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The Impact of Climate on Agriculture: A Ricardian Approach

by

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ABSTRACT

Because of the potential for global warming, there are widespread concerns about the impact of changing climate upon the productivity of land in farming and other sectors. This paper develops a new approach for measuring the economic impact of environmental factors such as climate on production by examining the direct impact of the environmental factor on land productivity as measured by land prices. This new method is applied to examine the effect of climate on agriculture using cross sectional farm data for almost 3000 counties in the United States. It finds substantial impacts of climatic variation on both land values and farm revenues. Among the central findings are that higher temperatures in all seasons except autumn reduce average farm values in the United States. More precipitation in all seasons except autumn increases farm values. The relationships are, however, nonlinear and complex.

I. INTRODUCTION

Over the last decade, scientists have studied extensively the greenhouse effect, which holds that the accumulation of carbon dioxide (CO_2) and other greenhouse gases (GHGs) is expected to produce global warming and other significant climatic changes over the next century. Numerous studies indicate that there is the potential for major impacts on agriculture, especially if there is significant midcontinental drying and warming in the U.S. heartland[1]. The greenhouse effect is but one of a number of major environmental consequences of human activities.

There are two approaches to valuing the impacts of environmental change. The traditional approach in the environmental valuation literature focuses upon measuring direct impacts on consumers. An alternative approach reflects the likelihood that a significant part of the damages from environmental changes come through impacts on production. For example, particulate emissions may increase the cost of operating processes which require especially clean settings. Changes in climate will affect agriculture, outdoor construction, electricity generation, ski resorts, and other sectors which involve natural systems or outdoor activities.

One issue addressed here is the development of a general theoretical approach that can be used directly to measure the impacts of environmental changes on production through their impact on land markets. This methodology, which is developed in Section II of this paper, takes into account adjustments that firms make in response to the environment.

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[1] See particularly the reports of the Intergovernmental Panel on Climate Change (IPCC [1990]) and the National Academy of Sciences Panel on Greenhouse Warming (NAS [1991]).

We then develop in Section III an application of this model to the specific question of climatic effects on agriculture. This issue is not new. Studies of the impact of climate on farming include scholarly studies such as Adams et al. [1988], Adams [1989], Adams et al. [1990], Callaway et al. [1982], Decker et al. [1986], and Rosenzweig [1986] as well as surveys in NAS [1983], EPA [1989], and NAS [1991].

Ricardian vs. Production-Function Approaches

The approach contained in the current literature on climate effects we label the production-function approach, to distinguish it from the approach developed here. Under the production-function approach, changes in yield are estimated directly from a production function. Frequently, all other inputs are frozen and only the variable of interest is permitted to change. Studies using the production-function approach all find that climate change can affect agriculture through the impact of precipitation, temperature, carbon dioxide levels, changes in pests, as well as by changing the costs of irrigation. Quantitative estimates have been generated (for example, see Adams et al. [1988], Adams [1989], and Adams et al. [1990]) from experimental or agronomical production models. Depending upon the atmospheric scenario and the model utilized, crop-yield models (CERES and SOYGRO) predict a 10% increase or a 20% decrease in harvests, although some authors estimate a more substantial decline in yields (see Rind et al. [1990]).

While these studies provide a useful baseline for estimating the impacts of climate change on farming, they have an inherent bias that will tend to overestimate the impact. This bias arises because the production-function approach will omit many of the possible substitutions and adaptations that society can make to changing environmental conditions. Most studies assume that there is no adaptation at all and simply calculate the impact of changing temperature on farm yields. Others allow some changes in fertilizer application or irrigation or limited changes in the cultivars. None permit a detailed adjustment to changing environmental conditions by the farmer. Further, the literature does not consider the introduction of completely new crops (such as tropical crops in the south); technological change; changes in land use from farming to livestock, grassland, forestry; or conversion to cities, retirement homes, campsites, or the 1001 other productive uses of land in a modern post-industrial society.

By not permitting a complete range of adjustments, previous studies have overestimated damages from environmental changes. Figure 1 shows the hypothetical values of output in four different sectors as a function of a single environmental variable, temperature, in order to illustrate the general nature of bias. In each case, we assume that the production-function approach yields an accurate assessment of the economic value of the activity as a function of temperature. The four functions are a simplified example of how the value of wheat, corn, grazing, and retirement homes might look as a function of the temperature. For example, the curve to the far left is a hypothetical "wheat production function," showing how the value of wheat varies with temperature, rising from cold temperatures such as point A, then peaking at point B, finally falling as temperatures rise too high. A production-function approach would estimate the value of wheat production at different temperatures along this curve. For example, point F would describe the effect of being at a high temperature.

The production-function approach fails to take into account, however, that there will be economic substitution of alternative activities as the temperature changes. For example, when the temperature rises above point C, adaptive and profit-maximizing farmers will switch from wheat to corn. As temperature rises, the production-function approach would calculate that the yield has fallen to F in wheat, but wheat is in reality no longer produced; the realized value is actually much higher, at point D where corn is now produced. At a slightly higher temperature, the land is no longer optimally used for corn but switches to grazing, and production-function estimates that do not allow for this conversion will again overestimate the losses from climate change. Finally, at point E, even the best agricultural model will predict that the land is unsuitable for crops or even grazing and that the damage is severe. A more complete approach will find that the land has been converted to retirement villages, to which old folks flock so they can putter around in the warm winters and dry climates.

All this is of course illustrative. But it makes the crucial point that the production-function approach will overestimate the damages from climate change because it does not, and probably cannot, take into account the infinite variety of substitutions, adaptations, and old and new activities that may displace no-longer-advantageous activities as climate changes. Of course, there is no guarantee that the picture will look anything like Figure 1. It might well be that the values of wheat are much greater than other activities. But the direction of the bias from the production function approach is unambiguous.

In this study, we develop a new technique that in principle can correct for the bias in the production-function technique by using economic data on the value of land. We call this the Ricardian approach, after the great English economist who explored the economic determination of land rents. In the Ricardian approach, instead of studying yields of specific crops under different controlled settings, we examine how climate in different places affects the rent or revenue from farm land. By directly measuring rents, we take into account direct impacts of climate on yields of different crops as well as the potential for substitution of different inputs, introduction of different activities, and other potential adaptations to different climates. For example, by changing seed, irrigation, harvest length, or fertilizer, a farmer might adjust to changes in climate in ways that crop-yield models may fail to measure. If markets are functioning properly, the Ricardian approach will allow us to measure the economic value of different activities and therefore to verify whether the economic impacts implied by the crop yield experiments in the production-function approach are reproduced in the field.

The results of the Ricardian approach can be seen in Figure 1. We assume that the "value" measured along the vertical axis is the net yield per acre of land; more precisely, it is the value of output less the value of all inputs (excluding land rents). Under competitive markets, the land rent will be equal to the net yield of the highest and best use of the land. This rent will in fact be equal to the heavy solid line in Figure 1. We label the solid line in Figure 1 the "best-use value function."

In general, we do not observe market land rents, for most land is owner-occupied; moreover, the land rent is generally a small component of the total rent, which includes also the rent on capital items. We can, however, observe farm-land prices, which in competitive markets will be equal to the present value of the land rents. If the interest rate and rate of capital gains on the lands are equal for all parcels, then the land price will be proportional to the land rent. Therefore, by observing the relationship of land prices to climatic and other variables, we can infer the shape of the solid, best-use value function in Figure 1.

The Ricardian approach used here is closely related to hedonic property and wage studies which attempt to measure the non-monetary components of market decisions such as purchases of houses and cars or choices of jobs. In hedonic wage studies, the non-monetary components are due to working conditions, risk, the quality of the location, and similar factors. Hedonic studies have been conducted for a number of different purposes. Nordhaus and Tobin [1972] applied the hedonic model to wages to estimate urban disamenities in their construction of the Measure of Economic Welfare. Rosen and Thaler [1975] applied the model to valuation on human life, while Roback [1982] applied this technique to detect regional wage effects. Cropper and Arriaga-Salinas [1980] and Blomquist et al. [1988] have recently used the model to develop measures of the quality of life. The approach has also been used with land values to estimate the value of environmental goods, such as the implicit value of households of air pollution. For a general discussion, see Freeman [1979] and Pearce and Markandya [1989]. Finally, Brown and Mendelsohn [1984] and Englin and Mendelsohn [1990] use the approach on recreation trips to value the characteristics of public lands.

This study measures the impact of environmental factors on production focusing upon the effect of climatic variables on agriculture. We examine both climatic data and a variety of fundamental geographical, geophysical, agricultural, economic, and demographic factors to determine the intrinsic value of climate on farming. The unit of observation is the U. S. county in the lower 48 states, and we are fortunate that there is a wealth of data at the county level in the U. S. We examine the effect of climatic variables as well as the non-climatic variables on both land values and on farm revenue, and the analysis includes a number of urban variables in order to measure the potential effect of development upon agriculture land values. The analysis suggests that climate has a systematic impact on agricultural rents through temperature and precipitation. These effects tend to be highly nonlinear and vary dramatically by season. The paper concludes with a discussion of optimal climates and the broader implications of the results.

II. MEASURING THE EFFECT OF ENVIRONMENT ON PRODUCTION

This section develops the analytical apparatus that underlies the valuation of climate in this study. We postulate a set of consumers with well behaved utility functions and linear budget constraints. Assuming that consumers maximize their utility functions across available purchases and aggregating leads to a system of inverse demand functions for all goods and service:

$$
\begin{array}{ll}
 & P_1 = D^{-1}(Q_1,\ Q_2, \dots,\ Q_n,\ Y) \\
 & \quad\ \ \cdot \qquad\qquad \cdot \\
(1) & \quad\ \ \cdot \qquad\qquad \cdot \\
 & \quad\ \ \cdot \qquad\qquad \cdot \\
 & P_n = D^{-1}(Q_1,\ Q_2, \dots,\ Q_n,\ Y) \qquad ,
\end{array}
$$

where P_i and Q_i are respectively the price and quantity of good i, i=1,..,n, and Y is aggregate income. The Slutsky equation is assumed to apply, so that (1) is integrable.

