An Economic Analysis of Reducing Nitrogen on Early Harvest Sugarbeets

Larry J. Held, Paul A. Burgener, Joseph G. Lauer, and Dale J. Menkhaus

Research Question

Both sugarbeet growers and sugar processors are interested in the impacts of lengthening the processing season by harvesting a certain percentage of sugarbeet acreage earlier in the season. Historically, many producers have not adjusted the rate of N on those acres intended for early harvest. This study compares the economics of reducing rates of N on sugarbeet acreage planned for early harvest, as opposed to a more typical practice of simply applying the same rate of N, regardless of intended time of harvest.

Literature Summary

A 1971 California study reported that optimal N rates for producing sugarbeets (in terms of maximum root yields) could be reduced from 160 lb N/acre (expected mid-August harvest) to 80 lb N/acre (expected early July harvest). However, associated economic benefits of reduced fertilization were not specifically addressed.

Study Description

This study was based on field experiments conducted at the University of Wyoming Powell Research and Extension Center (1988–1991), relating sugarbeet production to selected N rates (0–300 lb/acre) and harvest dates (10 September–24 October). Three years of data (1989–1990) were used to estimate a quadratic response function depicting economic performance of sugarbeets (net return over N and other related costs) as a function of rate of N and specified harvest date. A following year of data (1991) was reserved to test the predictive performance of the estimated function. For each of the 45 designated harvest dates (10 September–24 October), the optimal (i.e., maximum net return) rate of N was identified. In addition, a similar quadratic response function was developed for sugarbeet root yield (ton/acre) to identify the rate of N associated with attaining maximum root yield on a given harvest date.

From this design, the economics of three management options was examined across weekly intervals of the harvest season, including: (i) adjusting the rate of N with respect to the week of expected harvest (with an economic objective of maximizing net return); (ii) applying N at the same rate (200 lb N/acre), with no consideration of time of expected harvest; and (iii) adjusting the rate of N with a production-based objective of maximizing root yield (ton/acre). Given a fixed set of prices for sugar and N, sugarbeet net return values ($/acre) and corresponding rates of N (lb/acre) were then calculated for each of the above-mentioned management options, during selected weeks of the early (10–30 September) harvest season (Table 1), as well as selected weeks of the regular (1–24 October) harvest season.

Applied Questions

What is the economic advantage of fertilizing for maximum net return (management option 1) vs. fertilizing for maximum root yield (management option 3)?

Given a fixed set of prices for sugar ($21/cwt) and N ($0.27/lb), Table 1 shows fertilizing for maximum root yield (vs. maximum net return) re-

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quired 78 to 88 lb/acre of additional N, in conjunction with much lower net return values across all early harvest periods, ranging from a $24/acre reduction ($719 vs. $695) in the latest (24-30 September) period, to a $31/acre decrease ($576 vs. $545) in the earliest (10-16 September) period.

What is the relationship between optimal rates of N and time of intended harvest?

If the objective is to apply N for attaining maximum net returns, the optimal rate of N was found to be lower with earlier dates of harvest. From Table 1, the optimal rates (associated with management option 1) decreased from 165 lb N/acre in the late early period (24-30 September), to 153 lb N/acre in the mid early period (17-23 September), to only 141 lb N/acre in the very early period (10-16 September). Therefore, the rate of N should be reduced up to 12 lb/acre for each week of earlier intended harvest in the month of September. This recommended reduction was not particularly sensitive to changes in the base price for sugar ($21/cwt) and N ($0.27/lb).

Similarly, if the objective is to apply N for attaining maximum root yield per acre, the optimal rate of N also was found to be lower with earlier harvest periods. The weekly cutbacks of N per acre from the late early period (243 lb/acre), to mid early (236 lb/acre), to very early (229 lb/acre), were found to be 7 lb N/acre for each week of earlier intended harvest.

What is the economic benefit of reducing the rate of N (lb/acre) on sugarbeet acreage intended for earlier harvest (management option 1), as opposed to applying 200 lb/acre with no consideration given to time of expected harvest (management option 2)?

Table 1 shows reducing the rate of N, as opposed to simply applying 200 lb N/acre, enhanced net returns by amounts ranging from $5/acre ($719 vs. $714) in the late early period (24-30 September), to $9/acre ($652 vs. $643) in the mid early period (17-23 September), to a high of $14/acre ($576 vs. $562) in the very early period (10-16 September). This indicates the economic benefit of reducing N becomes increasingly more pronounced with earlier times of intended harvest.

