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IRRIGATED SUGARBEETS:

Yield Response and Profit Implications, Texas High Plains

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Contents

Irrigated Sugarbeets: Yield Response and Profit Implications, Texas High Plains

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Sugarbeets (*Beta vulgaris* L.) in Texas are grown solely in the High Plains. In 1985, four counties (Castro, Deaf Smith, Parmer, and Randall) contributed 98 percent of the 37,000 acres of sugarbeets harvested in Texas (Texas Agricultural Statistics Service, 1958-1985). Acreage increased dramatically in 1964, when Holly Sugar Corporation opened a processing plant at Hereford, Texas. Harvested acreage increased from the 2,000-acre range in 1958-1963 to 25,900 acres in 1964. Acreage continued to increase to a peak in 1969 of 37,000 acres but then declined to the lower 20,000-acre range in the early 1970's. By 1985, acreage again reached 37,000 acres, equal to the late 1960's level. Sugarbeet root yields averaged 19.2 tons per acre from 1958 to 1985 and ranged from a low of 13.1 tons per acre in 1975 to 22.8 tons per acre in 1981 (Texas Agricultural Statistics Service, 1958-1985).

Sugarbeets are typically grown in 5-year crop rotations to minimize the incidence of diseases. Thus, not more than one-fifth of a producer's acreage should be planted to sugarbeets in any one year. Sugarbeets typically follow wheat in the northern counties and cotton in the southern producing area but may also follow corn, sorghum, and other crops to a lesser extent.

The growing season for sugarbeets in the Texas High Plains extends from April through October, which includes the 6 months with the highest potential evapotranspiration (ET). The semi-arid climate, having an annual rainfall of only 18 inches and high summer temperatures and winds, necessitates irrigation for consistent production. Eighty-three percent of the annual rainfall occurs during the 6-month growing season. However, rain frequently occurs in high-intensity storms. Sugarbeets are typically grown on graded furrows, where the high soil moisture levels after irrigation can increase storm runoff. As a result, irrigation requirements are higher than may be expected. Emergence irrigation is a common practice to help ensure a stand. Sugarbeet leaves typically shade the soil effectively before the evaporation potential reaches its peak in July of slightly more than 0.30 inches per day (Schneider and Mathers, 1969).

Sugarbeets have traditionally received full irrigation in the Texas High Plains to produce high yields and to maximize profits. Fully irrigating beets was common when underground water supplies were abundant and energy costs for pumping were relatively low. However, as water supplies diminished and energy costs increased over the past decade, producers tended to reduce water applications.

Researchers have evaluated sugarbeets under water stress conditions and have found them to be stress tolerant but also highly responsive to irrigation up to the amount needed to totally satisfy evapotranspiration (Haddock, 1955; Hobbs et al., 1963; Carter et al., 1980a; Carter et al., 1980b; Winter, 1980).

The effects of irrigation and nitrogen on root quality have also been studied (Brewbaker, 1934; Haddock and Kelly, 1948; Archibald and Haddock, 1952; Haddock, 1959; Erie and French, 1968; Parashar and Dastane, 1973; Carter, 1980b; Barbieri, 1982; Winter, 1989). Research indicates that excessively high levels of nitrogen lowers sugar content.

Nicholson et al. (1974), in Colorado, developed a multivariate production function that predicted sugarbeet root yields as related to available nitrogen, consumptive use of water, and percentage of stand. The function explained only 52 percent of the observed variation in yield. In 1978, Hexem and Heady, using experimental data from Arizona, Colorado, and Texas, developed production functions reflecting the yield-water-nitrogen relationships for sugarbeets. The ability to explain these relationships varied from site to site and year to year. A range of approximately from

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40% to 93% of the yield variation was explained. The quadratic function developed at Plainview, Texas, for 1971 explained only 41 percent of the observed variation in yields. Hoyt (1984) developed a single variate production function, which predicted sugarbeet sucrose in pounds per acre relative to irrigation water applied plus rainfall. Although this relationship explained 92 percent of the variation in sucrose yields, it was based on only 1 year of data. Solomon et al. (1985) reviewed other sugarbeet functional forms relating evapotranspiration to yields.

Limitations of these yield relationships point to the need for an improved sugarbeet production function to assess causal factors of yield response in the Texas High Plains and to evaluate the profitability of production. The objectives of this research were to (1) develop a production function relating irrigation levels, nitrogen rates, and rainfall to root yields, and (2) assess the economic implications to gross sales, production costs, and profits.

Research Methods

The sugarbeet research was conducted at Bushland, Texas, on Pullman clay loam soil (fine, mixed Thermic Torrertic Paleustoll). This soil has a moderately permeable surface of about 10 inches thick. The subsoil, extending to 21 inches, is a very slowly permeable clay. Because of the very low permeability of this soil, loss of water or nitrate-nitrogen (NO_3-N) to deep percolation would have been negligible during these studies (Winter, 1981).

