Yield and Economic Implications of Sugarbeet Production as Influenced by Irrigation and Nitrogen Fertilizer[1]

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Introduction

The influence of irrigation and of soil nitrogen fertility levels on the yield of roots and sucrose by sugarbeets has been reported for various conditions of climate and soils (2, 5, 7, 9, 14, 16, 17)[3]. Recommendations developed for irrigation scheduling and nitrogen fertilization practices have usually been based upon a goal of maximum production and not of maximum profit to the producer. Even so, there has been considerable variation in the experimental results and in the conclusions drawn from the studies. Haddock (5) recommended that irrigation should begin when the soil moisture tension (matric suction) at the 12-inch depth is about 0.5, 0.8, and 2.0 bars for sandy loam, loam, and clay loam soils, respectively. In general, the yield of roots and sucrose has been shown to decrease as the matric suction allowed to develop between irrigations increases. An oversupply of water appears to be less harmful than a deficiency, but excesses may also decrease beet yields (12). Numerous studies have shown that the concentration and purity of sucrose in the root decrease as the soil nitrogen available to the crop is raised above critical levels, particularly during the latter part of the growing season (2, 8, 13, 15, 16). The reduction in sucrose content and purity often results in a maximum yield of extractable sugar at a lower level of nitrogen than that required for maximum root yield (15).

The magnitude of yield variability due to plant population density has not been satisfactorily determined. Plant density may vary due to spacing at thinning or to death of plants subsequent to thinning. Considerable controversy has occurred concerning the recommended row width and plant spacing (3, 10, 14). Moraghan (9) has shown that water use by the crop may be influenced by plant spacing. This could influence the results obtained from irrigation experiments.

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[3] Numbers in parentheses refer to literature cited.

The purpose of this study was to examine the economic implications of irrigation and nitrogen fertilizer levels in sugarbeet production at Walsh, Colorado in the extreme southeastern corner of the state. The region is one of very high potential evapotranspiration, due particularly to hot winds, and only a limited irrigated area has been developed from groundwater supplies. Three variables—available soil nitrogen, water use by the crop, and plant spacing—were analyzed in relation to root yield, sucrose percentage, and net return to be received by the producer. Knowledge of these relationships may be a useful tool in production planning. Using multiple regression techniques the relationship of nitrogen, water, and plant density to root yield and sucrose percentage is determined. These relationships are then incorporated into an equation defining the return received by the producer, and the input levels which maximize profit are derived. Production function analysis is a standard economic technique for examining input-output relationships. The basic procedure can be found in a number of sources, an excellent example of which is Heady and Dillon (6).

Field Study

Field plots were established on a deep clay loam soil at the Colorado State University Irrigation Research Center at Walsh, Colorado during 1970. Five levels of nitrogen fertilization and five irrigation treatments were included in an incomplete randomized block design, with 22 plots per block and two replications of each block. Treatment levels and replications are given in Table 1.

Table 1.—Irrigation and nitrogen fertilizer treatments.

	Irrigation Treatments			Nitrogen	Total
Treatment Designation	Max. Suction Bars[a]	No. of Irrigations	Inches Applied[b]	Fertilizer lbs/acre N	Number of Plots
I-0	0.65	7	21	0	4
I-100	0.65	7	21	100	4
I-400	0.65	7	21	400	4
II-50	1.00	5	15	50	2
II-200	1.00	5	15	200	2
III-0	3.00	4	12	0	4
III-100	3.00	4	12	100	4
III-400	3.00	4	12	400	4
IV-50	6.00	4	12	50	2
IV-200	6.00	4	12	200	2
V-0	9.00	3	9	0	4
V-100	9.00	3	9	100	4
V-400	9.00	3	9	400	4

[a] Soil water suction at 12-inch depth when irrigation applied.

[b] Acre inches per acre added to soil profile during growing season.

