Economic and Environmental Aspects of Nonuniform Agricultural Irrigation

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Abstract

This paper studies the effects of irrigation nonuniformity on nitrate leaching and profits for different levels of applied water. Controlling water application as irrigation uniformity increases can lead to reductions in nitrate leaching and sustain relative profits. Water conservation incentives are more effective than direct nitrate reduction incentives.

Economic and Environmental Aspects of Nonuniform Agricultural Irrigation

Agricultural drainage, a major source of nonpoint environmental pollution, degrades the quality of surface and ground water supplies for public and agricultural water uses. Decreasing drainage flows has become an important issue to farmers as agricultural water quality declines and regulatory agencies seek to reduce this source of pollution. One source of high drainage flows is applying irrigation water to leach undesirable accumulated salts and residues in the soil; another source is risk reduction, to ensure that all parts of a nonuniform field receive adequate supplies of water. Adoption of improved management practices and of modern technology that increases irrigation uniformity is increasingly being considered, especially for growers with higher value crops, high water prices, and nonuniform land (Caswell, Lichtenberg, Zilberman, 1990). This paper addresses the effects of irrigation uniformity and efficient levels of applied water when nitrate leaching, a prominent agricultural pollutant, is made an element in the farmer's decisions.

Uniformity is here used as a measure of how evenly water is applied throughout a field. The level of uniformity varies across a field as a function of soil variability and water application technology (Tanji and Hanson, 1990). Farmers typically apply more than the average water needed to a field, in order to ensure that less-watered parts of the field receive adequate water. Several studies have examined the effects of uniformity on crop yield, nitrate leaching and profit. Wallender and Rayej (1989, 1990) considered the effects of uniformity on cotton yield and profit. Over-irrigating to overcome nonuniformity resulted in an increase in water volume applied and nitrate leaching, and a reduction in profit. Dinar and Zilberman (1991) found that crops irrigated with higher quality water on nonuniform land use more water, generate more leaching, and result in lower crop yield than when the land is of better quality. Other studies have found similar results on more water-sensitive vegetable crops (Feinerman, Letey, and Vaux, 1983). Several studies have examined the use of uniformity improving technology. Warrick and Gardner (1983) found that better management of water application to increase uniformity is the most effective target for increasing crop yield, especially when confronted with increasing water prices and disposal costs (Dinar, Knapp, and Letey, 1989).

This paper looks at the effects of varying irrigation uniformity on a farmer's profits and nitrate leaching. It uses an agronomic model (the Erosion Productivity Impact Calculator (EPIC, Sharpley and Williams, 1990)) to simulate crop production and nitrate leaching, and it then uses available economic information to calculate the effects on farm operations. Salinas Valley head lettuce is chosen as a case study because of its economic importance and its relatively high water use and nitrate leaching potential. Finally, this study considers the effects of some policy options on farm profitability.

Conceptual Framework

Field data on farm irrigation distribution patterns indicate that irrigation uniformity across the field can be approximated by a normal distribution (Elliot, Nelson, Loftis, and Hart, 1980, and Karmeli, 1978). Uniformity is often expressed in units of Christiansen Uniformity Coefficient (CUC) (Christiansen, 1942), which varies from 0 (low uniformity) to 1 (high uniformity). For commercial lettuce farming in the Salinas Valley, uniformity is maximized, through laser leveling technology and intensive irrigation management, at approximately 0.95 CUC. For commercial fields, increasing uniformity beyond this level is usually economically impractical. Experimental research plots, in contrast, can attain uniformity nearing

1.0 CUC. This study examines uniformity for commercial operations for the range 0.4 - 1.0 CUC.

Varying the fraction of the field receiving adequate water for the plant is an important variable in determining optimal water application for profit and nitrate leaching. The beneficial water requirement is calculated as the sum of the plant evapotranspiration and leaching fraction needs throughout the cropping season. (The leaching fraction is the amount of water to adequately leach undesirable accumulated salts and residues in the soil.) For high valued crops such as lettuce, farmers usually aim toward 90% of the field receiving adequate water application. As a result, the majority of the field is over-irrigated, and nitrate leaching increases below the crop root zone. For this study, two levels of irrigation are considered: average (or 50%) of the field adequately (or over-) irrigated, and 90% adequately irrigated.