We also assume that a set of well-behaved production functions exist which link purchased inputs and environmental inputs into the production of outputs by a firm on a certain site:

$$(2) \qquad Q_i = Q_i(\mathbf{K}_i,\ \mathbf{E}),\ i = 1,..,n.$$

In this equation, we use bold face to denote vectors or matrices. Q_i is the output of good i, $\mathbf{K}_i = [K_{i1}, .., K_{ij}, .., K_{iJ}]$ where K_{ij} is the purchased input j (j= 1,..., J) in the production of good i, and $\mathbf{E} = [E_1, .., E_l, .., E_L]$ where E_l is the exogenous environmental input l (l=1,..., L) into the production of goods, e.g., climate, soil quality, air quality and water quality, which would be the same for different goods' production on a certain production site. Given a set of factor prices, R_j, for K_j , the exogenously determined level of environmental inputs, and the production function, cost minimization leads to a cost function:

$$(3) \qquad C_i = C_i(Q_i, \mathbf{R}, \mathbf{E}).$$

Here, C_i is the cost of production of good i, $\mathbf{R} = [R_1, \ldots, R_J]$, and $C_i(*)$ is the cost function. Firms are assumed to maximize profits given market prices:

$$(4) \qquad \underset{Q_i}{\text{Max}} \quad P_i Q_i - C_i(Q_i, \mathbf{R}, \mathbf{E}) \ ,$$

where P_i is the price of good i. This maximization leads firms to equate prices and marginal cost. Differentiating (4) with respect to any purchased factor and setting the result to zero also reveals the first-order conditions pertaining to each factor used in production:

$$(5) \qquad P_i \, \partial Q_i(\mathbf{K}_i, \mathbf{E})/\partial K_{ij} - R_j = 0 \quad .$$

Next consider the impact of changes in the exogenous environmental variables. Assume that the environmental change is from initial point $\mathbf{E}_A$ to new point $\mathbf{E}_B$. The change in value from changes in the environment are then given by:

$$(6) \ V(\mathbf{E}_A - \mathbf{E}_B) = \int_0^{\mathbf{Q}_B} \Sigma \, D^{-1}(Q_i) dQ_i - \Sigma \, C_i(Q_i, \mathbf{R}, \mathbf{E}_B) - \left[\int_0^{\mathbf{Q}_A} \Sigma \, D_{-1}(Q_i) dQ_i - \Sigma \, C_i(Q_i, \mathbf{R}, \mathbf{E}_A) \right]$$

where $\int\Sigma$ is the line integral evaluated between the initial vector of quantities and the zero vector, $\mathbf{Q}_A = [Q_1(\mathbf{K}_1, \mathbf{E}_A), \ldots, Q_i(\mathbf{K}_i, \mathbf{E}_A), \ldots, Q_n(\mathbf{K}_n, \mathbf{E}_A)]$, $\mathbf{Q}_B = [Q_1(\mathbf{K}_1, \mathbf{E}_B), \ldots, Q_i(\mathbf{K}_i, \mathbf{E}_B), \ldots, Q_n(\mathbf{K}_n, \mathbf{E}_B)]$, $C_i(Q_i, \mathbf{R}, \mathbf{E}_A) = C_i(Q_i(\mathbf{K}_i, \mathbf{E}_A), \mathbf{R}, \mathbf{E}_A)$, and $C_i(Q_i, \mathbf{R}, \mathbf{E}_B) = C_i(Q_i(\mathbf{K}_i, \mathbf{E}_B), \mathbf{R}, \mathbf{E}_B)$. It is necessary to take this line integral as long as the environmental change affects more than one output. If only one output is affected, then (6) simplifies to the integral of the equations for a single good. Note that as long as the Slutsky equation is satisfied, the solution to (6) is path-independent and unique.

The damages in (6) can be decomposed into two parts. On the one hand, costs have changed for the production of good i from $C_i(Q_i, \mathbf{E}_A)$ to $C_i(Q_i, \mathbf{E}_B)$. Second, production has changed from $\mathbf{Q}_A$ to $\mathbf{Q}_B$. The value of the lost production is the difference between the consumer surplus under the demand function and the original cost of production (see Figure 2).

The present study investigates the impact of environmental changes through their impact upon a particular factor, land. We now explicitly separate land out from the firm's profit function in (4):

$$(7) \qquad \max_{Q_i} \quad P_iQ_i - C_i(Q_i, \mathbf{R}, \mathbf{E}) - p_{LE}\, L_i,$$

where L_i is the amount of land used to produce Q_i, and P_{LE} is the annual rent per unit of land given the environment $\mathbf{E}$. We assume that there is perfect competition for land, which implies that entry and exit will drive pure profits to zero:

$$(8) \qquad P_iQ_i - C_i(Q_i, \mathbf{R}, \mathbf{E}) - p_{LE}\, L_i = 0 \quad .$$

If use i is the best use for the land given the environment $\mathbf{E}$ and factor prices $\mathbf{R}$, the observed market rent on the land will be equal to the annual net profits from production of good i.[2]

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[2] With imperfect competition, it is possible that a farmer could pay only as much as the next highest bidder for land and that this land payment would then be less than the productivity in the best use of the land. In addition, if the land is not put to the

Let us now reexamine the measure of environmental damages with this explicit land market. If we are examining changes in the environment which will leave market prices unchanged, then (6) can be expressed:

$$(9) \qquad V(\mathbf{E}_A-\mathbf{E}_B)= \mathbf{P}\ Q_B - \Sigma\ C_i(Q_i,\ \mathbf{R},\ \mathbf{E}_B) - [\mathbf{P}\ Q_A - \Sigma\ C_i(Q_i,\ \mathbf{R},\ \mathbf{E}_A)].$$

where $\mathbf{P} = [P_1,..,\ P_i,..,\ P_n]$. Substituting (8) into the above yields:

$$(10) \qquad V(\mathbf{E}_A-\mathbf{E}_B) = \sum_i (P_{LEB} - P_{LEA})\ L_i \quad .$$

where P_{LEA} is P_{LE} at $\mathbf{E}_A$ and P_{LEB} is P_{LE} at $\mathbf{E}_B$. Equation (10) is the definition of the Ricardian estimate of the value of environmental changes. Under the assumptions used here, the value of the change in the environmental value is captured exactly by the change in land rent.

Note that all of the valuation expressions listed above implicitly assume that firms adjust their market inputs in order to adapt to the changing environment. It is important to recognize, however, that the measure of environmental damage incorporates this adaptive behavior. Rewriting (9):

$$(11) \qquad V(\mathbf{E}_A-\mathbf{E}_B)= \sum_i P_i\ Q_i(\mathbf{K}_{iB},\ \mathbf{E}_B) - \sum_i \mathbf{R}\ \mathbf{K}_{iB} - \left[\sum_i P_i\ Q_i(\mathbf{K}_{iA},\ \mathbf{E}_A) - \sum_i \mathbf{R}\ K_{iA}\right].$$

As $\mathbf{E}$ deteriorates from $\mathbf{E}_A$ to $\mathbf{E}_B$, one would expect that farmers would adjust their purchases of $\mathbf{K}$ from $\mathbf{K}_{iA}$ to $\mathbf{K}_{iB}$ to reduce some of the losses, although the exact form of the adaptation will

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best use, the land payment may exceed the net productivity of the land.

generally be extremely complex. If one fails to incorporate these adjustments by firms and instead assumes that $\mathbf{K}$ is fixed, then (11) becomes:

$$(12) \quad V(\mathbf{E}_A-\mathbf{E}_B)= \sum_i P_i \; [Q_i(\mathbf{K}_{iA}, \mathbf{E}_B) - Q_i(\mathbf{K}_{iA}, \mathbf{E}_A)] \quad .$$

This latter measure uses changes in gross revenues as a measure of environmental damage; it is closely related to the production-function approach, in which limited or no adaptation occurs. Scientific experiments where all factors are tightly controlled except for an environmental change use measure (12).

The Ricardian measure in (10), which includes all optimizing adaptations, is superior to the gross revenue or production-function estimate in (12) because the former includes all adaptations. An important result, however, is that the Ricardian measure in (10) will always yield an estimate of environmental damage which is less than or equal to the estimate generated by the production-function approach in (12). This results is easily seen. The profits from adjusting all inputs and outputs optimally are clearly at least as great as the profits from not adjusting inputs or outputs at all or adjusting them incompletely. The former approach provides the estimate of the loss from the Ricardian approach while the later provides the loss from the production-function approach.

The impact of an environmental change on decisions is easily seen when there is only one input K and one environmental factor E in the production function of one good, Q=(K, E). Fully differentiating the first-order condition of profit maximization (5) with respect to E and K and simplifying yields:

$$dK/dE = - Q_{KE} \; / \; Q_{KK} \quad .$$

The optimal response by the firm to improvements in E will be to increase K if $Q_{KE} > 0$ and $Q_{KK} < 0$. For example, if reduced concentrations of ozone make corn respond more positively to fertilizer $Q_{KE}>0$, then farmers would increase fertilizer use with decreased ozone. If increased carbon dioxide decreases a plant's need for water and the marginal productivity of water $Q_{KE}<0$, then with more CO_2 farmers will reduce irrigation. The profit function described by (4) indicate adjustments of K with changes in E. If K is not permitted to adjust, the resulting profits for each level of production must be lower so that net societal benefits must be lower. Estimates that do not allow for adjustments in purchases of market inputs, for example by measuring just changes in revenue, underestimate the value of environmental improvements (or overestimate the value of environmental damages).

III. AN APPLICATION OF THE RICARDIAN TECHNIQUE TO AGRICULTURE

In this section, we apply the Ricardian technique by estimating the value of climate in U. S. agriculture. Agriculture is the most appealing application of the technique both because of the significant impact of climate on agricultural productivity and because of the extensive county-level data on farm inputs and outputs. As mentioned in the introduction, there is a vast literature on the impact of climate and weather on agriculture. All studies we have uncovered use the production-function approach, in which the physical impact of climate on crop yields is examined through statistical analysis or through experiments. Although this approach has great value for many purposes, it is unable to take account of the multitude of adaptations that individual farmers already make to different climates. As a complementary approach, we pursue the Ricardian approach outlined above as an independent way of investigating the impact of climate change.

Sources and methods[3]

The basic hypothesis is that climate affects the production function for crops. Farmers on particular units of land must take environmental variables like climate as given and adjust their inputs and outputs accordingly. By examining the rents that land earns across different environments, we can measure the direct effect of climate on rents. This approach makes a number of simplifying assumptions. We assume that prices are fixed across the sample. Moreover, we assume perfect competition in both product and input markets, which is probably tenable here. Most important, we assume that the economy has completely adapted to the given climate; that is, we assume that the observed land prices have attained the long-run equilibrium that is associated with each county's climate. To the extent that there are short-run distortions, affecting either the discount rate on land rents or the relative prices within the agricultural sector or between agriculture and the rest of the economy, the observed rents and estimated climatic values may not accurately represent the longer-run values and impacts.

We rely on data from the 1982 U. S. Census of Agriculture to obtain much of the data on farm characteristics in each county. For the most part, the data are actual county averages, so that there are no major geographic issues involved in obtaining information on these variables. The County and City Data Book, and the computer tapes of that data, are the source for much of the agricultural data used here, including values of farm products sold per acre, farm land and building values,[4] and

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[3] Appendix A contains a complete description and definition of the variables used in this study.

[4] The definition and source of the farm value variable is critical to this study and its derivation is described in Appendix B.

information on market inputs for farms in every county in the United States. In addition, in many of the equations, we include social, demographic, and economic data on each of the counties; these as well are drawn from the County and City Data Book.

