Plant Density and Nitrogen Rate Effects on Sugar Beet Yield and Quality Early in Harvest

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ABSTRACT

The sugar beet (*Beta vulgaris* L.) industry has adopted an early harvest option that lengthens the processing campaign by 15 to 30 d. Field experiments were conducted near Powell, WY, from 1989 to 1991, to determine whether plant density and N rate should be adjusted for earlier harvests. Main plots were N application rates of 0, 112, 168, 224, 280, and 336 kg N ha^{-1}; split plots were target plant densities of 37 100, 61 800, 86 500, and 111 200 plants ha^{-1}. Harvests were at regular intervals beginning 13 September and ending 25 October. During the harvest season, root yield increased 8.0 Mg ha^{-1}, sucrose content increased 29 g kg^{-1}, and recoverable sucrose increased 2.44 Mg ha^{-1}. The first 112 kg N ha^{-1} increased root yield 11.8 Mg ha^{-1}, while the next 56 kg N ha^{-1} increased root yield 5.2 Mg ha^{-1}. Sucrose content decreased from 164 to 157 g kg^{-1} as N rate increased from 0 to 336 kg ha^{-1}. The first 168 kg N ha^{-1} increased recoverable sucrose 2.48 Mg ha^{-1}. Plant density had no effect on root yield. Sucrose content increased 5 g kg^{-1} as plant density increased from 42 000 to 112 000 plants ha^{-1}. Recoverable sucrose increased from 7.40 Mg ha^{-1} at 42 700 plants ha^{-1} to a maximum of 7.79 Mg ha^{-1} at 88 600 plants ha^{-1}. No consistent harvest date × plant density interactions were observed for yield and quality measurements, suggesting that no adjustments in plant density were needed for earlier harvest dates. A harvest date × N rate interaction for recoverable sucrose implies that N rate should be decreased for earlier harvest dates.

THE SUGAR BEET INDUSTRY has adopted an early harvest option in the grower–processor contract. The earlier harvest lengthens the processing campaign by 15 to 30 d. Numerous experiments have determined the optimum plant density (Hofer et al., 1979; Smith, 1980) and N rate (Adam et al., 1983; Anderson and Peterson, 1988; Carter and Traveller, 1981; Carter et al., 1976; Halvorson and Hartman, 1975, 1980, 1988; Hills et al., 1983; James et al., 1978, Moraghan, 1987; Winter, 1990) for sugar beet yield and quality during normal harvest dates. Nitrogen rate recommendations are location-specific and usually range from 56 to 179 kg N ha^{-1}, although rates up to 364 kg N ha^{-1} are suggested for some locations (Hills and Ulrich, 1971). Maximum sucrose content and juice purity are achieved with the addition of 78 to 151 kg N ha^{-1} and plant densities of 79 000 plants ha^{-1} (Draycott and Durrant, 1974; Hofer et al., 1979). Excessive N rates adversely affect quality, especially at plant densities of <39 500 plants ha^{-1} (Hofer et al., 1979).

Highest sucrose yields are obtained by adjusting N rate for plant density and location. With optimum N, increasing plant densities from 22 200 to 49 400 plants ha^{-1} resulted in a substantial yield increase. Above 49 400 plants ha^{-1}, a slower rate of increase was observed, and yield stabilized at >76 600 plants ha^{-1} (Draycott and Durrant, 1974; Smith, 1980). Brei impurities generally decreased with increasing plant density from 19 800 to 118 600 plants ha^{-1} (Smith and Martin, 1977).

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Time of harvest may affect optimum N rate (Carter and Traveller, 1981; Hills and Ulrich, 1971). Burcky and Winner (1986) recommended that a beet crop with high plant density be harvested before a crop with lower plant density. This study examined the effects of N management and plant density on sugar beet root yield and quality at various harvest dates. This information will allow producers to make more informed decisions regarding early harvest options.