The economic component of the model determines the profits resulting from varying irrigation uniformity and water application. The variable costs of the model include water and management costs. Water costs are linearly related to the amount of water applied. In the Salinas Valley water costs are approximately $45 per acre foot at a well depth of 160 feet. This cost is substantial relative to overall profits. Management costs include laser leveling to obtain the optimal gradient for irrigation, and increased man-hours to oversee the development of the crop and the functioning of the irrigation piping, valves, and pressure system. Marginal management costs are assumed to increase with uniformity. This assumption is derived from evidence that improving uniformity from 0.4 - 0.7 CUC requires relatively little increase in management efforts, while costs increase from 0.75 - 0.95 CUC. For modeling purposes, CUC from 0.95 - 1.0 (the range obtained primarily in research plots) was included, although profits decline in this region for commercial growers due to over-management.

To incorporate the social cost of nitrate leaching into the farmer's management decisions, two different taxing methods are modeled: a Pigouvian tax on nitrate leached, and a surcharge on water use over a set level. The tax on nitrate, although practically impossible to measure at the farm level, is an explicit means to address the externality cost. Water surcharges to alleviate over-irrigation are becoming more common in irrigation districts, a method which implicitly decreases agricultural drainage pollution. Two levels of nitrate taxes and water surcharges are used to illustrate their effect on profits with varying uniformity: a tax of $0.50 and $2.50 per kilogram per hectare of nitrate leached, and a surcharge that doubles the cost of water if irrigation exceeds either 325mm or 600mm per crop.

Empirical Specification

The model simulates three years of production for spring and summer head-lettuce using 1989-1991 CIMIS (California Irrigation Management Information System) weather data. Each crop is pre-irrigated by sprinkler and then furrow irrigated three times, totalling 160mm of applied water, on the baseline uniform field; application increases with declining uniformity from this baseline amount. The field is divided into quadrants, varying normally in distribution uniformity. Nitrogen fertilizer is applied with irrigation three times during the cropping season. Although nitrogen application presumably increases as uniformity decreases, it is held constant to emphasize the effects of nonuniform water application on nitrate leaching and profit.

The economic modeling involves calculating the costs of production and revenue generated from crop yield (Huffman, Schulbach, and Yeary, 1986). Management costs are added for increasing irrigation uniformity. Revenue is obtained from production of two lettuce products, packed and shredded, with market prices $6.38 and $4.10 per carton, respectively (averaged from 1988-1990, Monterey County). Market allocation of the two products is determined mainly by fluctuating market prices and lettuce-head size. For this study, a reduction in 10% of the lettuce biomass is the criterion used in determining product allocation to shredded, although the same margin would presumably hold for over-sized lettuce (a consideration which the agronomic model used cannot simulate).

Modeling Results

The first step in examining the effects of uniformity on farm profits is to look at the physical relationships of biomass and leaching with uniformity. Figures 1a-b depict the effects of uniformity on nitrate leaching with 50% (average) and 90% adequate water application. The graphs are separated into field uniformity quartiles to show how leaching can differ across a field depending on water application. Irrigating to 50% causes nitrate leaching to decrease in the lower half of the field with declining CUC, since this part of the field receives less and less water as the field becomes more nonuniform. On average nitrate leaching slightly increases with increasing uniformity. This is because the increase in nitrate leaching in the lower two quartiles additively outweigh the decrease in nitrate leaching in the upper two quartiles. For 90% application, only the lower quartile indicates a slight decrease in nitrate leaching with declining CUC, and leaching increases in three-fourths of the field. Overall, the total nitrate leached is greater for 90% application than average application for all levels of CUC because of the higher water applications.

