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Perversion of Risk Aversion: An Application to Farm Planning and Intertemporal Resource Allocation

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Vast areas of the Texas Southern High Plains are undergoing a transition from irrigated to dryland crop production. Due to limited recharge of the Ogallala Aquifer in the region, irrigated acreage has declined by 27 percent from 1974 to 1984 (Texas Water Development Board). Continued mining of the Ogallala can be expected to increase pumping costs and reduce well yields. These two factors will ultimately diminish irrigated crop profitability. As acreage reverts from irrigated to dryland, crop production profitability is expected to decline and the variability of these net returns would increase. It is this transition from an intensive agriculture to an extensive one (i.e. irrigated to dryland) which offers a unique framework to evaluate the temporal and intertemporal aspects of optimal crop mix selection and resulting path of groundwater use under risk considerations.

Optimal crop mix selection under risk has received much attention in the literature over the past two decades (Adams et al., Pederson and Bertelsen, Barry and Robison). An early study by Scott and Baker used annual historic net returns in a quadratic programming model to evaluate optimal farm plans. This was one of the first studies to explicitly account for government price supports and their impact on net return risk in a whole farm context. One limitation of the Scott and Baker study and other similar studies is the use of annual net returns to express crop production risk, particularly if one considers multi-year crop rotations. Shrestha et al. indicate that a multi-period risk specification may be necessary in farm planning to account for multi-period investment alternatives and the seasonal acquisition of inputs (i.e. renting cropland, hiring labor, etc.). Relative to the Texas High Plains, a multi-year formulation is necessary to account for crop rotations produced under limited soil moisture, adjustment in commodity base acreage as well as the intra and inter-seasonal allocation of irrigation water.

Following the suggestion for additional research in the area of intertemporal risk preferences by Love and Robison, this study focuses on evaluating adjustments in crop mix and rate of groundwater extraction over time under different risk aversion scenarios. Because groundwater depletion tends to be a long term process, a multi-year recursive modelling structure was adopted. This recursive structure allows one to assess the temporal and intertemporal pattern of crop mix, path of net returns, and change in groundwater cost and availability across risk aversion scenario during the transition to dryland crop production.

Models and Procedures

Two general models were used to predict producer crop mix adjustments and rate of groundwater extraction for a representative farm on the Texas Southern High Plains. A multi-year/multi-crop growth simulation model was used to generate input data for the whole-farm optimization model. The multi-year/multi-crop growth model provided crop yield estimates by irrigation regime and crop rotation scheme under stochastic weather conditions. The firm level optimization model was capable of adjusting groundwater availability and cost as well as update objective function values over time depending on the quantity of water pumped in the previous time periods.

Programming Model

A firm-level Multi-Period Recursive Quadratic Programming (MPRQP) model was developed to evaluate optimal temporal crop rotation selection and the

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resulting path of groundwater extraction under different risk aversion levels. A multi-year formulation of the optimization model was deemed appropriate to account for the rotational sequence on crop yield, net returns, and machinery investment requirements for each cropping system.

The objective function of the MPRQP model was the maximization of discounted net present value subject to a marginal utility weighted variance-covariance matrix of net present values. The discounted net present value associated with each crop rotation represent the mean of stochastically generated crop yield and output price minus the variable cost of production over a 6 year time period. A real discount rate of 5 percent was assumed in this analysis. The variance of each system and covariance with other cropping systems was calculated using the discounted net present values from each of 10 random 6 year weather seeds.

The representative MPRQP model developed for the "mixed land" area of the Texas Southern High Plains had seventy-two production activities. These activities include twelve cropping systems evaluated under five furrow irrigation levels and a dryland option. The furrow irrigation system modelled in the mixed lands assumed an initial lift of 126 feet, saturated thickness of 65 feet, average application pressure of 15 PSI, application efficiency of 65 percent, and a beginning well capacity of 650 gallons per minute (Texas Dept of Water Resources). Furrow irrigation typically require fewer applications but more water per application compared to sprinkler irrigation systems. The mixed land typical farm was initially set at 832 cropland acres (U.S. Dept. of Commerce). A lease land option in the firm-level MPRQP models allowed for the expansion of cropland acres on a 160 acre parcel basis.

There were 12 critical water periods defined for each production season. Therefore, a total of seventy-two critical water periods were identified in the MPRQP model to account for intra- and inter-seasonal demand for irrigation water among the various cropping systems over a six year formulation. The sum of the water requirements for the production activities in each critical water period could not exceed the pumping capacity in that period.

