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Irrigation Water Values in the Willamette Valley:

A Study of Alternative Valuation Methods

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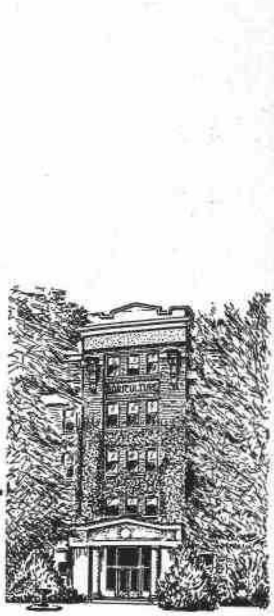

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Stanley F. Miller, Larry L. Boersma, and Emery N. Castle

INTRODUCTION

A substantial increase in the demand for water in the Willamette Valley of western Oregon stemming from a growing population, industrial expansion, and increased use of irrigation has focused attention on the importance of proper management and allocation of water. Although there is considerable precipitation in the area, the distribution is not uniform throughout the year. The months from November to February account for approximately 60% of the total precipitation. Only 10% occurs during the dry summer period extending from June to September. It is this period of scarcity which causes concern. Thus, a fundamental economic question is raised as to how water, as a limited flow resource, is to be optimally allocated among competing uses.

Agriculture is the greatest consumptive user of water in the valley. Currently, 84% of the total consumptive surface rights are held by agriculture in the Upper Willamette River Basin.[1] If agriculture is to maintain its present allocation in competition with other water uses, it will need to demonstrate that (1) water is being used in an efficient manner, and (2) irrigation is economically feasible in relation to alternative water uses, such as pollution abatement, industrial usage, and recreation.

The basic ingredient necessary to solve both the problems of efficiency and allocation is the marginal value product of water (MVP_w). An input is used efficiently if the marginal value product of the input is equated to its marginal unit cost.[2] In the case of water, this would be where $MVP_w = P_w (1 + f_w)$, where P_w is the price of water and f_w is the price flexibility of the supply curve for water. At this point, the marginal cost caused by the increased use of one more unit of water

[1] Oregon State Water Resources Board, *Upper Willamette River Basin* (Salem, Oregon, 1961), p. 31.

[2] Other conditions must be met, of course, for this statement to be true. For example, all resources must be assumed to be rationed and allocated by price.

is equal to the marginal revenue arising from the increased output. The marginal revenue in the case of pure competition is the price of a unit of output.

To obtain the marginal value product function of water used in irrigation, it is necessary to know the response of crops to water. The economic feasibility of irrigating the better drained soils is generally recognized. In fact, many of the better drained acreages and soils of the Willamette Valley are already irrigated. Any great expansion of irrigation will take place on the less productive and poorer drained soils. But without knowledge of the response to water of these soils, it will be impossible for farmers to decide how much can be paid for irrigation water, what expense is justified to improve the efficiency of existing irrigation systems, or how much water ought to be applied. At the present time, knowledge of the response of crops to irrigation on most of the poorly drained soils is lacking. Indeed, the feasibility of irrigating many of the more poorly drained soils has been questioned.

Units of a resource are optimally allocated among alternative use from an economic viewpoint when the value of the marginal product is equal in all alternative uses, that is, when the MVP_w used in agriculture is equal the MVP_w used in industry. The MVP_w in industry, in turn, should equal the MVP_w for all other uses. Resource prices provide the mechanism for transferal of resources. In a free market system, a higher price for (say) domestic water would trigger sales from water users whose MVP_w was low (say for irrigation) to domestic users. If diminishing marginal returns are operative, the MVP_w for domestic purposes would be lowered while the MVP_w for irrigation would be raised. Thus, the MVP_w for irrigation and the MVP_w for domestic purposes would tend to equalize over time.

However, many resources are not priced in the market place. In the case of water, the management and allocation is the result of both political and market forces. Both federal and state agencies play an important role. Agencies charged with allocation of public resources have turned to economists for help in making allocation and development decisions. However, economists are not agreed as to the proper techniques to be utilized in valuing these resources.

This study was designed to help answer both the allocation and efficiency problems. The principal objective was to investigate alternative methods for measuring the value of water used in irrigation. Other objectives were (1) to estimate the effect of varying amounts of irrigation water on the yield of bush beans and field corn produced on Willamette catena soils in the Willamette Valley, and (2) to evaluate the economic feasibility of irrigating bush beans and field corn produced on Willamette catena soils.

METHODS OF VALUING IRRIGATION WATER

Presently, there are three direct approaches for estimating water values in irrigation: budgeting or residual imputation, linear programming or activity analysis, and production function analysis.[3] Budgeting has been used by research and extension economists for many years. Hutson, Black and Holmes were early users of the technique.[4] Federal agencies used budgeting to value irrigation water;[5] however, the residual return after other input resources have received their payment is usually a composite payment to water, plus to several other nonmarket inputs such as management, family labor, and so forth. It is extremely difficult to separate the MVP for a single resource by using the budgeting approach.

Linear programming, the second method of valuing irrigation water, developed during the Second World War. The Simplex method of linear programming stems primarily from the work of George B. Dantzig.[6] Several recent studies, notably the work of Hartman and Whittlesey of Colorado,[7] have used linear programming to value irrigation water.

Both budgeting and linear programming involve the same basic assumptions. Linear programming can, in fact, be called systemized budgeting. Linear programming, however, does have the advantage of isolating a single optimum without resorting to the time-consuming, trial-and-error budgeting approach. It also allows the marginal value product, MVP, for each limiting factor of production to be determined simultaneously as the system of equations is solved. Since computer facilities are now readily available, linear programming provides answers much more economically and generally with higher degrees of precision than budgeting. For these reasons, budgeting was not used in the comparison of alternative methods of valuing irrigation

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[3] Several indirect approaches which utilize secondary sources of data, such as changes in land values, farm sales, and so forth, have been used to estimate irrigation water values. For an example of this type of approach and a discussion of several similar approaches, the reader is referred to: L. M. Hartman and R. L. Anderson, *Estimating Irrigation Water Values*, Colorado Agric. Expt. Sta., Tech. Bull. 81 (Fort Collins: Colorado State University Printing Press), 1963.

[4] Irving F. Fellows, ed., *Budgeting,* Connecticut Agric. Expt. Sta. Bull. 357 (Storrs: University of Connecticut Printing Press), 1960, pp. 41-43.

[5] Subcommittee on Benefit Costs, Proposed Practices for Economic Analysis of River Basin Projects, Report to the Inter-Agency Committee on Water Resources, Washington, D. C., 1958.

[6] Robert O. Ferguson and Lanven F. Sargent, *Linear Programming, Fundamentals and Applications* (McGraw-Hill, New York), 1958.

[7] L. M. Hartman and Norman Whittlesey, *Marginal Values of Irrigation Water,* Colorado Agric. Expt. Sta. Tech. Bull. 70 (Fort Collins: Colorado State University Printing Press), 1960.

water. It was, however, used to develop the input-ouptut analysis needed in the linear programming model.

Production function analysis, which utilizes survey and/or experimental data, has a shorter history than budgeting as a tool for economists in estimating marginal values of resources. Generally, the Cobb-Douglas function is used by economists in analyzing survey data, while several different functional forms are used in analyzing and interpreting experimental data.

The general form of the Cobb-Douglas function is:

$$\hat{Y} = aX_1^{\,b_1} X_2^{\,b_2} X_3^{\,b_3} \ldots X_n^{\,b_n} u,$$

$\hat{Y}$ = total poduction or gross income,
Xi = quantity of input factor,
a, b = parameters to be estimated, and
u = schochastic error term, which is assumed to be lognormally and independently distributed with zero mean and a constant, finite variance, σ_u^2.

Although the function is nonlinear, it can be changed into a linear function by taking the logarithms of both sides of the equation. It then can be estimated by the least-squares regression technique.

The major advantage of the Cobb-Douglas technique is its economical use of degrees of freedom in calculating parameter estimates while still providing curvilinear relationships. The major disadvantage is that the sum of squares is minimized in logarithmic form rather than in the "natural"[8] form. Since the regression is computed using the logarithmic transformation of the function, minimizing the residual sum of squares in this form does not minimize the residual sum of squares of the "natural" data. The least-squares logarithmic parameters are, therefore, biased estimators of the "natural" parameters. Obviously, this also means that the elasticities of output, returns to scale, and marginal productivities arising from the logarithmic function are biased.

Tests of significance are generally used to ascertain whether the regression coefficients are significantly different from some specified value. However, the validity of using tests of significance on parameters recognized as being biased is questionable. If the Cobb-Douglas function fitted in logarithms is converted to its natural form, statistical tests on the logarithmic parameters are difficult to interpret. Hence, tests of significance on the biased logarithmic coefficients reveal little about the significance of the "natural" coefficients.

