Relationships Between Applied Nitrogen Fertilizer and Postharvest Storage Properties of Sugarbeet Roots

L.G. Campbell[1] and K.K. Fugate[1]

[1]USDA-ARS Northern Crop Science Laboratory, 1605 Albrecht Blvd. N., Fargo, ND 58102

Corresponding author: Larry Campbell (larry.campbell@ars.usda.gov)

DOI: 10.5274/jsbr.53.1.2

ABSTRACT

While soil nitrogen deficiencies will result in a significant reduction in root yields of sugarbeet, excessive nitrogen will increase the concentration of impurities that interfere with sucrose extraction, decrease sucrose concentration, and reduce the overall value of the crop. Almost all recommendations for nitrogen management attempt to optimize growers' returns at harvest and make no assumptions regarding the role of nitrogen fertility on sucrose losses during postharvest storage. This study examined the impact of nitrogen fertilizer rates on changes in processing quality during storage. Based upon averages over three environments, seven fertilizer rates, and two storage intervals (30 and 90 days), each additional 43.2 kg ha^{-1} of nitrogen fertilizer reduced recoverable sucrose concentration by 5 kg Mg^{-1}. Differences between amino-nitrogen concentrations 30 and 90 days after harvest (DAH) increased by 100 ppm for each additional 53.4 kg ha^{-1} of nitrogen fertilizer. Nitrogen fertilizer rate did not have a significant effect on postharvest respiration rate or invert sugar concentration. However, respiration rates increased 0.88 mg CO2 kg^{-1} h^{-1} between 30 DAH and 90 DAH and invert sugar concentrations increased 1.37 g (100 g sucrose)$^{-1}$ during the 60 days between observations.

Additional Key Words: amino-nitrogen, *Beta vulgaris*, impurities, invert sugar, loss to molasses, postharvest respiration, recoverable sucrose.

Nitrogen fertilizer management is of utmost importance in optimizing economic returns from sugarbeet (*Beta vulgaris* L.). Insufficient available nitrogen will result in a significant reduction in potential root yield; however, excess nitrogen will increase leaf growth and the concentration of impurities that interfere with sucrose extraction (Bohn, 1998) and decrease sucrose concentration. Guidelines for optimizing root yield and quality for different production regions are based upon extensive trials over many years (Stout, 1961; Milford and Watson, 1971; Blumenthal 2001; Draycott and Christenson, 2003; Stevanto et al., 2010; Khan, 2015). Almost all recommendations for nitrogen management attempt to improve sucrose extraction rates while optimizing returns to growers at harvest (Hilde et al., 1983; Carlson, 2007) and make no assumptions regarding the role, if any, of nitrogen fertility in sucrose losses during postharvest storage (Campbell and Klotz, 2006; Bernhardson, 2009; Klotz and Campbell, 2009).

Dexter et al., (1966) reported high rates of nitrogen fertilizer not only reduced sucrose concentration and increased impurities, but roots from low or medium nitrogen fertilizer rate treatments also deteriorated slower than roots from high-nitrogen treatments. Van Eerd et al, (2012) observed quality differences among nitrogen fertilizer treatments at harvest but found no evidence that nitrogen fertilizer rate influenced the ability of sugarbeet to maintain quality when stored in outdoor piles. Evidence is quite limited, but there are observations suggesting that sugarbeet grown under low nitrogen fertility conditions are more susceptible to some common storage rot fungi than roots grown in adequately fertilized soil (Bugbee, 1977; Bugbee, 1982). Minimizing storage losses is complicated by interactions among cultural and environmental conditions during the growing season, harvest conditions, diseases prior to harvest and during storage, and cultivar on sucrose losses during storage (Tungland, 1998; Martin et al, 2001a; 2001b; Campbell and Klotz, 2006)

This study examines the impact of nitrogen fertilizer rate on changes in processing quality during postharvest storage.

MATERIALS AND METHODS

All roots used in the postharvest analyses were obtained from nitrogen fertilizer trials conducted by L.J. Smith (retired) on the Northwest Research and Outreach Center, Crookston, MN in 2011 and 2012. The trials were planted with HM4049RR (Hilleshög Sugarbeet Seed, Longmont, CO) in early May. Each experimental unit (plot) consisted of six 9-m rows with 56 cm row-spacing. Plots were defoliated with a commercial defoliator and harvested with a commercial-type harvester modified for research plots on 4 October 2011 and 24 September 2012. Samples were obtained from the two center rows of each experimental unit. Except for the applied nitrogen treatments, the trials were managed for optimal yield and quality.