The cultivars Mono-Hy D2 (1976-79) and Mono-Hy TX9 (1982-87) were seeded on 30-inch beds in late March or early April. Over the years of research (1976, 1977, 1978, 1979, 1982, 1984, 1986, and 1987), seeding rates were held constant at 6 to 7 seeds/ft, and the resulting stands were thinned to 8 inches between plants, resulting in 26,000 plants/acre. Irrigation plots each year included eight 30-inch-wide rows that varied over the years from 35 to 90 feet in length. The plots were relatively disease free compared with typical producer fields. Two or more of the center rows from each plot were harvested for yield in November. Sugarbeets were produced each year in level borders to improve the accuracy of measuring irrigation water applied to the plots and rainfall received on the plots. The amount of water applied was measured with an in-line flow meter. All treatments were uniformly watered for emergence in the spring. In most years, seasonal irrigations of three different levels were applied during the period of about June 10 to September 10.

Total available nitrate-nitrogen in the root zone was measured from 0 to 6 feet deep each year before planting. In some years, varying rates of fertilizer nitrogen were applied according to expected root yield (which depended mainly on irrigation) and residual nitrogen levels. This research negated the interaction between high nitrogen rates and sugar content by avoiding excessive rates of nitrogen that could lower sugar content. Other inputs except irrigation and nitrogen were the same for all irrigation treatments.

Sugarbeet root yields were determined for each of the 8 years (Appendix Table 1, Appendix A). During this period, 2 to 6 replications of each treatment were evaluated, giving a total of 246 observations (Appendix Table 1, Appendix A). Available nitrogen (residual + applied) ranged from 40 pounds to 458 pounds, and total irrigation water (preplant + seasonal) ranged from 3.0 inches to 30.5 inches.

Sugarbeet Production Function

From the aforementioned research data, a production function predicting root yields was developed. A multivariate regression analysis using the Reg Procedures (SAS) resulted in the following predictive equation:

$$
\begin{array}{lllllll}
[1]\ Y = & 6.8723 & + 0.032813\,TI^2 & - 0.000607\,TI^3 & + 0.063821\,TN & - 0.000112\,TN^2 & + 0.000454\,TITN \\
 & [1.064] & [0.0037] & [0.0001] & [0.0065] & [0.000014] & [.00017] \\
 & (6.462) & (8.835) & (-5.445) & (9.781) & (-8.142) & (2.694) \\
 & + 0.018088\,MJ^3 & - 1.144391\,SEP & + 1.143603\,OCT^2 & - 0.339079\,OCT^3 & & \\
 & [0.0023] & [0.36798] & [0.2894] & [0.0788] & & \\
 & (8.025) & (-3.110) & (3.952) & (-4.301) & &
\end{array}
$$

$R^2 = 0.868,\ F = 171.727,\ df = 245$

Brackets include the corresponding standard error of the estimate of each regression coefficient. The corresponding t-values are given in parentheses. All regression coefficients were significant at the 1 percent level.

Variables in the equation are as follows:

Y	=	yield of sugarbeets in tons of roots per acre,
TI	=	total irrigation (in.) applied, including preplant or emergence,
TN	=	total nitrogen (residual + applied) in pounds,
TITN	=	cross product of total irrigation x total nitrogen,
MJ	=	May, June rainfall in inches,
SEP	=	September rainfall in inches, and
OCT	=	October rainfall in inches.

The negative signs of the exogenous variables SEP and OCT^3 reflect harvesting losses caused by untimely rainfall. Although a more desirable functional form would have included a rainfall-irrigation interaction term, the nature of the research (being on level borders) prevented statistical significance.

Producer Yields and Research Yield Adjustment

Ten sugarbeet producers were selected from a list of producers, two from each of five counties in the Texas High Plains. Nine of the 10 producers were using furrow irrigation practices and were the basis for evaluating current production practices. Five-year average root yields of surveyed producers ranged from 18 to 34 tons/ac, an average yield being 23.3 tons/ac, which were much lower than research yields. Producer yields may vary from research yields for a number of reasons: lack of timeliness of disease and insect control, soil variability, stand variability, weeds, harvest losses, severe weather incidents, and other factors such as lower water use efficiency in graded furrows compared with level borders. For these reasons, after evaluating three adjustment alternatives, the production function yields estimated by Equation 1 were reduced by 30 percent to reflect producer yields (see Appendix B for adjustment procedure).

[2] $Y = [6.8723 + 0.032813\,TI^2 - 0.000607\,TI^3 + 0.063821\,TN - 0.000112\,TN^2 + 0.000454\,TITN + 0.018088\,MJ^3 - 1.144391\,SEP + 1.143603\,OCT^2 - 0.339079\,OCT^3] \times 0.70$

Stages of Production and Range of Economically Rational Irrigated Production

Given the production response function (Equation 2), the stages of production and the range over which economically rational production would occur can be defined. Irrigation levels outside this rational production region are considered irrational given the assumption of maximizing net returns. Figure 1 shows the yield response function related to varying irrigation amounts based on 300 pounds of total nitrogen.

A 40-year-average monthly rainfall period was used to depict a long-term weather history using data from Amarillo, Texas (1947-1986), the nearest NOAA reporting station, where May = 2.76 inches, June = 3.51 inches, September = 1.89 inches, and October = 1.51 inches (NOAA). As a result, Equation 2 can be reduced to a simpler equation by entering the average precipitation.

