SOIL CONSERVATION OR COMMODITY PROGRAMS: TRADE OFFS DURING THE TRANSITION TO DRYLAND CROP PRODUCTION

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ABSTRACT

Predicted crop yields and wind erosion rates from a multi-year/multi-crop growth simulation model provided input into a multi-period recursive QP model to evaluate erosion implications during the transition to dryland crop production on the Texas Southern High Plains. Three farm-program participation options were considered in this study. Participation in an extension of the current farm program resulted in an increase in net returns and wind erosion rates above nonparticipation. Imposition of a soil loss limit without consideration of a flexible base option can significantly reduce discounted present values. Increasing risk aversion across producers affects crop mix selection which can result in lower per acre wind erosion rates for this particular region.

Key words: farm size, production costs, stochastic dynamic programming

According to the 1977 National Resources Inventory, approximately 23 percent of the nation's cropland was subject to annual wind erosion rates in excess of five tons per acre (U.S. Department of Agriculture). A large percentage of these acres is located in portions of the Great Plains which overlay the Ogallala Aquifer. Due to physical and economic principles related to the Ogallala, irrigated agriculture on the Texas High Plains is expected to revert to dryland crop production (Lacewell and Lee). From 1977 to 1982, dryland acreage on the Southern High Plains increased from 40 percent of harvested acres to 50 percent (Texas Department of Water Resources). Irrigated acreage simultaneously declined at a rate of 2 to 3 percent per year. Risk relative to crop yields and net returns is perceived to be much greater under dryland as compared to irrigated cropping systems.

Critical to the reversion to dryland crop production are the potential impacts on natural resources from alternative adaptations of the agricultural sector. As irrigation levels decline and dryland acreage increases, the incidence of wind erosion is expected to increase. For the Texas High Plains, this is occurring at a time when farm policy is emphasizing long-term soil conservation. One program, conservation compliance, requires a conservation plan to be developed by 1990 and implemented by 1995 for producers to receive farm program benefits. In some cases, a soil conserving plan may not be as profitable in the short term as traditional cropping practices. Long term profitability of soil conservation practices depends on relative prices as well as inherent soil properties and the ability to substitute selected inputs (fertilizers, lime, irrigation water, etc.) for soil productivity over time. With farm program participation rates in excess of 90 percent in some areas of the Southern High Plains of Texas, conservation compliance coupled with current base acreage restrictions may prohibit the adoption of certain profitable cropping systems during the transition to dryland crop production.

The purpose of this study was to estimate annual stochastic net returns and wind erosion levels associated with several irrigated and dryland cropping systems. This information provided input into a firm-level multi-period recursive quadratic programming model that was used to evaluate the likely path of transition from irrigated to dryland crop production. A second objective was to evaluate the impact of different soil loss limits on cropping system selection and discounted net returns. The final objective was to assess the impact of producer risk references on crop selection, discounted net returns, and wind erosion levels given current commodity program provisions.

PREVIOUS RESEARCH

Soil conservation research has received much attention recently in the agricultural economics literature. While the regions of study vary and research methods differ, previous applied studies have focused almost exclusively on water-based soil loss.

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The purpose of this section is to briefly review prior soil conservation research as well as to identify those studies that link soil conservation decisions with risk-averse preferences or commodity program provisions. While this is not an exhaustive review of the relevant literature, it does provide a basis to begin to address farm level soil conservation incentives given the transition to dryland crop production on the Texas High Plains.

Burt (1981) used control theory to evaluate the farm level economics of soil conversation. As Burt pointed out, the concern with soil conservation decisions centers on the change in productivity over time at a given site. In Burt's study, two state variables were defined to describe the soil resource in the Palouse region. The two variables were depth of topsoil and the percent of organic matter in the top six inches of the soil profile. He concluded that the approximate optimal decision rule is very accurate in soil conservation applications because of the slow and smooth change in the state variables over time. Burt also concluded that the particular results derived in the Palouse cannot be readily extrapolated to other regions of the country. This is especially the case for the low organic sandy soils of the Texas Southern High Plains.

Miranowski applied a multiple-period linear programming model to evaluate optimal tillage practices and crop rotation selection for a watershed in Iowa. He found that under increasing crop price expectations, the market system should provide incentives for producers to adopt farming practices that are more conservation oriented. One limitation of this particular study is that it did not explicitly account for commodity program provisions that affect relative crop prices and crop rotation selection.

Taylor and Young estimated the effect of water-based erosion on crop yield given technological progress. They indicated that a dual penalty exists in the future resulting from current soil erosion. The first penalty is a direct reduction in future yields as topsoil depth is depleted. The second penalty is a reduction in the future benefits stemming from technological improvements on eroded soil versus the improvements on less eroded soil.