Clark Edwards has employed an iterative approach to approximate the "natural" parameters using first-order terms of Taylor's

[8] Natural form refers to the original cardinal form of the function.

expansion.[9] However, this approach embodies a different assumption pertaining to the error term than is generally assumed. A multiplicative error term is assumed in the Cobb-Douglas function which converts to an additive term when the logarithmic transformation is made. A single, additive error term is implied by Edwards' approach.

In general, Edwards found a tendency for the parameters to be lower when the function was fitted in logarithmic form than in "natural" form and a tendency for the sum of squares of the exponents to be greater.[10] Depending upon the degree of discrepancy existing between the logarithmic and "natural" parameters, opposite conclusions could be reached. If the logarithmic sum of coefficients indicated increasing returns to scale, while "natural" parameters indicated decreasing or constant returns to scale, incorrect conclusions could be drawn from employing the results of the logarithmic function when the "natural" function was "true," or vice versa.

Edwards did not provide means for performing tests of significance on the coefficients. Since the tests of significance of the coefficients fitted in logarithmic form do not apply to the "natural" parameters, it is believed that this is not a great disadvantage.

The polynomial functions, i.e., square root and quadratic, are generally fitted to data from controlled experiments. They are more flexible than the Cobb-Douglas function. They allow all degrees of substitutability to exist among factor-inputs. They also have readily usable statistical tests. Smith, Thomas, and Wiersma used this method to value irrigation water for irrigated corn production.[11]

METHODS AND PROCEDURES

The data for this study are derived from two basic sources: (1) physical response experiments conducted cooperatively by the staffs of the Departments of Soils,[12] Farm Crops, Horticulture, Agricultural Engineering, and Agricultural Economics, Oregon State University; and (2) a survey of farms in Benton, Linn, Polk, and Marion counties.

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[9] Clark Edwards, "Non-linear Programming and Non-linear Regression Procedures," *Journal of Farm Economics, XLIV* (February 1962), pp. 100-114.

[10] *Ibid.*, p. 105.

[11] LaVon E. Smith, D. Woods Thomas, and Daniel Wiersma, *An Economic Analysis of Water, Nitrogen and Seeding Rate Relationships in Irrigated Corn Production,* Indiana Agric. Expt. Sta. Res. Bull. 755 (Lafayette: University Press), 1962.

[12] D. D. Evans, Department of Soils, assumed the major leadership responsibility for the program until his resignation September 1, 1963; thereafter, L. L. Boersma, Department of Soils, assumed this responsibility.

The experiments are designed to obtain production functions for field corn and bush beans where yield or gross return per acre is the dependent variable and water is the independent variable. The water input is measured in acre-inches. The cross-sectional survey also is designed to obtain a production function for water. The dependent variable is gross return per acre. The independent variable, water, is the actual application rate of the surveyed producers measured in acre-inches.

Controlled Physical Experiment

The experiments were conducted during 1963 and 1964 on soils of the Willamette catena. These soils form a broad level bench across the valley floor and extend over approximately 800,000 acres.[13] Soils comprising the Willamette catena include the following soil series in decreasing order of drainage severity: Dayton, Concord, Amity, Woodburn, and Willamette. Woodburn and Dayton soil series were chosen as soils for detailed physical experimentation in order that extrapolation from the results could be extended to other members of the catena. It was believed that Woodburn is representative of the better drained members of the catena, while Dayton represents the poorly drained soils.

The Willamette Valley is an important production area of fruits and vegetables for canning and freezing. It was desired, therefore, to determine the feasibility of further expansion of irrigated processing crops on poorly drained members of the Willamette catena. Bush beans were selected as the intensive crop to be studied. A single variety, Gallatin 50, was used in the analysis.

It was also desired to have some indication as to the irrigation feasibility of a number of less intensive crops. After much consideration, field corn grown for grain was selected as a "bench mark" crop. It was believed that from an economic standpoint irrigated corn was a marginal-type crop. Thus, if irrigated corn were found to be feasible, the profitability of several more intensive crops would be indicated.

The basic Dayton field-corn data were obtained from a complete factorial experiment with four replications.[14] Three treatments were employed:

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[13] A study presently under way by Department of Soils personnel will provide accurate information on the number of acres of the different soils in the valley.

[14] A complete description of the experiments can be found in: *Progress of Research on Irrigation Feasibility for Dayton, Amity, Woodburn, Willamette, and Related Soils of the Willamette Valley,* Oregon Agric. Expt. Sta., Special Rept. 172, 1964.

1. Irrigation—four levels
   - W_0—no irrigation.
   - W_1—irrigated when tension was equivalent to 6 bars at 6-8 inches below original surface.
   - W_2—irrigated when tension was equivalent to 1.5 bars at 6-8 inches below original surface.
   - W_3—irrigated when tension was equivalent to 0.8 bars at 6-8 inches below original surface.
2. Nitrogen application—three levels
   - N_1—60 pounds of available nitrogen per acre.
   - N_2—120 pounds of available nitrogen per acre.
   - N_3—180 pounds of available nitrogen per acre.
3. Stand density—two levels
   - S_1—15,000 plants per acre.
   - S_2—25,000 plants per acre, except for W_0, in which density was held to 10,000 plants per acre.

The field-corn experiment conducted on the Woodburn soil was almost identical to the Dayton experiment. Irrigation occurred when tension reached the same levels, but at one foot below the surface of the soil rather than six inches. The yields for the Woodburn soil are given in the Appendix. The 1963 Dayton experiment will not be discussed in detail in this report. The experiment was not conducted during 1964; therefore, no between-year comparison can be made.

Bush-bean data were obtained from two identical experiments in 1963, one on Woodburn soil and the other on Dayton soil. A complete factorial design with four replications was employed. Woodburn yields are given in the Appendix.

1. Irrigation—four levels
   - W_1—irrigated when tension was equivalent to 2.5 bars at one foot below top of the ridge.
   - W_2—irrigated when tension was equivalent to 1.5 bars at one foot below top of the ridge.
   - W_3—irrigated when tension was equivalent to .8 bar at one foot below top of the ridge.
   - W_4—irrigated when tension was equivalent to 0.5 bar at one foot below top of the ridge.
2. Nitrogen—two levels
   - N_1—50 pounds of available nitrogen per acre.
   - N_2—100 pounds of available nitrogen per acre.

Several mathematical equations were fitted to the field-corn production data. All of the equations fitted corresponded to agronomic and economic theory in that they provided for decreasing incremental returns as water was increased. Statistical measurements, such as the coefficient of multiple correlation and standard tests of significance, were used to select the function for further analysis.

The function selected for the Woodburn soil was:

$$\hat{Y} = .497 + \underset{(.992)^{15}}{11.605W} + \underset{(.140)}{.409N} - \underset{(.065)}{.488W^2} - \underset{(.0005)}{.002N^2} + \underset{(.00003)}{.00008WS} + \underset{(.00000019)}{.0000007WNS}.$$

The partial derivatives of yield with respect to water multiplied by the product price provide estimates of the MVP_w. The marginal value productivity schedules for the Woodburn functions are shown in Table 1.

TABLE 1. MARGINAL VALUE PRODUCTS OF WATER, FIELD-CORN EXPERIMENT, WOODBURN SOIL, HYSLOP AGRONOMY FARM, 1963

Application rate per acre	MPP[1]	MVP_w[2]	MVP_w assuming a 75% irrigation efficiency
acre-inches	*bushels*	*dollars*	*dollars*
2	11.51	16.23	12.17
4	9.55	13.46	10.10
6	7.60	10.72	8.04
8	5.65	7.97	5.98
10	3.69	5.20	3.90
12	1.74	2.45	1.84

[1] MPP is the partial derivative of yield with respect to water.
[2] MVPw equals MPP times the price of corn. The price of corn used was $1.41 per bushel.

As seen in Table 1, the marginal value of 4 acre-inches of water is $13.46. This assumes a 100% irrigation efficiency. Under actual farm conditions, 100% efficiency is never obtained. Using a hypothesized efficiency of 75%,[16] the MVP_w is reduced to $10.10 per acre-inch of water actually pumped from the source $\left(\frac{13.46}{1.00} \cdot \frac{X}{.75} = 10.10\right)$.

The optimum application rate of water is reached when the $MVP_w = P_w$. The operating cost of sprinkler systems was equated to the MVP of water. The resulting water quantity would be an optimum only if water were a free commodity. At the present time, however, there does not exist a single "price" for water that would apply generally. It should be recognized, therefore, that the subsequent estimates of the "optimum" amount of water to use will tend to be on the generous side.