[3] $Y = 2.615027 + 0.0229691\,TI^2 - 0.000424\,TI^3 + 0.0446747\,TN - 0.000078\,TN^2 + 0.0003178\,TITN$

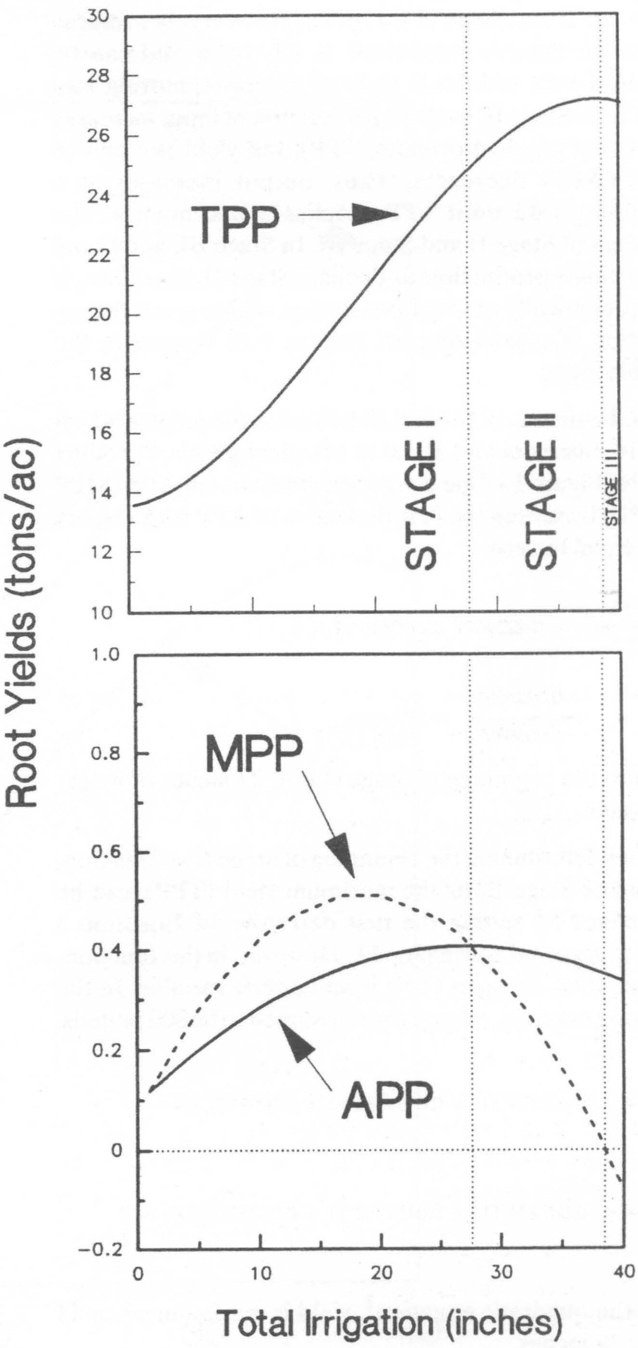

Figure 1. Sugarbeet production function with 300 pounds of total nitrogen.

In Stage I (Figure 1), additional units of input (irrigation water) increases the productivity of all other inputs; i.e., average yield is increasing. The greatest efficiency in the use of variable inputs is at the boundary of Stage I and Stage

II (Figure 1); i.e., average physical product (APP) of irrigation water is maximum at this point. However, net returns are not necessarily maximized at this point and can be increased with additional units of the input, moving into Stage II. In Stage II, each additional unit of input increases yield (total physical product, TPP), but yield per unit of water (APP) decreases. Thus, output increases at a decreasing rate until TPP reaches a maximum at the boundary of Stage II and Stage III. In Stage III, additional inputs cause production to decline. Stage II, therefore, is the economically rational production region given the assumption of maximizing net returns with respect to the variable input.

The beginning of Stage II is defined as the point at which APP is maximum and equal to marginal physical product (MPP) (Figure 1). One can solve for maximum APP (MPP = APP) by setting the first derivative of APP with respect to TI equal to zero.

$$\frac{d\,APP}{d\,TI} = 0.0229691 - 0.000848\,TI = 0$$

$$TI = \frac{-0.0229691}{-0.0008498} = 27 \text{ inches}$$

Thus, the beginning of Stage II is at 27 inches of irrigation water.

After determining the beginning of Stage II at 27 inches, the end of Stage II, or the maximum yield (TPP), can be determined by setting the first derivative of Equation 3 equal to zero and solving for TI. However, in this functional form, total nitrogen (TN) is an implicit variable. In the following example, nitrogen was assumed to be 300 pounds.

$$\frac{d\,Y}{d\,TI} = -0.001274\,TI^2 + 0.0459382\,TI + 0.0003178\,TN$$

$$\frac{d\,Y}{d\,TI} = -0.001274\,TI^2 + 0.0459382\,TI + 0.0003178(300) = 0$$

By the quadratic equation[1], yield is maximum when TI equals 38 inches.

$$TI = \frac{-0.0459382 - \sqrt{(0.0459382)^2 - 4(-0.0012747)(0.09534)}}{(2 * -0.001274)}$$

$$TI = 38 \text{ inches}$$

[1]The quadratic equation equals:

$$\frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a} \quad \text{where } Y = ax^2 + bx + c = 0$$

Thus, the economically rational production region (Stage II) for irrigation is defined as being between 27 and 38 inches, given 300 pounds of total nitrogen (Figure 1). The end of Stage II varies with the level of nitrogen. For example, with 100 pounds TN, yield is maximum at 36.7 inches irrigation water compared with 38.6 inches with 400 pounds TN. Figure 2 indicates a family of alternative production functions with 100, 200, 300, and 400 pounds TN. As TN increases, yields generally increase at a decreasing rate for each production relationship. However, a high level of 500 pounds TN reduces yields at all levels of irrigation below those of 300 and 400 pounds TN (not shown).