The effects of uniformity on biomass is illustrated in Figures 2a-b. For average application, the upper three quartiles receive enough water to support a crop, even with declining CUC. The lower quartile declines sharply due to under-irrigation. For 90% application, the upper three quartiles receive adequate irrigation up to 0.7 CUC. For CUC below this, most of the field is over-irrigated, causing nutrients to leach from the soil and dramatic reductions in crop biomass.

The effect of uniformity on profits with a nitrate tax is illustrated in Figures 3a-b. The $0.50 tax is relatively small in overall costs to the farmer. Profits are almost the same for the two water application scenarios down to 0.75 CUC. After that point, profits with average water application dramatically decline, due to reduction in quality and head-size of lettuce from under-irrigating the lower quartile of the field. With 90% application, the dramatic decline in profits does not occur until approximately 0.7 CUC. From the range 0.55-0.75 CUC (a poorly managed field), profits are higher for the farmer applying water adequately to 90% of the field. With a $2.50 tax on nitrates, the situation is different. Here, it pays to irrigate only to average application down to 0.75 CUC. With practices of 90% adequate irrigation, relative profits decline steadily.

The effects of uniformity on relative profit with a water surcharge is depicted in Figures 4a-b. With the "exceeding 300mm" surcharge, profits are almost the same down to 0.75 CUC. For the "exceeding 172mm" surcharge, relative profits are substantially higher for average application than 90% application for the same range of uniformity. The reason for this difference is that irrigating to average application does not exceed the surcharge level for the entire range of uniformity, whereas 90% application exceeds this level at 0.75 and 0.90 CUC for the 600mm and 325mm targets, respectively. Comparing Figures 3 and 4, for the range above 0.7 CUC, higher relative profits are achieved with average application for both a water surcharge and a direct tax on nitrate. The relative profit differences between 50% and 90% application become more apparent as the taxing schemes become more stringent. Overall, the two regulations effectively internalize the social cost of the externality and create an incentive to avoid over-irrigation, thereby decreasing overall nitrate leaching.

Discussion of results

Unlike large field crops, vegetable farmers aim toward maximizing crop uniformity by irrigating to achieve at least the beneficial water needs of 90% of their crop. This is usually obtained by substantial over-watering as irrigation uniformity declines. With increasing water costs and other economic considerations, farmers highly manage their irrigation systems to increase uniformity. Still, for most farmers, little progress has occurred in reducing irrigation volume with improvements in application uniformity. The consequence is a degradation in the quality of agricultural and municipal groundwater.

For the case study on lettuce, the effects on nitrate leaching from applying water to meet 90% of the crops needs as opposed to the average crop needs is significant. Yet, in the managed range of irrigation uniformity (0.7-0.95 CUC) the effect on relative profits is relatively unnoticeable. This implies with high uniformity, farmers can aim toward adequately irrigating to the average crop needs, maintain relative profits, and reduce the amount of nitrates leached. From a policy viewpoint, it appears that controlling irrigation volume provides an added reason to irrigate to average crop water needs.

This study bases its cost estimates and management practices on those for the average farmer in the region. It does not include harvesting responses to changing output prices for lettuce and quality considerations. Additionally, although this study models the most common soil type of the region, different soil types can change the physical and economic outcome of the model.

The effects of nonuniformity on crop yield and irrigation management are issues which farmers are aware of in acting to maximize profits. It is thus important to take into consideration uniformity in determining practices which reduce nitrate leaching and sustain profits.

