Sugarbeet Response to Residual and Applied Nitrogen in Texas

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Abstract

Nitrogen (N) management for sugarbeet can be very difficult on slowly permeable, deep soils in semi-arid regions with limited leaching. Nitrogen application rates on wheat, sorghum, and corn preceding sugarbeet were varied to determine if economically optimum N rates for those crops provide favorable residual N (RN) for sugarbeet. This provided a range of residual nitrate nitrogen (NO_3-N) levels for sugarbeet production. Sugarbeet response to a factorial combination of RN and applied N (AN) rates was studied. Residual NO_3-N following economically optimum fertilization of prior crops was 1 to 67 lb acre^{-1}, 0-4 ft, (1 to 75 kg ha^{-1}, 0 to 1.2 m), low enough to maximize sugarbeet quality. Sugarbeet yields near 40 ton acre^{-1} (90 Mg ha^{-1}) with >16% sucrose (>160 g kg^{-1}) were produced in every experiment. Recoverable sucrose yield response to optimum AN was +101% at RN = 10 (i.e. optimum AN doubled yield at RN = 11 kg ha^{-1}, 0 to 1.2 m), but was never >+6% when RN equaled or exceeded 84 lb acre^{-1} (94 kg ha^{-1}). Sucrose and quality were reduced when RN was high enough (>136 lb acre^{-1}, 152 kg ha^{-1}) that no positive response to AN was observed. High RN (0 to 4 ft, 0 to 1.2 m) reduced quality even when RN below 4 ft (1.2 m) was low because N availability late in the growing season remained too high. For example, 30 lb acre^{-1} RN + 240 lb acre^{-1} AN (34 kg ha^{-1} RN + 269 kg ha^{-1} AN) gave an August petiole NO_3-N of 1,000 ppm (mg kg^{-1}) compared to 17,500 ppm for 261 RN + 0 AN (292 RN + 0 AN). Sucrose was 16.4% (164 g kg^{-1}) with 36.7 ton acre^{-1} (82 Mg ha^{-1}) for the former case and 13.9% (139 g kg^{-1}) with 38.6 ton acre^{-1} (86 Mg ha^{-1}) for the latter. Nitrogen requirement ((RN + AN) ÷ ton acre-1) declined from 8 lb ton^{-1} (1.6 kg Mg^{-1}) at RN = 10 to 4 lb ton^{-1} (0.8 kg Mg^{-1}) at RN = 120. Reducing RN prior to sugarbeet offers the greatest opportunity for improving sugarbeet quality in Texas.

Additional key words: *Beta vulgaris,* yield, quality, soil, wheat, corn, sorghum, impurities, petiole nitrogen, sucrose, molasses, nitrogen requirement.

INTRODUCTION

Sugarbeet must be N deficient prior to harvest to achieve high quality. The necessary period of deficiency is usually 4 to 8 weeks (Hills et al., 1982), but may be less with thicker stands and smaller roots (Loomis and Ulrich, 1962). Excessive N after mid-season increases impurities (Carter, 1986a) and moisture content of the root (Carter, 1986b), thus lowering extractable sucrose and percent sucrose (Carter and Traveller, 1981). If a N deficiency (petiole nitrate below 1000 ppm) develops within 3 months of harvest, it is better to continue the deficiency than to apply additional N (Hills et al., 1963; Hills et al., 1982; Loomis and Nevins, 1963). In Texas, sugarbeet grown on clay loam soils that are not N deficient by August seldom become deficient even when harvested in November. This is probably due to reduced N assimilation brought on by cooler weather and a continuously expanding root zone owing to deep soils. Most of the soils used for sugarbeet production in Texas will accumulate nitrate with normal water management if over-fertilized (Winter, 1981, 1984, 1986).

Residual soil NO_3-N (RN) levels are frequently well correlated to sugarbeet response to applied N (AN) (Cattanach et al., 1992; Giles et al., 1975; Hills et al., 1982; Reuss and Rao, 1971). In North Dakota, the current recommendation is for 6 lb ton^{-1} RN + AN based on a 2 ft soil NO_3-N test. The data upon which this recommendation is based considered RN to 5 ft depth. A 2 ft soil sampling depth is now used based on cost effectiveness. Deeper sampling is recommended under certain conditions. When 2 to 4 ft RN exceeds 30 lb acre^{-1}, AN is reduced by 80% of the excess. Many additional guidelines are provided (Cattanach et al., 1992). In California, the recommendation is to apply no N when RN exceeds 200 lb acre^{-1}, 0-3 ft, and to rely on petiole testing to correct the rare mid-season deficiency which may occur (Hills et al., 1982). Recommended N applications for a 30 ton acre^{-1} crop are: 140, 110, 80, 50 and 0 lb acre^{-1} AN when RN equals 0, 50, 100, 150, and 200 lb acre^{-1}, respectively. Both California and North Dakota recommendations result in a higher total of RN + AN at high RN than at low RN. North Dakota only partially accounts for higher levels of RN below 2 ft and California recommends lower totals at low RN.