Optimal Irrigation Level and Nitrogen Rate

Although the aforementioned mathematical analyses determined the stages of production, no determination was made of the most profitable levels of inputs (TI and TN). To determine the optimal input levels to maximize profits with all other inputs held constant, the first derivatives of the production function with respect to the inputs are set equal to the ratio of the input cost and the product price ($/ton of sugarbeets) and are solved simultaneously (see Appendix C). A product price of $37.01/ton ($P_{SB}$) reflects the 1986 price received by producers for beets yielding 14 percent sugar. The cost of applying irrigation water was $4.01/ac inch ($P_I$), which includes a $0.45/ac-inch cost of irrigation labor (Texas Agricultural Extension Service, 1987). The cost of nitrogen (including application) was $0.11/pound ($P_N$). The optimal input levels that maximized profits (given P_{SB} = $31.07, P_I = $4.01, P_N = 0.11) were 35 inches of irrigation water and 333 pounds of total nitrogen. Deviation from these levels will result in suboptimal profits.

Economic Analysis of Returns to Management and Risk

Development of the aforementioned relationship of yield to water and nitrogen permits an expanded analysis of the potential profitability of sugarbeet production in the Texas High Plains. Surveyed growers provided information on production practices for the analyses. The per acre returns to management and risk were estimated over a range of sugar prices and at alternative irrigation levels.

Nine of the 10 producers surveyed using furrow irrigation practices were the basis for evaluating current production practices and costs. For each producer surveyed, an enterprise budget was generated estimating the individual's cost of production using the Texas Agricultural Extension Service MBMS budget generator (McGrann et

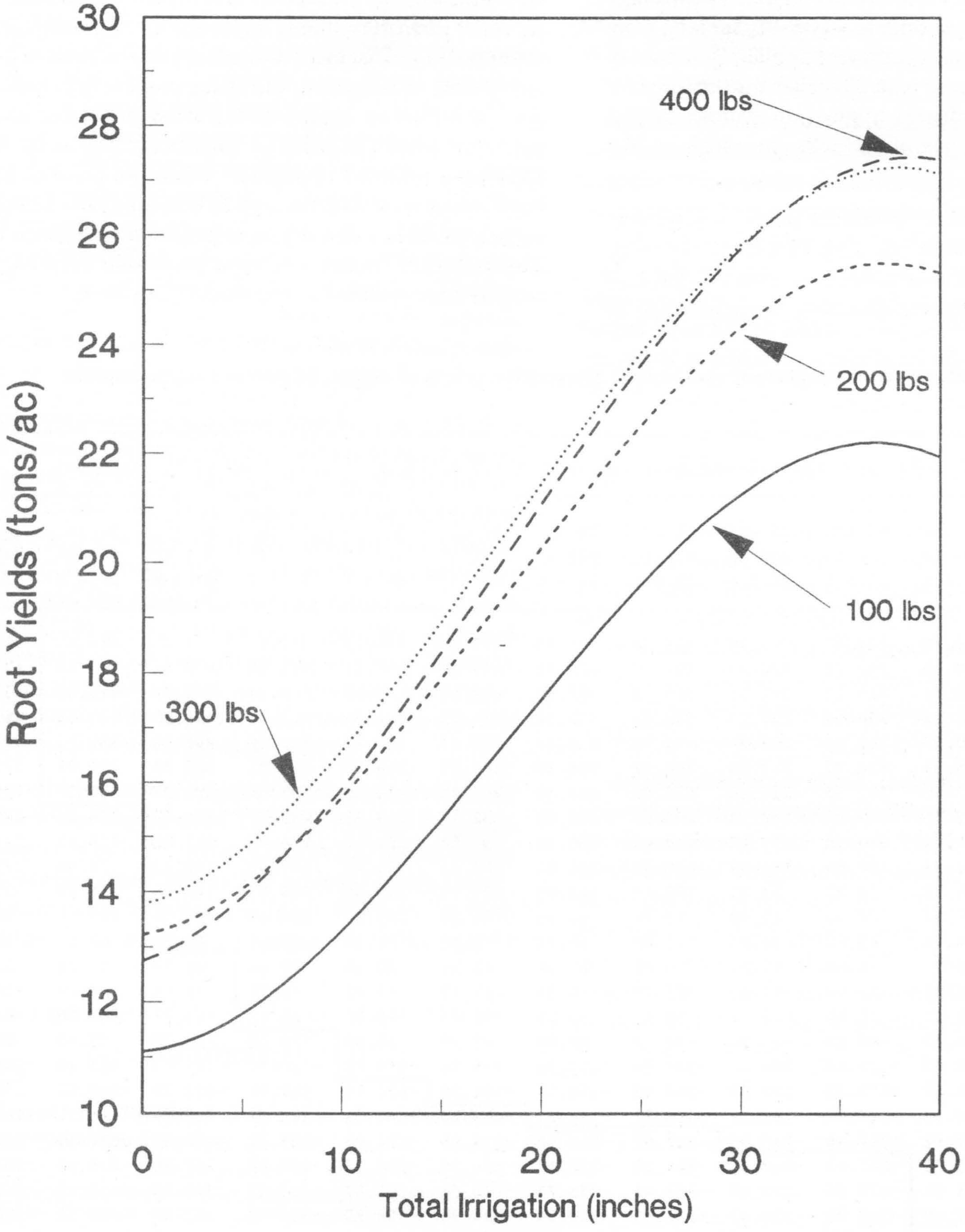

Figure 2. Sugarbeet production functions at various levels of total nitrogen.