The rest of the data required much more effort. Data about soils were extracted from the National Resource Inventory (NRI) with the kind assistance of Drs. Daniel Hellerstein and Noel Gollehon of the U. S. Department of Agriculture. The NRI is an extensive survey of land characteristics in the United States. For each county, NRI has collected several soil samples, each providing a measure of salinity, clay content, sand content, flood probability, soil erosion (K factor), rain erosion (R factor), slope length, wind erosion, whether or not the land is a wetland, and numerous other variables that are not used in this analysis. Each sample also contains an expansion factor, which is an estimate of the amount of land the sample represents in that county. Using these expansion factors, we average this data to yield an overall county estimate for each soil variable.

Climatic data is available by station rather than by county, so it was necessary to estimate county-average climates. To begin with, climate data was obtained from the National Climatic Data Center, which gathers data from 5511 meteorological stations throughout the United States. The data include information on precipitation and temperature for each month from 1951 through 1980. Since the purpose of this study is to predict the impacts of climate changes on agriculture, we focus on the long-run impacts of precipitation and temperature on agriculture, not year-to-year variations in weather. We consequently examine the climatological normal variables -- the 30-year average of each climatic variable for every station. In this analysis, we collect data on normal daily mean temperatures and normal monthly precipitations for January, April, July, and October. We focus on these four months in order to capture seasonal effects of each variable. For example, cold January temperatures may be important as a control on insect pests, warm but not hot summers may be good for crop growth, and warm October temperatures may assist in crop harvesting.

In order to link the agricultural data which is organized by county and the climate data which is organized by station, we conducted a spatial statistical analysis which examines the determinants of the climate of each county. Although the specific climatic variables we analyze in this study have been measured frequently, there are some counties with no weather stations and others with several. Some of the weather stations are not in representative locations, such as the station on the top of Mt. Washington. Furthermore, some counties are large enough or contain sufficient topographical complexity that there is variation of climate within the county. We therefore proceeded by constructing an average climate for each county.

First, we assume that all the weather stations within 500 miles of the geographic center of the county provide some useful climate information. The 500-mile circle invariably draws in many stations, so that our measure does not depend too heavily on any one station.

Second, we estimate a climate surface in the vicinity of the county by running a weighted regression across all weather stations within 500 miles. The weight is the inverse of the square root of a station's distance from the county center since we recognize that closer stations contain more information about the climate of the center. We must estimate a separate regression for each county since the set of stations within 500 miles and the weights (distances) are unique for each county. The dependent variables are the monthly normal temperatures and precipitations for January, April, July, and October. The independent variables include latitude, longitude, altitude, and distance from closest shoreline. The regression fits a second-order polynomial over these four basic variables, including interactive terms, so that there are 14 final variables in the regression, plus a constant term. Eight regressions (4 seasons times 2 measures) for each county given 3000 counties leads to over 24,000 estimated regressions.

Third, we calculate the predicted value of each climatic variable for the geographic center of the county. The predicted values of normal precipitation and temperature from the climate regressions are the independent variables for climate in the property value regressions. This complicated procedure is intended to provide accurate estimates of the climatic variables for each county.

Empirical Results

We now discuss the empirical results of this analysis. We begin with the results for the climate parameters. Figure 3 shows the temperature stations while Figure 4 shows the precipitation stations used to construct the individual climates of each county. As can be seen, these form a dense set of stations for most regions of the United States with the exception of some of the desert Southwest.

The estimates of the climate parameters for individual counties are too numerous to present, but we show two selected counties in Tables 1-A and 1-B. These show the independent variables as well as the coefficients and summary regression statistics for Fresno, California and Des Moines, Iowa. Note that more coefficients are significant in the Fresno than the Des Moines regressions. There is more variation across the sample in Fresno because of the effects of the coast and nearby mountain ranges. Although there are more significant coefficients in the California regression, the Iowa regression has a better overall fit and smaller standard errors. In general, the fit east of 100 degrees longitude (the east slope of the Rocky Mountains) was tighter than in the West. By and large the equations do very well in predicting monthly temperature and vary from precise to somewhat less satisfactory for the noisy precipitation variable.

In order to gain some sense of the reliability of this geographic approximation method, we predicted the climate for each of the weather stations. Dropping the weather station itself, we predicted the climatic variables for the station from all stations within 500 miles in the manner explained above. Comparing these results with the actual measurements from each station reveals that the approximation method predicts between 87% and 97% of the variation in precipitation in the continental United States and between 97% and 99% of the variation in temperature. It should be noted that, even in a statistically stationary environment, the observations of "climate" themselves contain error because they contain only 30 observations. Depending upon the relative importance of idiosyncratic error in climate vs. misspecification error in our equation, it might well be that the predictions are actually a superior estimate of the local climate than are the recorded observations themselves.

Combining the agricultural and climatic data, we wish to predict agricultural land values. Land values are the present value of future expected rents. There is little reason for the riskless interest rate to vary across counties in the U. S., but the risk and capital-gains components of land value might vary considerably. For example, California agricultural land near growing cities might well have a larger capital-gains component than would rural land far from cities in an economically stagnant coal-mining region of Appalachia. Moreover, there are major potential errors in measurement of land values since values are estimated by farmers, and such estimates are often unreliable. However, there is no reason to believe that the errors of measurement are correlated with independent data such as temperature or precipitation. The major effect of measurement errors will be imprecision of the econometric estimates rather than bias in the estimation of the coefficients or an ultimate bias in the estimate of the economic value of climate on agriculture.

The next and crucial stage is to use the climate data in the estimates of economic value. The geographic distribution of farm value per acre is shown in Figure 5 and of farm revenues per acre in Figure 6. Both variables are measured in 1982. The unit of observation is the county. We use estimated climatic variables along with soil variables and socioeconomic data to estimate the best-value function across different counties. Table 2 shows the crucial regressions for the second stage. There are 2933 observations.

In order to give a sense of the importance of the non-farm variables in the model, we begin with a model which contains only climate variables. The first set of regressions in Table 2 is a quadratic model which includes the eight measures of climate (four months of precipitation and temperature). For each variable a linear and quadratic term are included. This flexible functional form can reflect the nonlinearities that are apparent from field studies; the nonlinear terms introduce an appreciably better set of estimates.

In the second set of regressions, we add the balance of the urban, soil and other environmental variables to include other factors influencing land values and farm revenues. In these equations, we attempt to control for the influence that urban development and soils will have upon land values. As proxies for urban development, we include population density, net migration, and per capita income. Soil characteristics are measured using the percent of the land which is flood-prone, the percent of the land which is wetland, estimated potential for soil erosion, the salinity of the soils, whether soils are sandy or clay, and the slope length of the land. Other environmental factors included are solar energy, which is proxied by latitude, and altitude.

The full regression controls for urban development and soils with the additional included variables. The full specification is therefore more appropriate for estimating the impact of climate on farming, particularly if the omitted variables are spuriously correlated with land values. On the other hand, the more limited quadratic regression may be doing a better job of capturing the entire spectrum of the land rent function by endogenously incorporating non-farm land uses and allowing for the value of land in non-farm uses.

The results of this analysis are shown in Table 2. The squared terms for most of the climate variables are significant implying the observed relationships are nonlinear. However, the squared terms are not all negative as expected. Some of the squared terms are positive, especially for precipitation. The positive coefficient on the squared term implies that the function has a minimum value from which it increases in both directions. The expected negative coefficient implies that there is an optimal value from which the value function decreases in both directions.

The marginal effect of changes in climate on agricultural values show the estimated impact on agricultural values of a one-degree or one-inch-per month increase in the climatic normals; those depend upon the season and the evaluating point. The marginal value for each variable evaluated at the national mean is presented in Table 3. For example, the full regression in Table 2 predicts that a one degree increase in monthly January temperature would reduce farm value by $86 per acre but a one degree increase in October temperature would increase farm values by $165 per acre.

In the quadratic model, warmer temperatures reduce farm values in all seasons except autumn. Wetter months increase farm values in winter and spring but not in summer and autumn. Adding the socioeconomic and environmental controls alters the seasonal patterns for farm values described above. Increasing temperatures in April are now beneficial and the benefits of warmer autumns are still present but reduced in half. Overall, annual increases in temperature are more harmful. The effect of precipitation on farm value changes so that summer rains are now unimportant and autumn rains are more harmful. The net effect of including controls is to reduce the benefits of an increase in annual precipitation.

Because marginal effects differ across seasons, overall annual effects will vary depending upon their seasonal distribution. One scenario is for a uniform change across all seasons. In this case, with the quadratic model, a one degree F increase in temperature results in a $10 decrease in farm value per acre. With the full model, a one degree F warming lowers average farm values by $62 per acre. An annual increase of one inch of precipitation spread uniformly across all seasons, according to the quadratic model, would increase property values by $39 per acre. Including control variables changes the net precipitation effect to an increase of only $27 per acre.

Without the full set of control variables, temperature changes have relatively little impact on farm value as compared to precipitation. When the non-farm controls are added, the losses from higher temperatures become from five to seven times as large, whereas the gain from increased precipitation is reduced by almost a third. One interpretation of these results is that the control variables eliminate both the potential for non-farm adaptation and the role of potentially spurious non-farm influences which are spatially correlated with climate. These non-farm influences place a higher value on warmer temperatures (the South) and wetter settings (the Coast), thus lowering the estimated damages from temperature but raising the gains from rains. By controlling these unwanted effects, the full model may more accurately describe the impacts on agriculture; at the same time, the equations without controls may capture non-agricultural adjustments of the kind illustrated in Figure 1.

The control variables in Table 2 provide a rich set of results in and of themselves. It is clear that economic variables play a role in determining both the value of farms and their current annual gross revenues. Farm values are higher in denser, growing, and wealthier counties presumably because of higher local demand for food and the potential for conversion of land to non-farm uses. Farm values also respond as expected to other environmental factors such as solar flux (latitude) and altitude. Salinity, likelihood of flooding, wetlands and soil erosion all act negatively as expected. Irrigation increases the value of land by a substantial amount according to the model; this is not surprising given the importance of irrigation in many areas in the arid West. Slope length was slightly beneficial to land values but reduced farm revenues; long gradual slopes apparently have mixed effects.

Table 4 shows the estimated best and worst climate parameters according to the full model in Table 2. In these, we simply solve for the extremum of the quadratic function in temperature and precipitation. These results have relatively low reliability because of a variety of specification errors and the potential for dependence of some of the independent variables (such as salinity) on climatic variables. Nevertheless, they provide some interesting information especially concerning January and October. The optimal January temperature is <u>colder</u> than the average U. S. temperature by a significant margin, reflecting the value of cold weather in killing pests. Second, January rain is clearly beneficial, perhaps because it contributes to soil moisture without requiring clouds during the growing season. The farm value column of Table 4 also reveals the value of a warm dry October, shown by the optimal precipitation being zero and the minimum temperature being a cool 40 degrees.