Farm program participation in the region is in excess of 90 percent of eligible cropland acreage. Interview information from A.S.C.S. personnel in the region provided data on county-wide base acreage and farm program yield by crop. These values were desegregated to the firm-level MPRQP model. Initial base acreage for the model was set at 782 acres of cotton, 34 acres of sorghum, and 16 acres of wheat. All lease land was assumed to have proportionate regional commodity base acreage. The inclusion of base requirements was necessary to evaluate relative crop mix profitability, variability of net returns, and rate of groundwater extraction under the current farm program.

The main purpose of this analysis was to identify the impact of risk averse preferences on optimal temporal crop mix selection and rate of groundwater extraction. Three risk aversion classes were identified and applied to the MPRQP model. The mean discounted net present value and the associated variance from the optimal linear programming solution were retained to estimate each risk aversion class. A maximal risk aversion coefficient was derived by setting a certainty equivalent formula to zero and solving for the Pratt risk aversion coefficient r(x). This maximal risk aversion coefficient was multiplied by 25 percent increments to identify each class. The three risk aversion classes evaluated in this study were set at r(x) = .000003, .000006, and .000009, respectively.

Because groundwater depletion tends to be a long-term process, a recursive structure of the MPRQP model was necessary to consider intertemporal adjustments in water availability, as well as changes in price and technical coefficients. A set of recursive equations were developed to extend the multi-year model through eight recursive cycles to cover a 48 year planning horizon. The first series of recursive equations adjust pumping capacity during each critical water period. Total acre inches pumped in period t, where t is equal to a six year period, was used in the following equation from Knowles to update saturated thickness in period t + 1:

$$SATN = SAT - (ACIN/12)/(CONTA*CFST)$$

where SATN is the new saturated thickness, SAT is the previous saturated thickness, ACIN is the acre inches pumped over the previous six year period, CONTA is contributing aquifer acres, and CFST is the coefficient of storage. The contributing aquifer acres for the representative farm was estimated by multiplying total cropland acres times 1.373 based on the research by Ellis, Lacewell, and Reneau. The coefficient of storage was set at .15 to correspond to previous hydrologic research in the area (Knowles). Pumping lift was then updated by taking the previous lift and adjusting it by the change in saturated thickness.

Average well yield for the farm was estimated with the following equation from Hughes and Harman:

$$GPM = 800 * (SATN/210)^2$$

where GPM represents gallons per minute. The 1984 Inventory of Irrigation in Texas (Texas Department of Water Resources) was used to establish the number of irrigation wells for the representative farm. Pumping capacity, expressed in acre inches pumped per 10 day interval, was estimated with the following equation:

$$PRH = (30.4 * 22.4 * GPM)/1357$$

Pump and well down time was assumed to be 5 percent of total pumping hours.

A third recursive equation was used to update pumping costs for irrigation water in the next time period. This equation from Kletke, et al. is expressed as follows:

$$PC = .0014539 * (lift+(2.31*PSI)*PNG)/(EFPMP*EFDS)$$

where PC is the cost per acre inch, PSI is the pressure requirement of the system, PNG is the price of natural gas in mcf, EFPMP is pump engine efficiency, and EFDS is the water distribution efficiency. The price of natural gas was set at $3.50 per mcf. The updated pumping cost per acre inch was then used to adjust discounted net present values for each irrigated cropping system in the subsequent time period.

Cropping System Simulation

Biophysical crop growth simulation models have been applied to evaluate a number of agricultural problems. Boggess and Amerling used a biological crop growth model to analyze irrigation decision investments. Mapp and Eidman used a soil moisture-crop yield simulation model to assess alternative irrigation strategies within a whole farm planning context.

A daily crop growth simulation model known as EPIC (Erosion Productivity Impact Calculator) was calibrated and used to estimate crop yield by rotation and irrigation regime. EPIC simulations have been performed on 163 test sites in the continental U.S. and Hawaii. These tests have shown that EPIC produces valid results under a variety of climatic conditions, soil characteristics, and management practices (Williams). The components of EPIC include weather simulation hydrology, erosion, nutrient cycling, tillage, soil temperature, plant growth, economic accounting, and plant environment (Williams, Renard, and Dyke). Unlike other biophysical simulation models, EPIC is capable of simulating multi-crop/multi-year cropping systems.