al., 1986). A comparison between the high-cost and low-cost producer indicated a difference of over $115/ac in total costs. There was a $70 difference ($315-$245) in the total preharvest cost between these two producers. The average preharvest costs of all producers was $302, ranging from $245 to $346. The high-cost producer applied 31 inches of irrigation water, compared with 23 inches for the low-cost producer. Overall, producers applied an average of 26.5 inches, ranging from a low of 20 inches to a high of 34.8 inches.

Equation 2 (adjusted for producer yields) was used to estimate yields and profits per acre (Table 1). Through partial budgeting, yields were estimated at various levels of irrigation and at the corresponding optimal level of nitrogen. In addition, profits were estimated using alternative sugar prices and assuming a sugar content of 14 percent. Production costs except for nitrogen and irrigation were based on the average costs of the survey. Nitrogen was $0.11 per pound (including application cost), and irrigation water cost $4.01/ac inch. Calculated on the basis of 2-inch increments of irrigation, the budgeting analysis indicated that 36 inches of water was the most profitable level of irrigation when the price of sugarbeets was at or above $33.14/ton ($24/cwt of sugar). When the price of sugarbeets was from $24.68 through $31.76/ton ($18 - $23/cwt of sugar), 34 inches was the most profitable irrigation level. Thereafter, 32 inches was most profitable until negative returns were realized at and below $22.10/ton.

Table 1. Per acre net returns to management and risk at alternative prices of sugar, 14 percent sugar content.

Price per ton sugar beets	NSP per 100 lb. sugar	Irrigation level (in./ac), total nitrogen (lbs/ac), and yield (tons/ac)										
		18 in. 299 lb. 20.4 t	20 in. 303 lb. 21.5 t	22 in. 307 lb. 22.5 t	24 in. 311 lb. 23.5 t	26 in. 315 lb. 24.4 t	28 in. 319 lb. 25.2 t	30 in. 323 lb. 26.0 t	32 in. 327 lb. 26.6 t	34 in. 331 lb. 27.1 t	36 in. 335 lb. 27.4 t	38 in. 339 lb. 27.5 t
$41.42	$30.00	346.78	375.40	403.39	429.98	454.45	476.05	494.04	507.67	516.20	518.89	515.00
$40.04	$29.00	318.56	345.76	372.35	397.60	420.81	441.25	458.22	471.00	478.87	481.12	477.04
$38.66	$28.00	290.34	316.12	341.31	365.22	387.16	406.45	422.40	434.33	441.54	443.35	439.08
$37.28	$27.00	262.12	286.48	310.27	332.84	353.52	371.65	386.58	397.66	404.21	405.58	401.12
$35.90	$26.00	233.90	256.84	279.24	300.46	319.87	336.85	350.77	360.98	366.88	367.81	363.16
$34.52	$25.00	205.68	227.20	248.20	268.07	286.23	302.05	314.95	324.31	329.55	330.04	325.21
$33.14	$24.00	177.46	197.56	217.16	235.69	252.58	267.25	279.13	287.64	292.21	292.27	287.25
$31.76	$23.00	149.25	167.92	186.12	203.31	218.94	232.45	243.31	250.97	254.88	254.50	249.29
$30.38	$22.00	121.03	138.28	155.09	170.93	185.29	197.65	207.49	214.30	217.55	216.73	211.33
$29.00	$21.00	92.81	108.64	124.05	138.55	151.64	162.85	171.67	177.63	180.22	178.96	173.37
$27.62	$20.00	64.59	79.00	93.01	106.17	118.00	128.05	135.85	140.95	142.89	141.19	135.41
$26.24	$19.00	36.37	49.36	61.98	73.78	84.35	93.25	100.03	104.28	105.56	103.42	97.45
$24.86	$18.00	8.15	19.72	30.94	41.40	50.71	58.45	64.22	67.61	68.22	65.65	59.49
$23.48	$17.00	-20.07	-9.92	-0.10	9.02	17.06	23.65	28.40	30.94	30.89	27.88	21.53
$22.10	$16.00	-48.29	-39.56	-31.14	-23.36	-16.58	-11.15	-7.42	-5.73	-6.44	-9.89	-16.43
$20.72	$15.00	-76.51	-69.20	-62.17	-55.74	-50.23	-45.95	-43.24	-42.41	-43.77	-47.66	-54.39
$19.34	$14.00	-104.73	-98.84	-93.21	-88.12	-83.87	-80.76	-79.06	-79.08	-81.10	-85.43	-92.35
$17.96	$13.00	-132.95	-128.48	-124.25	-120.51	-117.52	-115.56	-114.88	-115.75	-118.43	-123.20	-130.31
$16.58	$12.00	-161.17	-158.12	-155.29	-152.89	-151.17	-150.36	-150.70	-152.42	-155.77	-160.97	-168.27
$15.20	$11.00	-189.39	-187.76	-186.32	-185.27	-184.81	-185.16	-186.51	-189.09	-193.10	-198.74	-206.22
$13.82	$10.00	-217.61	-217.40	-217.36	-217.65	-218.46	-219.96	-222.33	-225.76	-230.43	-236.51	-244.18
$12.44	$9.00	-245.82	-247.05	-248.40	-250.03	-252.10	-254.76	-258.15	-262.44	-267.76	-274.28	-282.14
$11.06	$8.00	-274.04	-276.69	-279.43	-282.41	-285.75	-289.56	-293.97	-299.11	-305.09	-312.05	-320.10
$9.68	$7.00	-302.26	-306.33	-310.47	-314.80	-319.39	-324.36	-329.79	-335.78	-342.42	-349.82	-358.06
$8.30	$6.00	-330.48	-335.97	-341.51	-347.18	-353.04	-359.16	-365.61	-372.45	-379.76	-387.59	-396.02
$6.92	$5.00	-358.70	-365.61	-372.55	-379.56	-386.68	-393.96	-401.43	-409.12	-417.09	-425.36	-433.98
$5.54	$4.00	-386.92	-395.25	-403.58	-411.94	-420.33	-428.76	-437.25	-445.79	-454.42	-463.13	-471.94
$4.16	$3.00	-415.14	-424.89	-434.62	-444.32	-453.98	-463.56	-473.06	-482.47	-491.75	-500.90	-509.90
$2.78	$2.00	-443.36	-454.53	-465.66	-476.70	-487.62	-498.36	-508.88	-519.14	-529.08	-538.67	-547.86
$1.40	$1.00	-471.58	-484.17	-496.70	-509.09	-521.27	-533.16	-544.70	-555.81	-566.41	-576.44	-585.82