An alternative approach for assessing soil conservation benefits was the development of an economic-based erosion damage function by Walker. The damage function in this case related crop yield to topsoil depth in the Palouse. While the erosion damage function could be generalized to consider multiple crop rotations, it is likely that additional soil properties would need to be included to evaluate conservation benefits in other regions of the country. In a concluding comment, Walker indicated that incorporation of risk into the analysis would be worthwhile in evaluating erosion control economics.

Given this suggestion, a study by Kramer, McSweeny, and Stavros used a single period quadratic programming model to determine optimal crop selection and erosion levels given uncertain net revenues and days suitable for field work. They found that risk-averse preferences in crop mix selection resulted in higher levels of per-acre soil loss. This response was apparently due to an increase in the proportion of soybean acreage. In another study, Segarra, Kramer, and Taylor evaluated the impact of probabilistic soil-loss constraints on firm-level decisions. They indicated that soil loss follows a probability distribution that should be considered in an analysis of soil conservation policy.

A final area of previous literature that merits review pertains to the interaction of government commodity programs and conservation policy. This is an area that has received much attention in recent years. Ervin, Heffernan, and Green examined the efficiency and distributive effects of cross-compliance for erosion control. They indicated that cross-compliance is likely to benefit larger farms and high-equity firms relative to smaller or more highly leveraged operations. Cross-compliance may provide the greatest economic incentive for erosion control on land for which the net social benefits may be small compared to those on more erosive land.

Hoag and Young used simulation analysis to evaluate the impact on net returns and risk of various commodity and conservation programs. As they noted, commodity programs have been criticized for encouraging crop production on highly erodible land to sustain base acreage and provide a low-cost source of land to idle under different acreage reduction programs. In their farm level study, Hoag and Young evaluated three farm program scenarios. These scenarios included nonparticipation by the producer in either commodity or conservation programs, historic commodity programs, and historic commodity programs with the Soil Conservation Act provisions of 90 percent cost-sharing and a cropland base-acreage protection option. The results from their study indicated that commodity programs increase net returns above nonparticipation as well as reduce net return risk. A cropland base acreage protection program can significantly reduce the cost of land retirement and hence erosion control.

In one of the few studies on wind erosion, Huszar estimated the off-site cost of wind erosion in New Mexico. He found that the off-site cost of wind erosion appears to be a decreasing function of the erosion rate. Results from the 1982 National Resources Inventory revealed that wind erosion accounts for 37 percent of annual total soil erosion in the U.S. However, previous economic research on soil conservation and erosion control has focused extensively on water-based erosion as measured by the Universal Soil Loss Equation (USLE). The USLE is a predictor of gross soil movement. As such, the appropriateness of erosion standards based only on a single form of erosion is questionable. Soil loss limits based on water erosion research may not be physically or economically feasible for regions subject to severe wind erosion episodes.

MODELS AND PROCEDURES

Biophysical simulation techniques have been applied to a number of agricultural problems. Mapp and Eidman used a soil moisture crop yield simulation model to evaluate alternative irrigation strategies at the whole farm level. Boggess and Amerling used drop-growth models to provide input into an investment analysis of irrigation systems in Northern Florida. Specific to the assessment of soil erosion, Taylor and Young indicated that simulation models offer more flexibility as compared to programming models in representing the complex interaction through time of soil erosion on crop yields and farm income.

A daily time-step crop growth simulation model known as EPIC (Erosion Productivity Impact Calculator) was calibrated and used to estimate crop yields and soil erosion under 10 randomly generated 48-year weather patterns (Williams, Renard, and Dyke). The crop growth parameters and wind erosion components of EPIC were calibrated with crop growth data and wind erosion events in the region (Zobeck and Fryrear). The components of EPIC include weather simulation, hydrology, erosion-sedimentation, nutrient cycling, tillage, soil temperature, plant growth, economic accounting and plant environment (Williams, Renard, and Dyke).

For this study, the EPIC model simulated irrigated and dryland crop production for 12 cropping systems on an Amarillo soil type in Dawson County, Texas. The Amarillo or sandyland type soils account for approximately 50 percent of the 4.12 million cropland acres on the Southern High Plains (U.S. Department of Agriculture). The crop rotations, irrigation levels, and tillage practices simulated were based on interview information from Texas Agricultural Experiment Station scientists in the region. Each cropping system was subject to the same 10 random 48-year weather patterns. Output from each simulation gave temporal estimates of crop yield by rotation as well as erosion from wind and water. Due to the time-step simulation process, crop yield in a given year was not only a function of the climatic conditions in that year, but also the soil moisture condition from the previous year. Unlike single crop simulation models, EPIC is capable of simulating multi-year/multi-crop rotation. This framework was necessary to account for soil erosion due to the wind and the subsequent impact upon crop yields within each rotation.