[15] Figures in parentheses on the line below the coefficients are the standard errors of the regression coefficients. All the coefficients are significant at the .05 level.

[16] This figure is used in: Fred M. Tilestone and John W. Wolfe, *Irrigation Requirements,* Oregon Agric. Expt. Sta. Bull. 500, 1951, p. 20.

Stippler estimated the operating costs per acre-inch of water applied in a survey of Willamette Valley farms.[17] According to his study in 1950, the cost per acre-inch for a sprinkler system of adequate capacity was $1.50. After adjusting his costs to correspond to 1963 prices, the cost per acre-inch rose to $1.94. One dollar was variable costs; $0.94 was noncash or fixed costs.[18]

Assuming 60 pounds of nitrogen per acre, 15,000 plants per acre,[19] and $1.94 as the price of water, the Woodburn function indicates an economic optimum allocation of 12.4 acre-inches of water.[20] The maximum physical output occurs with an input of 13.8 acre-inches.

The Woodburn field-corn experiment was duplicated during the 1964 production season. Yield response from the various treatments can be seen in the Appendix. The function fitted to the 1964 data was:

$$\underset{}{\hat{Y}} = 13.053 + \underset{(1.675)}{16.935W} + \underset{(.273)}{.196N} - \underset{(.096)}{.501W^2} - \underset{(.001)}{.001N^2} + \underset{(.00005)}{.000025WS} + \underset{(.0000003)}{.0000004WNS}$$ [21]

Maximum physical production occurs with a water input of 17.2 acre-inches; economic optimum production occurs with an input of 15.3 acre-inches.

The bush-bean experiments were also conducted on Woodburn and Dayton soils. Useful yield data were obtained from the Woodburn site.[22] However, no analysis of the data from the Dayton soil experiment was made because of the extreme variation among replications caused by manganese toxicity. Soon after their emergence, many of the primary and trifoliate leaves of the bean plants showed ab-

[17] Henry H. Stippler, *Sprinkler Irrigation in the Pacific Northwest*, U. S. Department of Agriculture. Agric. Info. Bull. No. 166, 1956, pp. 94-95.

[18] For a full discussion of the adjustment method employed, see: Stanley F. Miller, *An Investment of Alternative Methods of Valuing Irrigation Water*. Ph.D. thesis. Corvallis, Oregon State University, June 1965.

[19] These figures correspond approximately to the average nitrogen and stand levels of the producers surveyed.

[20] The reader is cautioned to bear in mind the inherent dangers of specifying points of economic optimal and maximum physical production from one year of data. Several additional years of experience would be necessary to estimate these points of production adequately.

[21] In order to compare effectively the 1963 and 1964 experimental functions, identical forms were employed for both years. To do otherwise would have allowed some of the variability between years to be a direct result of using different functional forms. Several of the included variables in 1964 are not significant at the .05 level: N, N^2, WS. This is due in part, but not entirely, to imposition of a specified functional form to the data. An analysis of variance of the 1964 field-corn data indicated that nitrogen was not significant at the .05 level in affecting yield. The reason for this is not wholly known at the present time.

[22] Data are presented in the Appendix.

normal foliage symptoms. Yields from replications affected by this malady were the lowest, regardless of the level of nitrogen and irrigation. Subsequent analysis by soil specialists suggested that manganese toxicity may have been the cause of the chlorotic and retarded growth of the beans.

The return from beans is not solely a function of gross production. The grade of the beans is an important factor. In order to get a meaningful measure of return, yields from each replication were graded individually. The grade yield was then multiplied by the grade price.[23] This became the dependent variable, $\hat{Y}$, in the models.

Again, several functional forms were fitted to the data. A modified square-root function was selected for further analysis on the basis of proper signs and the statistical significance of the parameters. The function selected was:

$$\hat{Y} = -260.07 - 100.55W + 596.13 \sqrt{W} - 55.08 \sqrt{N} + .49WN.$$

TABLE 2. MARGINAL VALUE PRODUCTS OF WATER, BUSH-BEAN EXPERIMENT, WOODBURN SOIL, HYSLOP AGRONOMY FARM, 1963

Application rate per/acre	MVP_w	MVP_w assuming a 75% irrigation efficiency
acre-inches	*dollars*	*dollars*
2	134.88	101.16
4	73.12	54.84
6	45.80	34.35
8	29.47	22.10
10	18.35	13.76
14	3.74	2.80
15	1.05	.79

The maximum yield occurs when 15.4 acre-inches of water are applied with a constant 65 pounds of nitrogen. The economic optimum occurs with a water input of 14.7 acre-inches. The marginal values of water are shown in Table 2.

The Woodburn bush-bean experiment was also repeated in 1964, as was the Dayton. However, the results of neither experiment will

[23] Prices used in this study were:

Grade	Sieve size	Price/ton
1	1, 2, and 3	$140
2	4	135
3	5	75
4	6	50
No value	7 and over	1

be reviewed here. The 1964 Dayton experiment did not have a meaningful 1963 counterpart; therefore, no comparison could be made. The 1964 Woodburn experiment did not provide reasonable results. The unreasonableness of the data was probably due to faulty moisture-tension blocks.

Survey

The survey data for this study were from a random sample of 1963 field-corn and bush-bean producers in Benton, Polk, Linn, and Marion counties in western Oregon. A questionnaire was prepared and information gathered from 45 field-corn growers; 43 records were sufficiently complete for analysis. Records were obtained from 26 bush-bean growers; 19 were sufficiently complete for analysis.[24]

The field-corn population was assumed to consist of producers having a 1959-60 base corn acreage. Records of base corn acreages are maintained by the various county Agricultural Stabilization and Conservation committees. The population was stratified by soil types (Willamette catena) and the use or nonuse of supplemental irrigation.

Upon sending enumerators into the field to collect the survey data, it was found that many of the farmers who had a corn acreage base were not producing field corn during the 1963 growing season. According to a running tabulation of enumeration success, only 31% of the producers with base acreage actually produced field corn during 1963. The percentages of the producers interviewed, by counties, are given in Table 3.

TABLE 3. NUMBER AND PERCENTAGE OF FIELD-CORN PRODUCERS ENUMERATED, SURVEY AREA, 1963

County	Field-corn producers having 1959-1960 corn base	Field-corn producers enumerated	Enumeration percentage of total
Marion	343	33	10
Benton	5	1	20
Linn	52	9	17
Polk	10	0	0

The population of bush-bean producers was obtained through the cooperation of commercial packing plants located in the survey

[24] Selected practices, materials used, and yields of the surveyed producers are summarized in the Appendix.

area. Most bush beans are irrigated; therefore, the population was stratified only on the basis of soil.

It was necessary to associate the field-corn and bush-bean production with specific Willamette catena soils. This was done through the use of farm maps provided by the Soil Conservation Service. In the case where a SCS farm map did not exist, county soil maps were used.

In order to fit production functions statistically from the cross-sectional data, input categories must be defined that include a number of input items. The general rule for grouping input items is to group together perfect substitutes and complements. Use of this rule allows large numbers of inputs to be grouped into a relatively few categories, thus saving degrees of freedom and avoiding the problem of multicollinearity.

The Cobb-Douglas function which was fitted to the corn survey data was:

$$\hat{Y} = aX_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} u$$

$\hat{Y}$ = gross income arising from the sale of dry shelled corn per acre,
X_1 = dollar value of purchased inputs per acre,
X_2 = hours of machinery use per acre,
X_3 = water use in acre-inches per acre,
X_4 = drainage in feet per acre,
u = the stochastic error term.

In order to eliminate the possibility of the land variable being highly correlated with the other independent variables, each of the independent as well as the dependent variables was put on a per-acre basis.[25]

Purchased inputs, X_1, is an aggregation of the dollar value of purchased items necessary to produce $\hat{Y}$. Purchased inputs in this study included per-acre expenditures on items such as fertilizers, sprays, seeds, custom work, gas, and electricity.

Separating the contribution of an input which is used in several productive enterprises on a multienterprise farm is a difficult task. To solve this problem better, inputs were measured as much as possible in physical terms. Thus, the contribution of machinery (X_2) measured in physical terms is the hours of machinery (powered and non-powered) used per acre, the contribution of irrigation equipment (X_3) is the water which is applied, and the physical measurement of drainage (X_4) is the feet of tile per acre.