The sugarbeets were planted on April 6 and thinned and side-dressed with ammonium nitrate on June 5 and 6. Each plot consisted of eight 22-inch rows 30 feet in length, surrounded by a border dike and separated from adjacent plots by alleys approximately seven feet wide. Electrical resistance units (Bouyoucos gypsum blocks) were placed in each plot at the 12-inch depth. Irrigation treatments were based upon the soil water suction as measured by the gypsum blocks. When the average suction for the plots in a given treatment reached the desired value (see Table 1), those plots were irrigated by applying three inches of water, metered accurately into each basin. Application efficiency, therefore, approached 100 percent. The number of irrigations and the seasonal application rates are given for each irrigation treatment in Table 1. Seasonal consumptive use of water was calculated for each irrigation treatment from the amount of water added by irrigation and precipitation and the difference in soil moisture content at the beginning and end of the season. On July 8 soil samples were taken in the alleys at the corners of adjacent plots. The samples were obtained in one-foot increments to a depth of four feet and were analyzed for organic matter and nitrate nitrogen contents. Using conversion factors of 30 pounds per acre foot of nitrogen for each percent organic matter and 3.6 pounds per acre foot for each ppm of NO_3-N, the amount of residual soil nitrogen becoming available to the crop was estimated. This was added to the fertilizer application to provide the amount of nitrogen available to the crop for each plot (11). The average for all plots was approximately 107 pounds per acre of residual soil nitrogen. Petiole samples were collected from random plants in each of the four center rows of each plot on September 2. These were analyzed for total nitrogen content.

Climatological data, summarized in Table 2, were obtained from an official weather station at the Research Center and from a thermograph used to measure soil temperature. Rainfall for the growing season was 12.46 inches compared to the long-term average precipitation in the area of 11.77 inches for the months of April-October. An unusually high amount of rainfall occurred in August.

The plots were harvested on October 23 and 24. An area four rows wide and 22 feet long in the center of the plots was used in order

Table 2.—Summary of climatological data.

Month	Air Temp. (°F)		Soil Temp. at 4 in. (°F)		Rainfall (inches)	Open Pan Evaporation (inches)
	Maximum	Minimum	Maximum	Minimum		
April	65.3	33.8			1.12	9.76
May	82.0	50.2			0.19	14.04
June	86.5	55.0	83.3	67.3	0.30	16.17
July	91.4	64.4	87.6	68.2	2.77	13.66
Aug.	92.1	66.4	81.9	64.9	5.11	14.35
Sept.	83.1	50.4	76.5	61.5	2.47	10.25
Oct.	64.0	55.0			0.50	5.17

to avoid border effects. The beets harvested from each plot were counted and percent stand was calculated as the number of beets per 100 feet of row. A sample of beets from each plot was obtained at random for tare, sucrose percentage, and apparent sucrose purity determinations. The average yield and quality for Baca County, Colorado in 1970 was 13.5 tons per acre with 13.7 percent sucrose and 86.0 percent purity.

Table 3.—Average yield and quality of sugarbeets at harvest and petiole nitrogen content on September 2.

Treatment	Root Yield Tons/Acre	Sucrose %	Purity %	Extractable Sugar Tons/Acre	Petiole N %
I-0	18.6	16.8	96.4	2.92	1.20
I-100	19.5	15.6	94.9	2.90	1.43
I-400	21.8	12.7	91.6	2.52	2.67
Ave.	20.0	15.1	94.3	2.78	1.77
II-50	19.0	15.9	96.5	2.91	1.29
II-200	17.4	14.2	92.5	2.25	2.06
Ave.	18.2	15.0	94.5	2.58	1.68
III-0	13.9	14.2	96.0	1.82	1.18
III-100	17.2	15.3	94.4	2.49	1.65
III-400	14.1	12.0	88.2	1.49	2.55
Ave.	15.1	13.8	92.8	1.94	1.79
IV-50	16.9	16.9	97.9	2.83	1.13
IV-200	15.3	12.0	90.3	1.66	1.96
Ave.	16.1	14.5	94.1	2.24	1.55
V-0	13.2	15.1	95.8	2.00	1.12
V-100	14.4	14.0	93.4	1.87	1.34
V-400	14.5	10.4	87.3	1.32	2.51
Ave.	14.0	13.2	92.2	1.73	1.66

The total water use by the crop, as determined from irrigation applications, rainfall, and soil water contents at the beginning and end of the season, varied almost directly with the amount of water made available by irrigation (Table 4). Comsumptive use by the crop grown under irrigation treatment I was probably very near the potential for the climatic conditions of the season since the soil moisture stress was maintained at very low levels all season. Transpiration was restricted in the other treatments due to limited availability of soil water during varying periods prior to each irrigation. Nitrogen fertilizer levels within irrigation treatment did not influence seasonal water use. This is as expected since evapotranspiration is essentially controlled by soil water and climatic conditions whenever the crop provides full ground cover. Water use efficiency for the various treatments, expressed in terms of sucrose production per unit of water, is given in Table 4. The values are calculated for both total water use by the crop and for irrigation water applied.