Note: The average selling price for sugar in 1986 was $22.51 per 100 lb. sugar or $31.07 per ton of sugarbeets. The solid heavy line denotes the boundary of profit maximization (column to the left of the line) or loss minimization (negative returns).

Sensitivity of Profit-Maximizing Input Levels

When water supplies were abundant and when irrigation energy costs were low, producers highly irrigated sugarbeets. However, as underground water supplies diminished and energy costs increased sharply during the past decade, producers recently tended to limit irrigation amounts. The 1987 survey of producers indicates that two-thirds were irrigating at levels too low to be in Stage II, the stage of economically rational production. The level of irrigation applied by a producer is sensitive to input costs, sugarbeet prices, and seasonal water availability. The following analysis evaluates the sensitivity of maximum-profit irrigation levels to sugarbeet prices and variations in pumping costs and nitrogen prices.

Varying the price of sugarbeets from $20/ton to $40/ton resulted in a narrow range of profit-maximizing irrigation level of only 0.7 inches (36.4 to 37.1 inches), at an irrigation cost of $1/ac inch. At $6/ac inch, the range of optimal irrigation levels was only 4.3 inches (30.0 to 34.3 inches). As the cost of irrigation water increased from $1/ac inch to $6/ac inch and the price of sugarbeets held constant at $31.07/ton (1986 price), the profit-maximizing irrigation level decreased only 3.7 inches, from 36.9 to 33.2 inches. Hoyt (1984) also found that profit-maximizing water quantities were not significantly affected by varying sugar prices at low and medium water costs in Colorado.

The profit-maximizing irrigation level was also relatively insensitive to varying rates of TN. The optimal irrigation level changed by only 2.9 inches (33.8 to 36.7 inches) when nitrogen ranged from 100 to 500 pounds. Furthermore, ranging the price of nitrogen from $0.05 to $0.20/lb changed the profit-maximizing amount of TN by only 31 lbs/ac.

Summary

Eight years of sugarbeet production resulted in the following production function:

$$Y = 6.873 + 0.032813\,TI^2 - 0.000607\,TI^3 + 0.063821\,TN - 0.000112\,TN^2 + 0.000454\,TITN + 0.018088\,MJ^3 - 1.144391\,SEP + 1.143603\,OCT^2 - 0.339079\,OCT^3$$

with an $R^2 = 0.87$. A reduction from research yields of 30 percent was needed to adjust this function to reflect producer field yields. In the research, total irrigations (including prewater) ranged from 3 to 30.5 inches and total nitrogen (residual + applied) ranged from 40 to 458 pounds for a total of 246 observations. The range over which economically rational production would occur was calculated to be 27 to 38 inches of total irrigation given 300 pounds of total nitrogen. The optimal (profit maximizing) irrigation level was calculated to be 35 inches given the price of sugarbeets of $31.07/ton and the cost of applying irrigation water of $4.01/ac inch. A comparison of this level to those of the surveyed producers indicates that producers in the Texas High plains on the Pullman clay loam soils are under-irrigating sugarbeets.

Sugarbeets are relatively drought tolerant where water supplies are limited. However, in areas of adequate water supplies, this analysis indicates that producers should irrigate at the higher irrigation levels to maximize profits. The profit-maximizing irrigation level decreased only 3.7 inches when the cost of irrigation water increased from $1/ac inch to $6/ac inch. When sugarbeet prices were varied from $20 to $40/ton and water cost held constant, the profit-maximizing water level was not significantly affected.

Limitations of the Analysis

This economic analysis is limited in that it does not allow for interactions between nitrogen rates and sugar content of sugarbeets. Research suggests that high rates of nitrogen decrease sugar percentage. The research was not designed to evaluate this interaction because the irrigation treatments were adequately fertilized but not excessively fertilized. Thus, the analysis considers only impacts on root yields but does not evaluate impacts on sugar quality.