The fertilizer treatments consisted of seven rates of applied nitrogen ranging from 0 to 201.6 kg ha^{-1} in 33.6 kg ha^{-1} increments. The fertilizer for the 2011 crop was applied the previous fall (2010). For the 2012 crop, root samples from fall (2011) and spring (2012) nitrogen applications were examined. The nitrogen source was broadcast-incorporated urea. The residual nitrogen at the sites was approximately 56 kg ha^{-1} (0 – 1.2 m depth) and 11 kg ha^{-1} of 10-34-0 starter fertilizer was applied to all plots at planting.

Harvested roots were immediately transported to Fargo, washed, placed in perforated plastic bags, and stored at 4.4°C and 90–95% relative humidity. Concentrations of the impurities sodium, potassium, and amino-nitrogen were determined 30 and 90 days after harvest (DAH) and used to calculate sucrose loss to molasses (LTM, Hilde et al., 1983) which was used, along with sucrose concentration to calculate recoverable sucrose per ton (RST). Storage respiration rate and invert sugar concentration were also measured 30 and 90 DAH.

The respiration rate of 10-root samples was determined using an infrared carbon dioxide gas analyzer (Li-Cor LI-6252, Lincoln, NE) and an open system with continuous airflow over the roots (Campbell et al., 2011). Immediately after completion of the respiration rate measurements, the roots were run through a beet saw to obtain a brei sample for measuring sucrose, impurities, and invert sugar concentrations. Sucrose concentration was measured polarimetrically (Autopol 880, Rudolph Research Analytical, Flanders, NJ) using aluminum sulfate-clarified brei samples (McGinnis, 1982). Sucrose and recoverable sucrose concentrations for the 30-DAH samples were expressed on a fresh weight basis. Concentrations for the 90-DAH samples were adjusted to account for weight changes during storage and expressed on a fresh weight concentration with a sodium concentration equivalent to the sodium concentration of the corresponding sample 30 DAH (Tungland et al., 1998). The aluminum sulfate-clarified filtrate used to determine sucrose concentration was used to measure impurities and invert sugar concentrations. Sodium and potassium concentrations were determined by flame photometry (Corning 410C, Cole-Parmer Instrument Co., Chicago, IL). Amino-nitrogen concentration was determined with a spectrophotometer (Spectronic-21D, Milton Roy Co., Ivyland, PA) using the copper method (International Commission for Uniform Methods of Sugar Analysis, 2007). Invert sugar (glucose + fructose) concentrations were determined colorimetrically using end point, enzyme-coupled assays (Klotz and Martins, 2007) and expressed as grams per 100 grams of sucrose [g $(100\ g\ S)^{-1}$].

The data were analyzed as a randomized complete block with a two-factor treatment design with four replicates in each of three environments (Carmer et al. 1989). The two factors were (1) the seven nitrogen rates (0 – 201.6 kg ha^{-1}) and (2) the time in storage (30 or 90 DAH). The three environments were combinations of crop year and time of nitrogen application; 2011-Fall, 2012-Fall, and 2012-Spring. Data were analyzed using the PROC GLM procedure (SAS 9.4, SAS Institute, Inc., Cary, NC). The least significant difference (LSD) with $\alpha = 0.05$ was used to determine when differences among treatment means were significant.