Table 4.—Seasonal consumptive use and water efficiency.

Treatment	Consumptive Use (inches)	Water Use Efficiency Pounds Sucrose per Acre Inch (C.U.)	Water Use Efficiency Pounds Sucrose per Acre Inch (irrigation)
I-0	34.3	170	278
I-100	34.8	167	276
I-400	35.2	143	240
II-50	30.8	189	388
II-200	31.0	145	300
III-0	27.3	133	303
III-100	27.5	181	415
III-400	27.6	108	248
IV-50	27.6	205	472
IV-200	27.8	119	277
V-0	24.5	163	444
V-100	23.8	157	416
V-400	25.4	104	293

Production Function Analysis

Root yield

A production function for sugar beet yield was fitted through multiple regression techniques. The equation which exhibited the best fit was the following:

$$[1]\quad \begin{aligned} Y = {} & 30790.92765 - 822.84063\,S + 13.19953\,N \\ & + 1810.44025\,W + 1.60913\,S^2 - .10324\,N^2 \\ & - 41.68863\,W^2 + .34872\,SN + 13.70151\,SW + .46103\,NW \end{aligned}$$

$R^2 = .5222$ $\qquad$ $F = 4.1286$

Where:

Y = estimated yield of sugar beets, measured in pounds per acre

N = amount of available nitrogen (total of applied and residual), measured in pounds per acre

W = consumptive use of water, measured in inches per acre

S = percentage stand, using one beet per foot = 100 percent stand as the basis

The model explains about 52 percent of the observed variation in yield and the F-statistic is significant at the .0012 level. In the linear formulation of the model, only the coefficient for water was significantly different from zero at the five percent probability level. The full quadratic form, as in equation [1], was chosen because it exhibits diminishing returns to the independent variables and has a higher proportion of explained variance. However, in the full quadratic form, none of the regression coefficients is significantly different from zero at the five percent level.

Alternative formulations were tested, in which applied nitrogen and applied irrigation water were the independent variables, but they were less satisfactory than equation [1] in terms of the above measures of statistical reliability. Data representing the variables in equation [1] were also fit to linear and logarithmic equations, but these approaches were also less satisfactory.

Equation [1] was used to predict yields of sugar beets at various levels of available nitrogen and water consumption, given 100 percent stand. The results are displayed in Table 5. The equation could also be evaluated at any other plant density within the range of the observations.

Table 5.—Predicted yield of sugar beets in pounds per acre, at 100 beets per 100 feet and varying levels of nitrogen and water.

Total Water Consumption	Available Nitrogen (lb./A.)							
(in.)	50	100	150	200	250	300	350	400
21	15,648	17,762	19,359	20,440	21,004	21,053	20,585	19,601
23	18,387	20,546	22,190	23,317	23,928	24,022	23,601	22,664
25	20,792	22,998	24,687	25,860	26,517	26,658	26,282	25,391
27	22,864	25,116	26,851	28,070	28,773	28,960	28,631	27,785
29	24,602	26,900	28,681	29,947	30,696	30,929	30,646	29,846
31	26,006	28,350	30,178	31,490	32,285	32,564	32,327	31,592
33	27,078	29,467	31,342	32,699	33,540	33,866	33,675	32,967
35	27,815	30,252	32,171	33,575	34,462	34,834	34,689	34,028
37	28,219	30,702	32,668	34,118	35,051	35,468	35,370	34,755
39	28,290	30,818	32,830	34,326	35,306	35,770	35,717	35,148
41	28,027	30,602	32,660	34,202	35,228	35,737	35,731	35,208
43	27,430	30,051	32,156	33,744	34,816	35,371	35,411	34,934

The number of beets per 100 feet of row was not an experimental variable in the study. However, considerable variation in stand did occur in the experiment, and thus a variable representing stand was included in the statistical analysis. The values estimated for the coefficients of the stand variables (S and S^2) in equation [1] imply that within the range of the experimental observations, yield exhibits slightly increasing returns to percentage stand. That is, if water and nitrogen are held constant, an increase in stand by a given percentage is predicted to increase yield by an even greater proportion. A wider range of observations on the stand variable would no doubt encounter a range of diminishing returns.