Other locations have found RN to have greater effects on sugarbeet than AN. In Colorado, soil NO_3-N had a greater effect on sucrose and plant N uptake than did AN (Giles et al., 1975). Soil NO_3-N was measured to 2 ft and recoverable sucrose did not respond to AN when RN exceeded 116 lb acre^{-1}. In Washington state, soil RN was measured to 6 ft or to a limiting layer (James et al., 1971). Low RN combined with appropriate AN gave more dependable control of root quality than cases where RN was high enough to preclude positive response to AN. Only 3 of 9 sites with RN of 40 to 80 lb acre^{-1} gave a positive response to AN. Sucrose was 2% (20 g kg^{-1}) lower with RN of 160 to 240 lb acre^{-1} plus zero AN than with 0 to 40 RN plus 200 AN. A study on Nunn clay loam in Colorado found that RN, 0-5 ft, had similar effects on N uptake by sugarbeet as an equivalent amount of AN (Reuss and Rao, 1971).

Soil sampling depth for RN would seem to have obvious consequences on whether RN and AN are equivalent in effects on sugarbeet. If samples are taken to significantly less than the rooting depth of sugarbeet, which often seems to be the case, then measured RN only partially accounts for total RN that may affect the crop. The ratio of shallow to deep soil NO_3-N varies with location and soil (James et al., 1971; Ludwick et al., 1977; Moraghan, 1982; Winter, 1986). Sampling more of the root zone usually significantly improves correlation of soil test values to crop response (Ludwick et al., 1977; Winter, 1986). However, shallow samples are frequently well correlated with deeper samples (Ludwick et al., 1977; Reuss and Rao, 1971) which makes shallow samples economically attractive. Spatial variability of RN can be large (Reuss et al., 1977; Winter, 1986). If so, sampling resources may be better spent on more shallow samples rather than deeper samples.

Mineralizable N may be an important N source for sugarbeet (Carter et al., 1976; James et al., 1971). However, on the low organic matter soils of the irrigated western US, this factor is mostly ignored when making N recommendations.

Economically optimum N rates on sugarbeet are affected by several factors other than the physiological response of sugarbeet to N.

Payment system, hauling charges, and fertilizer cost affect N economics. Sugarbeet payment at many locations was once based solely on root yield. Fertilizing for recoverable sucrose rather than root yield lowered optimum AN rates by 80 lb $acre^{-1}$ (Adams et al., 1983).

This research was conducted to determine if economically optimum N rates on crops prior to sugarbeet result in favorable RN profiles for sugarbeet production, to determine the yield and quality response of sugarbeet to RN as compared to AN, and to refine N recommendations for sugarbeet in Texas.

MATERIALS AND METHODS

All research was conducted on Pullman clay loam soil which has been described in detail (Unger and Pringle, 1981). This soil, a fine mixed thermic Torrertic Paleustoll, is a clay loam from the surface to the estimated normal sugarbeet rooting depth of 9 ft except in the clay B horizon from 1 to 2 ft depth. Soil organic matter in the Ap horizon is about 1%. Leaching of NO_3-N is usually minimal in this soil (Winter, 1986). All research for these studies was conducted on level borders. This somewhat increases the possibility of leaching; however, all irrigations were applied to minimize leaching and, therefore, more closely simulate furrow or sprinkler irrigation. This was done by adjusting applications (usually 3 inches of water) to allow for complete intake in 12 hr or less. All irrigation water or precipitation remaining after 24 hr intake time was drained from the plots. Normal intake in 24 hr is about 4 inches. Available water holding capacity is 8 to 9 inches of water in a 6 ft soil depth (Unger and Pringle, 1981).

The N rate studies on wheat, corn, and sorghum grown prior to sugarbeet had from 3 to 6 N rates and four replicates (Table 1). In the case of experiment 6 (E6), the indicated rates were applied 2 years consecutively to the same plots. Corn was harvested for forage in 1989 and for grain in 1990 in E6. The other N rate studies on prior crops were conducted one year. In experiment E1, N was applied twice to the same wheat crop because the wheat was harvested for forage in late October, allowed to regrow, and harvested for grain the next spring. This experiment was intended to simulate wheat grown for grazing

Table 1. Nitrogen applied to crops grown prior to sugarbeet, resultant yields, and residual nitrate profile prior to sugarbeet.