Table 1. Rates of N and corresponding net return values associated with three alternative management options.†

	Fertilizer management options					
	(i) Adjust N by harvest period to maximize net return		(ii) Apply N at the same rate (200 lb)		(iii) Adjust N by harvest period to maximize root yield	
Harvest period	Rate of N	Net return	Rate of N	Net return	Rate of N	Net return
	lb/acre	$/acre	lb/acre	$/acre	lb/acre	$/acre
Late early (24-30 Sept.)	165	719	200	714	243	695
Mid early (17-23 Sept.)	153	652	200	643	236	624
Very early (10-16 Sept.)	141	576	200	562	229	545

† Based on a net sugar price of $21/cwt, and N price of $0.27/lb.

An Economic Analysis of Reducing Nitrogen on Early Harvest Sugarbeets

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Both sugarbeet (*Beta vulgaris* L.) producers and sugar processors have interests in lengthening the harvest and processing season by harvesting a certain percentage of sugarbeet acreage earlier in the year. As a general practice, many growers have not adjusted their rates of N on acres intended for earlier harvest. Previous research has shown benefits of increased production from reducing the rate of N on acreage planned for earlier harvest. However, similar benefits of increased profitability were not considered. This study was designed to examine the economic benefit of reducing N on acreage intended for earlier harvest. A response function was estimated from three years (1988-1990) of field trials at the University of Wyoming Powell Research and Extension Center to relate net return from sugarbeets to (i) the amount of N/acre (0-300 lb) and (ii) selected date of harvest (from 10 September-24 October). For each of the 45 harvest dates (10 September-24 October), the optimal (highest profit) rate of N was identified. A fourth year of field data (1991) was then used to test the predictive performance of the estimated function. As opposed to simply applying N at a constant rate of 200 lb/acre (with no regard to time of intended harvest), reducing the rate of N by 12 to 14 lb/acre for each week of earlier harvest increased net return in the early (September) harvest season. Specifically, the increase in net return (from lower rates of N) ranged from $5/acre for sugarbeets harvested in late September (24-30 September), to $14/acre for sugarbeets harvested in early September (10-16 September).

BOTH SUGARBEET growers and sugar processors are positioning themselves for changes in the industry. One of these adjustments involves lengthening the processing season by harvesting sugarbeets earlier in the season. Lengthening the processing season is largely an attempt to get more use from large capital investments incurred by growers and sugar companies. Because sugarbeet yield and quality are lower with earlier harvest dates, growers are compensated for delivering beets prior to the traditional 1 October date to offset the impact of lower root yield and sucrose content (Lauer, 1990). As an example, the 1991-1992 early harvest contract offered by Western Sugar Company paid growers in the Lovell area of northwest Wyoming increasingly higher premiums for beets that were harvested earlier in September. Specifically, growers were paid a premium of $0.43/ton on 25 September (the last day of the early harvest period) followed by a $0.43/ton increase for each day of earlier harvest thereafter (e.g., $0.86/ton on 24 September), finally reaching a premium of $6.88/ton on 10 September (the earliest day of early harvest). It should be noted that Western Sugar has required growers to commit a small percentage of their acreage to the early harvest program.

In a California study, Hills and Ulrich (1971) found that if sugarbeets are harvested earlier, optimal rates of N (in terms of maximum root yield) could be reduced from 160 lb/acre (mid-August harvest) to 80 lb/acre (early July harvest). However, advantages from the standpoint of profitability were not considered in their analysis. Although reduced rates of N could generate higher profits, many growers in the Lovell area plant and fertilize their sugarbeets with no regard to time of expected harvest. The Lovell area, under contract to the Western Sugar Company, is an important production area. It includes 140 of Wyoming's 584 sugarbeet growers (U.S. Beet Sugar Assoc., 1990). As of 1991, there were nearly 33 000 acres of sugarbeets in this area, comprising approximately 47% of Wyoming's total sugarbeet acreage (Wyoming Dep. of Agriculture, 1993). The purpose of this article is to examine the economic benefit associated with reducing rates of N on acreage intended for early harvest in this region.

MATERIALS AND METHODS

The analysis was based on field trials conducted at the University of Wyoming Powell Research and Extension Center (1988-1991), measuring sugarbeet performance (root yield and sucrose content) as a function of rates of N and harvest dates. The initial 3 yr of data (1988-1990) were used to estimate a response function relating net return from sugarbeets to the amount of applied N and particular harvest date to determine optimal (maximum net return) N rates for given harvest dates. The last year of data (1991) was reserved to test the predictive performance of the response function estimated with the three years of earlier data (1988-1990).