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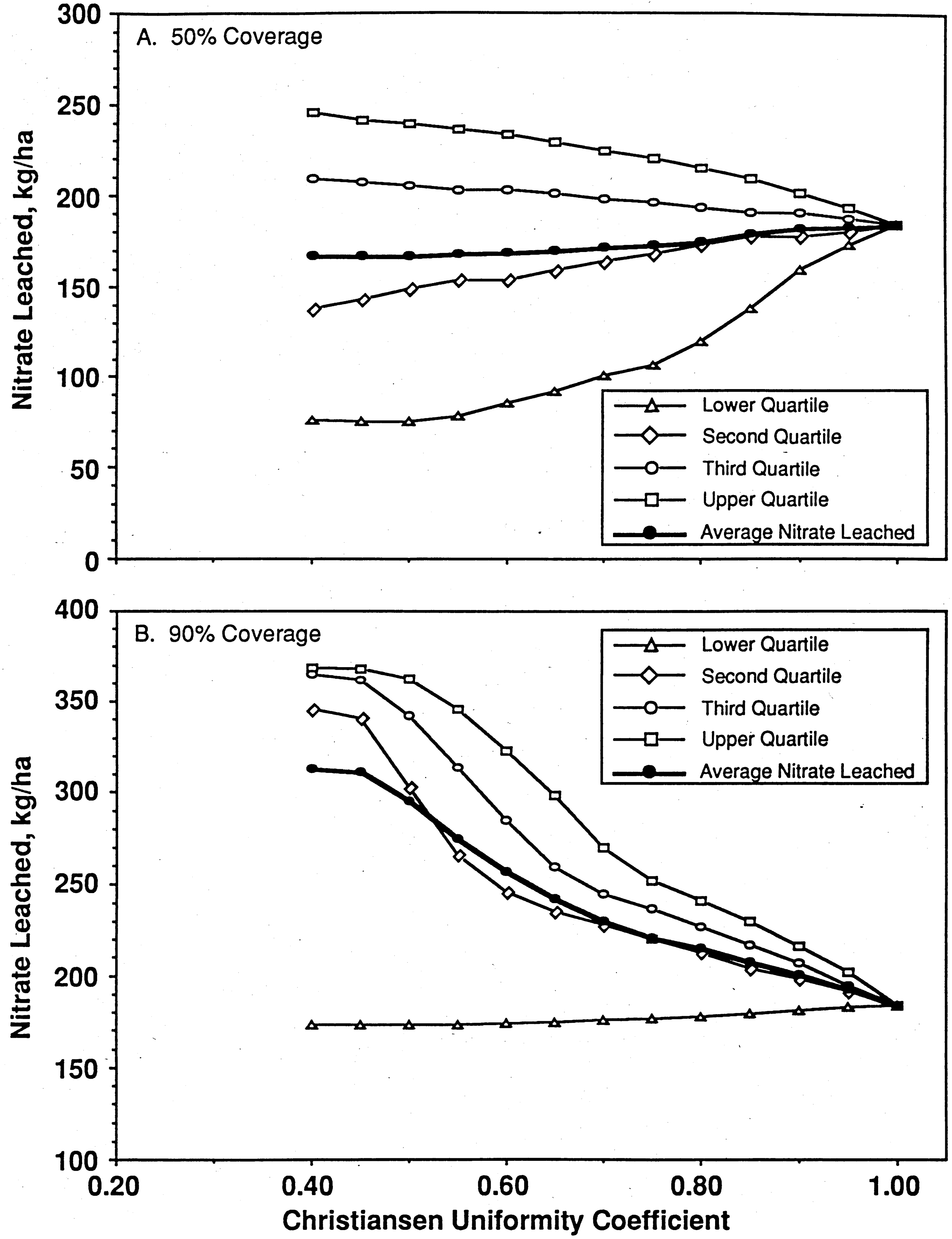

Figure 1: Effect of non-uniform water application on nitrate leaching. (a) 50% Coverage; (b) 90% Coverage.