PROGRAMMING MODEL

A firm-level Multi-period Recursive Quadratic Programming Model (MPRQP) was developed for the Southern High Plains to evaluate crop rotation selection and paths of transition from irrigated to dryland crop production under different assumptions of producer risk aversion, farm program participation, and soil loss limits. A six-year multi-period formulation of the optimization model was deemed appropriate to account for rotational impacts on crop yield, net returns, and machinery complement requirements associated with each cropping system. Randomly correlated crop prices, budgeted costs of production, and commodity program provisions were combined with stochastic crop yields to estimate net present value distributions for each cropping system.

The mean-variance modelling framework has been criticized in the past for placing undue restrictions on the problem compared to the expected utility criteria. Typically stated, these restrictions require that the agents' utility function be quadratic or that the random alternatives be normally distributed. Meyer has shown an additional theoretical condition which is sufficient to ensure consistency between the expected utility approach and mean-variance approach. This condition, known as location and scale, maintains that two cumulative distribution functions F(x) and G(x) are said to differ by location (α) and scale (β) if $F(x) = G(\alpha+\beta x)$ where $\beta>0$.

The location and scale condition is automatically satisfied with the structure of the MPRQP model given random crop prices and stochastic crop yields. An extension of Sandmo's model of the competitive firm can serve to illustrate this condition. Sandmo's model of the competitive firm that faces price uncertainty can be expressed as:

(1) $\pi = \tilde{P} \cdot X - C(X) - B$

where π is profit, $\tilde{P}$ is random price, X is output, C(X) is variable cost, and B is fixed cost. This model can be redefined to satisfy the location scale condition

(2) $\pi = [-C(X) - B] = [X]\,[\tilde{P}]$

where [-C(X) - B] is a location parameter and [X] is the scale parameter. The Sandmo competitive firm level model can be expanded to consider two sources of risk as follows:

$$(3) \quad \pi = \tilde{P}\cdot\tilde{X}\cdot A - C[A]-B$$

where π is whole-farm profit, $\tilde{P}$ is randomly correlated crop price, $\tilde{X}$ is stochastic per-acre yield, A is acres, C[A] is per-acre variable cost of production, and B is fixed cost. This particular structure also satisfies the location and scale condition:

$$(4) \quad \pi = [-C[A] - B] + [A][\tilde{P}\cdot\tilde{X}]$$

Meyer provides a more detailed explanation of the location and scale condition which, if satisfied, ensures the consistency between mean-variance and the expected utility approach.

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 represents the mean of stochastically generated crop yield and output price minus the variable cost of production over a six-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 were calculated using the discounted net present values from each of 10 random weather patterns. The following is a matrix formulation of the MPRQP model:

$$(5) \quad \begin{array}{rl} \text{MAX } CS - \phi\, X'QX & \\ \text{S.T. } AX & \le B \\ DX - EW & \le 0 \\ W & \le V \\ FX & \le Z \end{array}$$

where X is a vector of multi-year cropping system alternatives, C is a vector of mean discounted present values by system, ϕ is the Pratt Risk Aversion Coefficient scaled to present values at the whole-farm level, Q is a variance/covariance matrix of discounted present values, A is a matrix of variable inputs and resource requirements, B is a vector of resource endowments, D is the matrix of plant irrigation water requirements across all cropping systems over a six-year time period, W is a matrix of water requirements for each 10-day pumping interval, E is a vector of pumping efficiencies, V is a vector of pumping capacity by 10 day intervals over six years, F is farm program base-acreage requirement by crop within each cropping system, and Z is a vector of farm program base acreage by crop for the farm.

Eighty-two production activities were included in the formulation of the MPRQP model. These activities consisted of 12 cropping systems evaluated under six irrigation regimes and a dryland option. The sprinkler irrigation regimes ranged from a preplant plus three post-plant irrigations to a single post-plant application. There were 12 critical water periods selected for each production season. Thus, a total of 72 critical water periods were identified to account for intra-seasonal and inter-seasonal competition for irrigation water among the various cropping systems over the six-year planting horizon. Each critical water period consisted of a 10-day pumping interval.

Additional resource constraints were necessary to evaluate base-acreage requirements under current farm program provisions. Interview information from Dawson County A.S.C.S. personnel provided information on county-wide base acreage and farm program yield by crop. These values were disaggregated to the firm-level model. The MPRQP model was initiated at 1,200 total acres with a cotton base of 1,125 acres, a sorghum base of 27.2 acres and a wheat base of five acres. A lease-land option in the model allowed for expansion of cropped acres on a 160-acre parcel basis with assumed proportionate commodity base.

The final set of temporal production constraints consisted of soil erosion limits. The mean of stochastically generated wind erosion for each cropping system was used as a technical coefficient to evaluate optimal cropping selection and discounted net returns given potential conservation compliance provisions. Unlike the Universal Soil Loss Equation (USLE) which predicts gross soil loss, EPIC is capable of predicting net wind erosion for a given cropping system. Depending upon soil type, topography, climate, and crop production technology, net soil loss due to wind may be a more appropriate measure of sustainable crop productivity (i.e., t-value) compared to a gross predictor of soil movement. Gross predictors of soil movement may not accurately account for changes in soil physics due to wind erosion. Two annual net soil loss constraints of six and nine tons per acre were evaluated for the Southern High Plains representative farm.