MATERIALS AND METHODS

Experiments were conducted at the University of Wyoming Research and Extension Center near Powell, WY, during 1989, 1990, and 1991. The soil was a Garland clay loam (fine-loamy over sandy or sandy-skeletal, mixed, mesic Typic Haplargid). Management practices were typical of those utilized commercially in many furrow-irrigated mountain valleys of the western USA.

Soil characteristics and management procedures are listed in Table 1. Preplant soil samples from the 0- to 30-cm depth were analyzed for residual nutrient levels. Soil test K is typically high in this soil and was not analyzed in 1990 and 1991. Phosphorous fertilizer (P_2O_5) in the form of triple superphosphate was applied at rates recommended for a 67 Mg ha^{-1} root yield goal. Ammonium nitrate fertilizer was the N source for all N treatments. The N treatments were broadcast preplant and immediately incorporated. The sugar beet cultivar Hilleshog Mono-Hy R2 was planted 2 cm deep in rows 56 cm apart. The seeding rate was 39 seeds m^{-1} of row in 1989 and 13 seeds m^{-1} of row in 1990 and 1991. Various combinations of the herbicides cycloate (*S*-ethyl cyclohexylethylcarbamothioate), desmedipham {ethyl [3-[[(phenylamino)carbonyl]oxy]phenyl]carbamate}, diethatyl-ethyl [*N*-(chloroacetyl)-*N*-(2,6-diethylphenyl)glycine], ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate], and/or phenmedipham {3-[(methoxycarbonyl)amino]phenyl (3-methylphenyl)carbamate} were applied at recommended rates in an 18-cm band (Table 1). Hand weeding controlled escaped weeds. Aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-(methylcarbamoyl)oxime] granules were applied preplant at the rate of 11.2 kg a.i. ha^{-1} to control the sugar beet root maggot, *Tetanops myopaeformis* (von Röder). Duration of furrow irrigations was sufficient to refill the soil profile to field capacity (12–24 h sets).

The experimental design was a randomized complete block in a split-plot arrangement with four replications and plot measurement over time (Gomez and Gomez, 1984). Main plots were N application rates of 0, 112, 168, 224, 280, and 336 kg N ha^{-1}. Split plots were target plant densities of 37 100, 61 800, 86 500, and 111 200 plants ha^{-1}. Split plots were nine rows wide and measured 7.6 m long. Plots were thinned to target densities and later checked for doubles and late germinating seed (Table 1). Plots were harvested between 13 September and 23 October at 20 d intervals during 1989 and 14 d intervals during 1990 and 1991. On each harvest date, sugar beet plants within the experimental unit of one 3.05-m row section of each plot were hand topped and lifted.

The sampled row section was measured for plant density, tare, root fresh mass, sucrose content, and purity parameters by the Western Sugar Company in Billings, MT. Purity parameters were measured by freezing brei samples and later analyzing for Na and K by flame photometry (William, 1984), and amino N by

Table 1. Plot management and soil characteristics of sugar beet studies grown at Powell, WY, during 1989 to 1991.

	1989	1990	1991
Previous crop	barley	oat	barley
Soil sample date	27 Mar.	10 Feb.	20 Mar.
Organic matter, g kg^{-1}	1.4	1.1	1.5
pH (saturated paste)	7.8	7.6	7.8
P, mg kg^{-1}	14.0	14.0	9.0
K, mg kg^{-1}	226.0	–	–
NO_3-N, mg kg^{-1}	6.0	6.0	14.0
Seeding date	20 Apr.	19 Apr.	24 Apr.
Herbicide, pre-plant or post emergence @ rate, kg a.i. ha^{-1}	pre: cycloate @ 2.5 + ethofumesate @ 1.9	pre: ethofumesate @ 2.2 + diethatyl-ethyl @ 2.2 post: phenmedipham + desmedipham @ 0.84	pre: ethofumesate @ 2.2 + diethatyl-ethyl @ 2.2 post: phenmedipham + desmedipham @ 0.28, 0.37, and 1.12
Irrigation dates	27 Apr., 26 June, 8 July, 21 July, 31 July, 11 Aug., 28 Aug., 14 Sept., 4 Oct.	28 Apr., 28 June, 13 July, 2 Aug., 17 Aug., 4 Sept., 21 Sept., 2 Oct.	1 May, 3 July, 19 July, 27 July, 7 Aug., 26 Aug., 29 Sept.
Plot thinning date	1 June	7 June	14 June

ninhydrin procedures (Quinn, 1974; Lawrence and Grant, 1963). Sucrose loss to molasses was calculated using a modified Carruthers and Oldfield (1960) formula. All measurements are calculated on a fresh weight basis (e.g., sucrose content = grams of sucrose per kilogram of fresh roots).