Exp. no.	Prior crop	Year grown	Nitrogen on prior crop		Yield of prior crop		Notes on prior crop	Residual NO_3-N prior to sugarbeet			Year sugarbeet grown
			Fall	Spring	forage	grain		0-4 ft	0-9 ft	4-9 ft	
			lb acre^{-1}		lb acre^{-1}			lb acre^{-1}			
1	wheat	1988-89	0	0	1710 b	240 b	severe hail	30	47	17	1990
			120	120	3340 a	1140 a	reduced	67	80	13	
			240	240	3530 a	1140 a	grain	136	154	18	
			360	360	3300 a	1020 a	yield	261	319	58	
2	wheat	1988-89	0	0	0	540 a	severe hail	45	83	38	1990
			160	0	0	840 a		110	154	44	
			320	0	0	960 a		206	244	38	
3	sorghum	1989	0	0	0	4290 b	moderate	2	32	30	1990
			0	120	0	4930 a	drought	1	29	28	
			0	240	0	5260 a	stress	5	19	14	
			0	480	0	5070 a		123	173	50	

Table 1. *(Continued)* Nitrogen applied to crops grown prior to sugarbeet, resultant yields, and residual nitrate profile prior to sugarbeet.

Exp. no.	Prior crop	Year grown	Nitrogen on prior crop		Yield of prior crop		Notes on prior crop	Residual NO_3-N prior to sugarbeet			Year sugarbeet grown
			Fall	Spring	forage	grain		0-4 ft	0-9 ft	4-9 ft	
			lb acre^{-1}		lb acre^{-1}			lb acre^{-1}			
4	sorghum	1990	0	0	0	5250 b	excellent	10	46	36	1991
			0	120	0	9380 a	crop	21	48	27	
			0	240	0	7970 ab		69	104	35	
			0	480	0	8730 a		351	431	80	
5	wheat	1989-90	0	0	0	2420 b	excellent	18	31	13	1991
			120	0	0	5830 a	crop	23	49	26	
			240	0	0	6020 a		133	199	66	
			360	0	0	5750 a		267	424	157	
6	corn	1989	0	0	10,500 b	3400 c	silage in	16	52	36	1991
		1990	0	120	18,470 a	6220 b	1989,	17	73	56	
			0	240	19,890 a	8840 a	grain in	34	122	88	
			0	360	18,240 a	9350 a	1990	84	240	156	
			0	480	18,610 a	8130 a		192	359	167	
				600	18,960 a	8310 a		238	471	233	

and grain, a common practice in this area.

Nitrogen rates applied to sugarbeet were 0, 120, 240, and 360 lb acre^{-1} as subplots within each RN level established by previous cropping. The above N rates were applied as NH4NO_3 in May when subarbeet had 4-8 leaves and were immediately incorporated with a cultivator. Nitrogen was applied after sugarbeet establishment to improve spatial accuracy of placement relative to prior treatments and to avoid any negative effects of AN on emergence. The N was applied in irrigation furrows of beds spaced 30-inches apart. The sugarbeet cultivar 'Mono Hy TX18' was planted in late March at 87,000 seed acre^{-1} and irrigated for emergence soon after planting. All pests of sugarbeet were well controlled in all experiments so these factors did not significantly limit yield.

Sugarbeet subplot size for AN rates was 30 ft long by 6 beds wide. Harvest area for yield was 22 to 24 ft of the center two beds. Three to four end beets were trimmed from each end of each harvested row to reduce border effects. From 2 to 4 root samples of 25 to 30 lb each were collected at random from each plot and analyzed for sucrose, tare, and Na, K, and amino-N impurities. These data were used to calculate yield, sucrose, sucrose loss to molasses, and recoverable sucrose (Carruthers and Oldfield, 1960)

Soil samples for NO_3-N were collected by 1 ft increments to 9 ft depth from each N rate following harvest of prior crops. Several cores were collected from each plot and were composited by 1 ft increments across the four replicates within prior crop N rates of each study to reduce sample analysis costs. Soil samples were analyzed for NO_3-N using 2 molar KCl extraction and a Cadmium reduction procedure (Kamphake et al., 1967). Sugarbeet petiole NO_3-N was determined using a nitrate ion electrode.