Data

The experimental design used in this 4-yr study (1989-1991) consisted of four replications of a randomized complete block in a split-plot arrangement over time. There were six sample observations per replication at each harvest date and N rate in 1988; and four sample observations per replication at each harvest date and N rate in 1989, 1990, and 1991. Treatments each year included six rates of fertilization ranging from zero to 300 lb N/acre, and several selected harvest dates in September and October (Table 1). All N treatments were spring preplant applications of ammonium nitrate (34-0-0). On each harvest date, sugarbeets in 10 ft of row within each plot were topped and hand lifted. Each sample was bagged and sent to the Western Sugar Company lab in Billings, MT, and measured for tare, fresh root mass, su-

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crose content, and purity. The purity samples were frozen and analyzed later to determine sucrose loss to molasses.

Gross return was calculated using the 1991-1992 Western Sugar Company Grower Contract, offering early harvest premiums noted above. Gross return was based on a net sugar price of \$21/cwt, minus pol difference (pile loss) adjustment (after 30 September), plus early harvest incentive payments (prior to 1 October). The pol difference was calculated by taking the pile loss from the previous 5 yr as computed by Western Sugar Company, dropping the high and low values among the 5 yr, and averaging the three remaining values. A producer is required to bear 60% of the resulting storage loss. Higher storage losses essentially translate into lower net sucrose percentages. This, in turn, has an adverse impact on sugarbeet price (\$/ton), since the Western Sugar Company contract specifies lower prices (\$/ton) in conjunction with lower sucrose percentages.

Costs for N fertilizer (\$0.27/lb), hauling (\$2.37/ton), and interest on capital (12.5%) were subtracted from the gross return value to derive return over specified costs (i.e., net return). Specified costs in this analysis include only those which are directly affected by the management options and exclude a vast array of other operating and ownership costs. Therefore, while this net return measure is useful for making economic comparisons among the selected management options, it should not be considered as a measure of sugarbeet profitability to compare with other crops. Examples of calculating net return for an early harvest and regular harvest date are shown in Table 2.

The net return values (as calculated in Table 2) were used as the basis for estimating a function to directly relate economic performance in the form of net return to the rate of N and date of harvest. The disadvantage of this approach is the net return function is based on specific prices for sugar (\$21/cwt) and N (\$0.27/lb). Using a biological response function, e.g., root yield = f(N, date of harvest), would normally allow more flexibility for changing prices of output or inputs. In this particular analysis, however, N is only one of several costs included in the net return calculation, and hauling cost in particular is problematic, since it depends upon a specific output level (i.e., root yield per acre). Moreover, the price of sugarbeets (\$/ton) is dependent upon another output variable (i.e., percentage sucrose) as specified in the Western Grovers contract. As discussed later in the paper, alternative net return functions were estimated given alternative price levels for sugar and N to evaluate the sensitivity of optimal N rates to changing prices.

Response Function

A quadratic response function was selected to estimate the response of net return to the two variables under consideration (rate of N and harvest date). Choosing a particular functional form for estimation can be difficult. Heady and Dillon (1972, p. 104) note:

> . . . it appears unlikely that a single mathematical form of a production function is most appropriate for all situations, and different individuals may give equally valid reasons for selecting alternative types. . . In case previous knowledge and theory are nil, researchers might be faced to select functions with contrasting algebraic properties and subject them to tests of best fit.

Table 1. Harvest dates and rates of N by experiment years.

Treatment	1988	1989	1990	1991
	Year			
Date of harvest	15 Sept.	13 Sept.	13 Sept.	12 Sept.
	20 Sept.	3 Oct.	27 Sept.	25 Sept.
	27 Sept.	23 Oct.	11 Oct.	9 Oct.
	3 Oct.	--	25 Oct.	23 Oct.
	10 Oct.	--	--	--
Rate of N, lb/acre	0	0	0	0
	64	100	100	100
	114	150	150	150
	164	200	200	200
	214	250	250	250
	264	300	300	300

Choosing a quadratic function for this analysis was based on limited prior knowledge of a "true" functional form for how net return responds to N and time of harvest. Previous research has demonstrated the advantages of a quadratic functional form in estimating the response of crop yield to fertilization (NAS, 1963; Heady, 1954; Taylor et al., 1985). Hills and Ulrich (1971, p. 117) show root yield (ton/acre) as well as sucrose yield (lb/acre) responding to added N in a nonlinear fashion, with properties of diminishing marginal productivity and a defined point of maximum production, both of which can be captured with a quadratic form (Heady and Dillon, 1972, p. 106). The merits of the quadratic form selected for this analysis were judged in part by its strength of fit in terms of R^2 as well as its predictive performance for a selected year (1991) outside the data set from which it was originally estimated (1988-1990).