Treatment mean comparisons were made using least significant difference when F-values were significant ($P \leq 0.05$). Stepwise regression was used to describe relationships between measured variables and treatment levels. Linear, quadratic, and cubic coefficients were sequentially added to the model and included when they contributed significantly ($P \leq 0.15$) to the variation in the dependent variable. For the combined analysis, all early harvest dates (prior to 1 October) were averaged and compared with the average of all normal harvest dates (after 1 October). The chi-square test (Gomez and Gomez, 1984) was used to verify homogeneity of variance.

RESULTS AND DISCUSSION

Historically, the sugar beet harvest begins shortly after 1 October in the intermountain western USA. The early harvest portion of the sugar beet campaign begins between 1 and 15 September. In the Big Horn Basin area of northwestern Wyoming, growers typically try to establish harvest plant densities of 49 400 to 61 800 plants ha^{-1}. Nitrogen rates are usually split-applied, and annual totals range from 224 to 280 kg ha^{-1}.

The high seeding rate in 1989 made thinning difficult, and target densities were not obtained for all populations. This may have caused some distortion in partitioning sum of squares and may explain the significant linear, quadratic and cubic effects for density (Table 2). Lower seeding rates in 1990 and 1991 resulted in harvested plant densities that were closer to the target plant densities, and only linear effects were significant.

Two- and three-way interactions among N rate, plant density, and harvest date were not consistently observed between years (Table 2). The sum of squares associated with interactions were generally small compared with the sum of squares associated with main effects.

In all years, root yield, sucrose content, and recoverable sucrose increased with later harvest date (Table 3). Over the duration of the harvest season, root yield increased 8.3, 5.7, and 4.8 Mg ha^{-1} and sucrose content increased 32, 28, and 32 g kg^{-1} in 1989, 1990, and 1991, respectively, with later harvest date. Brei K decreased with later harvest date in all years; brei Na decreased with later harvest date in 1989 and 1990, but increased in 1991; and brei amino N increased with later harvest date in 1989 and 1991, but decreased in 1990. Sucrose loss to molasses was not consistently affected by harvest date, remaining unchanged in 1989, decreasing in 1990, and increasing in 1991. Recoverable sucrose increased 2.72, 2.42, and 2.33 Mg ha^{-1} in 1989, 1990, and 1991, respectively. Root yield, sucrose content, and recoverable sucrose increased linearly at the rate of 0.16 Mg ha^{-1} d^{-1}, 0.73 g kg^{-1} d^{-1}, and 0.061 Mg ha^{-1} d^{-1}, respectively, as the harvest season progressed (Fig. 1). No relationship between sucrose loss to molasses and harvest date was observed.

The effect of N rate on all yield and quality measurements was linear in every year, with the exception of sucrose content in 1989 and brei K in 1990 (Table 2). The first 112 kg applied N ha^{-1} increased root yield by 12.6, 12.7, and 9.9 Mg ha^{-1} in 1989, 1990, and 1991, respectively, and the next 56 kg N ha^{-1} increased it by 4.9, 3.9, and 7.0 Mg ha^{-1} (Table 3). In 1989 and 1990, root yield increases were linear and quadratic, with the rate of increase small beyond the initial 168 kg N ha^{-1}. Sucrose content was unaffected by N application rate in 1989, but decreased slightly in 1990 and 1991 as N rate increased. In all years, brei Na and brei amino N increased with increasing N, while brei K increased slightly in 1989, was not affected in 1990, and decreased in 1991. With N increasing from 0 to 336 kg ha^{-1}, sucrose loss to molasses increased 1.49, 2.55, and 2.88 g kg^{-1} in 1989, 1990, and 1991, respectively. The first 168 kg N ha^{-1} increased recoverable sucrose 2.78, 2.45, and 2.3 Mg ha^{-1} in 1989, 1990, and 1991, respectively. Maximum recoverable sucrose was observed at the N rates of 336, 224, and 168 kg N ha^{-1} for 1989, 1990, and 1991, respectively.