Nitrogen requirement for purposes of this discussion is defined as (RN + AN) ÷ ton acre^{-1}. The 0 to 4 ft RN value is used in this calculation and is emphasized throughout this discussion because local producers use the 0 to 4 ft RN for their management decisions.

Net return of sugarbeet above fertilizer cost was calculated based on the payment system of Holly Sugar Corp. for the Hereford, Texas factory and using local fertilizer N costs. Holly's payment system is structured such that the grower is paid nearly on the basis of recoverable sucrose. Optimum AN for sugarbeet was determined by solving the quadratic regression of net return vs AN for its maximum value (Little and Hills, 1978).

Data were analyzed using SAS general linear models and regression procedures (SAS Institute, Inc., 1985). In the regression analysis to relate optimum AN, yield, and quality to RN, means within RN levels were used because replicated soil RN values from individual main plots were not available. A total of 21 RN levels were deemed representative and useable for regression analysis.

RESULTS AND DISCUSSION

Prior Crops

Information about the crops grown prior to sugarbeet are presented in Table 1. Growth and yield of prior crops were normal for this area with the exception of experiments 1 and 2 (E1 and E2) where wheat yields were severely reduced by spring hail. A significant grain or forage yield response to N was observed in all experiments with the exception of E2 where hail made it difficult to measure any response. The economically optimum N rates on prior crops were near 120 lb $acre^{-1}$ on all experiments except E1 where optimum was 120 fall + 120 spring and E6 where corn for grain responded to N rates up to about 240 lb $acre^{-1}$.

The 0 to 4 ft residual NO_3-N levels for sugarbeet following optimum fertilization of prior crops were near 67, 45, 1, 21, 23, and 34 lb $acre^{-1}$ for E1 through E6, respectively. These are much lower values than typical for this region and indicate that RN can be adjusted to grow high quality sugarbeet without shortchanging prior crops. Grower values are probably higher because of over-fertilization; however, we can not rule out other factors such as soil type or irrigation method.

Nitrate in the pre-sugarbeet profiles was generally low to moderate below 4 ft (Table 1). Previous work indicated that total nitrate in the 4 to 12 ft profile averaged roughly equal to the total amount in the 0 to 4 ft profile (Winter, 1986). The ratio of deep to shallow nitrate can of course vary considerably (James et al., 1971; Ludwick et al., 1977; Moraghan, 1982; Winter, 1986). The nitrate below 4 ft in E1 through E4 would be considered low for Pullman soil, whereas, E5 and E6 are near normal in relationship to 0-4 ft values (Winter, 1986).

Sugarbeet Growth, Yield and Quality

Sugarbeet growth and yield were excellent in all six experiments (Fig. 1). Yields peaked near 40 ton acre^{-1}. nearly twice factory average. Sucrose exceeded 16% with better treatments in every experiment, again, well above factory averages. There were no severe weather events or damaging pest problems that significantly affected sugarbeet yield or quality. There was a statistically significant (statistics not shown) 7 to 18 ton acre^{-1} root yield response to AN at the lowest RN level in every experiment (Fig. 1). Experiment 2 was the least responsive site to AN. The other experiments demonstrated significant root yield response to AN at the lowest 2 or 3 RN levels (Fig. 1).

Sucrose declined with increasing AN and was significantly depressed by moderate RN even in the absence of AN (note E1 of Fig. 1). In E1, even a RN level of 136 lb acre^{-1} reduced sucrose 1% point (10 g kg^{-1}) or more at all AN levels. This occurred in E1 despite very low levels of RN below 4 ft. (Table 1). These results agree closely with previously reported responses (James et al., 1971).

Petiole nitrate levels for E1 are shown in Table 2. Lower sucrose at higher RN is due to the fact that petiole nitrate remains too high late in the season. This occurred at 0 to 4 ft RN of 136 to 261 lb acre^{-1} with zero AN and despite 4 to 9 ft RN of only 18 to 58 lb acre^{-1} (Table 1). In Pullman soil, sugarbeet quality is reduced even at moderate RN values because the crop is apparently unable to exhaust soil nitrate prior to harvest. This can occur even when there is no unusual concentration of RN below 4 ft.