The same variables were employed in both the field-corn and bush-bean functions, with the exception that date of planting replaced

[25] A full discussion of tests for multicollinearity conducted in this study are given in: Miller, *loc. cit.*, pp. 58-60.

drainage in the bush-bean analysis. Date of planting reflects the contribution of drainage services. Better drained soils are capable of earlier plantings. A significant correlation was found between date of planting and gross income per acre. Early plantings yielded greater gross returns than later plantings. Thus, date of planting was employed in the bush-bean function to indicate both contributions, that of drainage and earlier plantings.[26]

Gross income for bush beans reflects not only the yield of beans in tons per acre but also the grades of the beans. Premium prices are paid for beans of the highest two grades. It is, therefore, an advantage to the producer not only to have large yields but also to have beans of high quality. Gross income, $\hat{Y}$, reflects both producer objectives.

Survey data were again gathered in 1964. An attempt was made to obtain information from all of the previously sampled producers, both field-corn and bush-bean producers. Seventeen usable bush-bean records were obtained from the 19 previously sampled producers. One grower did not produce bush beans in 1964, the other did not wish to participate. Forty-one responses were obtained from the 43 previously sampled field-corn producers; however, only 25 of the 1963 growers produced field corn in 1964. The same production functions were fitted to the two sets of crop data for both 1963 and 1964.

Similarity in yields between Willamette, Woodburn, and Amity soils suggested that the yields from these different soils could be pooled for each crop. Previous studies conducted on Willamette catena soils led to the hypothesis that little difference exists between the yields of these soils.[27] It was further hypothesized that a greater usage of tile drains exists on the poorer drained members of the catena; thus, explaining in part the similarity of yields.

In an attempt to test the validity of the first hypothesis, an analysis of variance was performed on several variables which one might a priori expect to differ between soils of different inherent abilities—gross income per acre, date of planting, estimated land values, land preparation routines, and nitrogen application rate. Willamette and Woodburn soils were placed in one stratification, Amity and Dayton soils were placed in another. The number of records ob-

[26] It is recognized that date of planting is not an ordinary input in production; however, in order to plant early, adequate natural or artificial drainage must be available. Early planting dates imply the existence of artificial drainage in poorly drained soils.

[27] J. L. Anderson, *Response of Field Corn to Irrigation,* Master's thesis. Corvallis, Oregon State University, 1963; and Sydney C. James, *Techniques for Characterizing Oregon Soils for Agricultural Purposes in Terms of Physical and Economic Productivities,* Ph.D. thesis. Corvallis, Oregon State University, June 1961.

tained on Dayton soil was negligible; therefore, the Amity-Dayton stratification was primarily Amity soil. The differences between the cited variables of the two stratifications were not significant at the 5% level.

To test the second hypothesis, a chi-square test of homogeneity of means and an analysis of variance were utilized. It was concluded from these two tests that a significantly different drainage intensity existed between the two soil stratifications. Thus, the observed similarity in yields between the soils, it is believed, is explained in part by the increased use of artificial drainage, raising Amity soil to a par with Willamette and Woodburn. Because of the similarity of yields, the different soils were pooled for both bush beans and field corn and the analysis was performed on the composite.

Both sets of regression coefficients, logarithms and "natural,"[28] for field corn can be seen in Table 4. The coefficients of determination indicating the percentage of variation accounted for by all independent variables in the regression are .44 for the 1963 logarithmic fit and .47 for the "natural" fit. The coefficients are .43 and .54, respectively, for the 1964 data. The "natural" fit for both years explains more of the variation than the logarithmic fit.

TABLE 4. REGRESSION COEFFICIENTS FOR THE "NATURAL" LOGARITHMIC COBB-DOUGLAS FUNCTION, FIELD-CORN SURVEY DATA, 1963

		Logarithmic coefficients		"Natural" coefficients	
Input	Category	1963	1964	1963	1964
X_1	dollars/acre	.255	.322	.310	.154
X_2	hours/acre	.029	–.261	.003	–.050
X_3	acre-inches/acre	.057	.090	.057	.124
X_4	feet/acre	.018	–.001	.015	.004
a	constant	40.330	65.651	37.320	72.83

The marginal value product schedule for water for the 1963 "natural" fit is given in Table 5. The marginal value product curve for water was derived over the sample range of X_3, with the other input categories held constant at their arithmetic means.[29]

Regression coefficients, both "natural" and logarithmic, for the 1963 and 1964 bush-bean survey data are listed in Table 6. The coefficients of determination for the 1963 functions indicate that 36% of the variation in the "natural" fit is explained by the regression,

[28] From the iterative method employed by Clark Edwards.

[29] Generally, MVP schedules are found for Cobb-Douglas functions by holding all variables constant at their geometric means. However, Edwards' "natural" approach makes possible the use of arithmetic rather than geometric means.

while 37% of the variation of the logarithmic fit is explained. Fifty-two and forty-nine, respectively, are the coefficients of determination for the two 1964 functions.

TABLE 5. MARGINAL VALUE PRODUCTS OF WATER, FIELD-CORN SURVEY DATA, 1963

Application rate	MVP_w	MVP_w (assuming a 75% irrigation efficiency)
acre-inches	*dollars*	*dollars*
2	2.38	1.78
4	1.25	.93
6	.85	.64
8	.64	.48
10	.52	.39
12	.44	.33
14	.38	.28

TABLE 6. REGRESSION COEFFICIENTS FOR THE "NATURAL" AND LOGARITHMIC COBB-DOUGLAS FUNCTIONS, BUSH-BEAN SURVEY DATA, 1963

		Logarithmic coeffiicients		"Natural" coefficients	
Input	Category	1963	1964	1963	1964
X_1	dollars/acre	.223	.055	.260	.035
X_2	hours/acre	.176	.378	.190	.302
X_3	acre-inches/acre	.069	.056	.073	.057
X_4	date of planting	.211	.041	.168	.043
a	constant	29.290	56.44	26.896	76.658

TABLE 7. MARGINAL VALUE PRODUCTS OF WATER, BUSH-BEAN SURVEY DATA

Application rate per acre	MVP_w	MVP_w (assuming a 75% irrigation efficiency)
acre-inches	*dollars*	*dollars*
2	9.70	7.28
4	5.10	3.82
6	3.50	2.62
8	2.68	2.01
10	2.18	1.64
12	1.84	1.38
14	1.58	1.18

The marginal value product schedule for water for the 1963 "natural" fit is given in Table 7. Once again, the marginal value product curve for water was derived over the sample range of X_3. The other input categories were held constant at the arithmetic means.

Linear Programming

Four separate linear programming models were developed to obtain MVP_w schedules.[30] Model A represents a mid-Willamette Valley farm producing only two crops, field corn (grown for grain) and bush beans. Four production activities are available: (1) field corn, irrigated; (2) field corn, nonirrigated; (3) bush beans, irrigated; and (4) bush beans, nonirrigated. Results from the 1963 surveyed farms were used to estimate the levels of input for the model. The level of output was derived from the survey field-corn and bush-bean functions using the average level of input use. The input-output coefficients, a_{ij}, were obtained by dividing the input by the output. Unlimited quantities of labor and capital were assumed available at the cost of $1.25 per hour and $1.10 per hour, respectively.

Variable inputs are the only ones used in the models. Model B is identical to Model A, except the yields derived from the 1963 survey functions were obtained with a water-input level corresponding to the irrigation requirement estimated by the Blaney-Criddle consumptive-use technique.[31]

The water supply level in the models is initially zero, but by the use of parametric programming the water supply is iteratively increased until it becomes nonrestrictive.[32] In this way, the MVP_w schedule is obtained.

In all models, nonirrigated corn production is the first activity brought in when no irrigation water is available. Thereafter, as the water supply is parametrically increased, irrigated bush beans compete with nonirrigated corn for the available land. Finally, as water be-

[30] For a complete description of the models, see: Miller, *loc. cit.*, pp. 87-93.

[31] Since only one year of data (1963) was used to determine the input-output coefficients for the linear programming models, only 1963 weather statistics were employed to estimate the consumptive-use requirements.

[32] Parametric programming adds the largest multiple of a specific nonbasic vector to the optimum solution so that one of the elements becomes zero and nonrestrictive. Thus, it is possible to obtain all points where the shadow price or marginal value product changes. Parametric programming is an efficient procedure because it eliminates the necessity of rerunning the entire model with several different water requirements.

comes less restrictive and the maximum bean acreage is reached,[33] irrigated corn appears in the solution.

Two linear programming models were developed to give some indication of the MVP_w, using results from the experimental plots. Models C and D both used the same input coefficients as the previous two models, with the exception of water. Model C used the optimum water allocation and subsequent production from the Woodburn field-corn and bush-bean experimental functions. The nonirrigated field-corn yield of .5 tons per acre obtained from the Woodburn field-corn function was used. The bush-bean experimental design did not provide an estimate of nonirrigated bush-bean production; therefore, the non-irrigated coefficients in the model were the same as for the two previous models. Model D is identical to Model C, except that the Blaney-Criddle consumptive-use requirements are used to obtain the estimated irrigated yields from the production functions.