Sucrose percentage

It is equally important in this study to be able to predict the effects on sucrose percentage when each of the inputs is varied, since contract payment formulas are based on sucrose percentage as well as on beet tonnage and the net return which the sugar processor receives on the market. The grower cannot directly control the price of the refined sugar, but he can influence the first two variables, and through them his returns and profits are affected.

In order to be able to predict sugar percentage, the experimental results were subjected to regression analysis and equation [2] derived:

$$[2]\quad \%S = 7.75434 + .00007\,S + .00318\,N + .2761\,W - .00008\,S^2 - .00002\,N^2 - .00625\,W^2 - .00002\,SN + .00178\,SW + .00003\,NW$$

$R^2 = .6636$ $F = 6.36$

Where:

$\%S$ = predicted percentage sucrose, and the other symbols are as previously defined

In the linear formulation, coefficients for water and nitrogen were significantly different from zero at the five percent level of probability and for stand at the ten percent level.

Equation [2] was used to generate the values shown in Table 6. Sugar percent consistently decreases with increases in available nitrogen, and decreases more rapidly at very high levels. In general, sugar content increases as total water use increases, except at very high levels. Abundant water tends to offset the negative effects of high levels of nitrogen. Two factors which were not considered in this experiment, temperature and light (and their interaction), probably play as important a part, or more so, than do nitrogen and water as influences on sugar percentage.

For the purpose of this study, purity percentage was ignored in the Production Function, since none of the samples from the test fell below 80 percent purity, the point at which a penalty is imposed by the sugar company. Purity was used to calculate extractable sucrose, however.

Table 6.—Expected sugar percentages, at 100 beets per 100 feet and varying levels of nitrogen and water.

Total Water Consumption (in.)	Available Nitrogen (lb./A.)						
	50	100	150	200	250	300	350
21	13.8	13.7	13.6	13.3	12.9	12.5	11.9
23	14.1	14.1	13.9	13.7	13.3	12.8	12.3
25	14.4	14.4	14.2	14.0	13.6	13.2	12.6
27	14.7	14.7	14.5	14.3	13.9	13.4	12.9
29	14.9	14.9	14.7	14.5	14.1	13.7	12.9
31	15.1	15.0	14.9	14.6	14.3	13.8	13.3
33	15.2	15.1	15.0	14.8	14.4	14.0	13.4
35	15.2	15.2	15.1	14.8	14.5	14.1	13.5
37	15.3	15.2	15.1	14.8	14.5	14.1	13.5
39	15.2	15.2	15.0	14.8	14.5	14.1	13.5
41	15.1	15.1	15.0	14.7	14.4	14.0	13.4

Payment to grower

The total price received by the grower is based on both percentage sugar content of the beets and the processor's "average net return" on sugar. The processor's average net return on sugar is determined by deducting from the price for which the processor sells refined sugar certain specified operating expenses. The schedule specifying payments per ton for varying levels of sugar content and average net return is typically provided in the company's grower contract.

The actual net returns in the study area were $ .0853/lb. in 1969, $ .0922/lb. in 1970 and $ .0984/lb. in 1971. Hence, we used $ .10 per lb. in subsequent calculations.

Using the guidelines found in the contract (1), a simple formula for price per ton of sugar beets was calculated by a regression fit to the contract table.

Net Receipts to Grower

The information from the above sections provides the basis for determining net receipts per acre to the grower under alternative water and nitrogen applications. The total payment per acre of sugar beets is a direct function of three variables: the yield of sugar beets per acre, the average sugar percentage, and the average net return (ANR) on sugar to the processor. Both the yield of sugar beets and the sugar percentage are in turn dependent on the amounts of water and nitrogen and the plant population used in beet production.

Gross return per ton estimates for alternative nitrogen and irrigation applications were generated using the price formula, percent of sucrose values drawn from equation [2], and assuming ANR = $ .10. Each figure thus generated was then applied to the appropriate sugar beet yield derived from equation [1].