The greater influence of RN than AN on late season petiole N can easily be seen in Table 2. When RN was 30, AN of 240 lb acre^{-1} gave a desirable petiole N of 1000 ppm on 16 August. In contrast, RN of 261 with AN of zero gave an August petiole N of 17,500 ppm. Sucrose was 16.4% with 36.7 ton acre^{-1} for the former case compared to 13.9% with 38.6 ton acre^{-1} for the latter case (Fig. 1). The quality advantage of supplying most of the N requirement from AN vs RN is easily understood by studying this example and by contrasting the effects of the two N sources on petiole N as documented in Table 2. Optimum levels of AN at low RN provide readily available N early in the season for canopy growth and root yield. Petiole N then rapidly declines. In contrast, at RN levels where there is little root yield response to AN, petiole N may decline only modestly or none during the growing season. These responses are very similar to those found in Washington (James

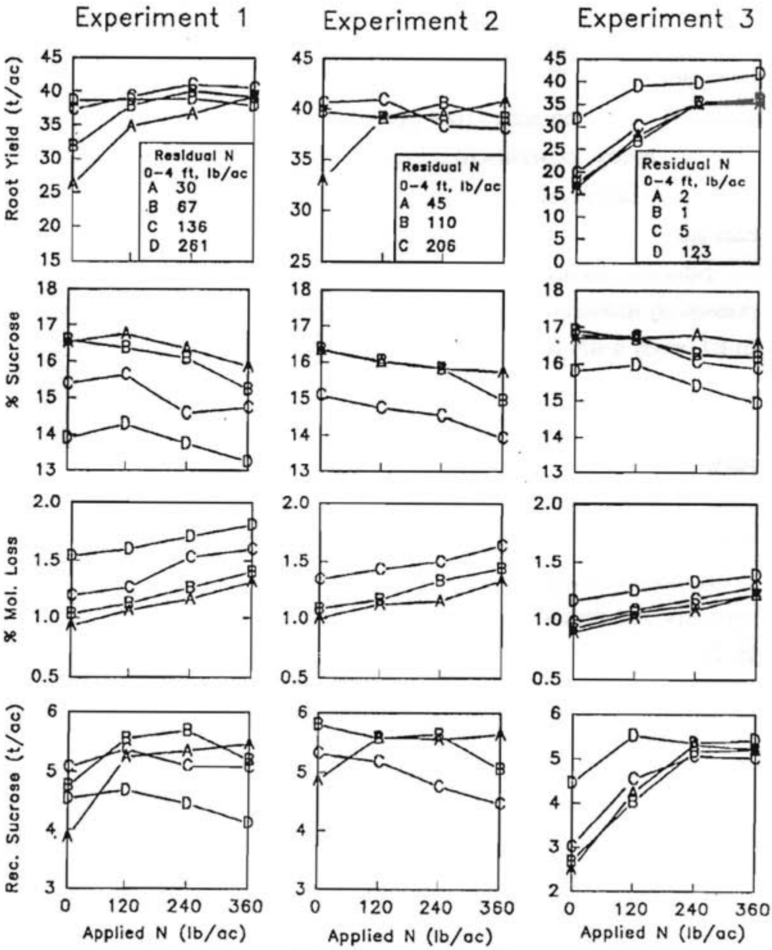

Figure 1. Sugarbeet root yield, sucrose, loss to molasses and recoverable sucrose yield as influenced by residual and applied N on Pullman clay loam soil at Bushland, TX. *(Continued on next page).*

et al., 1971). High RN has effects similar to applying AN during mid to late season, i.e., sucrose and quality decline and excessive dry matter partitioning to the tops occurs (Carter and Traveller, 1981).

High levels of both RN and AN cause major increases in measured root impurities which account for increases in sucrose loss to molasses (Fig. 1). High N uptake greatly increases Na and amino-N in the root at harvest with comparatively minor increases in K (data not shown).