RESULTS

The average amino-nitrogen concentration over the three environments and two sampling dates ranged from 526 ppm when the only nitrogen sources were the residual soil nitrogen and starter fertilizer to 1178 ppm when 201.6 kg of nitrogen were applied (Tables 1 and 2). Although differences were not significant for all comparisons, the amino-nitrogen concentration increased in response to each 33.6 kg increment increase in applied nitrogen (Fig. 1A). Differences among environments between the amino-nitrogen concentration 30 and 90 DAH resulted in a significant environment X DAH interaction. The difference between the average concentration 30 DAH and 90 DAH for the fall applied nitrogen in 2011 was only 42 ppm, compared to more than 10 times that (455 ppm) for the fall applied nitrogen in 2012 and an even greater difference (500 ppm) for the 2012 spring applied nitrogen. Increasing differences between the average 30 and 90 DAH amino-nitrogen concentrations as fertilizer rate increased resulted in a significant fertilizer X DAH interaction. The difference between 30 and 90 DAH corresponding to 33.6 kg ha^{-1} was 155 ppm; incrementally increasing to 558 ppm amino-nitrogen when 201.6 kg ha^{-1} was applied. The average amino-nitrogen concentration of roots receiving 201.6 kg ha^{-1} was 2.1 times the concentration of roots receiving only starter fertilizer 30 DAH, compared to a corresponding 2.4-fold increase in amino-nitrogen after storage for 90 days.

The average sodium concentration of roots stored for 90 days was 84 ppm greater than the sodium concentration of roots stored for 30 days (Table 1). Respiration consumes sucrose, and since sucrose comprises approximately 75% of root dry matter, it reduces the total dry matter of the root during storage. However, all the sodium in the root at harvest remains in the root until processing, resulting in an increase in sodium concentration based upon root weight (Tungland et al., 1998). The amount of nitrogen fertilizer applied did not have a significant overall effect on the sodium concentration of roots (Table 2). The significant fertilizer X environment interaction for sodium concentration indicated in the analysis of variance (Table 2) was not due to any recognizable pattern of responses.

Fertilizer rate did not have a significant impact on potassium concentration (Table 1 and 2). A significant DAH X fertilizer interaction due to differences between 30 and 90 DAH ranging from 70 ppm for 33.6 kg ha^{-1} to 198 ppm for 67.2 kg ha^{-1} did not follow a discernable

Table 1. Effect of nitrogen fertilizer rate on amino-nitrogen, sodium, and potassium concentration and loss to molasses of roots from the 2011 and 2012 crop with fall applied nitrogen and the 2012 crop with spring applied nitrogen, Crookston, MN, stored for 30 and 90 days after harvest (DAH).

Applied nitrogen	2011 Fall		2012 Fall		2012 Spring		Mean		
	30 DAH	90 DAH	30 DAH	90 DAH	30 DAH	90 DAH	30 DAH	90 DAH	Mean
kg ha^{-1}	*Amino-nitrogen, ppm*								
0.0	407	491	418	715	469	655	431	620	**526**
33.6	478	491	418	672	477	676	458	613	**536**
67.2	562	574	541	926	486	879	529	793	**662**
100.8	661	680	499	1036	617	1184	592	967	**779**
134.4	645	699	791	1268	693	1210	709	1059	**884**
168.0	732	812	744	1286	845	1548	774	1215	**995**
201.6	1047	1115	756	1450	867	1806	899	1457	**1178**
Mean	**652**	**694**	**596**	**1051**	**637**	**1137**	**627**	**958**	**794**
	Sodium, ppm								
0.0	460	588	300	333	400	415	387	445	**416**
33.6	472	540	266	455	345	360	361	452	**406**
67.2	570	653	325	420	300	390	398	488	**443**
100.8	495	556	365	420	393	450	417	475	**447**
134.4	465	483	396	466	340	413	400	454	**427**
168.0	453	547	305	445	445	500	401	498	**449**
201.6	533	703	335	460	370	495	413	553	**483**
Mean	**493**	**581**	**327**	**428**	**370**	**431**	**397**	**481**	**439**
	Potassium, ppm								
0.0	1870	1840	1745	2025	1825	2025	1813	1963	**1888**
33.6	1745	1905	1790	1855	1800	1785	1778	1848	**1813**
67.2	1800	1905	1660	1940	1710	1920	1723	1921	**1822**
100.8	1850	1900	1585	1790	1800	1915	1745	1868	**1807**
134.4	1730	1910	1655	1820	1630	1730	1671	1820	**1746**
168.0	1840	1840	1525	1910	2015	1670	1793	1807	**1800**
201.6	1745	1815	1630	1840	1715	1885	1697	1847	**1772**
Mean	**1797**	**1873**	**1656**	**1882**	**1785**	**1847**	**1746**	**1868**	**1807**
	Loss to molasses, g kg^{-1}								
0.0	14	15	13	17	14	17	14	17	**15**
33.6	14	15	13	17	14	16	14	16	**15**
67.2	16	17	14	21	14	20	15	19	**17**
100.8	17	19	14	22	16	24	16	21	**18**
134.4	16	18	18	25	16	24	17	22	**19**
168.0	18	19	16	25	20	28	18	24	**21**
201.6	22	24	17	27	19	32	19	28	**23**
Mean	**17**	**18**	**15**	**22**	**16**	**23**	**16**	**21**	**18**

Table 2. Least Significant Difference ($LSD_{0.05}$) values for comparing means in Tables 1 and 3.