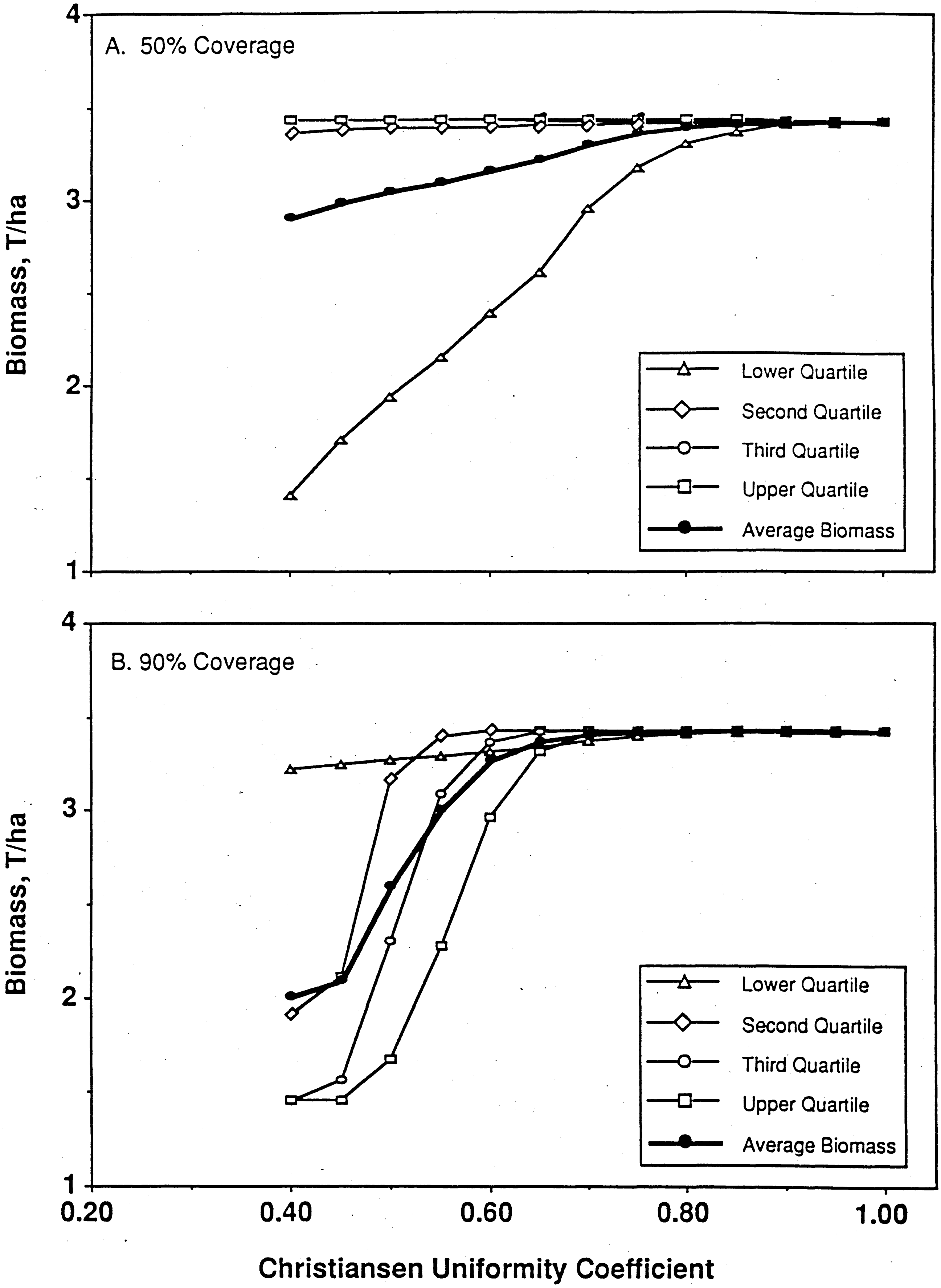

Figure 2: Effect of non-uniform water application on biomass accumulation. (a) 50% Coverage; (b) 90% Coverage.