RISK AVERSE PREFERENCES

Kramer, McSweeny, and Stavros indicated that risk attitudes can affect the adoption of soil conserving practices. In their study, risk aversion implied crop mixes with greater levels of per-acre soil loss. To evaluate optimal crop mix decisions and wind erosion implications, the non-linear objective function of the MPRQP model involved the maximization of discounted mean net present values less a PRATT risk aversion coefficient times the variance-covariance of expected net present values for all cropping systems. A real discount rate of 5 percent was assumed for this analysis.

The discounted net present value and variance from the linear programming solution of the MPRQP model were retained to estimate different risk aversion levels. A maximal risk aversion coefficient was derived by setting the following certainty equivalent formula equal to zero and solving for r(x):

$$(6) \quad CE = \mu - \frac{1}{2}\sigma^2 r(x)$$

where μ is the discounted net present value and σ^2 is the variance from the optimal linear programming model. The maximal risk aversion coefficient was multiplied by 25 percent increments to develop three risk aversion classes. The three classes represent slightly risk averse (SRA:r(x) = .0000032), moderately risk averse (MRA: r(x) = .0000064), and extremely risk averse (ERA: r(x) = .0000096). The final case considered is a risk neutral (RN: r(x) = 0) scenario.

RECURSIVE FORMULATION

A set of equations was developed to extend the multi-year model through eight recursive cycles. Because groundwater depletion and soil degradation tend to be long-term phenomena, a recursive structure was necessary to consider intertemporal adjustments in water availability and wind erosion impacts on crop productivity. The recursive formulation does not identify the optimal long-run rate of groundwater extraction or soil depletion for a producer over the 48-year planning horizon. Rather it was designed to evaluate producer adjustments to declining groundwater availability and changes in crop productivity.

The first series of recursive equations adjusted saturated thickness, pumping capacity, well yield, and per-acre-inch pumping costs in period t+1 based on groundwater extractions in period t. Due to limited recharge of the Ogallala, the cost of pumping water during a given time period is dependent upon initial groundwater conditions and previous pumping decisions. Discounted net present values for each irrigated cropping system in period t+1 were recalculated using adjusted pumping costs predicted for time period t+1. A second recursive equation determined the amount of loanable funds available to the representative farm in a given year. A lender's response function estimated by Sonka, Dixon, and Jones was assumed over each six-year simulation period. The firm's leverage ratio and equity were adjusted after each iteration (six-year period) to develop new estimates of borrowing capability. The updated loan amount was used as a maximum value in the capital requirements constraints.

The general operation of the MPRQP model consisted of the following steps. A vector of discounted net present values and corresponding variance-covariance matrix of net present values for all cropping systems was read into the model. These values were based on six years of simulated crop yield data under ten randomly generated weather patterns and stochastic crop price for each cropping system. Upon solution, optimal values of resource use and the discounted present value over the six-year period were retained and used to update economic costs and resource availability in the subsequent six-year period. A new vector of adjusted objective function values and its corresponding variance-covariance matrix were entered into the model for the next six-year period. This iterative procedure was replicated eight times to develop a cropping pattern selection and path of resource utilization over a 48-year planning horizon.

RESULTS

The results presented in this section focus on three main issues. The first issue relates to the likely path of transition from irrigated to dryland crop production for a risk neutral producer under three farm program assumptions. Associated with the transition, resource implications can be assessed. The second issue relates the potential impact of a soil loss limit on net returns during the transition process. The third issue is how risk averse preferences in crop selection affect the rate of soil erosion under current commodity programs.

Illustrated in Figure 1 are the discounted net returns by iteration for each of three assumptions regarding individual farm program participation. The first case designated as "farm prog" refers to farm program participation under 1986-1987 base-acreage restrictions and base yield for the representative farm. The second case is termed "flexible base." Under this assumption, base acreage between crops was relaxed to evaluate crop rotation selection. The final case, "nonpart," assumed that the individual chose not to participate in the farm program. In all cases evaluated, the discounted net returns declined over the 48-year planning horizon by 26 to 42 percent depending upon farm program assumption. This decline was due to reduced profitability of irrigated cotton caused by an increase in pumping costs and declining well yields. The optimal crop mix under farm program participation was dominated by continuous cotton. For the nonparticipant, the majority of planted acres were in a dryland continuous wheat system. The path of net returns under flexible base was greater than the farm program scenario over the 48-year planning horizon. Under flexible base, wheat and sorghum were initially shifted to cotton production. In the later peri-

