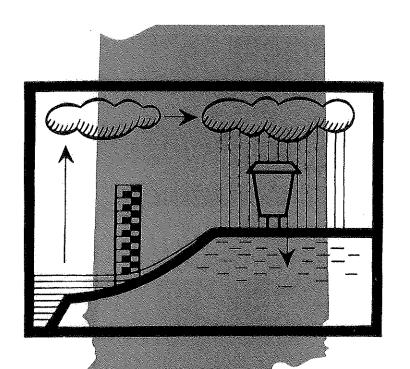
# AN ECONOMIC COMPARISON OF THE IRRIGATION OF CORN IN HUMID AND ARID REGIONS OF THE UNITED STATES



by

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June 1982

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

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Purdue University Water Resources Research Center
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#### ABSTRACT

The development of agricultural irrigation systems in the United States has varied greatly by regions of the country. In some areas public funds have been used to construct dams and aquaducts to store and convey water to irrigation fields. In other areas irrigation development from ground water aquifers has been financed entirely by private funds.

The objectives of this research are (1) to measure the marginal product of water in the production of corn in arid and humid regions of the United States and (2) to suggest implications of this analysis for public policy decisions in the future.

The analysis involved estimations of production functions for irrigated corn in several states based upon agronomic data from experimental test plots. Alternative functional forms were examined and the three-halves polynomial function was selected to compare the marginal products among the states. The results indicated differences exist among states in the marginal product of water in corn production.

Since these differences are not directly related to the areas where irrigation development has been publicly financed in contrast to privately supported, future public policy may want to take that into consideration. Policy options would include alternative subsidy programs for irrigation water supply systems, policies to influence the price of inputs other than water, policy to adjust the price of corn and elimination of all public support of irrigation development.

The results of this analysis are limited by considerations of the marginal products of other crops and the marginal product of water in other uses.

Neither of these issues were examined in this study because the research
concentrated upon the single crop of corn which is grown and irrigated in many
regions of the United States.

#### Introduction

#### Irrigation Development

Little economic research has been conducted to explore the consequences of increasing food production by irrigating land in different regions of the United States. Would irrigation investments yield greater returns in Western States or in the Great Plains? Would supplementary irrigation in the Midwest yield a greater return than irrigation in the West?

Historically there has been a major difference in public policy toward irrigation in the various regions of the United States. In the arid areas of the West and Southwest development of the agricultural irrigation system has been aided by the Federal provision of water at prices below the cost of water development. Systems there involve large publicly financed reservoirs, aquaducts, and pumping stations. Irrigation systems predominately involve flood irrigation of large level fields.

In contrast most of the irrigation development in the humid regions has been privately financed by the individual farmers. Typically this has involved water derived from ground water sources with center pivot sprinkler irrigation application systems. No major public investments were made in supplementary irrigation systems in the humid regions as was the case in the West and Southwest.

In order to compare and contrast these alternatives policy approaches to development of irrigation for agriculture, it would be useful to compare the returns to water use between the arid and humid regions. Since corn is one crop that is produced across all of the regions of interest, it was selected as an example to use which would be illustrative of the type of regional comparison of interest.

The objectives of this research are (1) to measure the marginal product of water in the production of corn in arid and humid regions of the United States (2) to suggest implications of this analysis for public policy <u>visa</u> <u>via</u> irrigation development in the future.

#### Previous Research

Substantial agronomic research has been conducted within specific states on the response of corn to various levels of plant populations, fertilizer application and water provided for growth. Production functions of a variety of forms have been estimated from these agronomic data Beringer, 1961; Moore, 1961; Minhas, 1974; Hexem, 1976; and Pomaredo, 1978; are only a few of many production function studies that could be cited.

Recently three publications have contributed to the understanding of comparisons among regions in the use of irrigation in agricultural production. Frank and Beattie, 1979, published a comparison of the economic value of irrigation water in several regions of the 17 Western States. This study was based on census data so similar procedures could be followed in each state to make comparisons consistent across the region. Hexem and Heady, 1978, published an alysis of the agricultural production functions developed from agronomic studies in states of arid and semi-arid climatic situations. Buller and Roth, 1981, examined the response of corn and grain sorghum to various levels of irrigation water in Kansas.