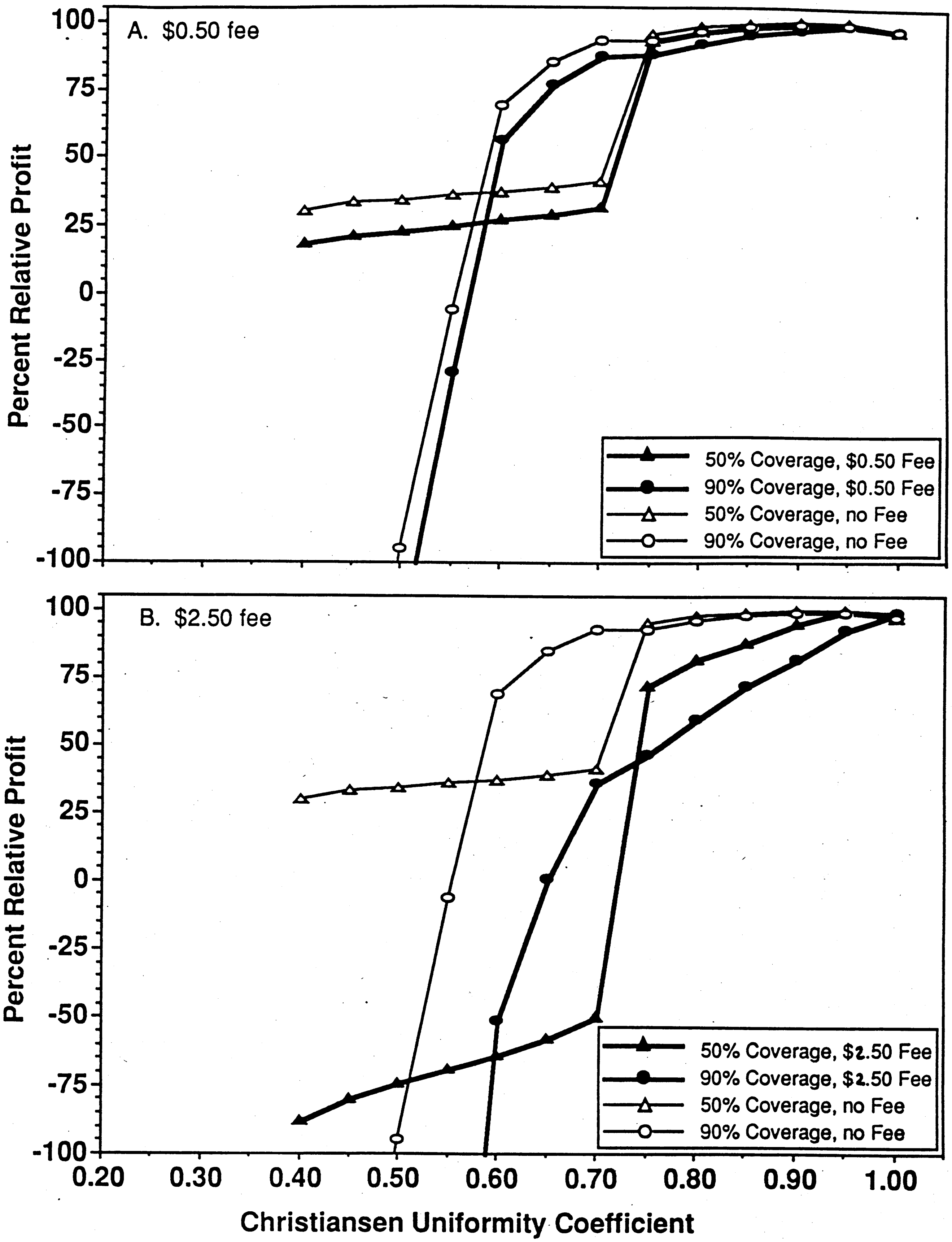

Figure 3: Effect of non-uniform water application and nitrate leaching fee on profit.
(a) $0.50 /kg NO3-N/ha fee; (b) $2.50 /kg NO3-N/ha fee.