One hypothesis suggested in the theory section is that the impacts of environmental effects would be exaggerated by a gross revenue model. We explore this hypothesis in Tables 2 and 3 by regressing the same climate and control variables on crop gross revenue. The marginal effects in Table 3 for the farm revenue model suggest similar seasonal patterns as the farm value equation except that April rain and warmth is clearly bad in the gross revenue equation. The net effect of either an additional degree F or an additional inch of rain using the full model is $7/year of reduced revenue. Assuming a 5% real interest rate, these annual effects suggest a loss in present value of $140/acre. In contrast, the property value study suggests only a $62 loss for warmer temperatures and a $27 gain for more precipitation.

One concern with the Ricardian approach to climate effects is that the results may not be robust over time but rather the result of a special condition of the year estimated. We consequently estimate the model again using data from 1978. These values have been converted to 1982 dollars using the GNP deflator obtained from the 1991 Economic Report of the President. The 1978 results are surprisingly similar to the findings using the 1982 data. The control variables have similar impacts in both years. The climate coefficients also have similar signs in both 1978 and 1982. Evaluating the marginal effects of climate in 1978 at the national mean and comparing the results with 1982 shows that the climate variables for each season are larger in

1978 than in 1982. For example, October rains are more damaging and other season rains are more beneficial in 1978. These differences cancel out so that the annual marginal precipitation effects are almost identical in 1978 and 1982. The marginal temperature effects in each season are also larger in 1978 than in 1982 but, in this case, annual impacts are also larger in 1978. The pattern of climate effects on agriculture is stable over time but apparently some factors can alter the magnitude of the effects from year to year.

The predicted overall effects from the existing climate across the United States are shown in Figures 7 through 10. Figures 7 and 8 are probably the most important summary of the results. These maps show the Ricardian values of climate by county in 1978 and 1982. To construct each map, we begin with the difference between the estimated climate for each county and the national average climate. We then multiply this climatic difference variable times the estimated coefficients for each climatic variables in Table 2. Figures 7 and 8 then show the estimated contribution of climate to the farm land value in each county. The results are both surprising and interesting.

Beginning with the economic "hot spots," we see that there are areas of high value along the northwestern coastal region--basically due to the moist and temperate climates in these regions. In addition, the grain belt west of Chicago shows up as a hot spot of high Ricardian climate values. The other area that stands out is the area of low climatic values along the southwest border regions. (Note that these estimates use the national average irrigation rather than actual irrigation values.) For the most part these have little agriculture, although irrigation raises production and farm revenues considerably as can be seen in Figure 6. Figure 8 represents the identical map as Figure 7 except that the analysis is based on 1978 data. Both models show almost identical geographic patterns. It would appear from this comparison that the results are quite stable.

Figures 9 and 10 separate out the Ricardian values of precipitation and temperature on farm values for 1982. The precipitation effect is quite revealing. There are significant positive effects of precipitation along the northwest coast and along the Gulf of Mexico coast. Negative effects are found roughly west of the 100th meridian and very strongly in the desert southwest.

The temperature effect is strongly positive in the midwest, with its combination of warm but not hot summers and cold winters. Negative effects of hot temperature are not surprisingly found along the southern border region, particularly in the southwest. Apparently, one must move significantly north into Canada before corresponding negative cold effects can be seen on the map.

IV. **CONCLUSION**

In this study, we examine the impact of climate on economic activity focussing on the agricultural sector. According to economic theory, the economic value of site-specific characteristics will be reflected in the land rents and will be discounted in land values of the site. We denote the effects on land rents as being Ricardian to capture the mechanism by which land markets capture the economic value of climate and other variables. More generally, in the presence of a competitive land market, differences in rents or land value across space and time can serve as an accurate measure of environmental impacts.

The use of the Ricardian technique allows an entirely different approach to the evaluation of the impact of climate and climate change from conventional techniques. Relying on land rents and values has the important advantage of incorporating the effects of adaptation in the economy--changes in techniques of production or the output mix by firms. By contrast, conventional estimates that rely upon changes in yield or output--an approach we call the "production-function approach"-- will tend to overestimate environmental damages.

This new methodology is applied to measure the effect of climate on agriculture. Examining counties across the United States, the effects of temperature, precipitation and other factors on farm value and farm revenue are estimated. Climate and especially temperature clearly affect agriculture revenues and land values. Warming is generally harmful to farm values except in the fall where it helps with drying and harvesting crops. However, this fall effect is quantitatively extremely large, so it may actually offset the damaging effects of warming in other seasons. Additional precipitation is generally beneficial to farms, again except in the fall and possibly in summer where it may be associated with low levels of sunshine. Interestingly, we find that precipitation in winter is just as valuable as the legendary spring rains.

The study is of interest for understanding the impact of climate on agriculture as well as the extent to which different approaches can overstate the impacts of climate change or underestimate the force of adaptation. In addition, the analysis can provide alternative estimates of the impacts of global warming upon American agriculture. The precise impact of global warming on agriculture is a topic that will be pursued in detail in future research.

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Appendix A. Definition of Major Variables Used in This Study

VARIABLE DEFINITION

CONSTANT - a term equal to one.

JANUARY TEMP- Normal daily mean temperature from 1951-1980 in the month of January, Fahrenheit

JAN TEMP SQ - JANUARY TEMP squared

APRIL TEMP - Normal daily mean temperature from 1951-1980 in the month of April, Fahrenheit

APR TEMP SQ- APRIL TEMP squared

JULY TEMP- Normal daily mean temperature from 1951-1980 in the month of July, Fahrenheit

JULY TEMP SQ- JULY TEMP squared

OCTOBER TEMP- Normal daily mean temperature from 1951-1980 in the month of October, Fahrenheit

OCT TEMP SQ - OCTOBER TEMP squared

JANUARY RAIN- Normal precipitation from 1951-1980 in the month of January, inches

JAN RAIN SQ - JANUARY RAIN squared

APRIL RAIN - Normal precipitation from 1951-1980 in the month of April, inches

APR RAIN SQ- APRIL RAIN squared

JULY RAIN - Normal precipitation from 1951-1980 in the month of July, inches

JULY RAIN SQ - JULY RAIN squared

OCTOBER RAIN - Normal precipitation from 1951-1980 in the month of October, inches

OCT RAIN SQ - OCTOBER RAIN squared

INCOME PER CAPITA- annual personal income per person in the county, 1984

DENSITY- resident population per square mile, 1980

DENSITY SQ- DENSITY squared

LATITUDE- latitude measured in degrees from southern most point in U. S.

ALTITUDE - height from sea level in feet

MIGRATION- net of incoming people minus outgoing people from 1980 to 1986 for the county

SALINITY- percent of land which needs special treatment because of salt/alkaline in the soils

FLOOD PRONE- percent of land which is prone to flooding

IRRIGATED- percent of land where irrigation provides at least 50% of water needs

WETLAND- percent of land considered wetland

SOIL EROSION- K factor-soil erodibility factor in hundredths of inches

SLOPE LENGTH- number of feet length of slope (not steepness)

WIND EROSION- measure of wind erosion in hundredths of inches

FARM VALUE- estimate of the current market value of farm land including buildings for the county expressed in dollars per acre, 1982

FARM REVENUE- gross revenue from crops sold in 1982 for the county in dollars per acre

Appendix B. Data on farms and value of land and buildings[5]

The data on farms and on farm land values is central to this study. This appendix describes the definition and sources of the data. The current definition of a farm, first used for the 1974 Census of Agriculture final reports, is any place from which $1,000 or more of agricultural products were sold or normally would have been sold during the census year.

Land in farms is an operating-unit concept and includes land owned and operated as well as land rented from others. The acreage designated as "land in farms" consists primarily of agricultural land used for crops, pasture, or grazing. It also includes woodland and wasteland not actually under cultivation or used for pasture or grazing, provided it was part of the farm operator's total operation.

The land is defined to lie in the operator's principal county, that is, the county where the largest value of agricultural products was raised or produced. Irrigated land includes land watered by any artificial or controlled means, such as sprinklers, furrows or ditches, and spreader dikes. Cropland includes land from which crops were harvested or hay was cut, land in orchards, citrus groves, vineyards, nurseries, and greenhouses, land used only for pasture or grazing that could have been used for crops without additional improvement, and all land planted in crops that were grazed before the crops reached maturity. Also included were all cropland used for rotation pasture and land in government diversion programs that were pastured.

Respondents were asked to report their estimate of the current market value of land and buildings owned, rented, or leased from others, and rented or leased to others. Market value

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[5] This description is drawn from the <u>City and County Data Book</u>, and the underlying data is from U.S. Bureau of the Census, <u>1982 Census of Agriculture</u>.

refers to the respondent's estimate of what the land and buildings would sell for under current market conditions. If the value of land and buildings was not reported, it was estimated during processing by using the average value of land and buildings from a similar farm in the same geographic area.

The value of products sold by farms represents the gross market value before taxes and production expenses of all agricultural products sold or removed from the place regardless of who received the payment. In addition, it includes the loan value received in 1982 for placing commodities in the Commodity Credit Corporation loan program.

TABLE 1-A

INTERPOLATING COUNTY CLIMATE MEASURES (FRESNO, CA)

	TEMPERATURE			PRECIPITATION		
	APRIL	JULY	OCTOBER	APRIL	JULY	OCTOBER
CONSTANT	131535	231764	124970	-58846	-184063*	16551
LONGITUDE	-32.8*	-59.6*	-29.2	26.7	45.2*	1.96
LATITUDE	-13.2	-18.2	-16.8	-19.6	21.7*	-16.33
LAT SQ	1.9E-4	2.8E-4	4.1E-4	1.6E-3	-3.1E-4	1.6E-3*
LONG SQ	2.0E-3*	3.8E-3*	1.7E-3	-2.3E-3	-2.7E-3*	-3.9E-4
LONG*LAT	1.8E-3	2.8E-3	2.1E-3	1.5E-3	-2.9E-3*	1.1E-3
ALTITUDE	-.56*	-1.44*	-1.00*	.525	1.28*	1.48*
ALT SQ	-1.6E-6*	-3.0E-6*	-2.3E-6*	-3.7E-6*	-6.5E-7*	-2.4E-6*
LAT*ALT	4.3E-5	8.8E-5	7.7E-5*	-4.8E-5	-1.1E-4*	-1.1E-4*
LONG*ALT	6.2E-5	1.8E-4*	1.1E-4*	-4.6E-5	-1.5E-4*	-1.7E-4*
SHORE DIST	-40.4*	-74.5*	-35.2	-5.47	59.4*	-26.6
SDIST SQ	2.6E-3	4.2E-3	2.2E-3	2.9E-3	-4.9E-3*	4.8E-3*
SDIST*LONG	5.2E-3*	9.6E-3*	4.2E-3	-1.3E-3	-6.7E-3*	2.6E-3
SDIST*LAT	2.0E-3	3.7E-3	2.3E-3	4.3E-3	-4.9E-3*	2.7E-3
SDIST*ALT	6.7E-5	1.3E-4	9.7E-5*	-1.9E-4	-7.0E-5*	-2.3E-4*
ADJ R^2	.999	.998	.999	.796	.777	.706
STD ERR	.13	.24	.13	.54	.13	.30
OBSERVATIONS	331	331	331	525	525	525

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[a] Variables marked with an asterisk are significant at the 5% level. Temperature is measured in Fahrenheit and precipitation in inches per month.