In the combined analysis, N rate affected all yield and quality measurements in a linear fashion, and significant quadratic effects were observed for root yield and recoverable sucrose (Table 4). Final plant density decreased slightly in a linear fashion, although this was significant only in 1991 (Table 2). Highly significant year × N rate interactions were observed for sucrose content, brei Na, brei amino N, and sucrose loss to molasses (Table 4). Depending on year, brei Na, brei amino N, and sucrose loss to molasses increased 19 to 58% as N rate increased from 0 to 336 kg ha^{-1} (Table 3). In every year, sucrose content always decreased 2 to 9 g kg^{-1} with increasing N rate.

Table 2. Mean squares from analysis of variance with orthogonal polynomial partitioning of all treatment main effects and interactions for yield and quality measurements of Hilleshog MonoHy R2 sugar beet grown at Powell, WY, during 1989 to 1991.

Source†	df	Harvest plant density	Root yield	Sucrose content	Brei impurities Na	Brei impurities K	Brei impurities Amino N	Sucrose loss to molasses	Recoverable sucrose
					1989				
Rep	3	794**	282*	70	1 587	56.4**	2.1	1.59	8.49**
N	5	219	2 723**	26	23 841**	28.3*	42.2**	14.42**	65.32**
N_L	(1)	972	11 327**	44	109 200**	86.0**	200.2**	70.10**	262.69**
N_Q	(1)	74	2 091**	55	4 561**	6.1	6.0	1.12	58.57**
N_R	(3)	15	66	10	1 852	16.5	1.5	0.30	1.77
error *a*	15	287	75	31	954	7.6	1.7	0.52	1.63
Density (D)	3	65 822**	35	185**	31 785**	268.5**	9.5**	14.64**	2.38
D_L	(1)	168 613**	81	332**	65 395**	495.1**	10.1**	24.23**	5.96
D_Q	(1)	23 383**	5	78*	21 642**	284.0**	12.7**	15.83**	1.14
D_R	(1)	5 470**	18	145**	8 318*	26.3*	5.7*	3.86**	0.03
N × D	5	178	47	23	2 308	14.8*	1.3	0.62	1.35
error *b*	4	194	56	18	1 541	6.4	1.3	0.46	1.58
Harvest (H)	2	1 020**	1 670**	24 684**	54 207**	195.1**	72.4**	0.91	177.23**
H_L	(1)	1 149**	3 342**	49 328**	105 959**	341.9**	142.1**	1.79	353.62**
H_Q	(1)	891*	58	40	2 455	48.3*	2.8	0.03	0.84
N × H	0	169	41	12	1 113	4.3	0.6	0.17	1.73
D × H	6	98	33	50	1 399	11.9	1.7	0.65	1.17
N × D × H	0	189	127*	12	1 259	7.4	2.4	0.97	3.48*
error *c*	144	142	70	12	1 089	10.0	1.2	0.58	1.87
					1990				
Rep	3	148	110	6	6 717	333.3**	4.5	5.94*	2.36
N	5	183	3 392**	526**	170 384**	11.9	202.3**	62.39**	63.26**
N_L	(1)	400	13 656**	2 320**	750 671**	4.7	990.0**	297.89**	210.69**
N_Q	(1)	197	3 235**	239**	86 252**	10.2	11.7	9.91**	104.30**
N_R	(3)	106	22	69	14 995	14.9	3.3	1.37	0.43
error *a*	15	115	121	36	6 739	31.2	1.9	1.52	2.88
D	3	51 147**	44	356**	70 998**	523.3**	17.1**	29.37**	1.83
D_L	(1)	153 184**	52	916**	178 812**	1 372.4**	5.4**	76.95**	0.91
D_Q	(1)	198	14	108*	21 721**	191.8**	5.5	9.94**	1.63