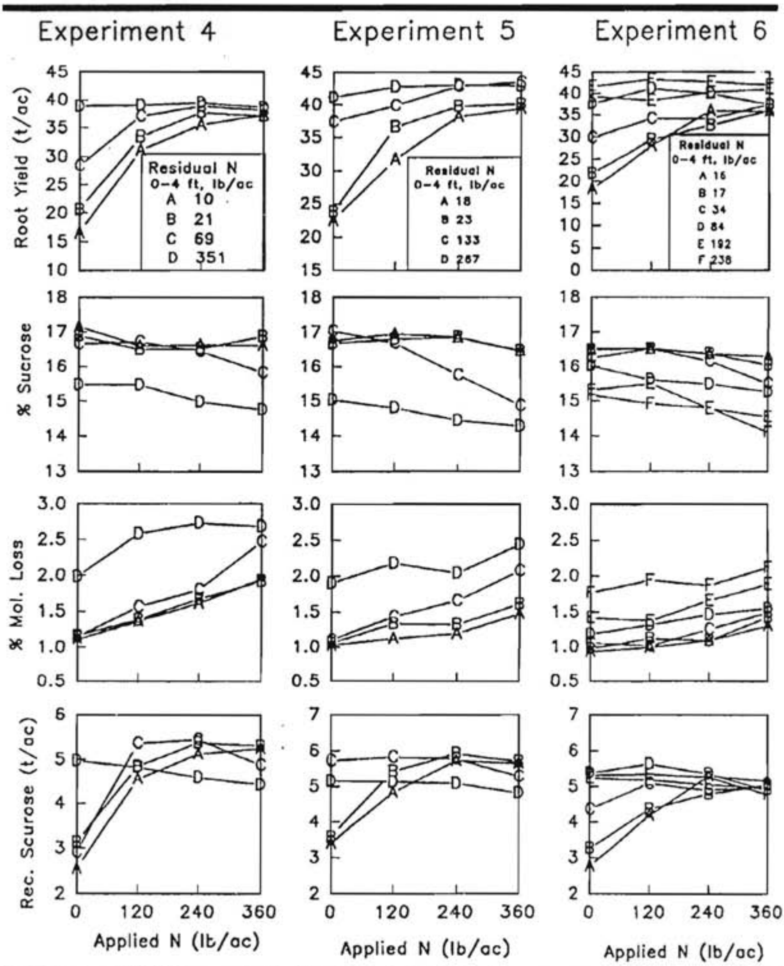

Figure 1. *(Continued from last page)* Sugarbeet root yield, sucrose, loss to molasses and recoverable sucrose yield as influenced by residual and applied N on Pullman clay loam soil at Bushland, TX..

These results are similar to those well documented in Idaho (Carter, 1986a, 1986b).

Experiment 3 exhibited some unusual characteristics that warrant exclusion from subsequent analyses. Residual N was very low, 1 to 5 lb acre^{-1}, 0 to 4 ft, at the three lowest RN levels (Table 1). This resulted in sugarbeet N deficiency immediately after emergence. Because no AN was provided until the 4 to 6 leaf stage, some root yield loss occurred even at the highest AN level (Fig. 1). If AN had been applied preplant, much of this yield loss could have been avoided. Nitrogen deficiency prior to the 4-leaf stage can severely reduce yield and even result in stand loss (James et al., 1971). Therefore, this experiment is excluded from subsequent analyses and discussion.

Table 2. Sugarbeet petiole nitrate response to AN and RN in experiment 1 following wheat at Bushland, Texas in 1990.

Residual N†	Nitrogen on beets	Petiole NO_3-N 24 June	18 July	16 Aug
lb acre^{-1}	lb acre^{-1}		ppm	
30/47	0	290	160	450
	120	3,980	240	400
	240	12,700	1,640	1,000
	360	31,300	6,060	1,000
67/80	0	380	350	1,100
	120	2,610	660	450
	240	17,100	1,140	700
	360	33,900	6,010	3,060
136/154	0	4,470	3,870	2,230
	120	10,800	5,930	3,900
	240	18,000	6,040	4,140
	360	30,400	9,040	12,100
261/319	0	16,800	12,700	17,500
	120	19,700	17,200	17,900
	240	30,900	19,200	23,300
	360	35,300	20,600	22,100

†Residual N 0-4 ft/0-9 ft.

RN and AN Relationships

The 21 RN levels of all experiments except E3 are shown in Table 3. Also shown are the calculated optimum AN rates, percentage extractable sucrose response to optimum AN, and the calculated N requirement.

Table 3. Sugarbeet response to optimum applied N at 21 levels of residual N for all experiments except no. 3 on Pullman clay loam soil at Bushland, Texas.

Residual nitrate-N 0-4 ft	Optimum applied N	Response to applied Na†	Nitrogen requirement
lb $acre^{-1}$	lb $acre^{-1}$	%	lb ton^{-1}
10	257	101	7.5
16	236	91	7.0
17	352	54	10.3
18	259	69	7.3
21	224	72	6.4
23	217	66	6.0
30	134	35	4.7
34	116	16	4.4
45	104	15	3.8
67	118	17	4.9
69	131	26	5.4
84	104	5	4.6
110	0	0	2.8
133	42	2	4.7
136	98	6	6.0
192	0	0	4.9
206	0	0	5.1
238	0	0	5.7
261	0	0	6.8
267	0	0	6.5
351	0	0	9.0

†Percentage increase in extractable sucrose yield at optimum applied N compared to zero applied N.