TABLE 1-B

INTERPOLATING COUNTY CLIMATE MEASURES (DES MOINES,IOWA)

	TEMPERATURE			PRECIPITATION		
	APRIL	JULY	OCTOBER	APRIL	JULY	OCTOBER
CONSTANT	6425	5006	8967	-32243	77324*	41650
LONGITUDE	-.919	-1.12	-2.55	7.72	-15.8*	-9.61
LATITUDE	-2.48	-.829	-1.55	10.0	-32.9*	-16.32
LAT SQ	2.5E-4	2.0E-5	3.2E-5	-9.7E-4	3.2E-3*	1.6E-3
LONG SQ	3.7E-5	8.1E-5	2.0E-4	-4.9E-4	6.8E-4	5.9E-4
LONG*LAT	2.0E-4	1.0E-4	2.4E-4	-9.9E-4	3.8E-3*	1.8E-3
ALTITUDE	-.13	.046	.34*	.353	3.02*	2.09*
ALT SQ	-1.2E-6	-1.3E-6*	1.6E-6*	1.1E-5*	-1.5E-6	2.1E-5*
LAT*ALT	2.1E-5	-1.6E-5	-6.9E-5*	-1.2E-4	-5.7E-4*	-2.8E-4*
LONG*ALT	1.1E-5	-9.7E-6	-4.9E-5*	-3.1E-5	-3.6E-4*	-3.2E-4*
SHORE DIST	1.14	-1.17	-.564	-.150	26.8	18.6
SDIST SQ	1.8E-4	-3.1E-4	-1.9E-4	5.8E-4	-1.2E-3	1.4E-3
SDIST*LONG	-4.4E-5	1.9E-4	-1.2E-4	-4.1E-4	-2.7E-3	-1.9E-3
SDIST*LAT	-3.6E-4	2.2E-4	9.0E-5	4.2E-4	-5.4E-3*	-3.8E-3
SDIST*ALT	-2.2E-5	3.2E-5	9.9E-5*	-1.7E-4	6.9E-4*	3.6E-4*
ADJ R^2	.999	.999	.999	.989	.987	.976
STD ERR	.04	.04	.04	.14	.17	.15
OBSERVATIONS	928	928	928	1477	1477	1477

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[a] Variables marked with an asterisk are significant at the 5% level. Temperature is measured in Fahrenheit and precipitation in inches per month.

TABLE 2

REGRESSION MODELS EXPLAINING FARM VALUES AND REVENUE[a]

INDEPENDENT VARIABLES	FARM VALUE ($/ACRE)			FARM REVENUE ($/ACRE/YEAR)	
	1982	1982	1978	1982	1978
CONSTANT	-18417	-2604.9	-5358.7	377.2	-1221.2
	(4.98)	(0.79)	(1.26)	(0.46)	(1.30)
JANUARY TEMP	-36.9	-9.93	28.31	-6.19	-9.93
	(4.43)	(1.19)	(2.68)	(3.00)	(4.26)
JAN TEMP SQ	-0.31	-1.20	-2.41	-0.064	0.071
	(1.36)	(5.72)	(9.03)	(1.23)	(1.21)
APRIL TEMP	662	427.9	661.3	79.30	94.04
	(7.94)	(5.92)	(7.24)	(4.42)	(4.67)
APR TEMP SQ	-7.31	-3.83	-5.78	-0.86	-1.05
	(9.41)	(5.71)	(6.84)	(5.16)	(5.61)
JULY TEMP	393.9	169.4	432.70	-50.36	-16.58
	(3.43)	(1.76)	(3.50)	(2.11)	(0.61)
JULY TEMP SQ	-3.71	-2.12	-4.36	0.18	-0.03
	(4.91)	(3.33)	(5.35)	(1.14)	(0.15)
OCTOBER TEMP	-425.9	-405.82	-827.41	16.92	9.07
	(3.40)	(3.74)	(5.97)	(0.63)	(0.29)
OCT TEMP SQ	6.82	5.02	9.18	0.21	0.28
	(6.28)	(5.30)	(7.61)	(0.90)	(1.05)
JANUARY RAIN	102.7	28.6	15.07	42.31	41.84
	(3.10)	(0.88)	(0.36)	(5.21)	(4.52)
JAN RAIN SQ	-5.68	4.13	3.25	-3.56	-4.20
	(1.86)	(1.44)	(0.87)	(4.98)	(5.12)
APRIL RAIN	181.6	168.8	146.92	-52.84	-43.01
	(2.44)	(2.59)	(1.77)	(3.26)	(2.35)
APR RAIN SQ	-10.7	-9.16	6.15	4.42	3.49
	(1.15)	(1.11)	(0.59)	(2.16)	(1.51)
JULY RAIN	-167.7	-330.2	-223.62	-46.42	-36.18
	(3.74)	(7.42)	(3.97)	(4.19)	(2.91)
JULY RAIN SQ	19.5	45.6	34.57	7.39	6.01
	(3.43)	(8.29)	(4.98)	(5.41)	(3.92)
OCTOBER RAIN	194.9	-51.1	-176.38	-153.31	-130.48
	(2.25)	(0.64)	(1.72)	(7.75)	(5.77)
OCT RAIN SQ	-39.6	-1.1	6.70	23.41	22.30
	(2.62)	(0.08)	(0.38)	(6.89)	(5.74)
INCOME PER CAPITA		.081	0.14	2.21e-3	8.31e-3
		(17.70)	(20.45)	(1.95)	(5.38)
DENSITY		1.22	1.21	0.14	0.156
		(15.89)	(12.30)	(7.42)	(7.19)
DENSITY SQ		-1.44e-4	-9.5e-5	1.32e-5	7.49e-6
		(4.36)	(2.34)	(1.60)	(0.84)
LATITUDE		-58.8	-101.3	-12.82	-9.50
		(3.99)	(5.35)	(3.50)	(2.28)
ALTITUDE		-0.212	-0.277	-0.06	-0.061
		(7.76)	(7.87)	(8.92)	(7.90)

(continue)

MIGRATION		1.6e-3	...	1.05e-3	...
		(1.81)		(4.75)	
SALINITY		-523.9	-482.8	-72.82	-102.64
		(2.55)	(1.84)	(1.43)	(1.77)
FLOOD PRONE		-284.2	-568.2	-13.65	0.32
		(5.90)	(9.21)	(1.14)	(0.02)
IRRIGATED		600.1	478.95	198.98	201.96
		(11.99)	(7.43)	(16.97)	(14.22)
WETLAND		-246.2	-249.05	7.24	32.77
		(2.02)	(1.59)	(0.24)	(0.95)
SOIL EROSION		-797.2	-1293.9	-168.12	-123.75
		(4.24)	(5.38)	(3.60)	(2.33)
SLOPE LENGTH		15.7	26.79	-3.80	-2.69
		(2.64)	(3.47)	(2.56)	(1.59)
SAND		-209.4	-127.22	16.49	27.87
		(4.17)	(1.98)	(1.32)	(1.97)
CLAY		114.5	97.87	11.23	8.20
		(5.60)	(3.72)	(2.21)	(1.41)
ADJ R^2	.671	.782	.779	.539	.504
OBSERVATIONS	2933	2933	2939	2933	2939

[a] Observations weighted by percentage of county land covered by cropland. Values in parenthesis are t-statistics.

TABLE 3

MARGINAL EFFECTS OF CLIMATE ON AGRICULTURE[a]

TEMPERATURE ($/degree Fahrenheit)

MONTH	FARM VALUE			FARM REVENUE	
	QUADRATIC 1982	FULL 1982	FULL 1978	FULL 1982	FULL 1978
JANUARY	-56.8	-85.50	-123.57	-10.24	-5.44
	(-6.19)	(-9.64)	(-10.88)	(-4.64)	(-2.17)
APRIL	-136.1	9.58	29.88	-14.76	-20.09
	(-10.75)	(0.83)	(2.04)	(-5.11)	(-6.22)
JULY	-168.2	-151.38	-228.75	-23.05	-20.79
	(-13.12)	(-14.19)	(-16.73)	(-8.69)	(-6.90)
OCTOBER	350.6	165.42	217.82	41.12	40.77
	(19.32)	(9.46)	(9.68)	(9.46)	(8.22)
ANNUAL[b]	-10.43	-61.87	-104.62	-6.93	-5.56
	(-3.38)	(-2.46)	(-3.25)	(-1.11)	(-0.78)

PRECIPITATION ($/monthly inch)

	FARM VALUE			FARM REVENUE	
	QUADRATIC 1982	FULL 1982	FULL 1978	FULL 1982	FULL 1978
JANUARY	72.9	50.25	32.11	23.63	19.80
	(3.17)	(2.30)	(1.15)	(4.34)	(3.21)
APRIL	111.3	108.51	187.35	-23.74	-20.04
	(4.06)	(4.62)	(6.23)	(-4.07)	(-3.02)
JULY	-24.9	4.18	29.71	7.77	7.83
	(-1.81)	(0.32)	(1.76)	(2.37)	(2.11)
OCTOBER	-2.9	-56.63	-142.92	-36.31	-19.03
	(-0.12)	(-2.54)	(-4.99)	(-6.56)	(-3.01)
ANNUAL[b]	39.10	26.58	26.56	-7.16	-2.86
	(3.42)	(2.58)	(2.01)	(-2.79)	(-0.98)

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[a] Marginal effects are calculated at the U.S. mean climate. The annual effect assumes uniform changes across all four seasons. The t-statistics are in parenthesis.

TABLE 4
BEST AND WORST CLIMATES FOR AGRICULTURE

MONTH	BEST OR (WORST) TEMPERATURE (Fahrenheit) FARM VALUE 1982	FARM VALUE 1978	FARM REVENUE 1982	FARM REVENUE 1978	ACTUAL TEMPERATUREa
JANUARY	-4.1	5.86	-48.26	(69.52)	31.5
APRIL	55.8	57.17	46.03	44.98	54.6
JULY	40.0	49.59	(139.78)	-298.0	75.8
OCTOBER	(40.4)	(45.05)	(-39.80)	(-16.29)	56.9

	BEST OR (WORST) PRECIPITATION (inches/month) FARM VALUE 1982	FARM VALUE 1978	FARM REVENUE 1982	FARM REVENUE 1978	ACTUAL PRECIPITATIONa
JANUARY	(0)	(0)	5.94	4.98	2.6
APRIL	9.21	(0)	(5.98)	(6.16)	3.3
JULY	(3.62)	(3.23)	(3.14)	(3.01)	3.7
OCTOBER	0	(13.17)	(3.27)	(2.92)	2.5

a. The actual temperature and precipitation measure the U.S. average value. Values in parentheses report worst levels.