COMPARISON OF PRODUCTION FUNCTIONS

Field Corn

Plotting the survey and the experimental field-corn functions on one graph provides an interesting and informative comparison (Figure 1). The Woodburn rather than the Dayton experimental function was plotted because it was more representative of the soils of the survey producers and hence made a more meaningful comparison with the Cobb-Douglas corn function. The experimental and survey functions were plotted by use of average survey input levels. At nonirrigated and lower levels of irrigation, production from the 1963 and 1964 survey function is considerably higher than predicted yields of the experimental function.[34]

The two field-corn production functions derived from the controlled experiments yield almost identical results except in the extreme ranges of the water input beyond 9 acre-inches. The two survey func-

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[33] One hundred acres of land were assumed to be available for crop production, of which only 50 acres were assumed to be contracted for bush beans.

[34] The survey data obtained in 1963 and 1964 have the advantage over the experimental data in that many nonirrigated observations from different local environments were obtained. It was originally thought that it would not be possible to obtain accurate observations of water application rates from the survey data. Therefore, it was thought it would be necessary to make analysis on a with-and-without basis. However, subsequent analysis indicated that yield estimates for several water application rates could be obtained. Thus, while the sampling scheme as originally developed was inefficient in obtaining a complete water response function, it did provide a good estimate of nonirrigated yields.

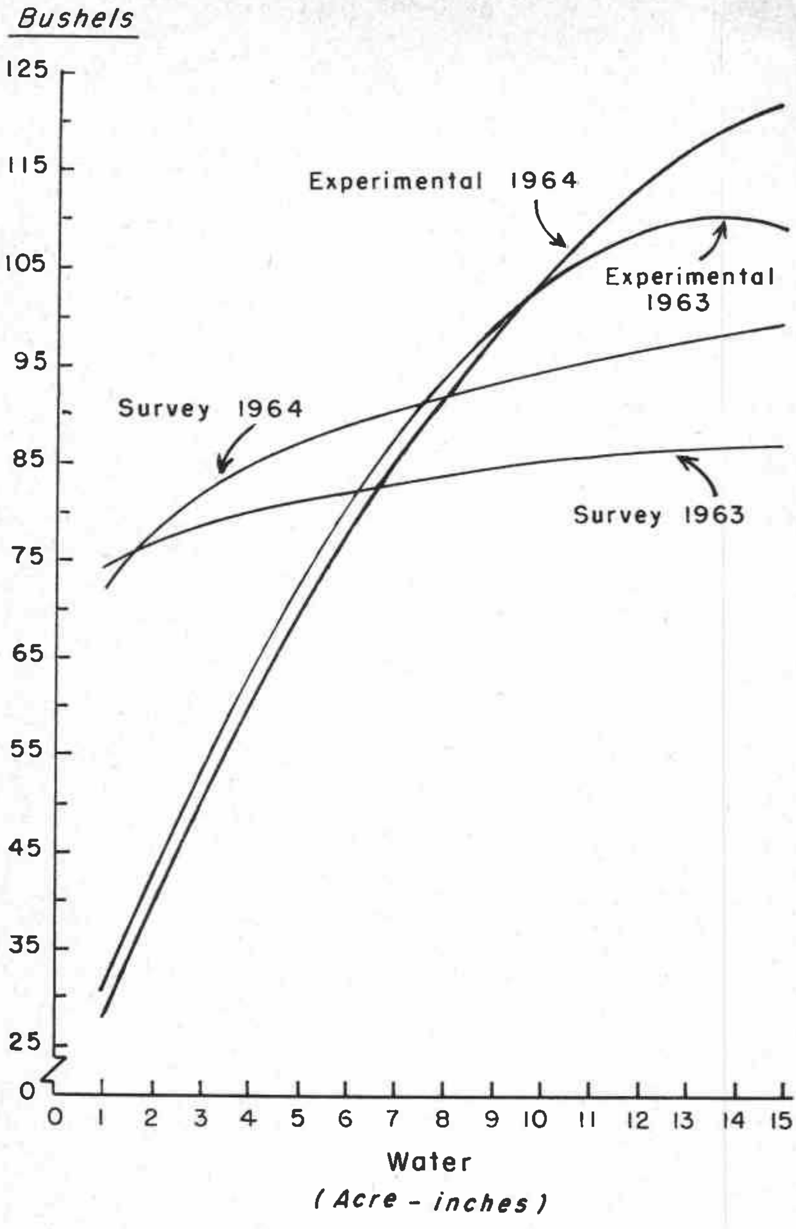

Figure 1. Comparison of the experimental and survey field-corn production functions.

tions start out at approximately the same level, but beyond 1½ acre-inches the 1964 function starts to diverge from the 1963 function (see Figure 1). It would thus appear that yields were more responsive to increased water in 1964 than in 1963.

At the water-input level of 6.1 acre-inches the 1963 experimental function is as high as the 1963 survey function. Thereafter it moves progressively higher. This is not surprising, considering that although the water-input range of the survey data varies from 0 to 11 inches per acre, only 3 of the 43 field observations are above 4 acre-inches. These three observations could not be expected to raise the function materially.

The yields of the three field observations beyond 4 acre-inches compare favorably with those obtained from the Woodburn experiment.[35] For example, one producer with a yield of 107 bushels of shelled corn per acre applied 11 acre-inches of water. The Woodburn function, with an 11-inch application rate, yields 106.8 bushels per acre. Another of the three producers had a yield of 89.3 bushels per acre with 7 inches of water. The function yields 88.2 bushels per acre at an application rate of 7 inches of water.

The 1964 survey and experimental functions intersect at approximately 7.5 acre-inches. Water inputs of the surveyed producers ranged from 0 to 9.2 acre-inches. The average water input was 5.0 acre-inches. Producers who used more than 5.0 acre-inches of water received yields in excess of predicted yields both from the survey and the experimental functions. For example, one producer who applied 9.2 acre-inches of water received a yield of 116 bushels per acre. The survey function at that level predicts a yield of 94 bushels; the experimental function predicts a yield of 101 bushels. Another producer received 107 bushels of corn with an application of 9.2 acre-inches of water. The survey function predicts a yield of 94 bushels, while the experimental function predicts a yield of 101 bushels at that level of input. Thus, the yields of producers who use more than 5.0 acre-inches of water were more consistent with yields of the experimental functions than the survey function.

At the average input level of 60 pounds of nitrogen per acre and an average water input of 4.05 acre-inches, the 1963 field-corn experimental function predicts a yield of 1.8 tons, while the 1963 survey function predicts a yield of 2.2 tons. The 1964 experimental function, with an average water input of 5.0 acre-inches, predicts a yield of 2.0 tons. The survey function at the same water-input level predicts 2.4 tons per acre.

[35] No attempt was made to adjust the individual survey observations for the difference in the nitrogen input.

Bush Beans

The same general relationships also hold between the 1963 and 1964 survey and 1963 experimental function for bush beans (Figure 2).[36] The two survey functions are very similar in shape and height. The maximum difference is $20. The survey functions are higher than, the same as, and then less than the experimental bush-bean function. As previously mentioned, there was no nonirrigated treatment in the bush-bean experimental design. The survey data did provide one point estimate of the nonirrigated yield.

Most of the bush-bean survey observations were at water-input levels between 3.2 and 6.0 acre-inches (95% in 1963 and 88% in 1964). In this interval the difference between the survey and experimental functions is not large; however, beyond 6 inches the experimental function climbs considerably higher than the survey function. There was only one farmer in 1964 who applied more than 6.0 acre-inches of water. Thus, neither survey function could be expected to estimate yields accurately at the higher application rates.

The 1963 bush-bean functions, survey and experimental, are very close at the average input level of 65 pounds of nitrogen and 4.6 acre-inches of water per acre. The experimental function predicts a yield of 3.1 tons per acre, while the survey function predicts a yield of 3.3 tons per acre. The 1964 function is even closer to the experimental function. At the same nitrogen level and with the average water input of 5.2 acre-inches, the experimental and Cobb-Douglas functions predict the identical yield, 3.6 tons per acre.

The significance of this comparison is obvious. For both field corn and bush beans, the experimental and the survey functions predict approximately the same yields over the relevant interval of water inputs. The close similarity between the functions suggests that experimental plot data may be interpreted in terms of farm conditions. By using the level of water and fertilizer inputs being used on farms, it may be possible to predict actual farm yields from an experimental function. The comparison also suggests that farmers may be able to approximate yields at the upper reaches of the experimental production function. Additional research is needed to explain the "gap" between actual farmer behavior and what these results suggest would be profitable.