For this study, the EPIC model simulated both irrigated and dryland crop production on an Acuff soil type. The crop rotations, tillage practices, and irrigation regimes simulated were based on survey and interview information from agricultural scientists in the region. Ten random weather patterns were generated over 48 years for each area. Each cropping system was subjected to the same 10 random weather patterns. Output from each simulation produces temporal estimates of crop yield by cropping system. Due to the daily simulation process in EPIC, crop yield in a given year was not only a function of the climatic conditions in that year, but also the soil moisture conditions from the previous year.

Random Crop Prices

Tew and Boggess indicate that several potential biases in risk of profits are introduced if output price is assumed static. This is a major concern if one is to consider the risk impacts of government commodity programs on crop mix decisions. The random price series used in this study were generated from a multivariate empirical probability distribution based on historic prices in the region. The method used to develop correlated output price distributions follows the procedure described by Richardson. Error terms about an O.L.S. trend line for prices was used to compute a correlation matrix which expresses the dependence between crop prices. The correlation matrix was then factored by the "square root method" and used to generate correlated deviates. The mean prices used in this study included $.55/lb for cotton lint, $91.66/ton for cotton seed, $4.08/cwt for grain sorghum, and $3.31/bu of wheat. The mean prices were combined with annual correlated percentage deviates to generate the series of random crop prices.

Results

The results presented in this section focus on three main issues. The first issue relates to optimal temporal crop mix selection and the resulting intertemporal path of discounted net present values under different producer risk aversion scenarios. The second issue relates to cumulative groundwater extraction and irrigation intensity at the whole farm level given risk averse preferences in crop mix decisions. The final issue addressed is how risk averse producers may respond to the transition from irrigated to dryland crop production.

Illustrated in Figure 1 are the discounted net present values for each six year period by risk aversion level. The first case designated "RN" refers to a risk neutral producer. The other cases include SLRA for slightly risk averse ($r(x)=.000003$), MRA for moderately risk averse ($r(x)=.000006$) and ERA for extremely risk averse ($r(x)=.000009$). For the risk neutral producer, discounted net present values are projected to decline by 54 percent over the eight six year periods. This steady decline is primarily caused by rising pumping costs thereby reducing irrigated crop profitability over time. By contrast, the path of discounted net present values for the risk averse cases appear much more erratic over the 48 year planning horizon. Risk averse producers adjusted both crop mix (irrigated and dryland) as well as total acres within each temporal optimization. The net result of the temporal optimization is an overall increase in the coefficient of variation (CV) of discounted present values across all six year periods for the risk averse producer. The CV for the risk neutral case was .314 compared to a CV of .515 for the SLRA, .486 for the MRA, and .499 for the ERA producer, respectively. This increase in the intertemporal variation of present values raises a

