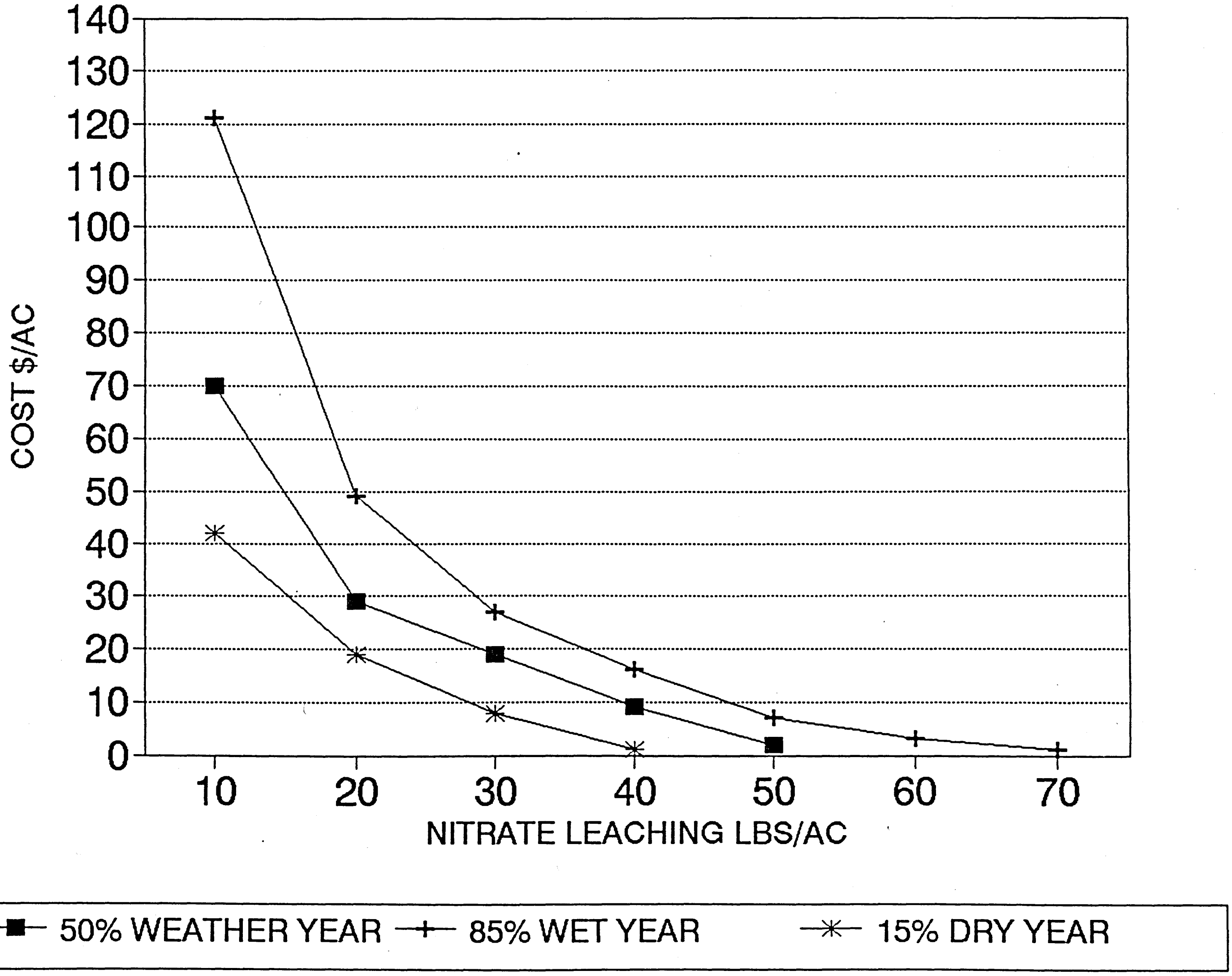
One result which may at first appear counter intuitive is the small effect of crop prices on pollution abatement cost (figure 3). This phenomena is specific to cropping economics in the growing are. Profits forgone by taking high value onions and potatoes out of production are so great that the farmer would prefer large irrigation capital investment to substituting the next most valuable crop sweet corn. The same is true of sweet corn and wheat. Consequently crop rotation changes are small when relative prices change.