Figure 1
Bias in Production Function Studies

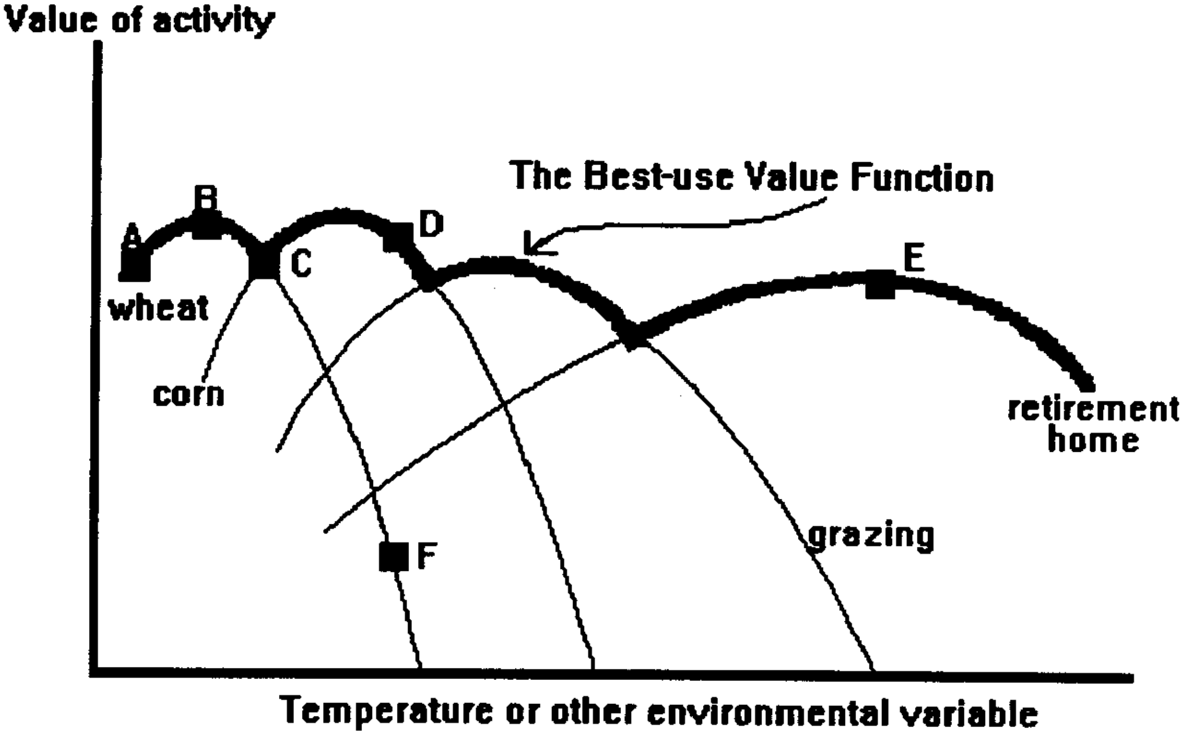

Figure 2

The Effects of an Environmental Change

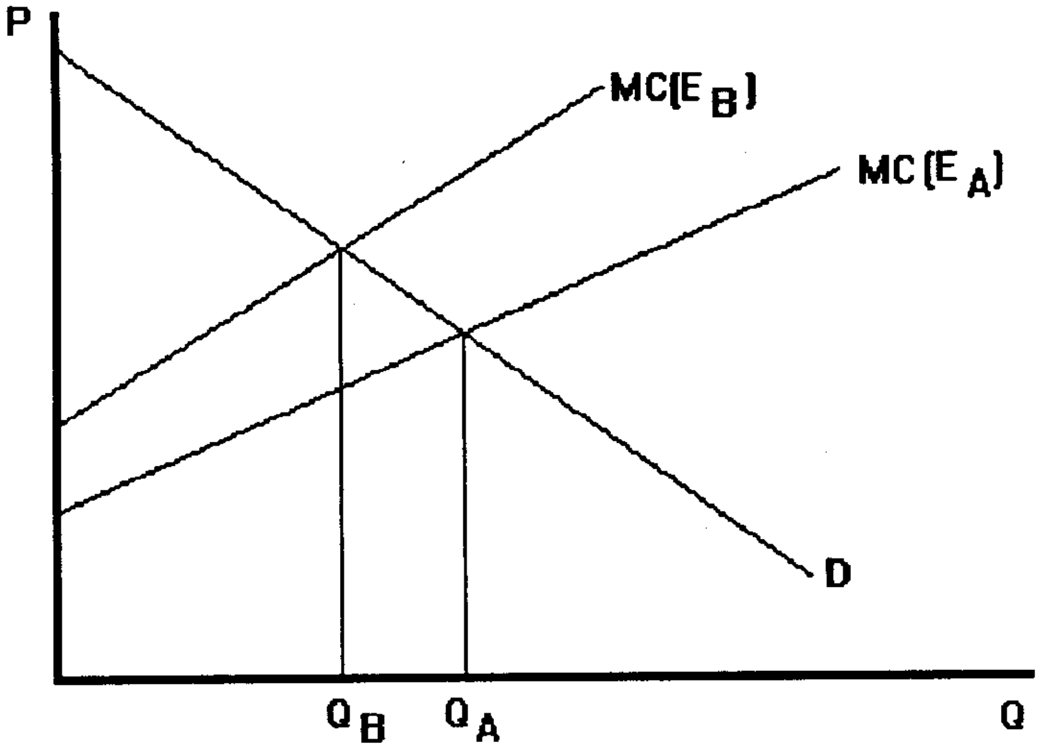

Figure 3

TEMPERATURE STATIONS

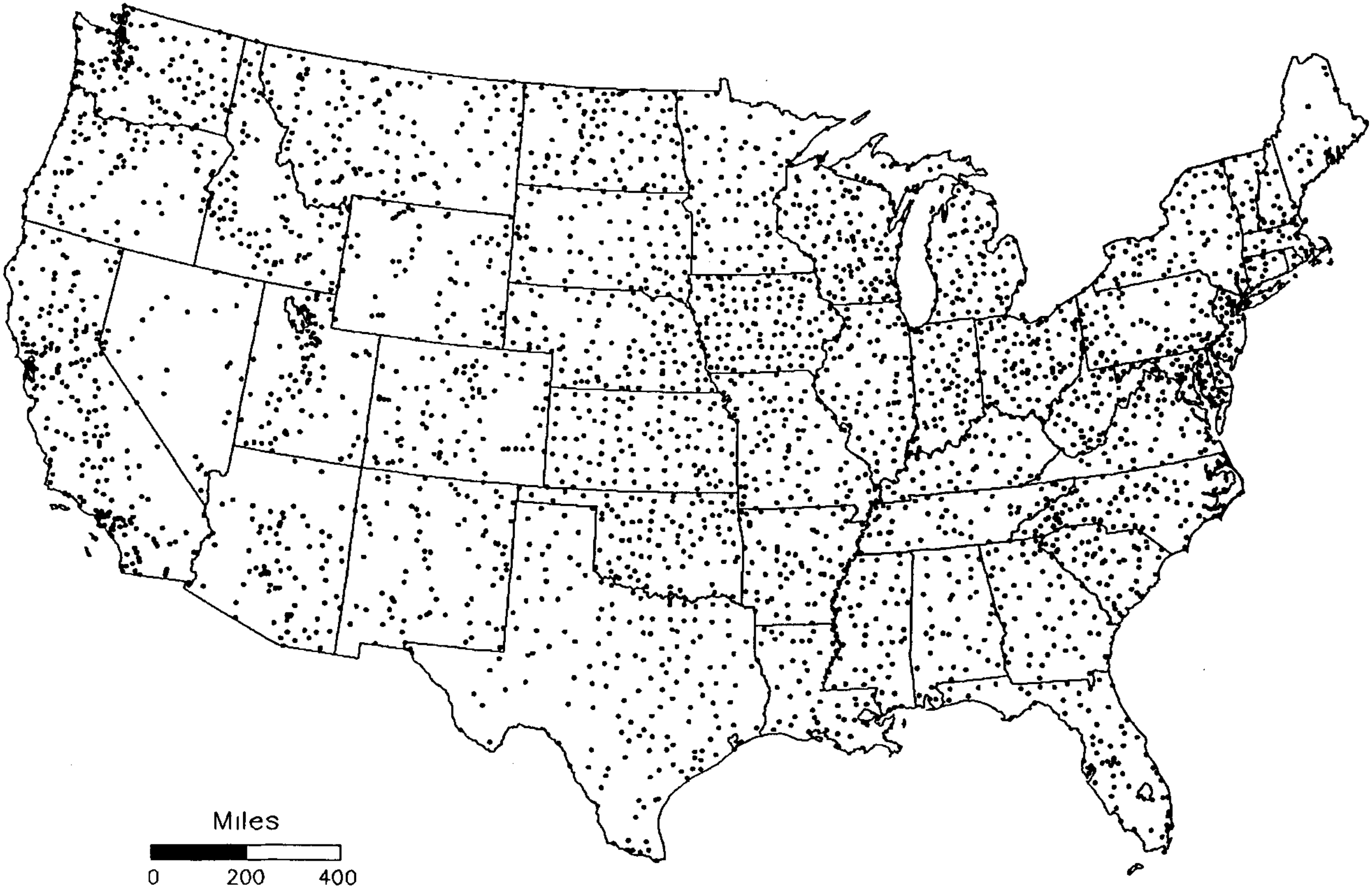

Figure 4