The general form of the quadratic response function for net return is:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_1^2 + \beta_3 x_2$$
$$\beta_4 x_2^2 + \beta_5 x_1 x_2 + \beta_6 D89 + \beta_7 D90 + e$$

where:

Y = net return (\$/acre);
x_1 = N fertilization rate (lb applied/acre);
x_2 = harvest date (day of the year);
D89 = dummy variable; 1 if year is 1989, 0 otherwise;
D90 = dummy variable; 1 if year is 1990, 0 otherwise;
βs = regression parameters; and
e = error term.

To avoid a singularity problem due to the use of an intercept shifter, the reference category for the dummy variables is 1988. Three years of data (1988-1990) were used to estimate the function, while the last year (1991) was held in reserve for testing the validity of the estimated function. The response function was estimated using ordinary least squares regression. The estimated response function was transformed to yield an overall adjusted equation which accounted for the average annual effect. The estimated parameters for the intercept shift variables ($\hat{\beta}_6$ and $\hat{\beta}_7$) were combined in the following manner to determine the average annual effect. First, the estimated coefficients associated with each intercept shift

Table 2. An illustration of deriving net return: An early vs. late harvest option.

	(i) Early harvest option with 200 lb N and 20 Sept. harvest			(ii) Regular harvest option with 200 lb N and 12 Oct. harvest		
1. Gross return, $/acre						
a. Yield, ton/acre	22.45			24.84		
b. Price, $/ton	× 33.95			× 37.70		
c. Pre-incentive return, $/acre		= 762.18			= 836.47	
d. Early harvest incentive						
yield (ton/acre)	22.45			24.84		
× incentive price ($/ton)	× 2.58			× 0		
= incentive value ($/acre)		= 57.92			= 0.00	
e. Gross return [1c + 1d]			820.10			936.47
2. Selected costs, $/acre						
a. Hauling						
yield (ton/acre)	22.45			24.84		
× hauling cost ($/ton)	× 2.37			× 2.37		
= cost ($/acre)		= 53.21			= 58.87	
b. Apply N						
rate (lb/acre)	200			200		
× price ($/lb)	× 0.27			× 0.27		
= cost ($/acre)		= 54.00			= 54.00	
c. Interest on hauling						
Interest rate (%)	12.5			12.5		
× no. of days, harvest to payment	× 86/365			× 64/365		
× hauling cost ($/acre)	× 53.21			× 58.87		
= cost ($/acre)		= 1.57			= 1.29	
d. Interest on N						
Interest rate (%)	12.5			12.5		
no. of days, planting to payment	× 275/365			× 275/365		
× N cost ($/lb)	× 54.00			× 54.00		
= cost ($/acre)		= 5.09			= 5.09	
e. Total selected costs, $/acre [2a + 2b + 2c + 2d + 2e]			113.87			119.25
3. Net return, $/acre [1e − 2e]			706.23			817.22

† The Western Sugar Company contract specifies higher prices ($/ton) with higher percent sucrose. Therefore, the 20 September harvest price ($33.95) is based on 15.91% net sucrose (15.91% sucrose minus 0% pol loss); and the 12 October price ($37.70) is based on 17.16% net sucrose (17.71% sucrose minus 0.55% pol loss).

variable were summed and divided by the number of intercept shift variables plus one (the base year, 1988), i.e., 2 + 1 = 3. The resulting value is then added to the intercept value from the estimated equation ($\hat{\beta}_0$) to determine the average annual effect of year on each of the dependent variables. This adjustment equation is as follows:

$$\hat{\beta}_0^{adj} = \hat{\beta}_0 + [(\hat{\beta}_6 + \hat{\beta}_7)/3]$$

Using the adjusted intercept ($\hat{\beta}_0^{adj}$), the basic response function is as follows:

$$\hat{Y} = \hat{\beta}_0^{adj} + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_1^2 + \hat{\beta}_3 x_2 + \hat{\beta}_4 x_2^2 + \hat{\beta}_5 x_1 x_2$$

The estimated function is shown below, with both the original and adjusted $\hat{\beta}_0$ (intercept) values. The coefficient values for both dummy variables are also reported, although these values are not used for computing net returns. These values are, however, used to calculate the adjusted intercept.