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[36] As was previously mentioned, a function was not fitted to the 1964 bush-bean data from the controlled experiment. However, because of the close similarity between the field-corn experimental functions, it is assumed that a close similarity exists between the two experimental bush-bean functions; therefore, for the purposes of this analysis, the 1963 and 1964 experimental functions will be considered identical.

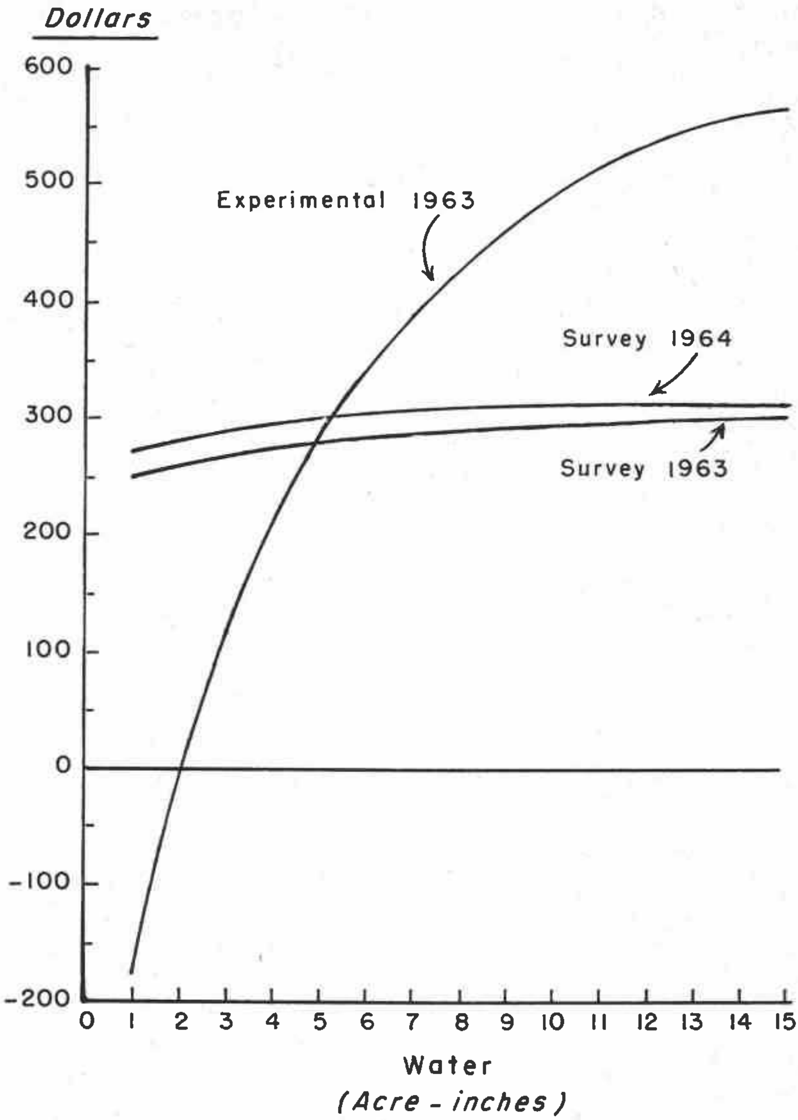

Figure 2. Comparison of the experimental and survey bush-bean production functions.

It was pointed out that the field-corn survey results provided an estimate of the nonirrigated yield and returns. Furthermore, it was shown at the mean levels of inputs that the estimated returns from the survey data were similar to the returns derived from the data of the experiments. Hence, it would appear that if one wanted to make a comparison between irrigated and nonirrigated production, survey data would be adequate. This information would be useful to an agency needing to decide whether irrigation water ought to be made available for crop production.

COMPARISON OF MARGINAL VALUE PRODUCTIVITY SCHEDULES OF WATER

Figures 3 and 4 give a graphic presentation of 1963 marginal value product schedules. The marginal value product measured in dollars is measured on the vertical axis while water is measured on the horizontal axis.

In order that the MVP's derived from the linear programming models and production functions could be plotted on the same graph, the horizontal axis was plotted in terms of inches per acre or 100 inches per 100 acres. In other words, as the water input changes from 1 to 2 acre-inches per acre, the MVP_w as derived from the Woodburn field-corn experimental function drops from $13.40 to $12.17. Likewise, in the linear programming models as the total water input for 100 acres changes from 100 acre-inches of water to 200 acre-inches, the MVP_w drops from $12.69 to $11.26.

The MVP's of water obtained from the survey field-corn function are lower than the MVP curve from the experimental field corn data (Figure 3). A priori, on the basis of the relation between the experimental and survey functions, one would expect this to be true. The comparison of the MVP_w of the survey function and linear programming Models A and B is interesting. Because of the input-output coefficients used in Models A and B, both models are directly related to the survey function. However, only when field corn becomes the marginal user of water can a comparison of the linear programming models and the Cobb-Doublas field-corn function be made. Irrigated corn production enters into the solution matrix in Model A with an MVP_w of $0.09 per acre-inch. The MVP_w remains the same until water becomes nonlimiting, thus forcing the MVP_w to zero. This occurs when the supply of water reaches 449 acre-inches, or a water input of 4.49 acre-inches for each of the 100 acres. The corresponding Cobb-Douglas MVP_w at 4.49 acre-inches is approximately $0.86 per acre-inch.

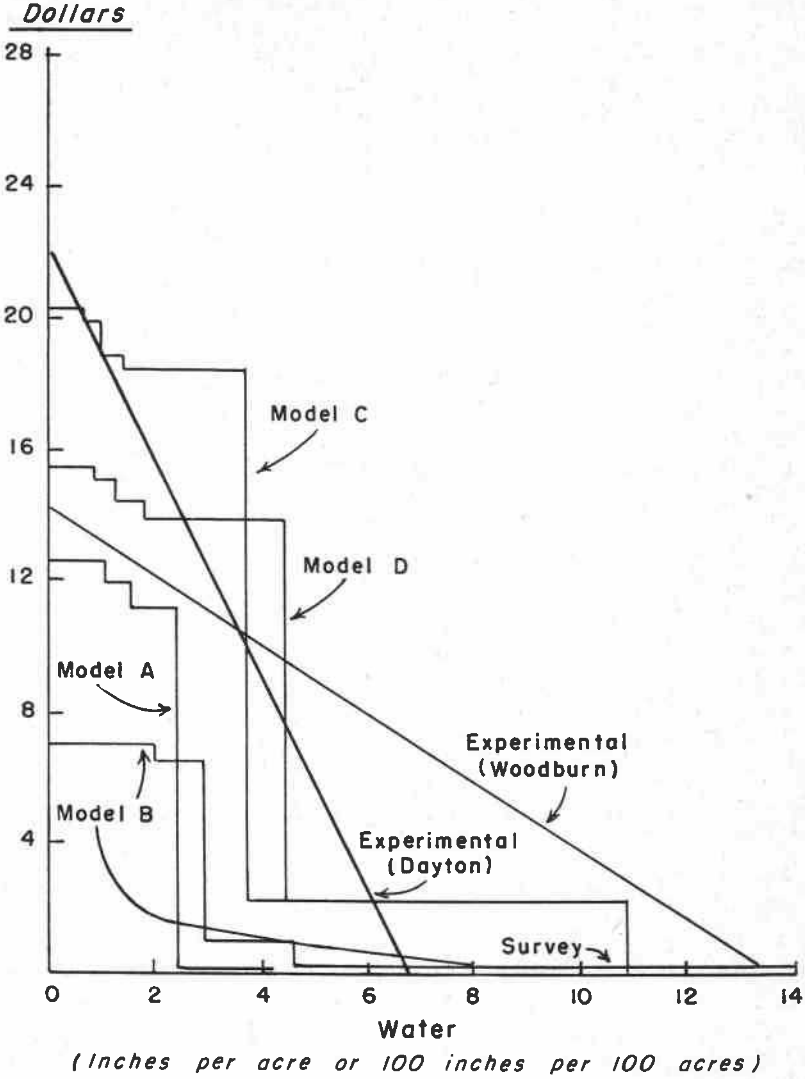

Figure 3. Comparison of MVP_w from linear programming models and 1963 field-corn production functions.