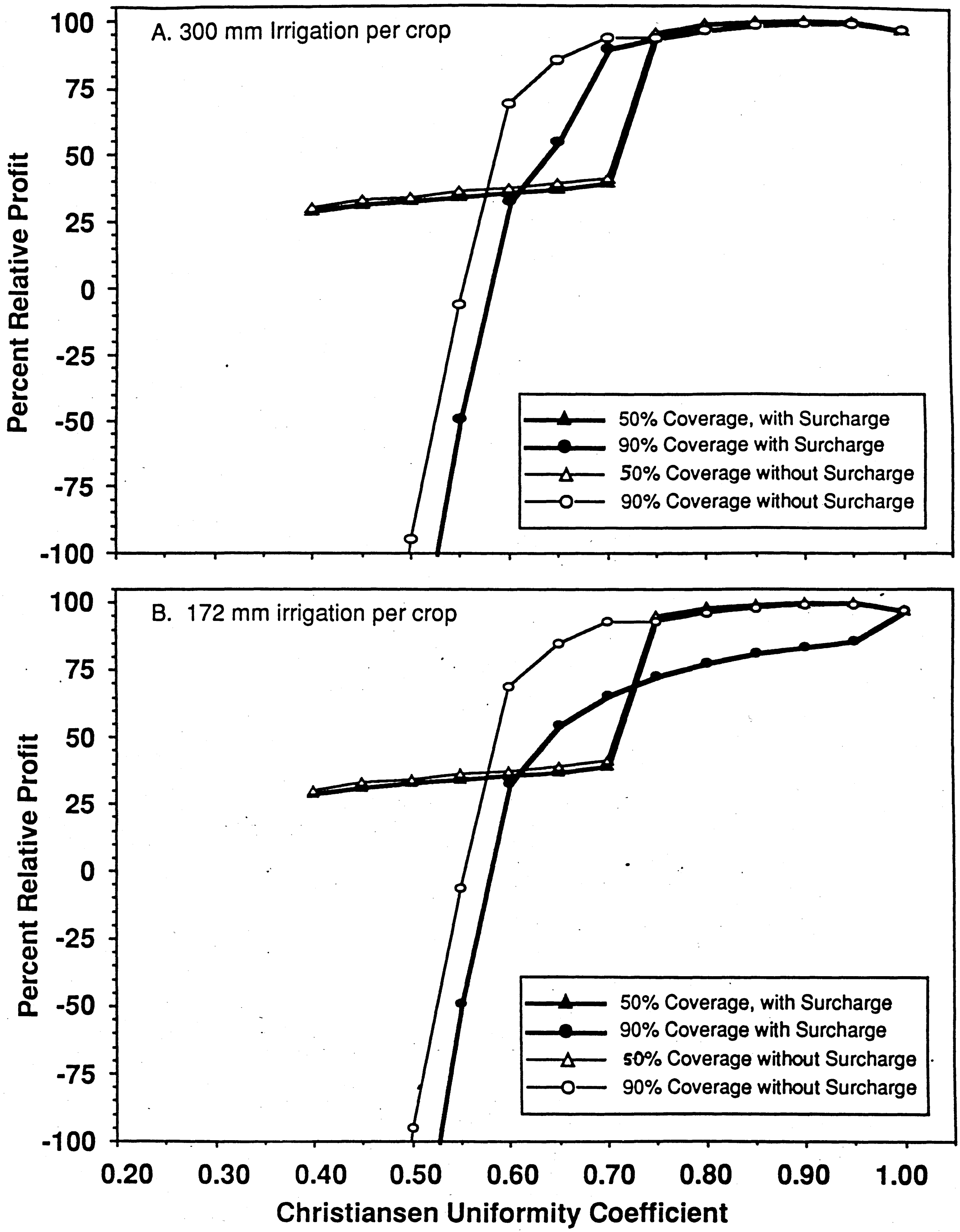

Figure 4: Effect of non-uniform water application and tiered water pricing on profit. (a) 300 mm water applied per crop; (b) 172 mm (ET plus 15% leaching fraction) water applied per crop.