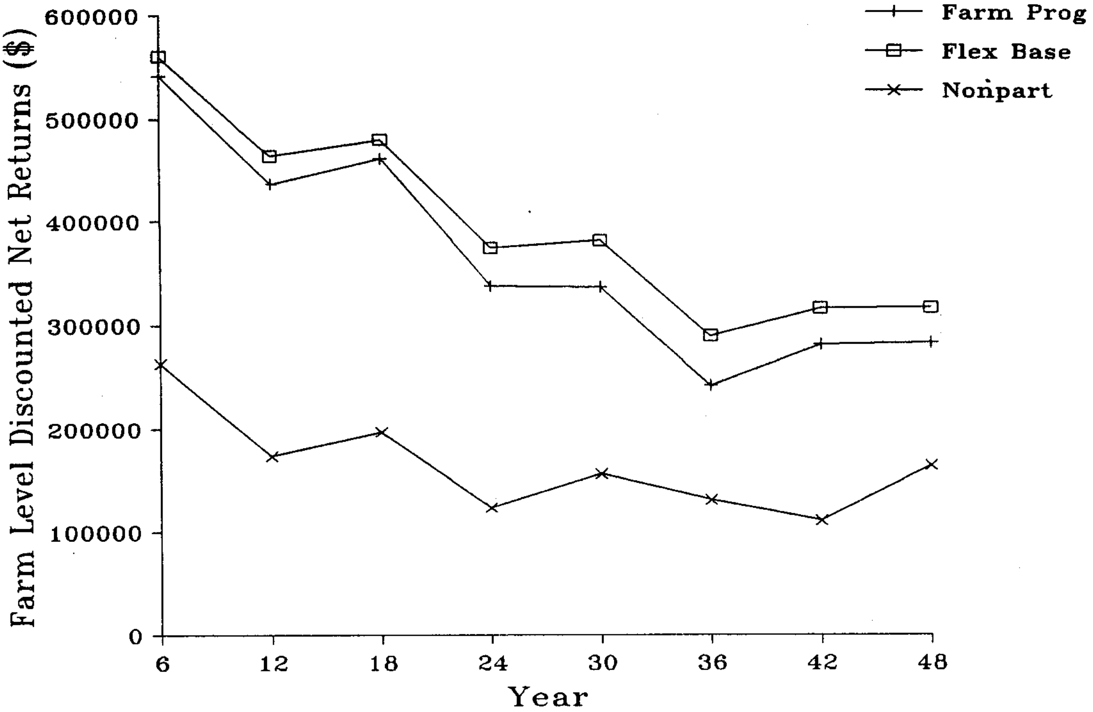

Figure 1. Whole Farm Discounted Net Returns by Farm Program Assumption for a Risk Neutral Producer.

ods, the cropping pattern for flexible base was predominately a dryland cotton-wheat-sorghum rotation.

Groundwater and soil represent two major resources available to a typical High Plains farm. Cropping system selection and farm program provisions can dramatically affect rates of utilization of both resources. Cumulative estimated wind erosion resulting from optimal temporal crop selection by farm program assumption is illustrated in Figure 2. Cumulative wind erosion was consistently greater under the farm program scenario since the optimal crop mix was primarily dryland continuous cotton. Average annual wind erosion from a dryland continuous cotton system was estimated at 11.6 tons per acre. By contrast, average annual wind erosion from a continuous dryland wheat system was estimated at 1.87 tons per acre. This result supports an earlier finding by Hoag and Young that commodity programs encourage the production of highly erosive crops to maintain base acreage.

Displayed in Figure 3 are the present value of net returns for each six years under a six- and nine-ton per acre soil loss limit, assuming farm program participation and the flexible base option. Given a six-ton limit, the present value of net returns declined by $360,000 or 67 percent within the first six years for the farm program participant compared to the unrestricted soil loss case. Under this type of restriction, a risk-neutral producer would have an economic incentive not to participate in the farm program. This is not the case with the flexible base option. With flexible base, the producer could adopt profitable crop rotations that would comply with either the six or nine tons per acre limitation. These results indicate that a flexible base option would be necessary to maintain farm income if these types of soil loss limits were enforced under the conservation compliance program.

An extension of the analysis was to evaluate the impact of producer risk attitudes on crop mix decisions and wind erosion implications. Unlike the risk-neutral scenario, risk-averse producers adjusted both crop mix and acres planted. The optimal crop mix under the farm program case was composed of various combinations of irrigated and dryland continuous cotton. The optimal crop mix for the flexible base alternative was a combination of a dryland cotton-wheat-sorghum rotation and an irrigated cotton-wheat rotation. A comparison of the farm-program case relative to the flexible-base option revealed a 40 percent reduction in acres planted across all iterations.