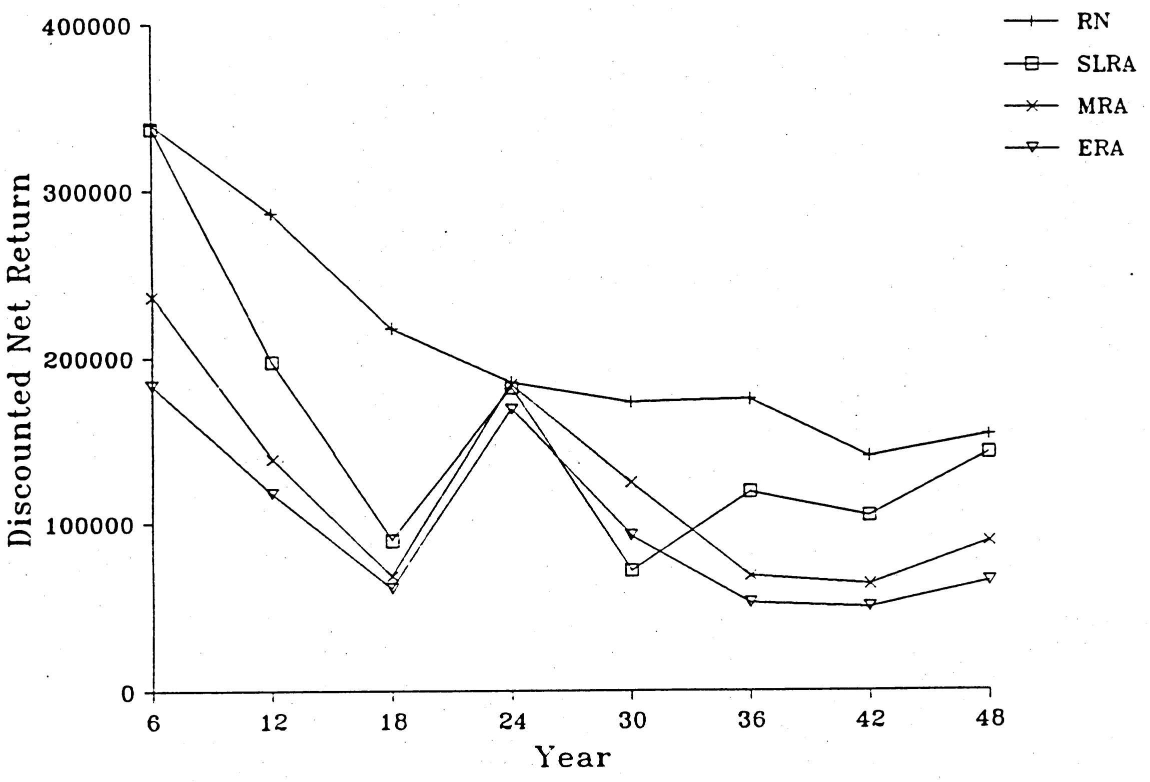

Figure 1. Discounted Net Present Value by Risk Aversion Level.

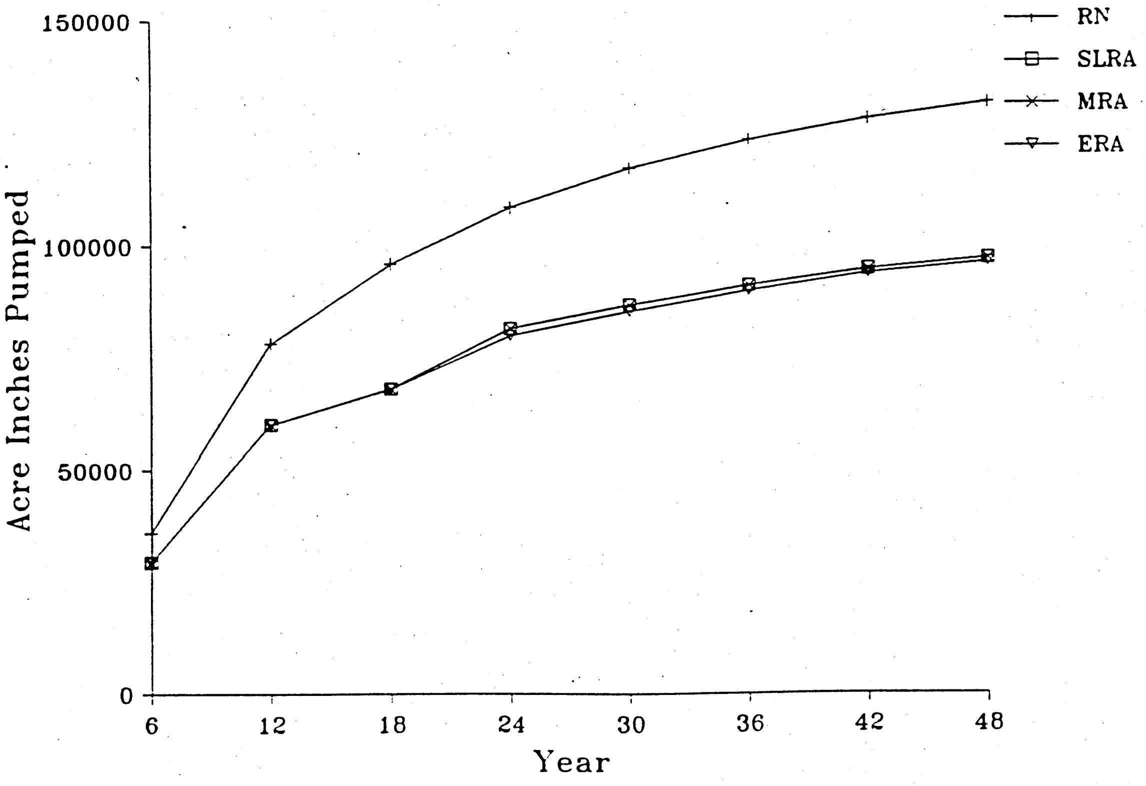

Figure 2. Cumulative Acre Inches of Irrigation Water Pumped by Risk Aversion Level.

serious question as to the general applicability of risk analysis is a sub-optimization framework.