Optimum AN was greater than 200 lb acre^{-1} when RN was less than 30 lb acre^{-1} (Table 3). When RN was 30 to 84 lb acre^{-1}, optimum sucrose to AN and at 7 of 9 RN levels above 84, response was zero or negative. As documented previously (8,11), a positive economic response was rarely measured in sugarbeet to AN at RN levels which would be considered low for most other irrigated crops. With sugarbeet, the negative impact of N on impurities and sucrose quickly overcomes any root yield increase as RN levels increase above 5 ppm (80 lb acre^{-1}, 0 to 4 ft). The caveat is that one must avoid early season N deficiency as occurred in E3

Nitrogen requirement appeared to be higher at very low RN values than at moderate values (Table 3, Fig. 2). This seems to be related to the general quality response on this soil. With very depleted RN (< 30 lb acre^{-1}), large amounts of AN were needed to maximize root yield with only a modest, but definite, decline in sucrose and quality (Fig. 1). At higher but still modest levels of RN (30 to 136 lb acre^{-1}), much

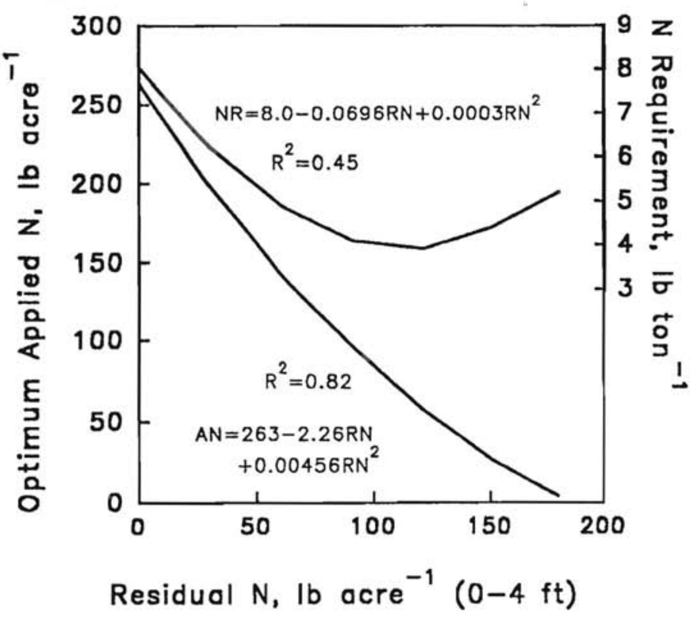

Figure 2. Quadratic regression lines to predict optimum applied N and N requirement based on soil residual N for Pullman clay loam at Bushland, TX.

less or no AN was required resulting in a low total N requirement. Nitrogen requirement then increased at higher RN values because root yield is increased very little above RN of 136 lb $acre^{-1}$. A declining N requirement between RN of 10 and 120 seems to be contrary to the current N recommendations of California (Hills et al., 1982) and North Dakota (Cattanach et al., 1992) but appears to agree with results in Washington (James et al., 1971) and Colorado (Giles et al., 1975).

Equations relating optimum AN, yield, and quality to RN are listed in Table 4. The equation predicting optimum AN based on RN has an R^2 of 0.82 (n = 21) and is displayed graphically in Figure 2. Predicted optimum AN ranges from 263 lb $acre^{-1}$ at RN = 0, to near zero at RN of approximately 180. The recommendation for AN at RN = 0 is nearly double the California recommendation (Hills et al., 1982). A small application of AN is recommended at RN between 84 and 180 where a positive economic response to AN is very difficult to measure. -This small application of AN will have a small negative effect on impurities at at harvest; however, it is good insurance against early season N deficiency. The detrimental effects of small early season N application are not large at any RN level. Even applying 120 lb $acre^{-1}$ AN when RN exceeds 200 lb $acre^{-1}$ does not have a large negative effect on sucrose or loss to molasses (Fig. 1). This further serves to emphasize that excessive RN, not excessive AN, is the primary N management problem on this soil.

The prediction of N requirement based on RN only has an R2 of 0.45; however, this does appear to be a significant function (Table 4). Nitrogen requirement at very low RN is double that at moderate RN (Fig. 2).

Residual N has major implications for sucrose, quality, and root yield. Sucrose declined 0.6% for each 100 lb $acre^{-1}$ increase in RN when optimum AN was applied (Table 4). This may not seem like much; however, when combined with increasing impurities, the loss in recoverable sucrose per ton has major implications for the processing side of the sugarbeet industry. On average, for each 100 lb $acre^{-1}$ increase in RN, root yield at optimum AN is estimated to increase by 1.21 ton $acre^{-1}$ (Table 4). This could be a real effect or it could be an

Table 4. Equations to predict optimum applied N; response to optimum applied N; and yield, quality, and N requirement at optimum applied N using residual N as the independent variable.