Another limitation of the analysis is that the estimated irrigation levels to maximize yields and profits were outside the experimental data range. The irrigation level of 38 inches of total irrigation to maximize yield was 7.5 inches above the experimental range. The maximum profit level of irrigation was 4.5 inches above the highest level used in the research (Appendix Table 1, Appendix A). Higher irrigation levels in future research efforts may improve the predictive ability of the production function.

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APPENDIX A
Research Data

Appendix Table 1. Sugarbeet treatments by irrigation, nitrogen, and precipitation used to formulate the sugarbeet production function, Bushland, Texas, 1976-87.

Year	Rep's	Mean Yield	Seasonal Irrg.	Pre Irrg.	Appl. N	Resid. N	May-June Precp.	Sept. Precp.	Oct. Precp.
		(tons/ac)	(in)	(lb.)	(lb.)	(in)	(in)	(in)	
87	6	20.7	0.0	3.0	0.0	96	8.21	4.46	1.25
87	6	21.3	0.0	3.0	89.2	96	8.21	4.46	1.25
87	6	23.8	0.0	3.0	178.4	96	8.21	4.46	1.25
87	6	23.7	0.0	3.0	267.6	96	8.21	4.46	1.25
77	2	14.2	0.0	5.0	60.0	120	4.19	0.43	0.28
78	4	24.2	0.0	5.3	40.0	171	9.57	5.34	0.33
76	2	15.6	0.0	6.0	0.0	398	2.60	2.31	1.63
86	6	18.2	0.0	8.7	0.0	40	6.77	1.88	2.49
86	6	20.2	0.0	8.7	53.5	40	6.77	1.88	2.49
86	6	20.5	0.0	8.7	107.0	40	6.77	1.88	2.49
86	6	22.0	0.0	8.7	214.0	40	6.77	1.88	2.49
82	3	15.3	0.0	9.1	0.0	75	5.85	2.15	1.02
82	3	19.6	0.0	9.1	53.5	75	5.85	2.15	1.02
82	3	20.3	0.0	9.1	107.0	75	5.85	2.15	1.02
82	3	23.0	0.0	9.1	160.6	75	5.85	2.15	1.02
87	6	20.4	8.1	3.0	0.0	96	8.21	4.46	1.25
87	6	23.4	8.1	3.0	89.2	96	8.21	4.46	1.25
87	6	24.8	8.1	3.0	178.4	96	8.21	4.46	1.25
87	6	27.1	8.1	3.0	267.6	96	8.21	4.46	1.25
82	3	17.8	3.4	9.1	0.0	75	5.85	2.15	1.02
82	3	22.6	3.4	9.1	53.5	75	5.85	2.15	1.02
82	3	22.2	3.4	9.1	107.0	75	5.85	2.15	1.02
82	3	23.2	3.4	9.1	160.6	75	5.85	2.15	1.02
84	3	20.4	0.0	13.1	0.0	182	4.81	0.74	3.44
84	3	19.7	0.0	13.1	53.5	182	4.81	0.74	3.44
84	3	19.9	0.0	13.1	107.0	182	4.81	0.74	3.44
84	3	20.8	0.0	13.1	214.0	182	4.81	0.74	3.44
77	2	22.8	10.0	5.0	120.0	120	4.19	0.43	0.28
76	2	21.8	12.0	6.0	40.0	398	2.60	2.31	1.63
86	6	24.1	10.3	8.7	0.0	40	6.77	1.88	2.49
86	6	25.7	10.3	8.7	53.5	40	6.77	1.88	2.49
86	6	29.0	10.3	8.7	107.0	40	6.77	1.88	2.49
86	6	32.3	10.3	8.7	214.0	40	6.77	1.88	2.49
87	6	24.6	16.2	3.0	0.0	96	8.21	4.46	1.25
87	6	30.9	16.2	3.0	89.2	96	8.21	4.46	1.25
87	6	33.3	16.2	3.0	178.4	96	8.21	4.46	1.25
87	6	33.2	16.2	3.0	267.6	96	8.21	4.46	1.25
78	4	35.1	14.0	5.3	80.0	171	9.57	5.34	0.33
82	3	18.8	10.4	9.1	0.0	75	5.85	2.15	1.02
82	3	24.3	10.4	9.1	53.5	75	5.85	2.15	1.02
82	3	24.6	10.4	9.1	107.0	75	5.85	2.15	1.02
82	3	27.2	10.4	9.1	160.6	75	5.85	2.15	1.02
84	3	29.2	8.0	13.1	0.0	182	4.81	0.74	3.44
84	3	30.3	8.0	13.1	53.5	182	4.81	0.74	3.44
84	3	29.7	8.0	13.1	107.0	182	4.81	0.74	3.44
84	3	28.6	8.0	13.1	214.0	182	4.81	0.74	3.44
78	4	40.9	19.1	5.3	120.0	171	9.57	5.34	0.33
77	2	34.2	20.0	5.0	180.0	120	4.19	0.43	0.28
86	6	25.6	18.0	8.7	0.0	40	6.77	1.88	2.49
86	6	30.1	18.0	8.7	53.5	40	6.77	1.88	2.49
86	6	31.5	18.0	8.7	107.0	40	6.77	1.88	2.49
86	6	36.4	18.0	8.7	214.0	40	6.77	1.88	2.49
84	3	32.8	16.0	13.1	0.0	182	4.81	0.74	3.44
84	3	34.2	16.0	13.1	53.5	182	4.81	0.74	3.44
84	3	31.8	16.0	13.1	107.0	182	4.81	0.74	3.44
84	3	32.9	16.0	13.1	214.0	182	4.81	0.74	3.44
76	2	28.9	23.9	6.0	60.0	398	2.60	2.31	1.63
79	6	37.0	22.5	8.0	89.0	218	4.84	0.39	1.82