Illustrated in Figure 4 are the per-acre wind erosion rates associated with the optimal crop mix by risk-aversion level assuming farm program participation over 48 years. The term RN refers to risk neutral, SRA represents slightly risk averse, MRA refers to moderately risk averse, and ERA represents an extremely risk averse case. In almost all cases, increas-

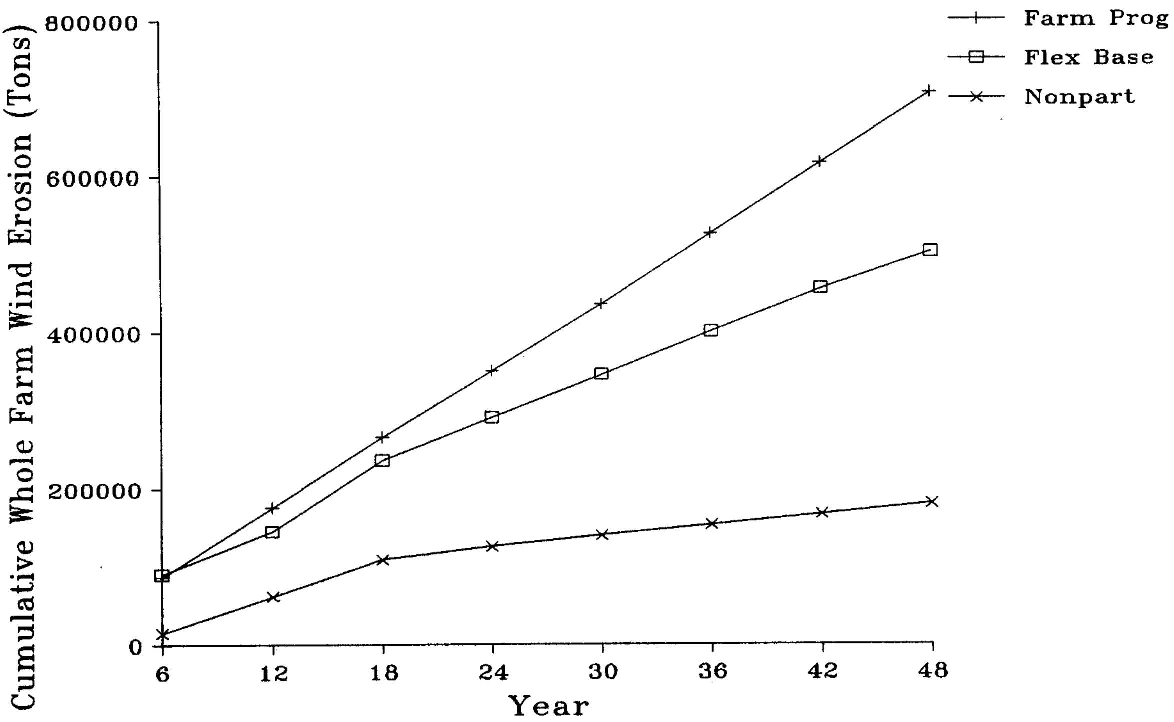

Figure 2. Cumulative Whole Farm Wind Erosion Over 48 Years by Farm Program Assumption for a Risk Neutral Producer.

ing risk aversion in crop mix selection resulted in a lower per-acre wind erosion rate. The reduction in per-acre wind erosion was caused by an increase in acres planted of an annual cotton-terminated wheat cropping system. This result is substantially different from the result presented in the study by Kramer, McSweeny, and Stavros. In their study, risk-averse behavior in crop mix selection implied crop mixes