#### Methodology

Production functions define input-output relationships in the production process. Developing a production function from experimental data involves the use of regression analysis to find an equation which minimizes the deviation of the experimental data from the estimated equation. Since there is an

interest in explaining a large proportion of the variation of the dependent variable by the independent variables, it is often of interest to access several functional forms to determine which one fits the experimental data best. However, the theoretical aspects of the particular functional forms are critically important in selecting those most appropriate for a particular analysis. For example, a linear production function suggests constant returns which is not theoretically consistent with the behavior expected from agricultural production processes.

In the analysis of the relationship between irrigation water and corn yield in this research, several functional forms were explored. They include linear, log, quadratic and polynomial functions. In the latter portion of the analysis section, the 1.5 polynomial function is utilized as the functional form to compare irrigation among several states. The 1.5 polynomial function has the characteristic that the marginal product of the imput declines at an increasing rate. This has certain advantages when estimating relationships for agricultural production. Details on the characteristics of each functional form are described in detail by Hexem and Heady, 1978.

#### Analysis

The analysis presented in this report is divided into three major sections. In the first section production functions relating corn yield to irrigation water applications and other variables are estimated for several alternative functional forms. In the second section, state experiment station agronomic test plot data from several states are fit to the three-halves (1.5) polynomial function. The third section compares the states based on the 1.5 polynomial function.

Data for comparison of alternative functional forms are available from agronomic research conducted in Kansas and Nebraska. Data for a comparison of states with the 1.5 polynomial production function are derived from research in Arizona, California, Nebraska, Kansas and Colorado.

## Alternative Functional Forms: Kansas Data

Production functions from a study conducted in Garden City, Kansas in 1976 included the yield of corn as influenced by the irrigation water, seed variety and plant population. Five different irrigation treatments were used for the experiments. These were: (1) pre-irrigation only, (2) mid-July irrigation only, (3) pre-irrigation and 1 July irrigation, (4) pre-irrigation and 1 July and 1 August, (5) pre-irrigation and 4 irrigations. While mid-July received the least irrigation water (18.25 inches), the most water applied was to the pre-irrigation plus 4 irrigations alternative (40.25 inches).

Rainfall was 12.25 inches between April 1 and September. Each irrigation treatment involved the applications of six inches of water to the test plot.

In 1976 the corn was planted on May 14 and harvested between October 6 and

October 25. Two different seed varieties were used i.e., Horizon KR 870 and Pioneer 3149. Plant population varied from 8200 to 27600 for Horizon and 8,300 to 27200 for Pioneer.

A linear regression function was fitted to the data. Yield was the dependent variable but alternative independent variables were used in different specifications of the function. Yield (Y) was defined in terms of bushels per acre, while water (W) was measured as acre inches utilized (including rainfall). Plant population (PP) was expressed in 10,000 plants per acre. Separate regression runs were made by including the types of irrigation treatments as dummy variables.

Yield, water, plant population and a variety dummy (V) were used as variables in the first regression run. The dummy was assigned a value of 1 if seed variety Pioneer 3149 was planted and 0 if Horizon KR 870 was planted.

The regression obtained was:

$$Y = 37.2 + 3.4 W + 25.6 PP + 14.6 V$$
  
S Error (7.44) (.44) (6.31) (3.84)

F(3.26) = 146.67

$$Adj R^2 = .94$$

Where: Y = yield in Bu., W = water in in., PP = plant population in 10,000's and V = seed variety.

All the regression coefficients were significant at the one per cent level. The regression coefficient of 3.4 implies that a one-inch increase in water applied would lead to an addition in corn yield of 3.4 bushels. The regression coefficient for plant population indicates that a 10,000 increase in plant population would lead to a 25.6 bushels increase in corn yield. A dummy coefficient of 14.6 implies that the yield from Pioneer 3149 would be 14.6 bushels per acre higher than horizon KR 870.