Dependent variable	Units	Intercept	Coefficients RN	Coefficients RN2	R2	F-value	Prob.> F
Opt. applied N	lb acre^{-1}	263	-2.26	+0.00456	0.82	40.7	0.0001
Response	%	74	-0.770	+0.00174	0.74	25.0	0.0001
Root yield	ton acre^{-1}	36.9	+0.0121		0.34	9.8	0.0056
Sucrose	%	16.67	-0.00599		0.59	27.5	0.0001
Recoverable	fraction	0.885	+0.719 x 10^{-5}	-0.77 x 10^{-6}	0.67	18.2	0.0001
N requirement	lb ton^{-1}	8.0	-0.0696	+0.3 x 10^{-3}	0.45	5.4	0.0198

artifact of the time of application of AN. If AN had been applied preplant instead of at the 4 to 8 leaf stage, there may have been even less or no root yield penalty associated with low RN levels. In any case, the measured yield penalty of low RN is more than offset by improved sucrose and reduced impurities.

Most of the relationships discussed between RN and AN follow very closely the results seen in Washington (James et al., 1971) and Colorado (Giles et al., 1975). Data from those locations would appear to agree with a nonlinear relationship between RN and AN as summarized for Texas in Fig. 2. The damaging effects of excessive RN on sugarbeet quality in soils such as Pullman clay loam are substantial and demonstrate why high RN is considered to be the primary factor limiting sugarbeet quality in Texas. In many cases, cropping our soils low enough in RN for high quality sugarbeet can take years of careful monitoring of RN values and judicious fertilization of prior crops.

The greater effect of RN than AN on sugarbeet yield and quality may be difficult to fully explain. Part of the explanation is that RN is almost never measured to the full rooting depth of sugarbeet. In our case, RN was measured to 4 ft whereas the crop roots to 8 or 9 ft. The lower early season availability of RN than AN at equal levels and lingering effects of RN late in the season (Table 2) are surely related to the large soil volume which the roots must explore to fully utilize RN. Since sugarbeet is a vegetative crop, fibrous root growth to increasing depth may continue late into the growing season. These factors, while possibly not the total explanation, seem sufficient to explain much of the differing response to RN compared to AN. One could speculate that RN is buffered by an unmeasured source of soil N; however, that is pure speculation. The soil was not tested for other N sources such as ammonia or mineralizable N. Further, one would think that the availability of any organic N sources would be nearly the same at all RN levels.

Nitrogen Recommendations

Nitrogen recommendations for the average grower based on these data are hampered by the differences in yield levels between factory averages and these experiments. Factory average yields for Holly's Hereford plant are about 22 ton $acre^{-1}$, not much more than half the yields in these experiments. However, N needs of sugarbeet probably are not proportional to yield. A 40 ton crop probably does not require twice as much N as a 20 ton crop (Smith, 1986). If this is true, using per acre recommendations would be better than per ton values. The amount of N adjustment necessary for differences in yield level would probably be dependent on what factors account for the differences in yield.

In Texas, sugarbeet N needs are increased by greater irrigation that increases yields (26). In North Dakota, 120 or 130 lb $acre^{-1}$ of N is the maximum recommendation with the assumption that added mineralization will provide for higher yielding conditions. The difference may be that North Dakota soils are much higher in organic matter and the crop is grown without irrigation. Thus, during wet, high yield years, mineralization could increase.

What is known for sure is that most sugarbeet grown in Texas never become adequately N deficient due to excessive soil NO_3-N. This can be corrected to some extent by reducing AN. To really improve sugarbeet quality in Texas and at other locations with excessive RN, a reduction in RN levels prior to planting sugarbeet must occur. This requires more careful fertilization of crops grown prior to sugarbeet and recognition of the carryover value of sugarbeet tops and other crop residues to the following crop in rotation.

The relationships between AN and RN discussed in this paper have important implications for precision agriculture. The type of detailed relationship presented in Table 4 and Fig. 2 is essential to maximize the benefit of this emerging technology. Using a straight linear relationship (constant total of AN + RN) where a nonlinear relationship similar to ours applies will result in continued under-fertilization of low RN areas and over-fertilization of high RN areas. The ability of precision agricultural techniques to improve economic return is highly dependent on proper functions to guide management decisions.

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