Net Return ($/acre)		$\hat{\beta}_0$ Intercept	$\hat{\beta}_0^{adj}$ adjust. intercept	$\hat{\beta}_1$ N-level
Y	=	−8658.4899	−8733.7825	−2.379625
		(3219.875)		(1.396943)

$\hat{\beta}_2$ N-level^2	$\hat{\beta}_3$ harvest date	$\hat{\beta}_4$ harvest date^2	$\hat{\beta}_5$ Interaction
−0.003979	+62.24131	−0.10244	+0.013638
(0.000812)	(23.29744)	(0.042128)	(0.005019)

$\hat{\beta}_6$ D89	$\hat{\beta}_7$ D90
−154.01441	−71.863335
(18.73254)	(17.18688)

$R^2 = 0.8499$ F value = 51.744

The values in parentheses are standard errors and all the estimated parameters are significantly different from zero at the $\alpha = 0.10$ level. The relatively high R-squared value suggests a good fit to the data, indicating the function's utility for predictive use. As noted above, the predictive performance of the response function also was tested using out-of-sample data (1991). The resulting ratios of actual (1991) values to predicted values for net return further reinforced its predictive capacity, in that predicted values were within 15% or less of actual net return values observed for 1991.

The optimal net return rate of N (X_1) for each of the 45 harvest dates between 10 September and 24 October (X_2) was derived with calculus and the estimated response function for net return (Y) as follows. For any given date, the optimal N level can be derived by taking the partial derivative of the net return function with respect to N, setting it equal to zero, and solving for N. Specifically, the first order condition for optimal N is: $\partial Y/\partial X_1 = \beta_1 + 2\beta_2 X_1 + \beta_5 X_2 = 0$, or $\partial Y/\partial X_1 = -2.379625 + 2(-0.003979)X_1 + 0.013638X_2 = 0$. Therefore, for any given date, optimal N is derived as $X_1 = (-\beta_1 - \beta_5 X_2)/2\beta_2$. For example, in the case of 10 September, where X_2 = day 254: $X_1 = [-(-2.379625) - 0.013638(254)]/[2(-0.003979)] = [-1.084427]/[-0.007958] = 136$ lb/acre. These respective values ($X_1 = 136$; and $X_2 = 254$) are substituted back into the estimated function to calculate the corresponding estimated net return ($540/acre) for that date and optimal rate of N.

RESULTS AND DISCUSSION

The optimal rate of N and corresponding net return are derived for each harvest date in the same manner descibed above (Table 3). Table 3 shows optimal N rates are markedly lower at earlier harvest dates, ranging from a low of 136 lb N/acre in the early season (10 September) to a high of 212 lb N/acre in the late season (24 October). This represents an average daily reduction of 1.7 lb N/acre (212 lb − 135 lb/45 d) for each day of earlier harvest, or in terms of this function, $\partial X_1/\partial X_2 = -\beta_5/2\beta_2 = 1.7$. Similarly, net returns associated with the optimal rates of N are notably lower with earlier harvest, ranging from $540 on 10 September to $895 on 24 October, representing an average daily decrease of $7.88/acre ($895 − $540/45 d).

Because lower optimal N rates are associated with earlier harvest dates, an economic penalty would be incurred by producers who fertilize at a higher rate (with a late harvest date in mind) but, after applying fertilizer, decide to harvest at a much earlier date. For example, assume a producer expects to harvest late (e.g., 24 October) and applies the optimal rate for that date (212 lb)—but subsequently decides to harvest very early (e.g., 10 September), when 136 lb (vs. 212 lb) would have been optimal. As a consequence of having applied too much fertilizer, net return on the 10 September harvest date is $23 acre lower with the 212 lb rate ($517) than the optimal 136 lb rate ($540), as determined by substituting the higher rate of N ($X_1 = 212$) in the net return function on 10 September ($X_2 = 254$) as opposed to the lower optimal rate of N ($X_1 = 136$).

Likewise, a penalty would be incurred for producers initially planning to harvest early, but afterwards deciding to harvest late. For example, if a 10 September harvest is originally planned, 136 lb N/acre would be the optimal rate. If a late harvest (e.g., 24 October) actually occurs, however, a net return of only $872/acre is realized from the lower rate (136 lb), vs. $895/acre associated with the optimal 24 October rate (212 lb). This represents a similar penalty of $12/acre ($895-$872), which again was determined by substituting the lower rate of N ($X_1 = 136$) in the net return function on 24 October ($X_2 = 298$) as opposed to the higher optimal rate of N ($X_2 = 212$). Of course, the economic penalty is less severe when expected harvest dates are closer to when harvest actually occurs.