Separate regression runs also were made for each crop variety.

Horizon KR 870 = Y = -36.1 + 3.8 W + 17.0 PP

S Error (11.95) (.71) (10.20)

F(2,12) = 75.00; Avg. yield 104.07

Pioneer 3149 Y = 23.6 + 2.9 W + 34.3 PP

S Error (8.17) (.51) (7.39)

F(2,12) 170.95, Avg. yield = 118.27

Adj  $R^2$  (Horizon) = .91

Adj  $R^2$  (Pioneer) = .96

Comparing the two regression runs, it can be seen that even though the average yield is higher for Pioneer 3149, the marginal product of water is higher for Horizon, i.e., 2.9 for Pioneer as opposed to 3.8 for Horizon. On the other hand, the regression coefficient for plant population for Pioneer is nearly twice that for Horizon. The adjusted  $R^2$  for Pioneer is higher (.96) as compared to Horizon (.91). It should be noted that the regression coefficient for plant population (Horizon) is not significant at the one per cent level.

### Alternative Functional Form: 1977 Nebraska Data

The data used in these production functions were collected during an agronomic experiment in North Platte, Nebraska in 1977. The main objective of the study was to evaluate the effects of preplant anhydrous ammonia with or without N-serve on error growth, N uptake, and grain yield. Irrigation rates applied were a percentage of active evapotranspiration (ET). The soil was a loamy sand to sand, irrigated by a solid set sprinkled system.

Five different functional forms were fitted to the data to explain yield responses. A dummy variable D, was used to represent treatments with N-serve and without N-serve. It was assigned a value of 1 if N-serve was present, 0 otherwise.

In general, except for D in the linear function, all coefficients are significant at the one per cent level. D in the linear function is significant at the 10 per cent level. The lowest R<sup>2</sup> is for the linear function, 0.67, but is highest, 0.88, for the quadratic functions raised to 0.5, 1.5, and 2.0.

$$Y = 23.99 + 2.09W + 0.15N + 3.02D$$
  
S Error (6.06) (0.30) (0.02) (2.14)

$$R^2 = 0.67$$
,  $F(3,56) = 40.18$ 

Where: Y = yield in kg., W = water in in., N = nitrogen in lbs. and D = N-serve.

The coefficients for the constant, water and nitrogen are all significant at the one per cent level, but the D coefficient is significant only at the 10 per cent level. All coefficients have positive values. The marginal product for water is 2.09 kgs. of corn for an acre inch of water applied to the field. Since this is a linear function the marginal product of water is constant throughout the range of the function.

An alternative model formulation was the double log form. The results of this approach are specified in the following equation:

$$\log Y = 1.95 + 0.50\log W + .21\log N + .05D$$
S Error (.20) (.06) (.02) (.02)
 $R^2 = 0.75, F(3,56) 61.37$ 

All the coefficients in the double log formulation are significant at the one per cent level. The value of  $R^2$  increased from 0.67 in the linear formulation to 0.75 in the double log formulation.

The marginal product of water is defined by the equation:

$$MP_{W} = e^{1.95} e^{0.05} \frac{N^{0.21}}{2\sqrt{W}}$$

This marginal product is always positive, but it varies with the amount of nitrogen applied.

Three forms of the quadratic functions were utilized in estimating quadratic production functions. The results of the analysis and the marginal product of water are presented below:

$$y = -608.00 - 32.12W - 0.59N + 3.47D$$

$$S \ Error (83.74) (4.53) (.10) (1.26)$$

$$+288.85W^{0.5} + 11.10N^{0.5} + 0.12WN$$

$$(38.88) (1.76) (0.003)$$

$$R^{2} = 0.88, \quad F(6,53) = 75.63$$

$$y = -172.11 + 33.92W + 0.54N + 3.45D$$

$$S \ Error (29.46) (4.66) (0.11) (1.27)$$

$$-5.11W^{1.5} - 0.04N^{1.5} + 0.01WN$$

$$(0.72) (0.01) (0.003)$$

$$R^{2} = 0.88, \quad F(6,53) = 74.02$$

$$y = -117.85 + 17.43W + 0.26N + 3.44D$$

$$S \ Error (23.09) (2.41) (0.08) (1.29)$$

$$-0.44W^{2} - 0.001N^{2} + 0.012WN$$

$$(0.06) (0.00) (0.003)$$

$$R^{2} = 0.88, \quad F(3,51) = 72.21$$

$$MP_{0.5} = -33.12 + \frac{144.43}{\sqrt{W}} + 0.12N$$

$$MP_{1.5} = 33.92 - 7.67 \sqrt{W} + 0.01N$$

$$MP_{2.0} = 17.43 - 0.88W + 0.01W$$

The three equations represent the marginal product of water with everything else held constant. Because the nitrogen coefficient is the same for all three functions, the effect of nitrogen, for any level of nitrogen, should be the same. Note that the marginal product of water becomes negative when the amount of irrigation exceeds 20 acre inches.

In terms of explanatory power and significance of the coefficients, there is not much difference among the 0.5, the 1.5 and the 2.0 quadratic function. The coefficients are all significant at the one per cent level. The F-statistic varies only from 72.21 to 75.63.

# Regional Comparisons With The 1.5 Polynomial Functions

The analysis in this section involves the estimation of production functions for corn from experimental data developed by agronomists in five states - Arizona, California, Nebraska, Kansas and Colorado. For analytical purpose these states have been classified into three groups according to the prevalent type of irrigation systems or water sources, (1) surface irrigation, (2) sprinkler irrigation, and (3) a combination of both types. The more Western States - California and Arizona falls under the first category because irrigation involves large dams to impound water, aquaducts to transport it, and flood irrigation of large level fields. The irrigation systems in Nebraska and Kansas are predominately supplied from groundwater resources and utilize a sprinkler for applying the water to the cropland. The states of Texas and Colorado fall under the third category with some part of the states utilizing sprinkler irrigation and the other sections of the state primarily surface irrigation.

California 1970... The California test data involved a preplant irrigation of 4 inches and the planting of Pioneer 3775 in 30 inch rows on Yolo loam at Davis, California. Inputs considered were water (W), nitrogen (N) and plant population (P).

Each plot was split with one half characterized by high plant population and the other half a low population. The planned high and low populations were 25,000 and 17,500 plants per acre. Previous research suggests a plant population of near 25,000 per acre to be optimal for high yields. The low

plant population was introduced to examine the level of yield relative to the high population subplots when water and fertilizer were at low levels. Actual plant population for the high treatment ranged from 23,000 to 26,000 plants per acre among the various subplots. Plant population for the low treatment ranged from 15,500 to 21,000 plants per acre. Water was applied at rates of 1.66, 8.66, 14.66, 20.66 and 26.66 inches per acre. When nitrogen was set equal to zero, average yields from plots with low plant population were plots higher than those from the high population plots. When N=150 and W=1.66 the low population plots outyields the high population ones. At higher levels of water and nitrogen, a higher plant population can be sustained and yields corresponding to the high population treatment were above those generated by the low population treatment.

The 1.5 polynomial function was fitted to the data. This represents the yield, water, nitrogen and plant population relationships for this experiment. The 1.5 polynomial was chosen instead of the linear because of the more desirable properties of the former. While the marginal product of a linear function is constant, the polynomial function exhibits a marginal product of water and nitrogen which decline at an increasing rate.

$$Y = 2107.13 + 813.12W + 12.38N + .028P - 113.95W^{15} - .68 N^{15} + 039 WN$$

T-Value (2.61) (9.76) (2.17) (.73) (-7.6) (-2.18) (.42)

 $R^2 = .93$  Adj  $R^2 = .92$  F (6,32) = 72.50

Where: Y = yield in bu., W = water in in., P = no. of plants and N = nitrogen in lbs.