D_R	(1)	58	65	45	12 460*	5.7	0.5	1.21	2.94
N × D	15	104	85	28	10 298**	18.1	1.7	1.72	1.89
error *b*	54	196	82	20	2 159	20.3	2.1	1.09	1.81
H	3	243	601**	15 810**	90 467**	605.2**	42.8**	34.84**	111.81**
H_L	(1)	30	1 635**	39 301**	171 733**	1 622.0**	56.7**	88.44**	291.87**
H_Q	(1)	2	153	7 522**	79 416**	10.2	47.0**	14.50**	40.19**
H_R	(1)	697**	14	607**	20 253**	183.4**	24.8**	1.59	3.38
N × H	15	148	69	28	4 340**	15.1	1.8	0.94	2.13
D × H	9	145	95	21	1 774	10.8	1.2	0.53	1.91
N × D × H	45	128	40	13	1 673	10.0	1.8	0.76	0.89
error *c*	216	100	57	13	1 530	11.4	1.3	0.63	1.32
					1991				
Rep	3	110	191	13	129 131**	16.4	34.7**	14.17**	4.13
N	5	402	2 311**	745**	157 332**	58.1**	196.2**	69.74**	37.63**
N_L	(1)	1 108**	7 249**	3 416**	767 973**	170.2**	924.3**	325.59**	83.90**
N_Q	(1)	233	2 890**	66	1 128	15.5	0.7	0.85	79.25**
N_R	(3)	222	471*	82	17 562	35.0*	18.6	7.42*	8.34*
error *a*	15	152	115	43	5 865	6.5	5.3	1.85	1.98
D	3	76 151**	70	913**	159 819**	444.9**	35.4**	43.25**	5.28**
D_L	(1)	228 433**	34	2 541**	463 209**	1 218.8**	97.1**	122.08**	6.67**
D_Q	(1)	3	161	177**	11 803	101.5**	7.8	7.56*	8.51**
D_R	(1)	16	16	22	4 444	14.4	1.2	0.12	0.67
N × D	15	143	64	23	5 478	22.6	1.6	1.38	1.23
error *b*	54	158	51	27	10 750	12.2	3.2	1.73	1.12
H	3	151	1 042**	18 853**	1 130 612**	378.7**	98.6**	66.83**	114.35**
H_L	(1)	289	1 624**	53 560**	2 468 397**	854.5**	167.5**	93.09**	321.16**
H_Q	(1)	157	1 025**	2 560**	30 384*	85.6*	85.0**	31.42**	8.67**
H_R	(1)	6	476**	439**	893 054**	195.8**	43.2**	75.98**	13.21**
N × H	15	103	39	20	2 913	7.2	3.0	0.56	0.95
D × H	9	156	66	37**	6 462	17.6	1.7	1.08	1.26
N × D × H	45	91	59	15	4 305	10.7	1.9	1.06	1.25
error *c*	216	109	57	13	6 447	12.6	1.9	0.98	1.17

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Plant density had no effect on root yield (Tables 3 and 4). Sucrose content increased 3 to 8 g kg^{-1} with increasing plant density, depending on year. All brei impurities and sucrose loss to molasses decreased with increasing plant density. Recoverable sucrose was not affected by plant density during 1989 and 1990 (Table 3), but in 1991 recoverable sucrose increased to a maximum between 64 300 and 85 300 plants ha^{-1} and in the combined analysis plant population had a significant effect on recoverable sucrose (Table 4).

Main effects accounted for a large portion of the sum of squares in the analysis of variance (Table 2). Nitrogen rate and harvest date were the major factors affecting yield and quality. Harvest date interactions with plant density

Table 3. Sugar beet yield and quality response to N, plant density, and harvest date during 1989 to 1991 at Powell, WY.