Table 3. Optimum rates of N and corresponding net return by time of expected harvest.

Harvest periods	Date	Optimum N	Net return
		lb/acre	$/acre
1. Very early season	10 Sept.	136	540
	11	138	552
	12	140	564
	13	141	576
	14	143	587
	15	145	598
	16	147	609
	average (10-16 Sept.)	141	576
2. Mid-early season	17 Sept.	148	620
	18	150	631
	19	152	641
	20	153	652
	21	155	662
	22	157	672
	23	159	682
	average (17-23 Sept.)	153	652
3. Late early season	24 Sept.	160	691
	25	162	701
	26	164	710
	27	165	719
	28	167	728
	29	169	737
	30	171	745
	average (24-30 Sept.)	165	719
4. Early regular season	01 Oct.	172	754
	02	174	762
	03	176	770
	04	178	777
	05	179	785
	06	181	793
	07	183	800
	08	184	807
	average (01-08 Oct.)	178	781
5. Mid regular season	09 Oct.	186	814
	10	188	820
	11	190	827
	12	191	833
	13	193	839
	14	195	845
	15	196	851
	16	198	857
	average (09-16 Oct.)	192	836
6. Late regular season	17 Oct.	200	862
	18	201	868
	19	203	873
	20	205	877
	21	207	882
	22	208	887
	23	210	891
	24	212	895
	average 17-24 Oct.)	206	880

Management Options

To more effectively compare various management options of fertilizing with regard to time of harvest, the schedule of 45 harvest days was grouped into six harvest periods representing time intervals of a more practical nature for decision-making: (i) very early (10-16 September); (ii) mid early (17-23 September); (iii) late early (24-30 September); (iv) early regular (1-8 October); (v) mid regular (9-16 October); and (vi) late regular (17-24 October). At planting time, the producer may be able to plan the "week," but is less likely to anticipate the "day" of expected harvest. Therefore, optimal daily N rates and corresponding net return values (shown in Table 3) were averaged for each designated harvest period to determine

Table 4. **Rates of N, root yields, and net return occurring in different harvest periods as a result of alternative management options.**

	Fertilizer management options								
	(i) Adjust fertilizer rate by harvest period to maximize net return			(ii) Apply fertilizer at same rate (200 lb) over all harvest periods			(iii) Adjust fertilizer rate by harvest period to maximize root yield		
Harvest periods	Applied N	Root yield	Net return	Applied N	Root yield	Net return	Applied N	Root yield	Net return
	lb/acre	ton/acre	$/acre	lb/acre	ton/acre	$/acre	lb/acre	ton/acre	$/acre
1. Very early (10-16 Sept.)	141	21.0	576	200	21.7	562	229	21.8	545
2. Mid early (17-23 Sept.)	153	21.9	652	200	22.4	643	236	22.6	625
3. Late early (24-30 Sept.)	165	22.8	719	200	23.2	714	243	23.4	695
4. Early regular (1-8 Oct.)	178	23.8	781	200	24.0	779	251	24.2	760
5. Mid regular (9-16 Oct.)	192	24.8	836	200	24.9	836	259	25.2	818
6. Late regular (17-24 Oct.)	206	25.8	880	200	25.7	880	268	26.2	865

an optimal N rate for a particular harvest period (vs. a specific date).

In the context of these six weekly harvest periods, the performance of three selected management strategies is compared in Table 4, including: (i) adjusting rates of N with regard to an expected harvest period, given the objective of maximizing net return, with weekly averages derived in Table 3; (ii) a nonadaptive strategy of fertilizing at the same rate (200 lb N/acre), regardless of the expected harvest period; and (iii) again adjusting rates of N with regard to expected harvest period, but with a different objective, i.e., maximizing production in the form of root yield (vs. maximizing net return). With respect to the nonadaptive option ii, applying N at rates up to 200 lb/acre is commonly observed in the Powell Area of Wyoming (Agee and Lauer, 1989, unpublished data).