This equation shows that the coefficient for P and interaction variable WN are not statistically significant at the 5% or 1% level. All the other variables are significant at the 1% level and are thus relevant variables. The f (6,32) value of 72.50 shows there is a strong relationship between

the explanatory variables and the dependent variable, yield, at the 1% level. The regression equation explains 93% of the total variation. There is no auto correlation present in the data.

The marginal product of water is defined by:

$$MP_{W} = 8.13 - 170.925 \text{ W}^{.5} + .039 \text{ N}$$

This represents the marginal product of water with other variable held constant. It shows that the marginal product of water becomes negative when the amount of irrigation water applied exceeds 23 inches.

Mesa Arizona 1971 + 1970 ... In 1971, following a preplant application of 250 lbs. per acre of 11-48-0 fertilizer and 8 acre-inches of water, Funks G. 4949 was planted in 40 inch rows on Laveen clay loam. Plant population was approximately 20,000 per acre. Inputs used were water (W), and nitrogen fertilizer (N). At fertilizer levels other than N = 0, the yield response to water is strong. The lack of response when N = 0 suggests a low level of preplant nitrogen in the soil. Average yields peaked at a point when N = 170 lbs. per acre and water treatment of 43.8 acre inch was applied. The 1.5 polynomial function below was fitted to these data.

$$Y = -2826.79 + 236.51 W + 24.38N - 13.79W^{1.5} - 2.11 N^{1.5} + .52 WN$$
T. Value (-.29) (.25) (1.68) (-.12) (-4.16) (1.23)
$$R^{2} = .92 \qquad \text{Adj } R^{2} = .87 \qquad F(5,7) = 16.86$$

$$DWT = 2.68$$

Where: Y = yield in bu., W = water in in., N = nitrogen in lbs.

Only those coefficients estimated for nitrogen variables are statistically significant at 10% or lower levels. The coefficients of water and the interaction term of water and nitrogen are not significant. The intercept or constant term is negative. Though the  $R^2$  is high and F value is significant at the 1% level, the 1.5 polynomial function does not adequately represent the yield-water-nitrogen relationship.

For 1970, the experimental design is similar to that used in the 1971 experiment. The seed variety planted was Funks G-711-AA. Preplant application of 300 pounds of triple Super Phosphate per acre and 10 acre inches of water were applied. Five levels of water treatment were applied, i.e., 35.2, 42, 47.3, 51.1 and 56.8 inches per acre. The five nitrogen treatments ranged from 0 to 320 pounds per acre, in increments of 80 pounds.

Comparison of the 1970 yields to the 1971 yields show that average yields in 1970 were considerably below the 1971 averages. At N = O yield response to increasing water treatment declines, but yield response to increasing nitrogen treatment at a given water level increases.

The 1.5 polynomial function was fitted to the data. This represents the yield-water and nitrogen relationship below:

$$Y = 7814.17 + 621 W + 5.89N - 62.47 W^{1.5} - .77 N^{1.5} + .25 WN$$
  
 $R^2 = .88$  F (5,7) = 0.74

All the coefficients are significant at the level of 10%. The f (5,7) value of 10.74 is significant at the 10% level. The marginal product of water in both years 1971 and 1970 are represented below:

$$MP_{70} = 236.5 - 20.685 \text{ W}^{.5} + .52\text{N}$$
  
 $MP_{71} = 621 - 93.705 \text{ W}^{.5} + .25\text{N}$ 

If the nitrogen coefficient is ignored, the marginal product of water is negative at approximately 44 and 130 acre-inches for 1970 and 1971 data sets, respectively.

Kansas... Data utilized for Kansas were obtained from experiments conducted at Colby in 1971. Prairie Valley 40 S hybrid was planted on Keith Silt Loam at the Colby Branch Experimental Station. The preplant estimated available water holding capacity of this soil is 8.1 acre inches in the top 4 feet and preplant nitrogen averaging 42 pounds per acre was applied. Plant population

treatment ranged from 21,000 to 26,000 plants per acre among the plots and water treatment ranged from 19.3 to 38.9 inches per acre. The five nitrogen treatments ranged from 0 to 360 pounds per acre, in increments of 90 pounds. Because water treatments varied with each plot, treatment combinations were not replicated. However, a maximum yield of 10409 lbs. per acre was attained when water equalled 35.1 acre inches, nitrogen equalled 360 lbs. and plant population equalled 22,900.