Main effect	Harvest plant density	Root yield	Sucrose content	Brei impurities Na	Brei impurities K	Brei impurities Amino N	Sucrose loss to molasses	Recoverable sucrose
	plants ha^{-1}	Mg ha^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	Mg ha^{-1}
Applied N, kg ha^{-1}					1989			
0	90 300	29.9	165	163	1370	79	6.48	4.79
112	88 200	42.5	165	177	1380	92	6.74	6.75
168	85 700	47.4	166	191	1390	114	7.13	7.57
224	85 600	47.9	165	191	1430	123	7.38	7.59
280	85 100	48.5	165	202	1430	134	7.57	7.67
336	84 900	50.1	164	228	1400	162	7.97	7.85
LSD (0.05)	NS	3.8	NS	13	40	18	0.31	0.56
					1990			
0	71 400	39.7	165	166	1470	107	7.18	6.28
112	73 300	52.4	164	171	1440	135	7.47	8.23
168	70 500	56.3	163	208	1450	169	8.12	8.73
224	70 500	58.0	161	220	1480	200	8.68	8.87
280	71 100	58.2	160	252	1460	230	9.16	8.80
336	68 100	58.5	157	302	1470	254	9.73	8.62
LSD (0.05)	NS	4.2	2	31	NS	16	0.46	0.64
					1991			
0	76 400	41.2	165	282	1370	116	7.52	6.49
112	75 800	51.1	164	311	1360	151	8.08	7.98
168	78 700	58.1	160	355	1410	209	9.22	8.79
224	73 500	54.3	160	364	1380	204	9.09	8.21
280	71 500	54.0	159	392	1400	229	9.62	8.07
336	72 400	56.2	156	416	1440	271	10.40	8.20
LSD (0.05)	4 600	4.0	2	29	30	27	0.51	0.53
Target plant density, plants ha^{-1}					1989			
37 100	43 200	43.6	163	223	1490	134	7.89	6.79
61 800	90 700	43.9	166	183	1370	107	6.95	7.02
86 500	100 600	45.1	165	184	1360	114	7.00	7.18
111 200	112 000	44.8	166	178	1370	114	7.00	7.16
LSD (0.05)	4 700	NS	1	13	30	12	0.23	NS
					1990			
37 100	43 100	54.4	159	253	1560	200	9.13	8.16
61 800	63 100	53.7	161	229	1470	185	8.51	8.18
86 500	79 900	54.4	163	195	1410	172	7.96	8.46
111 200	97 100	53.0	163	201	1400	172	7.98	8.22
LSD (0.05)	4 100	NS	1	13	40	13	0.30	NS
					1991			
37 100	41 400	52.1	156	404	1490	222	9.88	7.60
61 800	64 300	53.6	160	368	1400	201	9.13	8.09
86 500	85 300	52.8	162	328	1360	183	8.58	8.11
111 200	107 900	51.5	164	313	1330	180	8.36	8.01
LSD (0.05)	3 600	NS	1	30	30	16	0.38	0.30
Harvest day of the year					1989			
256	85 400	39.9	149	213	1450	88	7.11	5.64
276	84 200	45.0	165	196	1380	122	7.22	7.11
296	90 300	48.2	181	167	1370	142	7.30	8.36
LSD (0.05)	3 400	2.4	1	9	30	10	NS	0.39
					1990			
256	69 900	50.4	143	266	1530	213	9.26	6.72
270	72 400	53.8	163	205	1520	166	8.33	8.31
284	69 000	55.2	169	205	1410	177	8.07	8.84
298	71 900	56.1	171	202	1380	174	7.91	9.14
LSD (0.05)	NS	2.1	1	11	30	10	0.23	0.33
					1991			
256	76 700	51.7	142	255	1450	156	8.19	6.93
270	74 200	48.8	157	262	1400	188	8.46	7.16
284	73 900	53.2	170	463	1420	236	10.10	8.45
298	74 100	56.5	174	431	1310	205	9.18	9.26
LSD (0.05)	NS	2.1	1	23	30	12	0.28	0.31

were infrequently observed. Significant interactions were usually small, with changes in treatment levels following overall trends. The plant density × harvest date P-value for recoverable sucrose approached significance (P = 0.0532), but regression showed that no term was significant for the model. Since no consistent harvest date × plant density interaction was observed, no grower management changes in plant density are suggested for early vs. normal harvest dates.