With respect to option iii (maximizing production) a quadratic response function was estimated for root yield (tons/acre) as the dependent variable in a manner essentially identical to that for the net return function.

$$\begin{array}{cccc} \text{Root Yield} & \hat{\beta}_0 & \hat{\beta}_0^{\text{adj}} & \hat{\beta}_1 \\ \underline{\text{(ton/acre)}} & \underline{\text{Intercept}} & \underline{\text{adjust. intercept}} & \underline{\text{N-level}} \\ Y \;=\; & +0.17559 & -0.9347566 & -0.006814 \\ & (7.34649) & & (0.03995) \end{array}$$

$$\begin{array}{cccc} \hat{\beta}_2 & \hat{\beta}_3 & \hat{\beta}_4 & \hat{\beta}_5 \\ \underline{\text{N-level}^2} & \underline{\text{harvest date}} & \underline{\text{harvest date}^2} & \underline{\text{Interaction}} \\ -0.0000963 & +0.068765 & +0.0 & +0.000198 \\ (0.00002) & (0.26751) & (0.0) & (0.00014) \end{array}$$

$$\begin{array}{cc} \hat{\beta}_6 & \hat{\beta}_7 \\ \underline{\text{D89}} & \underline{\text{D90}} \\ -3.732334 & +0.401294 \\ (0.51545) & (0.47659) \end{array}$$

$$R^2 = 0.7766 \qquad F \text{ value} = 37.667$$

Similar to the net return function, the predictive performance of the root yield function was also tested with out-of-sample data (1991). Predicted root yields were within 20% or less of actual yields given various rates of N between zero and 300 lb/acre. Rates of N that yielded maximum root yield per acre were derived for each harvest date with the estimated root yield function, by taking the partial derivative of Y (root yield) with respect to N (X_1), i.e., $\partial Y/\partial X_1 = 0.006814 - 0.0001926\ X_1 + 0.000198\ X_2$, and then setting it equal to zero for each of the 45 harvest dates between 10 September ($X_2 = 254$) to 24 October ($X_2 = 298$). Yield maximizing rates of N (X_1) and associated harvest dates (X_2) were substituted back into the estimated net return function to derive net return values corresponding to maximum root yields (Table 4).

Table 5. **Optimum rates of N and corresponding net return by time of expected harvest, given alternative prices for sugar and N.**

	N price					
	(i) $0.24/lb		(ii) $0.27/lb		(iii) $0.30/lb	
Net sugar price	Optimum N	Net return	Optimum N	Net return	Optimum N	Net return
	lb/acre	$/acre	lb/acre	$/acre	lb/acre	$/acre
1. $24/cwt						
Very early	152	677	148	672	144	667
Mid early	163	771	160	765	156	760
Late early	175	853	172	847	168	842
Early regular	188	928	184	922	181	916
Mid regular	201	994	198	987	194	981
Late regular	215	1045	211	1038	208	1031
2. $21/cwt						
Very early	146	580	141	576	138	571
Mid early	158	657	153	652	150	646
Late early	170	724	165	719	161	713
Early regular	182	787	178	781	174	775
Mid regular	195	843	192	836	187	830
Late regular	208	886	206	880	200	873
3. $18/cwt						
Very early	140	484	136	480	131	475
Mid early	152	553	147	548	143	543
Late early	164	613	159	608	154	602
Early regular	177	668	172	662	167	656
Mid regular	190	716	186	710	181	703
Late regular	204	753	199	746	194	739

Table 4 shows adjusting N rates by harvest period with the objective of maximizing net return (option i) provides higher net returns than the two other options, particularly during the early harvest periods. For example, during September (harvest periods 1-3), reducing N in response to earlier expected harvest, as opposed to simply applying 200 lb N/acre, increases net return from $5/acre ($719 vs. $714) in period 3—to $14/acre ($576 vs. $562) in the very early period (1). During the regular October periods 4-6), however, net return is not as adversely affected by fertilizing at the constant 200 lb rate. As a rule, these results suggest that if maximizing net return is the objective (option i), N should be reduced approximately 12 to 14 lb/acre for each week earlier that harvest is scheduled to occur.

As expected, fertilizing at rates necessary to achieve maximum root yield (option iii) requires substantially more N than fertilizing for maximum net return (option i) and, in addition, generates substantially lower net return values. Specifically, managing for maximum root yield reduces net return by $31/acre in the very early period (from $576–$545) and by $15/acre in the late regular period (from $880–$865), indicating the penalty for fertilizing for maximum root yield (vs. net return) is a bigger concern for early vs. late harvest dates. In addition, fertilizing for maximum root yield (iii) is also worse with respect to generating much lower net return values than simply applying 200 lb N/acre with no regard to time of harvest (ii). Producers fertilizing for maximum root yield would certainly benefit from reducing N rates for each week earlier harvest is expected to occur. However, the weekly cutback shown in Table 4 (ranging from 7–8 lb N/acre) is somewhat lower than that associated with maximizing net return (12–14 lb N/acre).