PRECIPITATION STATIONS

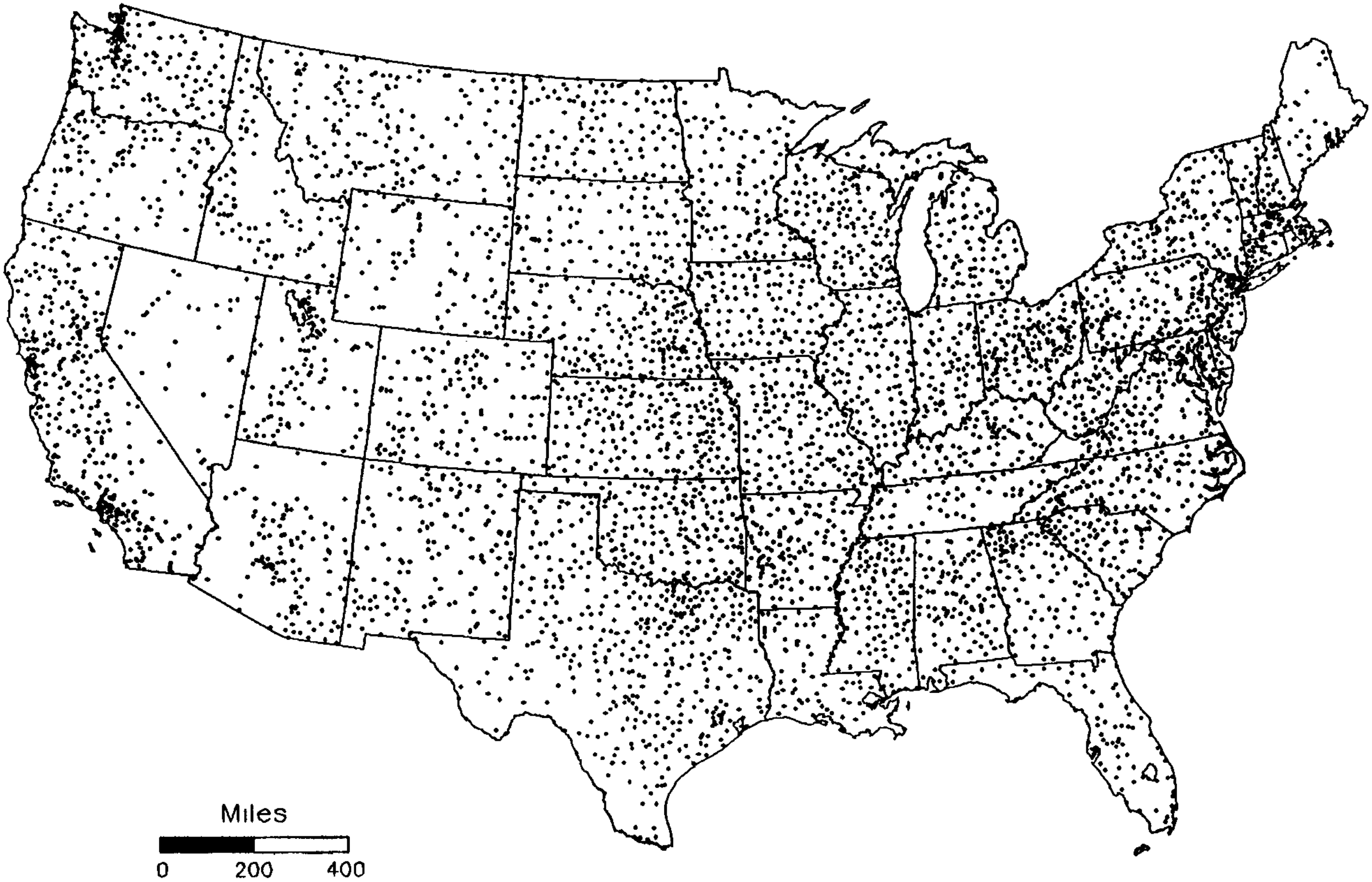

Figure 5

TOTAL FARM VALUE IN 1982

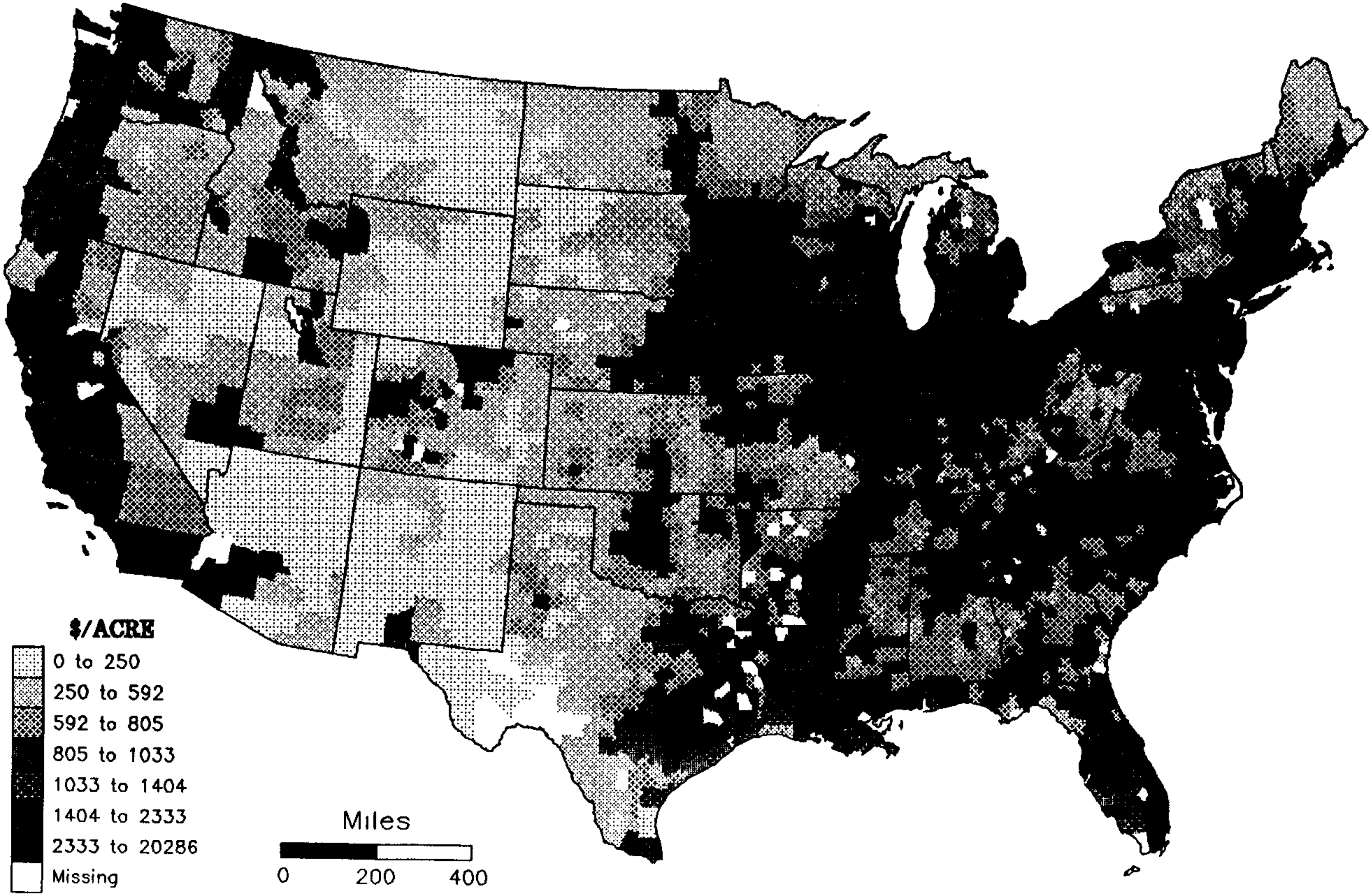

Figure 6

FARM REVENUE IN 1982

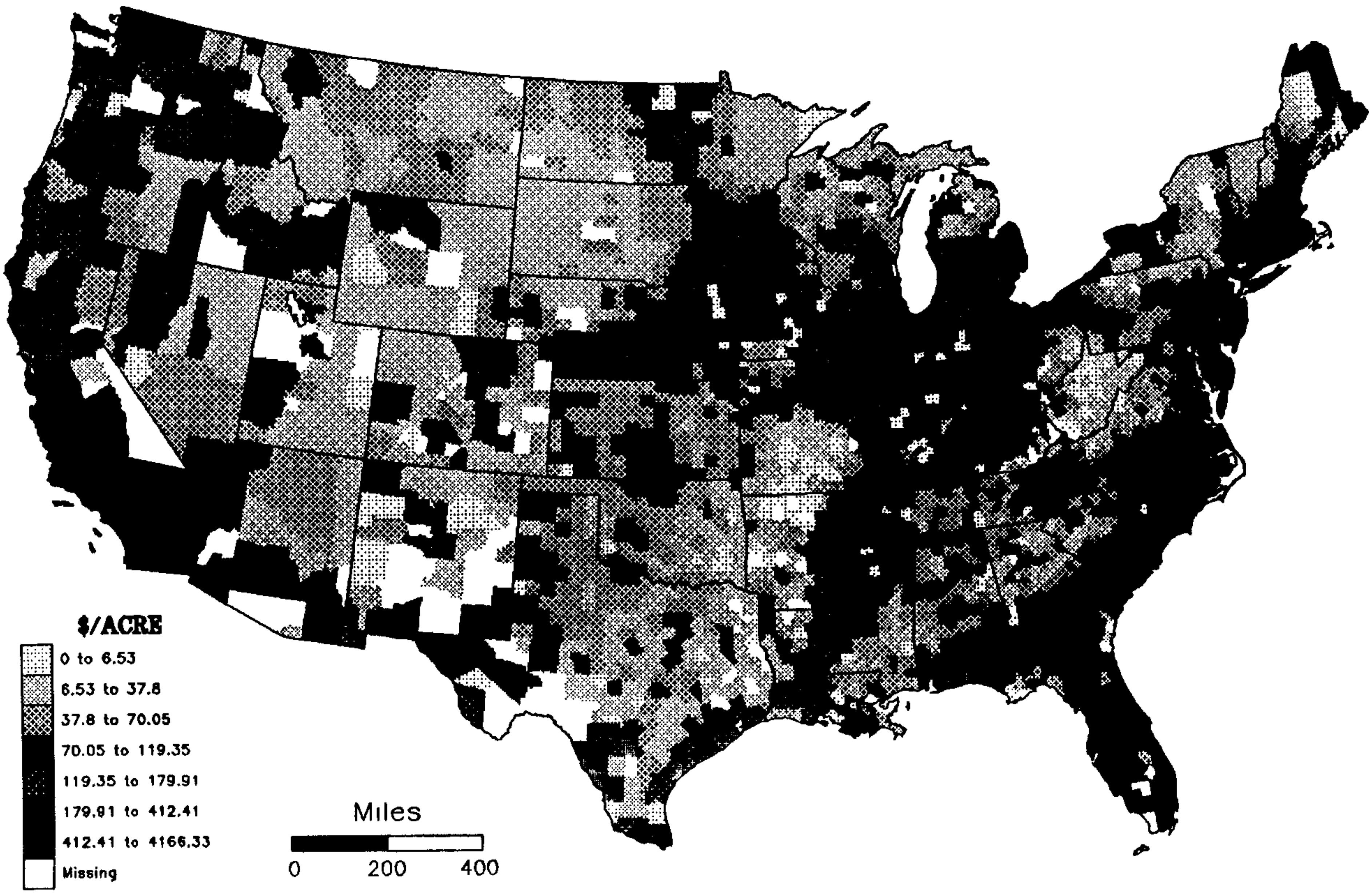

Figure 7

CLIMATIC EFFECTS ON FARM VALUE IN 1982