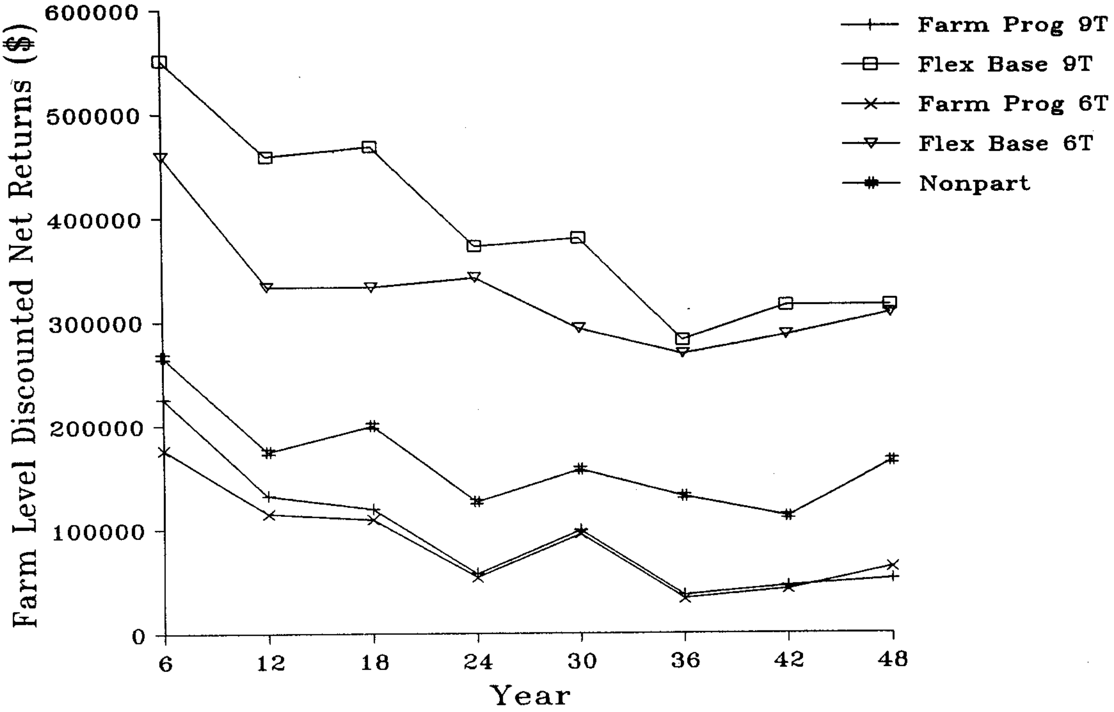

Figure 3. Whole Farm Discounted Net Returns Under a 6 and 9 Ton Per-Acre Soil Loss Limit.

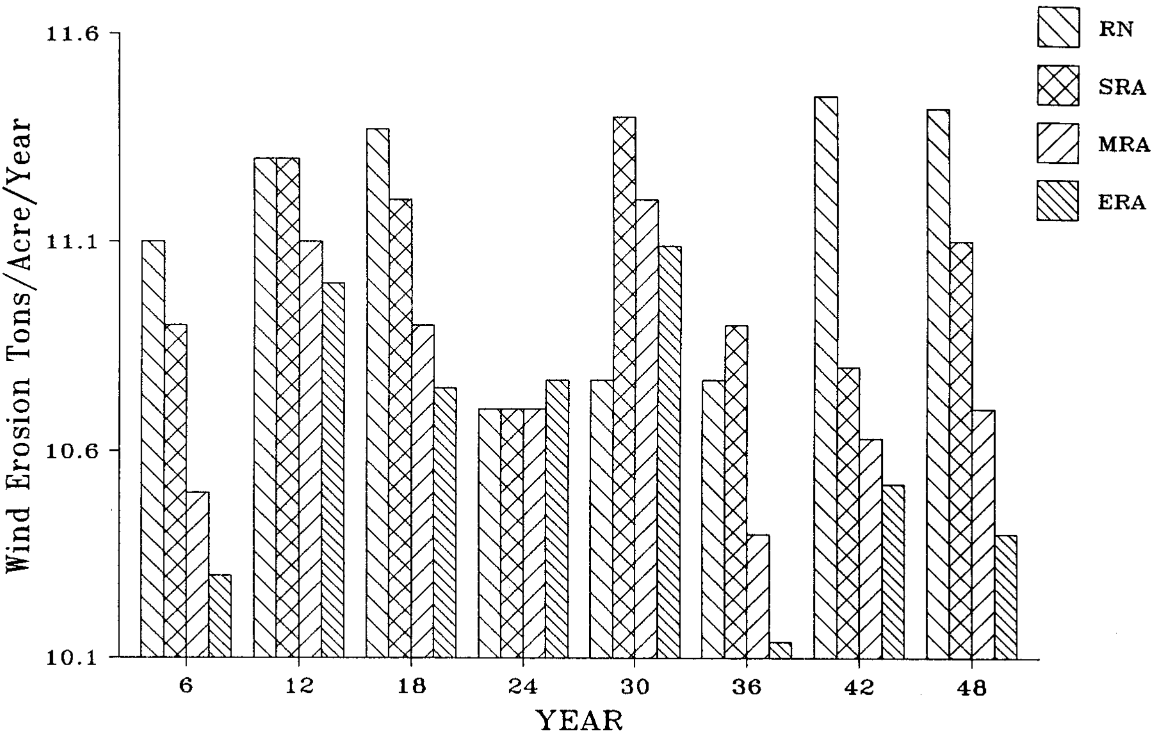

Figure 4. Average Multi-Year Per Acre Wind Erosion Rates by Risk Aversion Level for a Farm Program Participant.

with greater levels of per-acre soil loss. The difference in results from these studies could be based on differences in the measurement of erosion (i.e., U.S.L.E. versus wind erosion), crop production alternatives, or explicit considerations of farm program provisions.

SUMMARY

The Texas High Plains has evolved into a highly productive agricultural region based largely on the development or irrigation supported by the Ogallala Aquifer. Because recharge rates are low relative to pumping rates, continued mining of the aquifer can be expected to increase pumping cost thereby diminishing irrigated crop profitability. As more acres revert to dryland, the incidence of wind erosion can be expected to increase.