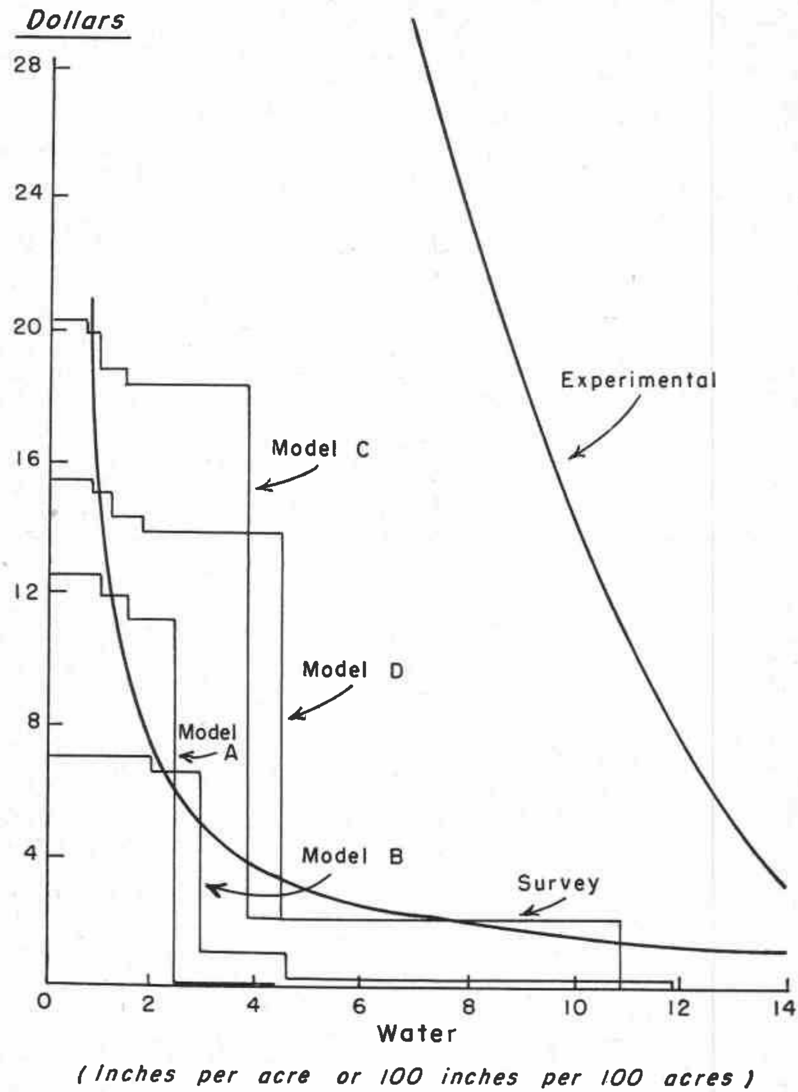

Figure 4. Comparison of MVP_w from linear programming models and 1963 bush-bean production functions.

Model B, which uses estimated consumptive-use requirements (Blaney-Criddle) in predicting yield from the survey function, employs greater amounts of water than Model A. The MVP_w when irrigated field-corn production enters the solution matrix is $0.19 per acre-inch and continues until 1,194 acre-inches of water are employed, at which point it drops to zero. At a water-input level of 11.9 acre-inches per acre, the MVP_w derived from the Cobb-Douglas function is approximately $0.33. Thus, even though some disparity exists between the MVP_w of the two linear programming models and the field-corn function, they appear to be in the same relative zone.

Both linear programming Models C and D, which use yield data from the experimental functions, give the same value of water. This assumes irrigated field corn, the marginal water user in the farm situation depicted by the linear programming models, sets the value of water. Model C is based upon the economic optimal application of water as derived from the experimental functions. Model D is also based upon the experimental functions but uses the Blaney-Criddle consumptive-use requirements to derive the estimated yields. Irrigated corn production comes into the solution matrix of Model C at a supply of 368 acre-inches and into the solution matrix of Model D at 440 acre-inches. In both models the MVP_w at these levels is the same, $2.25 per acre-inch of water.[37] This value continues until the water supply increases to 1,018 acre-inches in Model C and 1,090 in Model D. At the water-input level of 10.2 acre-inches per acre, the MVP_w as derived from the Woodburn function is approximately $3.65; at an input level of 10.8 acre-inches, the derived MVP_w falls to $3.00.

The comparison of the marginal value schedules of water for bush beans is also informative (Figure 4). During the initial parametric changes of the linear programming models, water is only used for irrigation of the beans. It can be noted from Figure 4 that during the initial parametric changes the programming models and the survey function for bush beans yield nearly the same MVP_w. The comparison of these models to the function fitted to the experimental data from Woodburn soil is not as close as was the case with the field corn.

AGENCY CONSIDERATIONS

What does this mean to the public agency which plans for water resource development? If it had access only to survey data in the form

[37] If one were to allocate 4.4 acre-inches of water on the basis of the MVP_w from the experiments for field corn and bush beans (Tables 1 and 2), all of the water would go to bush-bean production. However, in the farm situation depicted in the linear programming model, restrictions such as contract bean acreage, labor, and capital costs require the inclusion of irrigated field corn.

of a Cobb-Douglas or survey function, a lower productivity for water in agriculture would be estimated than if data from experimental plots were available. It was shown that equating the cost of water application to its marginal value productivity resulted in a greater application of water when the experimental function was used in contrast to the survey function. It was also shown that the MVP schedules derived from the experimental functions are higher and to the right of those derived from the Cobb-Douglas functions.

This can be readily seen not only by comparing the experimental and the survey functions but also by comparing the linear programming models. The MVP_w of Models C and D are higher at almost all points than those of Models A and B. Thus, using the equimarginal principle and assuming the marginal value of all competing uses of water to be $7.00 per acre-inch, Model A would dictate the allocation of 2.4 acre-inches of water to agriculture; Model B, 2.0 acre-inches; and Models C and D, 3.7 and 4.4 acre-inches, respectively.

Model B is based upon the Blaney-Criddle consumptive-use formula for estimating the physical water requirements for specific crops. For both crops considered in this study, the agency using the formula would allocate more water to agriculture than the farmers are actually using.

Model D is based upon the Blaney-Criddle consumptive-use formula, whereas Model C is based directly upon the data from the experiment. In regard to corn, the economic optimum amount of water to allocate was 12.4 acre-inches. With respect to bush beans, the amount to be allocated is 14.7 acre-inches. The Blaney-Criddle method would imply allocating 14 inches to field corn and 9.1 to bush beans. Furthermore, a price of approximately $13.80 per acre-inch or less would induce agricultural users to demand approximately the same quantity of water regardless of which linear programming MVP schedule was used. However, using the MVP_w schedule from the experimental function, a price of approximately $10 would allocate the same amount of water. From the evidence presented here, it appears that the Blaney-Criddle method provides results comparable to the running of a physical experiment and the derivation of the economic optimum therefrom. However, such close agreement is not evidenced for bush beans.

One other point should be made clear—an agency charged with allocating water generally approaches the problem by budgeting several different farm situations, usually with and without irrigation. From these budgets, a residual return to water is derived. The return is used to derive the net benefit of irrigation and the repayment schedule for the irrigation structures. Such an approach is useful but does not make the best use of the information available. Production function analysis (interfarm) would allow the incorporation of basic economic principles into the decision-making framework. It would permit estimation of the limits of resource use and the substitution of resources for one another. The use of the Cobb-Douglas type survey function also permits a curvilinear production function. In contrast, budgeting implies a linear production function, or that one can increase output indefinitely simply by adding to the resource inputs. Budgeting also does not provide a mechanism for resource substitution. In view of the advantages of production function analysis, agencies might well consider this procedure for future use.

SUMMARY AND CONCLUSIONS

The study was concerned with the comparison and evaluation of alternative methods of valuing irrigation water as an aid to the water-use and natural-resource planner. Obtaining accurate marginal value product schedules for water is essential to both the efficient use of water and its allocation among competing uses.

The development of data took two forms. First, a survey of bush-bean and field-corn producers in the four-county area of Marion, Linn, Polk, and Benton counties was undertaken. Field corn was selected as a survey crop because of its marginal nature as an irrigated crop. Bush beans were selected because bush-bean production is presently expanding on soils of the Willamette catena and appears to have possibility of continued expansion. Second, in cooperation with other departments on campus two physical experiments were designed and conducted on two soil series of the Willamette catena, Woodburn and Dayton. The Woodburn experiments were conducted at the Hyslop Agronomy Farm in Benton County, and the Dayton experiments on the Jackson Farm in Linn County.

Several estimating techniques were used in obtaining marginal value product schedules for water. These include: production function analysis using survey data, production function analysis using experimental data, and linear programming.

The following conclusions were reached on the basis of the analysis:

1. No significant difference exists between the cited management practices and the productivity of three of the Willamette catena soils—Willamette, Woodburn, and Amity. It was hypothesized that the reason for the similarity of yields and returns was the greater usage of drains by farmers in the survey area producing on Amity soils. The difference in the use of artificial

drainage was significant, both in the case of field corn and of bush beans.