The 1.5 polynomial production function below was fitted to the data.

This represents the yield-water-nitrogen-plant population relationship for this experiment.

$$Y = 14613.33 + 1731.72W + 42.53N - .0047P - 207.99W^{1.5} - 2.66N^{1.5} + .755WN$$

$$(-2.31) (2.37) (5.07) (-.19) (-2.18) (-8.99) (2.53)$$

$$R^{2} = .94 adj R^{2} = .93 f(6,31) = 101.70 DWT = 1.5064$$

Where: Y = yield in lbs., W = water in in., N = nitrogen in lbs., and P = plant population.

No plant population effect is discernible at the conventional levels of statistical significance. All the other variables are significant at the 5% level or lower and are thus relevant variables. The f (6,37) value of 101.70 shows there is a strong relationship between the explanatory variables and the dependent variable (yield) at the 1% level of significant. The regression equation explains 94% of the total variation. The Durbin Watson test for autocorellation falls in the inconclusive region at the 1% level of significance but closer to the region of absence of autocorellation.

The marginal product of water is represented below.

$$MP_{L} = 1731.72 - 311.985 \text{ W}^{.5} + .955 \text{ N}$$

Ignoring the nitrogen term, the marginal product of water turns negative when the amount of irrigation water applied is approximately 31 inches.

Nebraska 1976... Corn was planted on loamy sand to sandy soil irrigated by a solid set sprinkler system at the University of Nebraska, North Platte Station in 1976. The objective of the experiment was to evaluate the effect of preplant anhydrous ammonia with or without N-serve on corn growth, nitrogen uptake and corn yield. An average of .56 Kg of N-serve per hectare of anhydrous ammonia was applied. Watering rates applied were expressed as a percentage of actual evapotranspiration (ET). The three nitrogen treatments ranged from 100 to 200 pounds per acre, in increments of 50 pounds.

The 1.5 polynomial below was fitted to the data set.

$$Y = -28.37 + 12.42W - 0.02N - 0.41D - 1.68W^{1.5} + .0008N^{1.5} + .0003WN$$

$$(-1.68) (8.94) (-0.07) (-.37) (8.4) (.02) (.15)$$

$$R^{2} = 0.90 F (6,32) = 44.29$$

All the variables except water are not significant at the conventional levels, i.e., 10% or lower and have no perceptible influence on yield. The signs on the nitrogen variable is inconsistent with economic theory and reality, as additional use of nitrogen will improve yield continuously. The negative coefficient of the dummy variable implies that the use of N-serve reduces yield. The equation does not accurately represent yield-water-nitrogen relationship.

The 1977 estimated regression presented earlier in this section, is more consistent with reality and economic theory than the 1976 data, and represents more accurately the yield-water-nitrogen and N-serve relationship.

Colorado... Kitley K-4-117 was planted in 28 inch rows on Nunn Clay loam at the Agronomy Research Center in 1968. Plant population approximated 25,000 plants per acre. The five water treatments were 0, 2, 6, 5.15, 5.88 and 8.83 acre inches. The five nitrogen treatments ranged from 0 to 200 pounds per acre in increments of 50 pounds.

The polynomial 1.5 production function below was fitted to the data.

$$Y = 4512.92 + 906.60W + 16.53N - 134.17W^{1.5} - .83N^{1.5} - .01WN$$

$$(8.6) (2.37) (1.21) (-1.38) (-.9) (-.015)$$

$$R^{2} = .86 Adj R^{2} = .76 DWT = 2.578 F(5,7) = 8.56$$

The coefficients associated with nitrogen are not significant. Only coefficients associated with linear water and the intercept terms are significant at the 1% level and thus, are relevant variables. The regression equation explains 86% of the total variation.