Cumulative groundwater extraction rates for irrigation by risk aversion level are displayed in Figure 2. A risk neutral producer was projected to extract 35 percent more water over the 48 year planning horizon compared to the risk averse cases. This acceleration is due, in part, to the enhanced profitability of high water demand crops such as monoculture cotton. Cumulative whole farm groundwater extraction was estimated at 131,125 acre inches for the risk neutral producer, 96,864 for the slightly risk averse, 96,687 for the moderately risk avers, and 96,052 for the extremely risk averse producer. These levels translate to average annual per acre irrigation applications of 14.4 inches for this risk neutral, 15,3 for the slightly risk averse 15.4 inches for the moderately risk averse, and 15.5 acre inches for the extremely risk averse. Rather than reduce irrigation intensity, the more risk averse producer would reduce irrigated acre yet increase per acre application rates.

Illustrated in Figure 3 are total acres planted within each six year temporal optimization. Total acres planted declined across all iterations as risk aversion increased. Average annual cropped acreage was estimated at 977 acres for RN, 812 for SLRA, 577 for MRA, and 463 acres for the ERA case. For the risk neutral case, dryland continuous cotton acreage increased from 753 acres in the first six years to over 892 acres in years 42 through 48. The optimal crop mix for the risk averse cases consisted mainly of a dryland cotton annual terminate wheat cropping system. Acreage for this system declined from 425 in years 1 through 6 to less than 350 in years 42 to 48 for the moderately risk averse producer.

Figure 4 displays irrigated acreage as a percent of planted acreage by risk level. In this graph, the percent of irrigated acreage increased as the risk aversion level was increased. Based on the results from this study, risk averse producers may find the transition to dryland crop production particularly difficult. As acreage reverts to dryland, expected net returns decline and the variance increases relative to irrigated crop production. To maintain pre-transition income levels, producer will have to expand total dryland acreage yet, the results from this analysis indicate that risk averse producers tend to reduce dryland acreage not irrigation intensity in response to the increased income variability associated with dryland or limited irrigated crop production.

Conclusions

The Texas High Plains irrigates crops from an exhaustible aquifer. Continued mining of the Ogallala will increase pumping costs and reduce well yields. The combination of these two factors can decrease irrigated crop profitability to the point that it is more profitable to revert to dryland production practices. Producers, particularly risk averse operators, may find it difficult to maintain income levels during this reversion process.

Risk averse preferences in crop mix selection resulted in a decrease in cumulative groundwater extraction rates through reduced irrigated acres, but exhibited higher per acre applications rates as compared to the risk neutral case. More importantly, risk averse preference in temporal crop mix selection lead to an overall increase in present value variability relative to the risk neutral case. This predicted response was caused by the adjustment in total acres planted from period to period. The large amplitude of the present values by risk aversion level raises the issue of the appropriateness of extending temporal risk analysis into an intertemporal context.