2. The marginal productivity schedule of water from the survey data indicates that the value of irrigating field corn grown for grain is low under present management practices. This substantiates the hypothesis of the marginal nature of irrigated field-corn production as presently conducted in the survey area.

3. Over the interval of observed water application rates, the production functions fitted to both the survey data and the data from the experiments provide approximately the same yields. This suggests that farmers may use experimental results as a guideline for increasing production. By the addition of fertilizer and water, results comparable to experimental work may be obtained.

4. If an agency were only interested in a comparison between irrigated and nonirrigated production, survey data would be adequate. This is inferred from two points. First, the data from the survey gave more reasonable estimates of nonirrigated production than the data from the experiments. Second, at the mean level of water input, both the survey and the experimental functions gave almost identical estimates of yield. This information would be useful in deciding if irrigation ought to be made available for crop production.

5. In view of the additional information which is made available by the use of production function analysis with survey data, it is suggested that agencies charged with water allocation should examine interfarm production function analysis with the view of using it to replace or supplement traditional budgeting techniques.

6. Linear programming Models C and D yield the same estimates for the value of water. Both models are based upon the 1963 experimental functions, bush bean and field corn. The water input in Model C, however, is the economic optimal application rate, while in Model D it is the water requirement estimated by the Blaney-Criddle consumptive-use formula. It is concluded from the results of the two models that the Blaney-Criddle method provides results comparable to running a physical experiment and deriving the economic optimum therefrom.

7. The MVP_w schedule for both bush-bean and field-corn production functions fitted to data from the experiments are generally higher and to the right of the survey MVP_w schedule. This can also be shown by comparing linear programming Models A and B, which utilize survey input-output data, with Models C and D, which use input-output data from the experiments. Therefore, equating the cost of water application to the marginal value productivity schedule resulted in a greater application of water when data from the experiment were used in contrast to the survey data.

APPENDIX

Yields of Physical Experiments

APPENDIX TABLE 1. YIELDS OF BUSH BEANS IN TONS PER ACRE, WOODBURN SOIL, 1963

Treatment[1]	Replications 1	2	3	4
		tons per acre		
W_1 N_1	3.40	3.25	3.37	2.79
N_2	2.83	2.74	3.69	3.41
W_2 N_1	3.93	4.12	3.06	3.25
N_2	3.12	4.83	3.34	3.72
W_3 N_1	5.23	3.92	3.77	4.24
N_2	5.95	5.79	5.47	4.98
W_4 N_1	5.75	4.21	4.83	3.99
N_2	5.43	6.33	6.33	4.98

[1] Irrigation levels:
W_1—irrigated when tension was equivalent to 2.5 bars.
W_2—irrigated when tension was equivalent to 1.5 bars.
W_3—irrigated when tension was equivalent to 0.8 bars.
W_4—irrigated when tension was equivalent to 0.5 bars.
Nitrogen levels:
N_1—50 pounds of available nitrogen per acre.
N_2—100 pounds of available nitrogen per acre.

APPENDIX TABLE 2. YIELDS OF FIELD CORN IN BUSHELS PER ACRE AT 15.5 PERCENT MOISTURE, WOODBURN SOIL, 1963

Treatment[1]	Replications			
	1	2	3	4
	bushels per acre			
W_0 N_1 S_1	24.6	30.7	24.7	28.2
S_2	33.2	39.2	22.5	23.1
N_2 S_1	21.4	24.0	28.1	30.8
S_2	27.2	25.4	28.9	31.5
N_3 S_1	18.0	26.9	21.6	26.3
S_2	18.9	22.1	28.2	23.0
W_1 N_1 S_1	84.5	90.1	92.9	91.5
S_2	95.7	106.6	95.5	80.5
N_2 S_1	74.1	94.6	104.8	96.2
S_2	109.2	107.0	106.0	110.4
N_3 S_1	90.1	89.9	88.3	77.8
S_2	95.4	101.5	83.8	110.1
W_2 N_1 S_1	117.3	105.7	102.7	115.9
S_2	107.8	113.1	136.7	116.9
N_2 S_1	125.4	110.8	109.7	92.0
S_2	149.7	125.3	137.0	152.9
N_3 S_1	107.1	107.8	130.9	104.5
S_2	146.2	119.3	106.9	134.6
W_3 N_1 S_1	110.6	112.0	122.0	112.8
S_2	109.1	134.4	104.4	120.9
N_2 S_1	120.5	108.4	125.1	116.6
S_2	151.3	157.0	163.6	142.0
N_3 S_1	122.5	122.1	113.2	113.1
S_2	147.9	147.9	147.5	146.9

[1] Irrigation levels:
- W_0—no irrigation.
- W_1—irrigated when tension was equivalent to 6 bars.
- W_2—irrigated when tension was equivalent to 1.5 bars.
- W_3—irrigated when tension was equivalent to 0.8 bars.

Nitrogen levels:
- N_1—60 pounds of available nitrogen per acre.
- N_2—120 pounds of available nitrogen per acre.
- N_3—180 pounds of available nitrogen per acre.

Stand levels:
- S_1—15,000 plants per acre.
- S_2—25,000 plants per acre.

Appendix Table 3. Yields of Field Corn in Bushels per Acre at 15.5 Percent Moisture, Woodburn Soil, 1964

Treatment[1]	Replications 1	2	3
		bushels per acre	
W_0 N_1 S_1	43.0	22.5	36.9
S_2	14.2	32.9	7.4
N_2 S_1	32.2	18.3	38.1
S_2	20.6	18.4	13.9
N_3 S_1	26.1	29.8	27.1
S_2	20.2	20.0	25.7
W_1 N_1 S_1	78.6	78.5	85.2
S_2	105.4	80.0	87.6
N_2 S_1	92.2	92.7	68.2
S_2	108.6	81.4	104.4
N_3 S_1	97.8	95.0	81.4
S_2	103.4	83.2	93.9
W_2 N_1 S_1	120.5	94.8	95.3
S_2	121.4	114.3	116.4
N_2 S_1	128.2	109.5	95.9
S_2	119.0	130.1	113.1
N_3 S_1	121.1	125.1	102.3
S_2	105.8	123.5	127.1
W_3 N_1 S_1	131.8	132.4	122.0
S_2	146.3	108.7	118.2
N_2 S_1	135.2	128.9	141.9
S_2	148.9	125.3	146.1
N_3 S_1	131.9	137.1	129.5
S_2	146.6	130.2	146.7

[1] Irrigation levels:
- W_0—no irrigation.
- W_1—irrigated when tension was equivalent to 6 bars.
- W_2—irrigated when tension was equivalent to 1.5 bars.
- W_3—irrigated when tension was equivalent to 0.8 bars.

Nitrogen levels:
- N_1—60 pounds of available nitrogen per acre.
- N_2—120 pounds of available nitrogen per acre.
- N_3—180 pounds of available nitrogen per acre.

Stand levels:
- S_1—15,000 plants per acre.
- S_2—25,000 plants per acre.

Appendix Table 4. Specific Practices, Yields, and Materials Used, Field Corn and Bush Beans, Survey Area, 1963

Item	Unit	Field corn			Bush beans[1]
		Nonirrigated	Irrigated	Total	Irrigated
Completed questionnaires					
Willamette and Woodburn	Number	12	11	23	9[2]
Amity and Dayton	Number	12	8	20	9
Acres					
Average	Number	29.9	32.8	31.2	75.1
Range	Number	1-83	9-135	....	15-250
Date of planting					
Average	....	May 23	May 22	....	May 23
Range	....	May 13-June 15	May 5-June 1	....	May 15-June 7
Cultivations, per acre					
Average	Number	2.4	2.6	2.5	2.6
Range	Number	1-4	2-4	....	1-5
Available nitrogen, per acre					
Average	Pounds	49	71	59	66
Range	Pounds	0-100	32-163	....	48-96
Times irrigated					
Average	Number	0	1.5	....	2.8
Range	Number	0	1-3	....	2.4
Water application, per acre					
Average	Acre-inch	0	4.05	....	4.6
Range	Acre-inch	0	1.5-11.1	....	3.2-6.0
Drainage, per acre					
Average	Feet	152.0	100.5	129.6	236.0
Range	Feet	0-1,143	0-450	....	0-786
Yield, per acre					
Average	Tons	1.66	2.2	1.9	3.1
Range	Tons	1-2.8	1.25-3.0	....	2.4-3.9

[1] All bush bean producers sampled except one irrigated bush beans during 1963. The data is only for the irrigating producers.
[2] One nonirrigating producer grew bush beans on Willamette soil.