Several qualifications should be noted in interpreting these research results. First, sources of uncertainty are treated as independent here. If, in fact, they are correlated, effects of uncertainty illustrated could be either magnified (positive correlation) or diminished (off-setting correlation). Second, in the case of ground water pollution it is the long-run equilibrium concentration of nitrate that is of importance. If annual stochastic variations off-set one another over several years, there magnitude is not really important in determining policy, mean predictions are adequate. This may tend to be the case with weather and price effects. However, prediction errors may be systematically biased if models calibrated in one region are applied in another region.

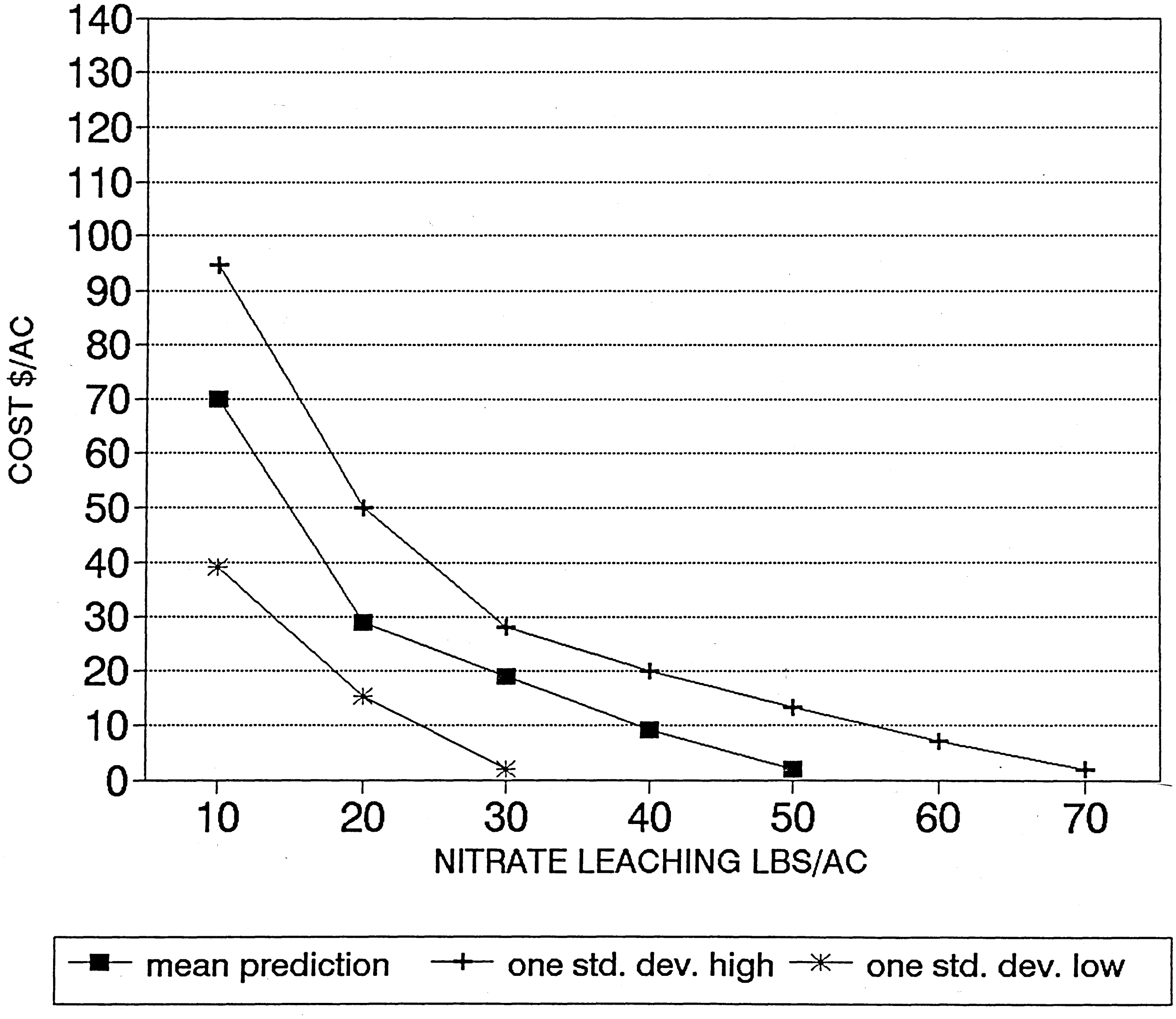
## CONCLUSIONS

The creditability policy recommendations by agricultural economists depends on the robustness of research results used to make such recommendations. This research investigates the cost of nitrate leaching reductions and the sensitivity of these costs to uncertainty in parameters driving the analysis. It is demonstrated that initial increments in nitrate leaching can be achieved at low cost the results hold even when 'insurance' against stochastic outcomes resulting in greater pollution per unit activity occur.