Farm program participation substantially increased discounted net returns in each six-year period above nonparticipation. This result is not surprising given current farm program participation rates in excess of 90 percent. Resource implications from farm program participation implies a greater level of wind erosion relative to nonparticipation. Farm program participation coupled with base-acreage restriction encourages the production of continuous cotton. Average annual wind erosion from continuous dryland cotton was estimated at two to six times greater than other cropping systems.

Imposition of a six- or nine-ton per acre per year soil loss limit reduced farm income. The largest reduction would occur for the farm program participant. This reduction was caused by compliance with crop base-acreage restrictions which limit the adoption of profitable multi-year/multi-crop production systems. With strict enforcement of base-acreage requirements, a producer would be better off by not participating in the farm program with these types of erosion limits. This raises a serious question as to whether conservation compliance will be effective in promoting consistency between soil conservation programs and commodity programs. One farm program option that would allow producers to obtain farm program benefits while complying with soil conservation standards is a flexible base provision. Under flexible base, cropping systems such as cotton-wheat- and cotton-wheat-sorghum rotation could replace monoculture cotton and provide substantial wind-erosion control.

REFERENCES

Boggess, W.G. and C.B. Amerling. "A Bioeconomic Simulation Analysis of Irrigation Investments." *So. J. Agr. Econ.*, 5(1983):85-92.

Burt, R.O. "Farm Level Economics of Soil Conservation in the Palouse Area of the Northwest." *Am. J. Agr. Econ.*, 63(1981):83-92.

Ervin, D.E., W.D. Heffernan, and G.P. Green. "Cross-Compliance for Erosion Control: Anticipated Efficiency and Distributive Impacts." *Am. J. Agr. Econ.*, 66(1984):273-278.

Hoag, D.L. and D.L. Young. "Commodity and Conservation Policy Impacts on Risk and Returns." *West J. Agr. Econ.*, 11(1986):211-220.

Huszar, P.C. "Economics of Reducing Off-Site Cost of Wind Erosion." *Land Econ.* 65(1989):333-340.

Kramer, R.A., W.T. McSweeney and R.W. Stavros. "Soil Conservation and Uncertain Revenues and Input Supplies." *Am. J. Agr. Econ.*, 65(1983):694-702.

Lacewell, R.D. and J.G. Lee. "Land and Water Management Issues: Texas High Plains." *Water and the Arid Lands of the United States.* London: Cambridge U. Press, 1988.

Mapp, H.P., and V.R. Eidman. "A Bioeconomic Simulation Analysis of Regulating Groundwater Irrigation." *Am. J. Agr. Econ.*, 58(1976):391-402.

Meyer, J. "Two-Moment Decision Models and Expected Utility Maximization." *Am. Econ. Rev.* , 77(1987):421-430.

Miranowski, J.A. "Impacts of Productivity Loss on Crop Production and Management in a Dynamic Economic Model." *Am. J. Agr. Econ.*, 66(1984):61-71.

Sandmo, A. "On the Theory of the Competitive Firm Under Price Uncertainty." *Am. Econ. Rev.*, 61(1971):65-73.

Segarra, E., R.A. Kramer and D.B. Taylor. "A Stochastic Programming Analysis of the Farm Level Implications of Soil Erosion Control." *So. J. Agr. Econ.*, 17(1985):147-154.

Sonka, S.T., B.L. Dixon and B.L. Jones. "Input of Farm Financial Structure on the Credit Reserves of Farm Business." *Am. J. Agr. Econ.*, 62(1980):565-570.

Taylor, D.B. and D.L. Young. "The Influence of Technological Progress on the Long Run Farm Level Economics of Soil Conservation." *West J. Agr. Econ.*, 10(1985): 63-76.

Texas Department of Water Resources. "Inventories of Irrigation in Texas 1958, 1964, 1974, 1979 and 1984." Report 294, August 1986.

U.S. Department of Agriculture. *Soil Survey of Dawson County, Texas.* Soil Conservation Service. Washington, D.C., 1959.

U.S. Department of Agriculture. *Data for Decisions: 1982, National Resources Inventory.* Soil Conservation Service. Washington, D.C., 1984.

U.S. Department of Agriculture. *Soil and Water Resources Conservation Act: 1980 Appraisal, Part 1.* Washington, D.C., March 1981.

Walker, D.J. "A Damage Function to Evaluate Erosion Control Economics." *Am. J. Agr. Econ.*, 64(1982):690-698.

Williams, J.R., K.G. Renard and P.T. Dyke. "EPIC: A New Method for Assessing Erosion's Effect on Soil Productivity." *J. Soil and Water Cons.*, 38(1983):381-383.

Zobeck, T.M. and D.W. Fryrear. "Chemical and Physical Characteristics of Wind Blown Sediment I. Quantities and Physical Characteristics." *Trans. Am. Soc. Agr. Eng.*, 29(1986):1032-1036.