The marginal product of water is represented by:

$$MP_{c} = 706.60 - 201.255 \text{W}^{.5} - .01 \text{N}$$

The marginal product of water turns negative when the amount of irrigation water applied is approximately 12 inches, ignoring the nitrogen term.

#### A Comparison of States

For various reasons, irrigation water is often allocated by means other than the price mechanism so that prices for the water are often "nominal" prices which are less than those which would prevail under free market conditions. This means that rationing and quotas are common in the allocation of water.

The production function differs considerably among the states due to the differences in (a) the goals of the experimental design, (b) soil conditions, (c) irrigation scheduling, (d) time of application as opposed to the quantity of water applied, (e) levels of nitrogen applied and (f) plant population. The variability in production is consistent with differences in the relative efficiency of water from one state to the other.

Assuming that the objective of production in each state is to maximize profit, water will be used in the production of corn to the point where the

value of the marginal product of water equals its unit cost.

$$VMP_{c} = P_{c} = P_{m}MPP_{c} = P_{m}^{1}/P_{c}$$

$$P_{c}MPP_{a} = P_{a}$$

$$P_{m}MPP_{k} = P_{k}$$

$$P_{m}MPP_{n} = P_{n}$$

$$P_{m}MPP_{n} = P_{n}$$

If irrigation of corn is being subsidized by a unit greater than the State level, i.e., by the federal government, to attain the optimum production of corn, all the above equalities must be satisfied simultaneously. Thus, the marginal earnings of water in each state must be equal to its cost. Dividing each equality by the input price on the right and rearranging the optimum criterion can also be expressed.

$$\frac{\text{VMPc}}{\text{P}_{c}} = \frac{\text{VMP}_{a}}{\text{Pa}} = \frac{\text{VMP}_{k}}{\text{P}_{k}} = \frac{\text{VMP}_{n}}{\text{P}_{n}} = \frac{\text{VMP}_{co}}{\text{P}_{co}} = 1$$
or
$$\frac{\text{P}_{m}^{\text{MPP}_{co}}}{\text{P}_{co}} = \frac{\text{P}_{m}^{\text{MPP}_{co}}}{\text{P}_{k}} = \frac{\text{P}_{m}^{\text{MPP}_{co}}}{\text{P}_{m}} = \frac{\text{P}_{m}^{\text{MPP}_{co}}}{\text{P}_{co}} = 1$$

Assuming that corn is a honogenous product with its price equal in all markets and the technology for obtaining water is identical in all the states such that the price of water is the same. Given that the federal government has available funds to subsidize the production corn under irrigation the following criteria will be satisfied:

$$MPP_{c} = MPP_{a} \dots = MPP_{co}$$

If MPP  $_c$  > MPP  $_a$  > MPP  $_k$  ... > MPP  $_{co}$  California with marginal productivity of water greater than that of the other states will be funded first and any other available fund will be allocated to the next highest MPP of water until

 $<sup>\</sup>frac{1}{\text{Lower}}$  case letters represent the states California (c), Arizona (a), Kansas (k), Nebraska (n), and Colorado (co).

the available fund is completely exhausted. If MPP  $_{c}$  = MPP  $_{k}$   $\cdots$  > MPP  $_{co}$  California or Arizona could be allocated the fund. If the available fund is not limiting water will be used to the point where the MPP = 0 for all the states.

Assuming that corn price is identical and the technology for obtaining water differs, available funds will be invested or allocated as follows:

California will be allocated the available funds when this relationship holds assuming average productivity and marginal productivity are decreasing.

Where 
$$\frac{MPP_{c}}{P_{c}} = \frac{MPP_{a}}{P_{a}} \dots = \frac{MPP_{co}}{P_{co}}$$

any of the states could be funded.