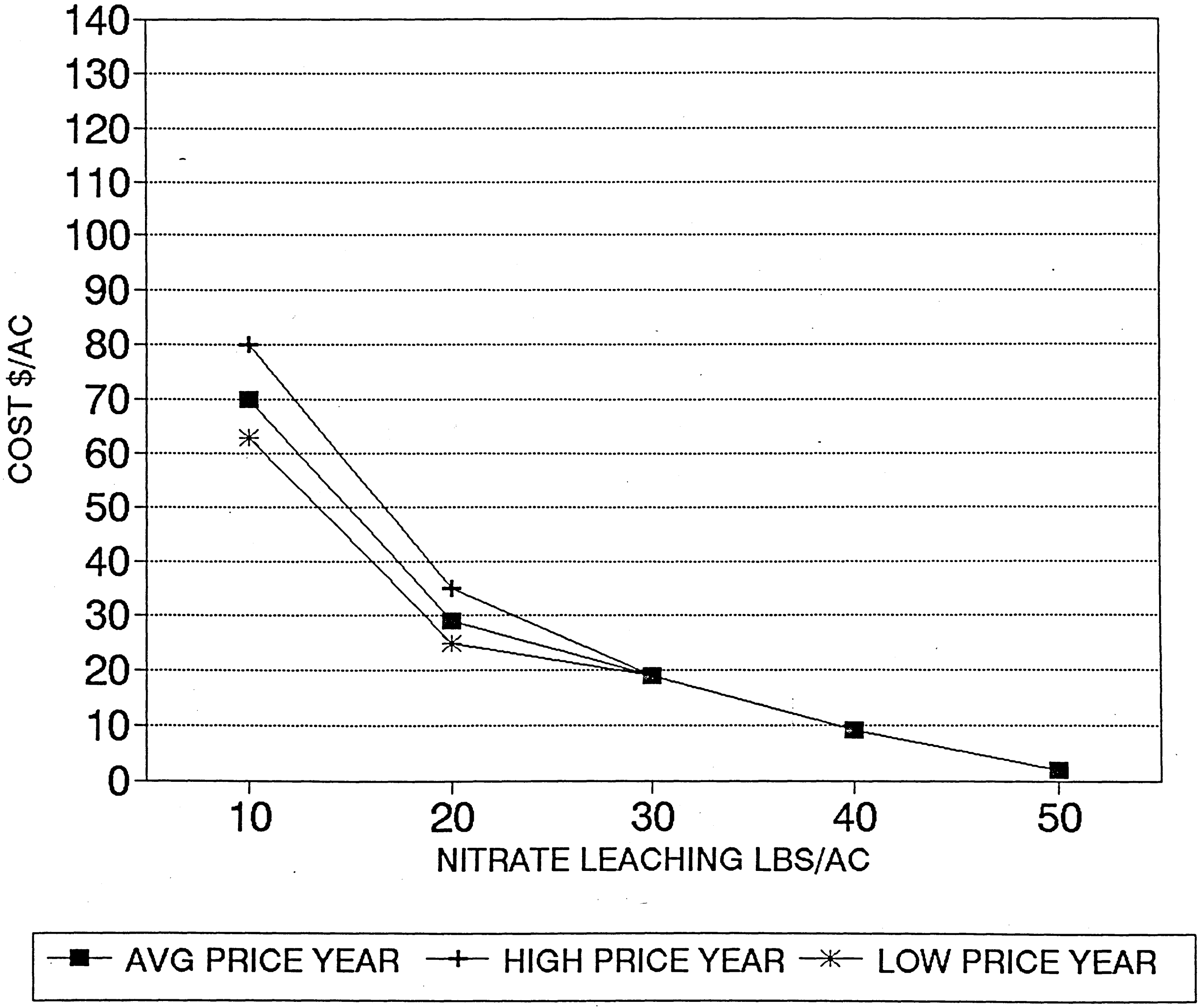
## FIGURE 1: NO3 LEACHING ABATEMENT COST WITH WEATHER UNCERTAINTY



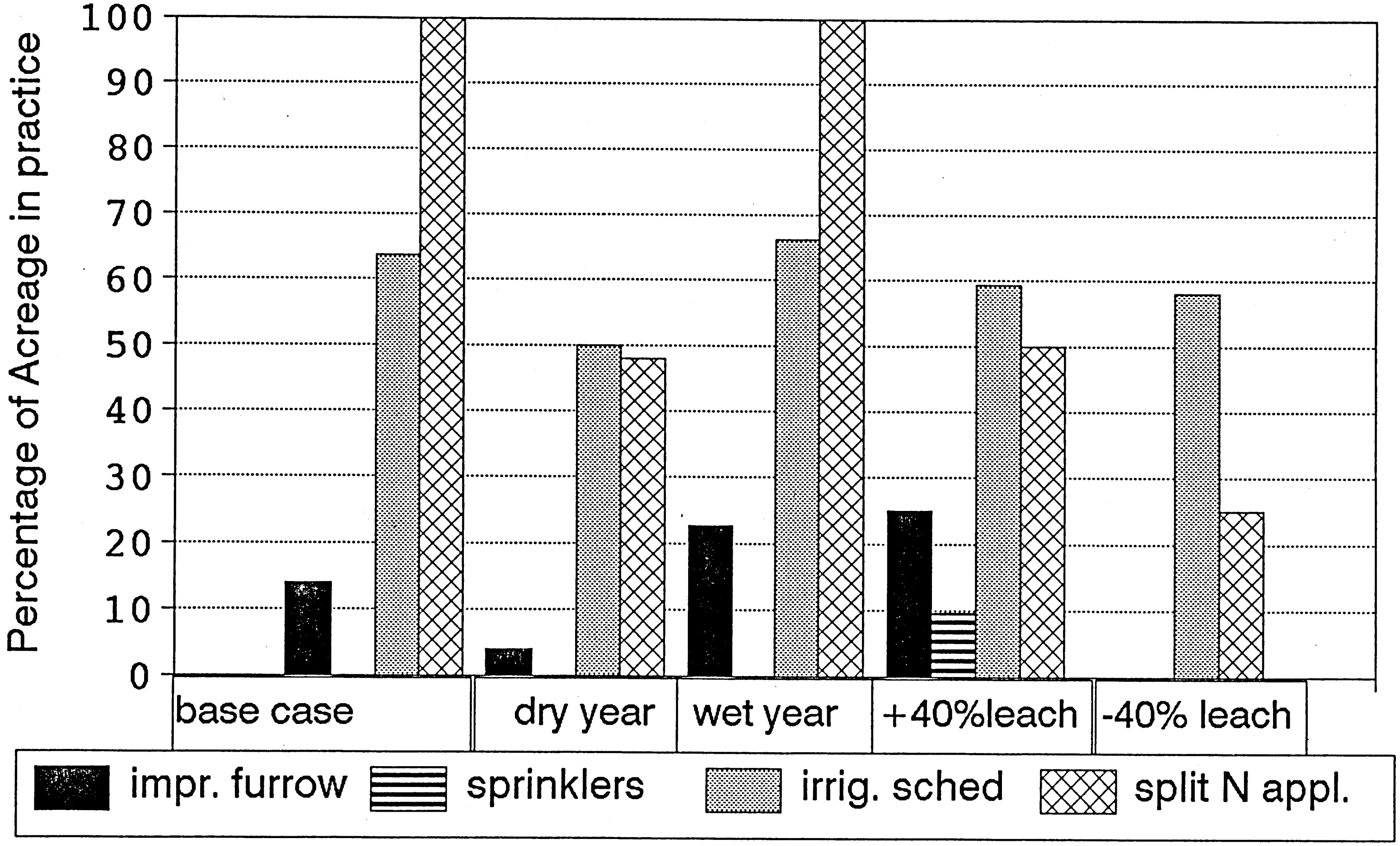
# FIGURE 2: NO3 LEACHING ABATEMENT