A significant harvest date × N rate interaction for re-

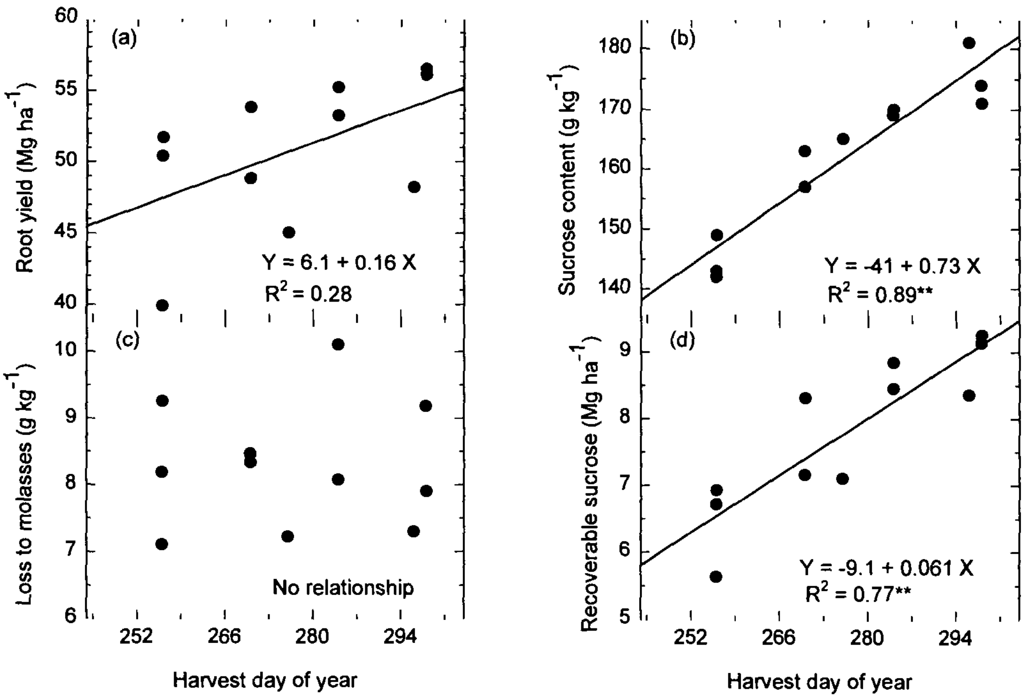

Fig. 1. Relationship between (a) root yield, (b) sucrose content, (c) loss to molasses, or (d) recoverable sucrose and harvest date of sugar beets when N rate and plant density data are combined for each year.

Table 4. Combined analysis of sugar beet yield and quality response to N rate, plant density, and harvest date during 1989 to 1991 at Powell, WY.