The marginal productivity of water obtained from the estimated production function for the different states is as follows:

If water use for the production of irrigated corn is supported from a federal source such that maximum output is attained, the states will irrigate to the point where the MPP = 0. The marginal productivity of water is zero for California at 23 acre inches, 44 acre inches for Arizona, about 31 acre inches for Kansas, about 18 acre inches for Nebraska, and about 13 acre inches for Colorado.

If the funds made available are adequate to obtain 21 acre inches of water, water will be allocated to the states such as Kansas utilizes 15 acre inches of water with a MPP = 524, California utilizes 3 acre inches of water with a MPP = 517, Arizona receives 2 acre inches of water with a MPP = 448 and Colorado receives one acre inch of water with a MPP = 506. This assumes identical input and product prices in all states.

However, if the cost of obtaining an acre inch of water in California is five times that of Kansas, then the marginal productivity of water in California should be at least five times that of Kansas, before funds should be allocated to corn production in that state. If, on the contrary, the cost of an acre inch is five times higher in Kansas than in California, no water will be diverted to Kansas until after 9 acre inches of water are provided to California.

#### CONCLUSIONS AND POLICY IMPLICATIONS

The objective of this research was to measure the marginal product of water in the production of corn in various regions of the United States.

In addition, policy implications of this analysis in relation to irrigation programs were to be assessed.

Economic theory indicates the most economically efficient allocation of water would be to those uses where the marginal product of water is the greatest, ceterus paribus. Since major variations occur in the marginal physical product for corn among states, a case can be made for irrigation investment in some states rather than others if corn is the only product produced. It is important to note that the states which had the highest marginal product are not necessarily those where the subsidy for irrigation development has been greatest.

In general, greater Federal subsidies have occurred in the past when water has been impounded and transported to farms for use in flood irrigation systems. In contrast, the cost of sprinkler irrigation systems from a ground water source have usually been borne entirely by the farmer with no Federal subsidy. As a consequence, past policy has shifted the production of corn from regions where the producers pay the full cost to those regions where producers are subsidized in part by Federal funds.

This conclusion suggests a variety of policy options:

(1) If corn is the only crop irrigated, it would appear efficient to subsidize irrigation water in relation to the marginal product of water in the production of corn rather than on the basis of the type of irrigation development. This assumes that there is some national need to maintain the production of corn at a level higher than would occur if no subsidy was provided for irrigation. This policy could be part of a national program to maintain

lower prices of food, for example, by passing from farmers to consumers the lower prices associated with increased corn production.

- (2) If increased corn production is desired, irrigation water subsidization is only one way to achieve it. Alternative approaches could involve subsidization of some other production inputs, such as, land or fertilizer rather than water. This could result in a different regional distribution of corn production than occurs through the subsidy to irrigation. Each alternative subsidy approach could be examined to determine which one achieved the greatest output of corn relative to the cost of the subsidy.
- (3) A multiple price approach by region is another policy option to achieve increased corn production. By subsidizing the corn price in some locations or nationally, it would be possible to increase the output of corn either locally or nationally in whatever amounts are considered to be appropriate.
- (4) A policy of no subsidy for irrigation development is another policy choice. In this case production of corn among regions would be based on the marginal product that exists within the region and the particular pattern of factor and product prices that influence that marginal physical product. This policy would alter the locational advantages of corn production in the various regions of the United States.

#### Limitations of this Study

There are several aspects of irrigation comparisons among regions that are not dealt with in this analysis. Recent studies of the production functions for corn have begun to emphasize the time irrigation water is applied rather than the total amount of water applied for irrigation over the whole season. Since these studies reflect different schedules of irrigation application and only the total amount of water was a factor in the production function, the marginal products derived are less useful in making

regional comparisons than would be the case if identical irrigation schedules had been used in each agronomic study.

Although the response to corn production is examined there is no consideration given to alternative crops. When climatic conditions permit the production of high valued crops, such as lettuce, in one region but not in another, it is essential to compare the marginal value product of water in its highest valued use to assess the proper allocation of water among regions. This analysis might be extended even further to encompass the marginal value of water in all industrial, commercial and agricultural uses in order to evaluate subsidy programs.

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