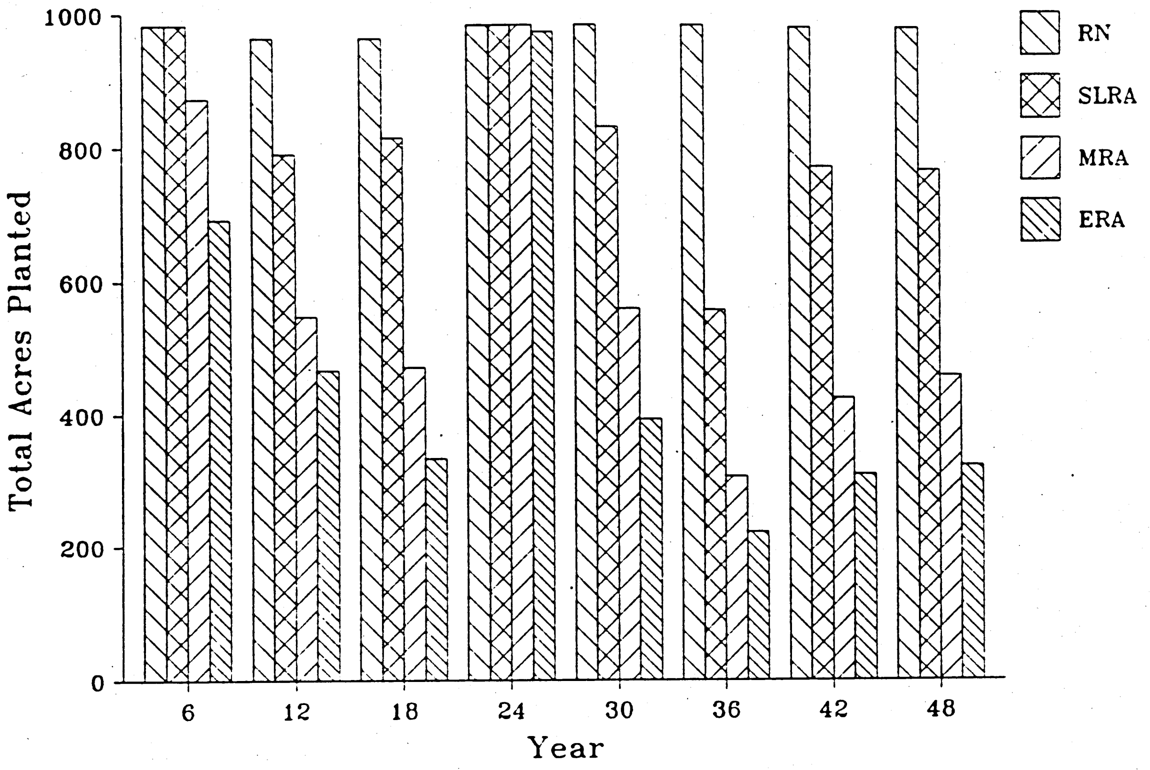

Figure 3. Combined Irrigated and Dryland Acreage Planted by Risk Aversion Level.

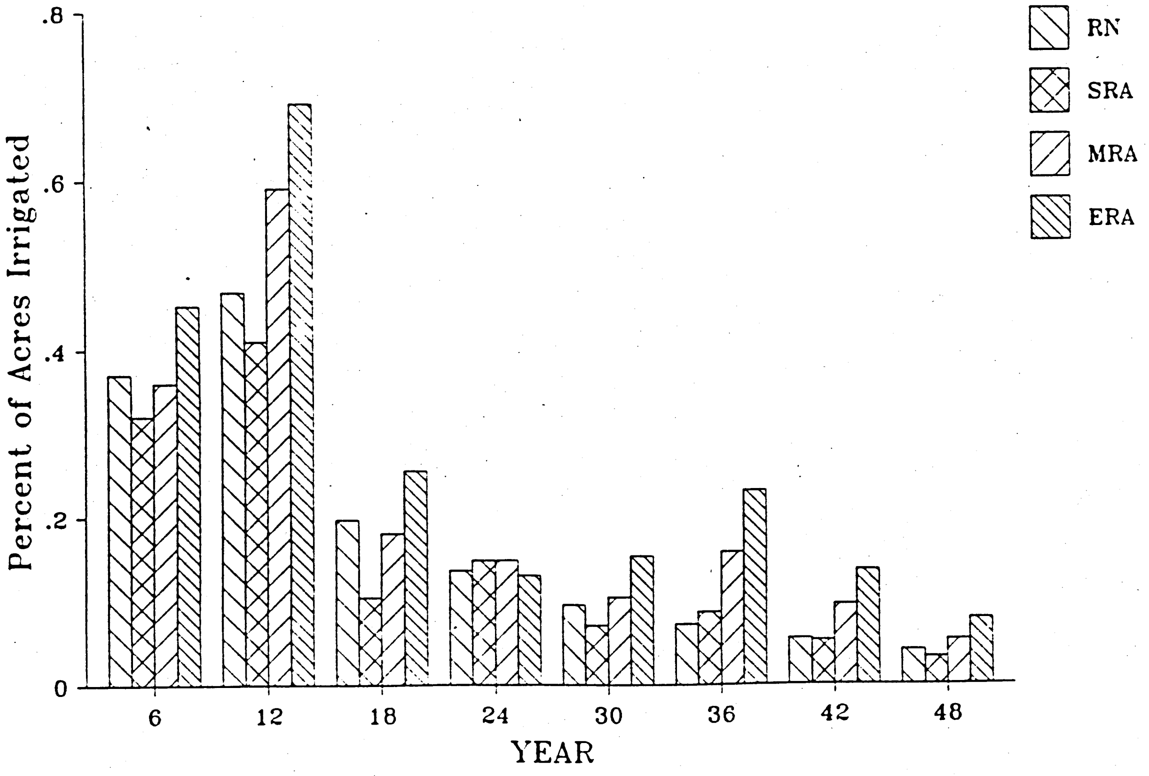

Figure 4. Irrigated Acreage as a Percentage of Total Acres Planted by Risk Aversion Level.

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