Main effect	Harvest plant density	Root yield	Sucrose content	Brei impurities Na	Brei impurities K	Brei impurities Amino N	Sucrose loss to molasses	Recoverable sucrose
	plants ha^{-1}	Mg ha^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	Mg ha^{-1}
N rate, kg ha^{-1}								
0	79 100	36.6	164	204	1410	99	7.05	5.76
112	79 000	48.4	163	221	1400	124	7.42	7.56
168	77 900	53.6	162	254	1420	162	8.16	8.24
224	77 000	53.0	161	260	1430	173	8.37	8.09
280	76 200	53.3	160	284	1440	195	8.78	8.06
336	74 800	54.4	157	318	1440	226	9.36	8.08
LSD (0.05)	2 700	2.6	3	31	NS	32	0.55	0.48
Target plant density, plants ha^{-1}								
37 100	42 700	49.7	158	296	1520	183	8.95	7.40
61 800	72 500	50.1	161	262	1420	163	8.20	7.66
86 500	88 600	50.4	162	237	1380	154	7.83	7.79
111 200	105 400	49.4	163	232	1370	153	7.77	7.69
LSD (0.05)	13 800	NS	2	27	30	14	0.38	0.23
Harvest period								
September	77 400	47.4	150	236	1470	150	8.08	6.74
October	77 200	52.4	172	277	1380	176	8.30	8.53
LSD (0.05)	NS	4.0	9	NS	NS	NS	NS	0.76
				ANOVA				
N	*	**	**	**	NS	**	**	**
N_L	**	**	**	**	*	**	**	**
N_Q	NS	**	NS	NS	NS	NS	NS	**
N_R	NS	NS	NS	NS	NS	NS	NS	NS
Y × N	NS	NS	**	**	NS	**	**	NS
Density (D)	**	NS	**	**	**	**	**	*
D_L	**	NS	**	**	**	**	**	*
D_Q	NS	NS	NS	NS	**	NS	*	*
D_R	NS	NS	NS	NS	NS	NS	NS	NS
Y × D	**	NS	**	**	NS	NS	**	NS
N × D	NS	NS	NS	NS	NS	NS	NS	NS
Y × N × D	NS	NS	NS	NS	NS	NS	NS	NS
Harvest (H)	NS	*	*	NS	NS	NS	NS	**
Y × H	NS	*	**	**	**	**	**	**
N × H	NS	NS	NS	NS	NS	*	NS	*
Y × N × H	NS	NS	NS	NS	NS	NS	NS	NS
D × H	NS	NS	NS	NS	NS	NS	NS	NS
Y × D × H	NS	NS	**	NS	NS	NS	NS	NS
N × D × H	NS	NS	NS	NS	NS	NS	NS	NS
Y × N × D × H	NS	NS	NS	NS	NS	NS	NS	NS

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

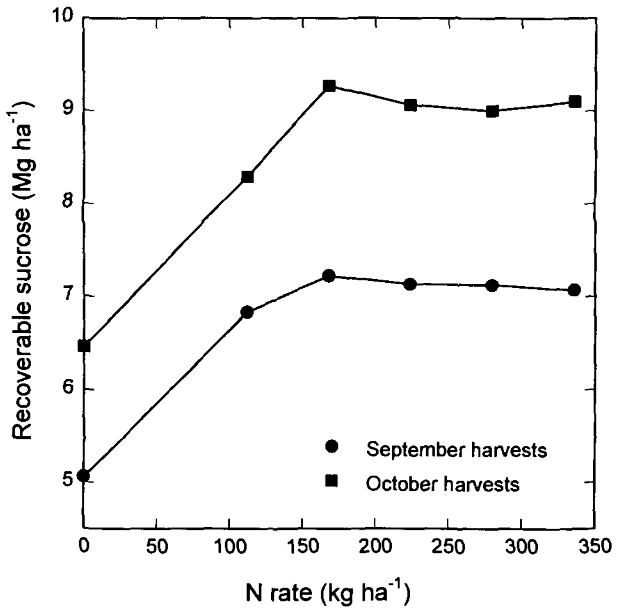

Fig. 2. Relationship between recoverable sucrose and applied N rate for sugar beet harvests during September and October when data are combined over year and plant density.

coverable sucrose indicated that a slight economic advantage may be realized by decreasing N rate for earlier-harvested sugar beet (Table 4). Recoverable sucrose leveled off at rates > 112 kg N ha^{-1} for early harvest dates in September (Fig. 2). For normal harvest during October, a total of 168 kg N ha^{-1} was required for maximum recoverable sucrose.

The small response in sucrose content, brei impurities, and sucrose loss to molasses to increasing N observed in this study may, in part, be due to leaching of N. Future research should evaluate production techniques that emphasize efficient use of N. Possible approaches include irrigation techniques to minimize leaching of fertilizer nutrients, split applications of N, and slow-release materials such as sulfur-coated ureas. Changes in irrigation management may alter production recommendations for sugar beet harvested early.

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