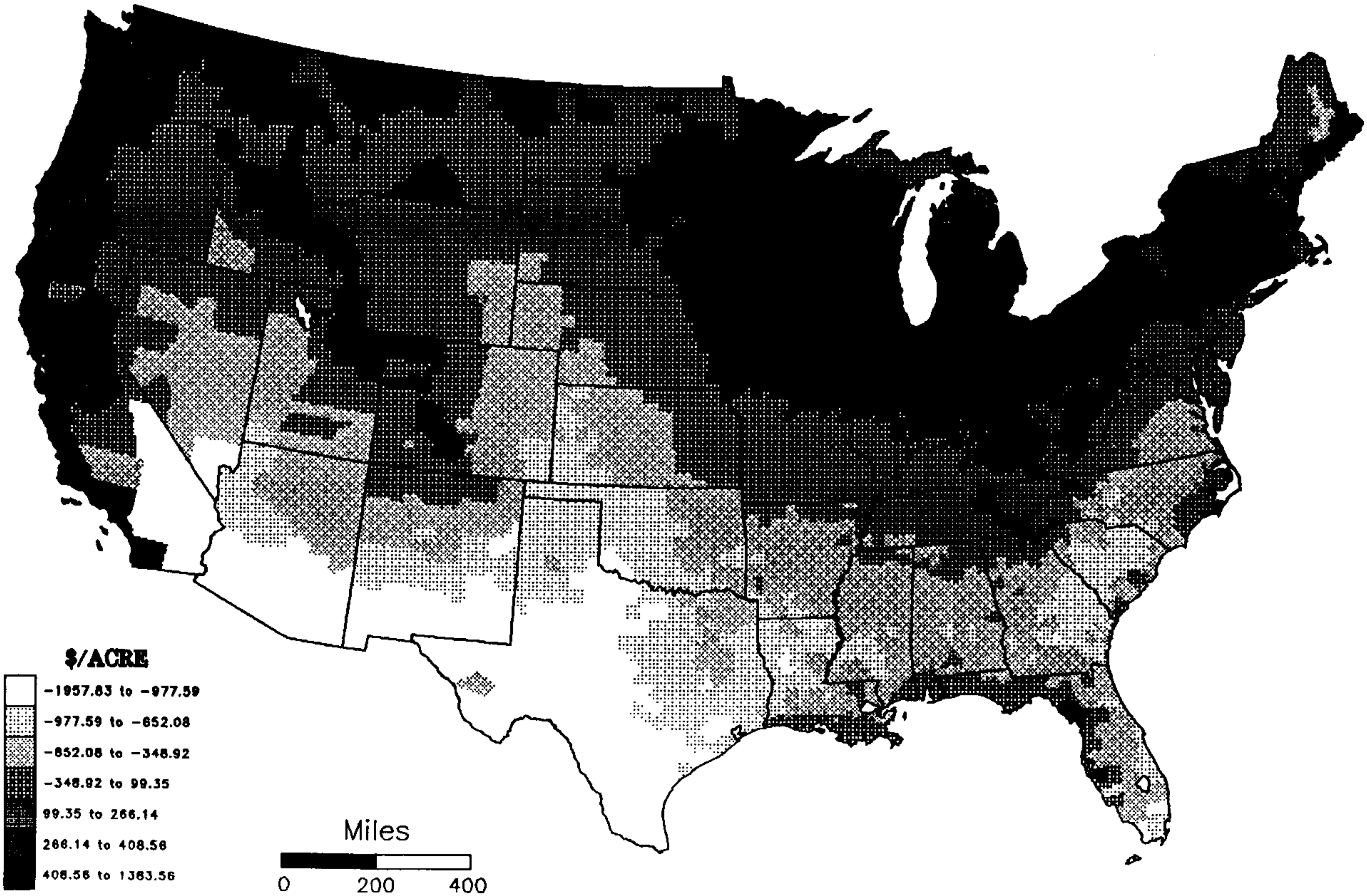

Figure 8

CLIMATIC EFFECTS ON FARM VALUE IN 1978

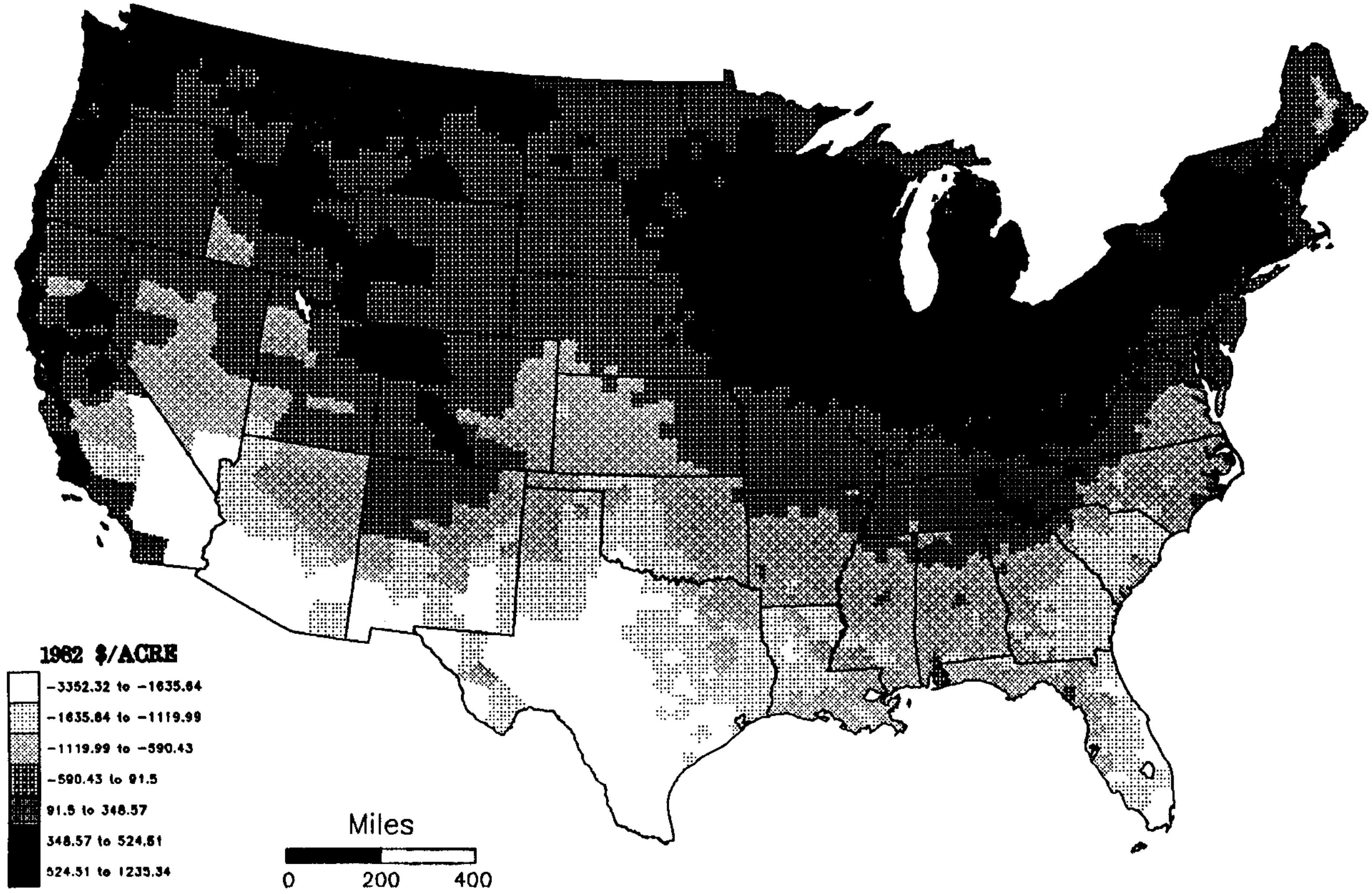

Figure 9

PRECIPITATION EFFECTS ON FARM VALUE IN 1982

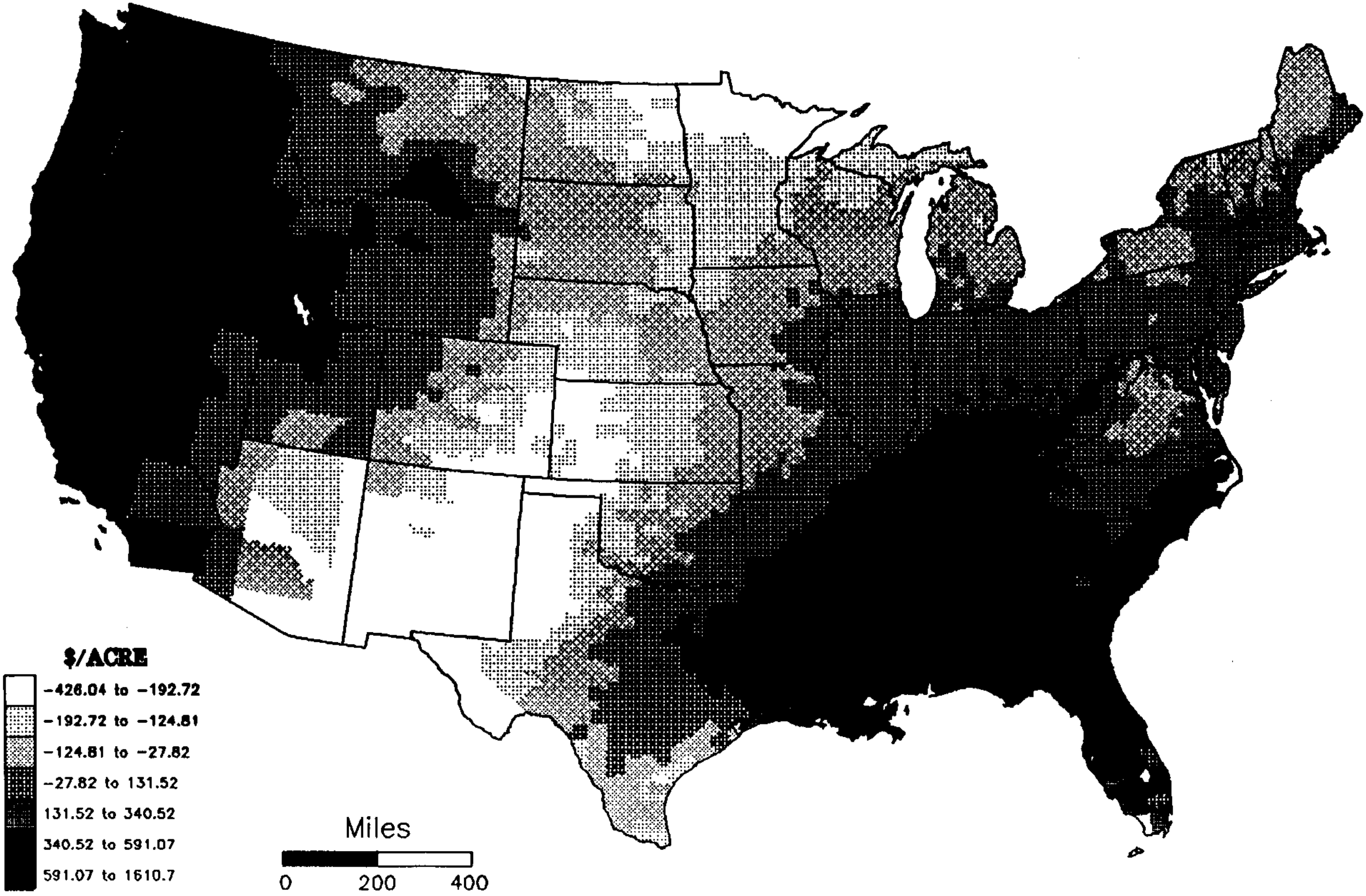

Figure 10

TEMPERATURE EFFECTS ON FARM VALUE IN 1982