To determine net receipts per acre to the grower, costs of applied water and nitrogen were subtracted from gross returns. Up to this point, water and nitrogen were expressed on a total available basis. However, in order to compute input costs, only the amount of irrigation water and fertilizer actually applied must be considered. To adjust total available nitrogen levels to nitrogen applied, 100 pounds (approximately the average residual nitrogen level of the soil) was subtracted. Thus, if the optimum amount of available nitrogen were 150 pounds per acre, the approximate amount necessary for the producer to apply would be 50 pounds per acre. In the case of irrigation water, adjustments must be made for effective rainfall, soil moisture depletion, and on-farm delivery losses. The long-term average rainfall in the area during the growing season has been 11.77 inches and the average soil moisture depletion measured in this particular experiment was 2.60 inches. It is further assumed that in commercial production one-third of the water diverted or pumped is lost during irrigation (i.e., farm irrigation efficiency is 67 percent).

A sample net return array is shown in Table 7. The figures in the table would vary as plant density, average net return on sugar, and the prices of water and nitrogen vary. Under the assumptions defined for Table 7, where variable water costs are $ .50 per acre inch and nitrogen costs $ .08 per lb., maximum net return over variable nitrogen and water costs would occur where approximately 100 pounds of nitrogen fertilizer and 37 inches of irrigation water are used. Note, however, that a fairly wide range of water and nitrogen inputs can lead to profits which closely approximate that of the optimum levels. Thus, any combinations of water diversion ranging from 28 to 40 inches and nitrogen ranging from 50 to 150 lbs. per acre delivered returns that were not strikingly less than the optimum.

Table 7.—Net return in dollars per acre over variable input cost[a].

Irrigation Water Diverted (in./A.)	Nitrogen Fertilizer Applied (lb./A.) 0	50	100	150
	$	$	$	$
10.5	122.81	129.26	129.63	124.95
13.5	146.01	151.68	153.37	148.51
16.5	166.53	172.65	174.47	169.48
19.5	185.27	191.79	194.04	188.87
22.5	200.59	207.46	209.99	204.97
25.5	212.07	220.90	222.04	218.84
28.5	221.04	230.39	233.46	228.65
31.5	227.48	237.13	238.81	236.06
34.5	229.59	239.60	241.55	239.07
37.5	229.03	237.59	241.68	239.52
40.5	224.11	234.74	237.33	235.48

[a] Return is net of nitrogen and water costs only. Assumptions: 100 beets per 100 feet, $ .10 average net return on sugar, $ .50 per acre-inch of water, 67 percent irrigation efficiency, $ .08 per pound of nitrogen.

Summary, Conclusions, and Limitations

Production functions for sugar beet root yield and sucrose percentage using total available nitrogen, consumptive use of water, and plant density as independent variables were derived from a field experiment conducted at Walsh, Colorado, during 1970. Coefficients of multiple correlation were .52 and .66, respectively. Yields and sucrose percentage were predicted for various nitrogen and water levels, using a given stand level of one beet per foot of row. A formula to relate the processor's average net return and sugar percentage of beets to the grower's price per ton was devised. Combining this formula with the predicted yields and sugar percentages produced an array of expected gross returns associated with varying levels of nitrogen and water. Input costs of water and fertilizer were subtracted to determine the maximum net return and optimal input levels. Net return over variable cost was highest at 37 inches of water diverted (assuming 67 percent application efficiency) and 100 pounds of nitrogen applied per acre.

Total available nitrogen levels tended to be high in this experiment as a result of a moderately high level of residual soil nitrogen (average 107 pounds per acre). Thus, little response to applied nitrogen was evident in root yields, and applied nitrogen fertilizer significantly decreased sugar percentage. Nitrogen had relatively little influence on net returns because of the relatively low cost of fertilizer.

Optimum water consumption is extrapolated beyond the bounds of the experimental data, and should be handled with caution. Also, the estimated cost per acre-inch of water, $ .50, reflects only variable pumping and application costs. It does not take into account the value of water as a nonrenewable resource (i.e., the fact that it may be worth more left in the aquifer for potential future use), nor does it account for the opportunity cost of water for other crops or purposes.

Plant density was not originally a variable in the experiment, but was included because a great deal of variation was evident. The range of spacings encountered in the experiment showed increasing returns to plant density; this would not be expected to hold as plants became very crowded.

These conclusions are applicable to the soil, climate, moisture, and fertility conditions experienced in this particular experiment, and can be applied to other situations only with due caution. Doll (4) has provided a pertinent discussion of the applicability of economic conclusions drawn from a single year's experiment.

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