Sensitivity Analysis

The optimal rates of N (associated with maximizing net return) at given times of harvest were presented (Table 3) on the basis of a net return function estimated with net sugar price of $21/cwt and N price of $0.27/lb. The sensitivity of optimal N rates and net return values to changes in the price of sugar and price of N was examined by estimating alternative net return functions for different sugar and N price combinations (Table 5). For the results shown in Table 5, net sugar price was varied $3/cwt from its base value of $21 (i.e., $24 and $18/cwt) and N price was changed $0.03/lb from its base level of $0.27/lb (i.e., $0.24 and $0.30/lb).

Increasing the price of N (from $0.24–$0.30/lb across Table 5) causes only modest reductions in net return values, ranging $9 to $14/acre. In contrast, reductions in net return values appear to be quite sensitive to lowering the price of sugar (reading down each column for a particular harvest season and price of N). For example, given N = $0.27/lb, net return in the very early period drops by $96/acre, from $672 ($24 sugar) to $576 ($21 sugar); and by another $96/acre from $576 ($21 sugar) to $480 ($18 sugar). In the late regular period, net return drops by $158/acre, from $1038 ($24 sugar) to $880 ($21 sugar); and by another $134/acre from $880 ($21 sugar) to $746 ($18 sugar).

Reductions in optimal rates of N, given higher N prices, are shown to be quite small. For example, given $21 sugar, the optimal N rate for early harvest drops only 8 lb/acre within the specified range of N price increases, from 146 ($0.24 N) to 138 ($0.30 N) lb. Similarly, decreasing the price of sugar results in only modest reductions in optimal rates of N. For example, given $0.27 price of N, the optimal rate of N in the very early period falls from 148 lb/acre ($24 sugar) to 141 lb ($21 sugar); and from 141 to 136 lb/acre ($18 sugar). In a similar manner, the optimal rate in the late regular period drops from 211 ($24 sugar) to 206 ($21 sugar) to 199 ($18 sugar) lb.

Table 5 also shows the net return difference between earlier vs. later harvest periods are more pronounced with higher sugar prices. For example, considering the column for N = $0.27/lb, the difference between very early ($672) vs. late sugar harvest ($1038) given the higher $24/cwt sugar price is $366/acre. This compares with only a $266/acre margin ($480 vs. $746/acre) between these same two periods given a lower ($18/cwt) sugar price. Finally, it is significant to note that the recommended reduction in optimal rates of N associated with each week of earlier anticipated harvest (i.e., 11–14 lb/week) changes very little across all specified combinations of sugar and N prices.

CONCLUSION

Historically, many producers in the study area have not adjusted rates of N on those acres intended for early harvest. This study was designed to examine the economic benefit of reducing N on acreage intended for earlier harvest. While adjusting rates of N may not be as critical for traditional late harvest dates, it becomes increasingly important if more acres are planned for early harvest. With the possibility of more early harvest acres on the horizon, producers should be encouraged to select their early harvest acres at planting time when N is applied. This appears to be especially true if decisions are based on an economic objective (e.g., maximum net return) as opposed to a production based objective (e.g., maximum root yield).

The early harvest premium is below the level needed to fully compensate for the value of lower root yield and sucrose content associated with earlier harvest. This difference has been the topic of ongoing contract negotiations between growers and sugar processors as suggested by Burgener (1992). It should be noted, however, that other possible benefits associated with earlier harvest (e.g., machinery cost efficiencies and reduced weather risks) were not included in this analysis. In addition, lower valued sugarbeets (resulting from earlier harvest) can be equally or more profitable than other competing crops in the region (Hewlett et al., 1991). Hence, the issue of developing an appropriate early harvest premium is not necessarily a simple matter of evaluating difference in net return values between the earlier- vs. late-harvested sugarbeets.

This particular study is limited to examining the economics of earlier vs. later harvest sugarbeets in a single enterprise context. Additional analysis of earlier vs. later harvest has to be continued within a total farm system framework. This type of system model should include the influence of expanded sugarbeet acreage and machinery cost economics, and late season weather risks, as well as the competitive status of sugarbeets (harvested at different times) with other crops. This competitive status should reflect not only differences in relative profitabilities, but seasonal resource requirements such as harvest time labor. Such an analysis could be conducted within a mixed-integer risk programming model, similar to that described by Held and Helmers (1991). Within this type of model, machinery costs could be internalized with alternative activities for sugarbeets harvested at different time intervals, along with other crops. In addition, the adverse impact of additional weather risk could be captured in terms of lower returns and increased income variability.

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