APPENDIX B

Producer Yield Adjustment Procedure

Three methods of estimating differences between producer yields and those obtained in the research were evaluated by selecting the method that minimized the average of the sum of deviations between predicted yields using Equation 1 and the 5-year average yield of the producers surveyed. The predicted yields, using Equation 1, were based on the producers' irrigation levels and nitrogen rates. However, 40-year normal monthly rainfall for Amarillo, Texas, was used for the rainfall variables.

The first method simply multiplied the predicted yields from Equation 1, using producer levels of irrigation and nitrogen, by 70 percent; the percentage research yields varied from the 1976-85 county average yields (Texas Agricultural Statistics Service, 1976-85). These adjusted yields were then compared with reported yields, and the sum of the deviations was averaged across producers, resulting in an average reduction of 9.2 tons/ac from predicted yields. The next two methods resulted in subtracting a constant amount from the predicted yields of Equation 1 rather than subtracting a percentage amount. The second method used 70 percent of the predicted yield of Equation 1 but was based on the surveyed average producer irrigation level of 26.5 inches irrigation water and 300 pounds nitrogen. Compared with reported yields, the average of the sum of deviations was a 10-ton reduction from predicted yields. The final method also reduced the predicted yield of Equation 1 by 30 percent but was evaluated at the end of Stage II as being 38 inches irrigation water and 300 pounds nitrogen. This resulted in an average of the sum of deviations of an 11-ton reduction from the predicted yields. Thus, the first of the three estimating methods, a 30 percent reduction from predictions of Equation 1, minimized the sum of the deviations between predicted and reported yields.

APPENDIX C

Simultaneous Solution of Optimal Irrigation Level and Nitrogen Rate

The simultaneous solution of the optimal irrigation level and nitrogen rate is accomplished by simultaneously solving the following two general equations:

$$\frac{dY}{dTI} = \frac{P_I}{P_{SB}} \quad \text{and} \quad \frac{dY}{dTI} = \frac{P_N}{P_{SB}}$$

The first derivative $\frac{dY}{dTI}$ is set equal to the ratio of the water cost and the product price ($/ton of beets).

$$\frac{dY}{dTI} = -0.0012747\,TI^2 + 0.0459382\,TI + 0.0003178\,TN = \frac{P_I}{P_{SB}}$$

$$= -0.0012747\,TI^2 + 0.0459382\,TI + 0.0003178\,TN = \frac{4.01}{31.07}$$

[1] $$= -0.0396049\,TI^2 + 1.427299\,TI + 0.0098740\,TN = 4.01$$

The first derivative $\frac{dY}{d\,TN}$ is set equal to the ratio of the nitrogen cost (including application) and the product price ($/ton of sugarbeets).

$$\frac{dY}{dTN} = -0.0001568\,TN + 0.0003178\,TI + 0.0446747 = \frac{P_N}{P_{SB}}$$

$$= -0.0001568\,TN + 0.0003178\,TI + 0.0446747 = \frac{0.11}{31.07}$$

[2] $$= -0.0048718\,TN + 0.0098740\,TI + 1.3880429 = 0.11$$

To simultaneously solve Equations 1 and 2, one must reduce the equations to one unknown. To solve for TI, TN must be cancelled when adding the two equations. This is accomplished by multiplying Equation 2 by 2.0267663 (0.0098740/0.0048718), which will cancel TN out of the summation of the equations.

[3] $$-0.0098740\,TN + 0.0200123\,TI + 2.8132386 = 0.2229443$$

Adding Equations 1 and 3 together results in the following:

$$
\begin{array}{rrrrl}
-0.0396049\ TI^2 & +\ 1.4272999\ TI & +\ 0.0098740\ TN & & = 4.01 \\
 & 0.0200123\ TI & -\ 0.0098740\ TN & +\ 2.1832386 & = 0.2229443 \\
\hline
-0.0396049\ TI^2 & +\ 1.4473113\ TI & & +\ 2.1832386 & = 4.2329443
\end{array}
$$

$-0.0396049\ TI^2 + 1.4473113\ TI = 1.4197057$

Solving for TI using the quadratic equation results in the following:

$-0.0396049\ TI^2 + 1.4473113\ TI - 1.4197057 = 0$

$$TI = \frac{-\ 1.4473113 - \sqrt{(-1.4473113)^2 - 4(-0.0396049)(-1.4197057)}}{2(-0.0396049)}$$

TI = 35 inches

To determine optimal TN, substitute (TI = 35) into Equation 2 as follows, and solve for TN:

$-0.0048718\ TN + 0.0098740\ (35) + 1.3880429 = 0.11$

$-0.0048718\ TN = -1.6236329$

TN = 333 pounds

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