COST WITH POLLUTION PREDICTION UNCERTAINTY



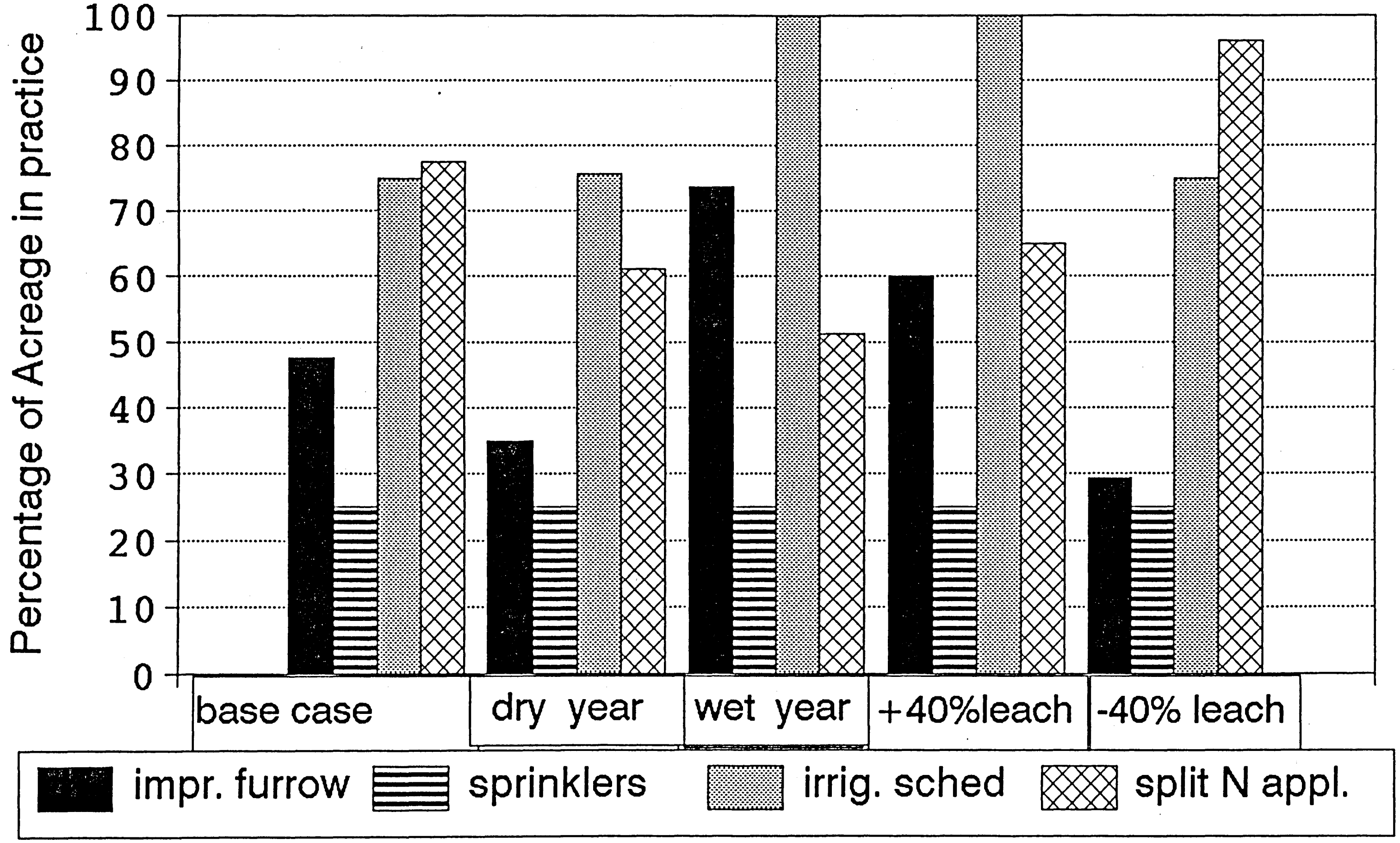
## FIGURE 3: NO3 LEACHING ABATEMENT COST WITH CROP PRICE UNCERTAINTY



# FIGURE 4: Production Activity Levels With 30% Nitrate Leaching Reduction



# FIGURE 5: Production Activity Levels With 80% Nitrate Leaching Reduction



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