	Source of Variation					
Variable	Environment	Nitrogen fertilizer	Days after harvest (DAH)	Fertilizer X DAH	Fertilizer X environment	DAH X environment
Amino-nitrogen	186	150	NS	173	NS	73
Sodium	97	NS	50	NS	92	NS
Potassium	NS	NS	NS	NS	NS	97
Loss to molasses	NS	2.3	NS	2.4	NS	1.2
Sucrose	NS	19	NS	NS	NS	15
Recoverable sucrose	NS	19	NS	NS	NS	16
Invert sugar	0.49	NS	0.61	1.14	NS	NS
Respiration rate	0.45	NS	0.76	NS	NS	NS

*NS indicates differences among means were not significant (P = 0.05).

pattern related to fertilizer rate similar to that observed for amino-nitrogen.

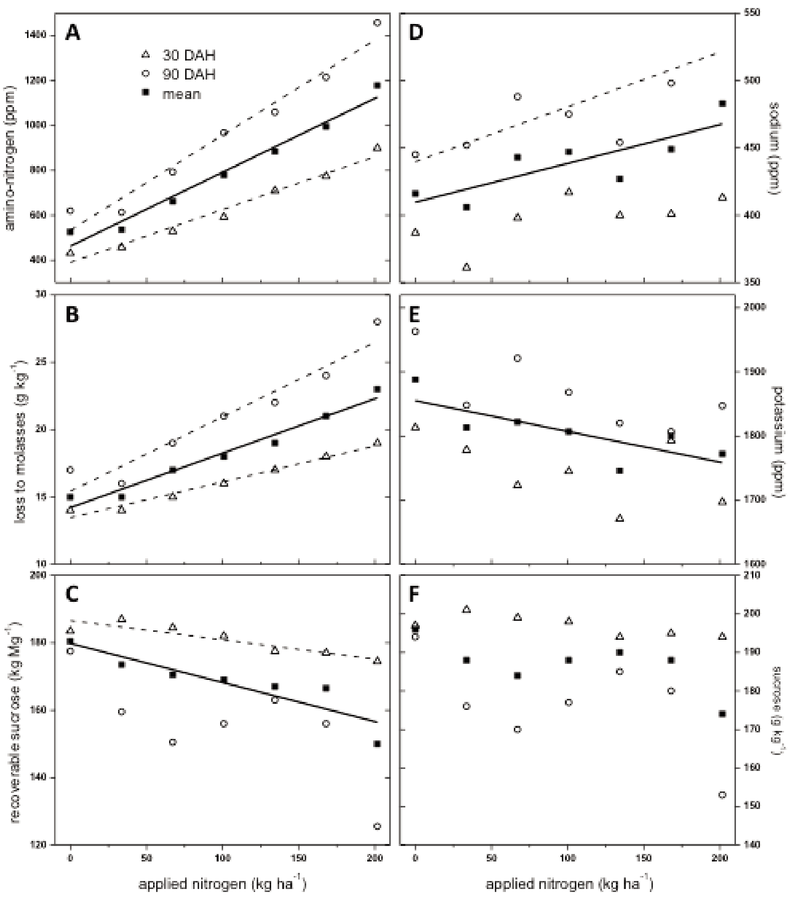
Sucrose loss to molasses was strongly influenced by the applied nitrogen (Table 1). The average LTM over all environments and both sampling dates increased from 15 g kg^{-1} for 0 and 33.6 kg nitrogen per hectare to 23 g kg^{-1} when 201.6 kg ha^{-1} was applied. Similar to amino-nitrogen concentration, the increase in LTM associated with increasing fertilizer rates was greater in roots stored for 90 d than in roots stored 30 d. The 3 and 2 g kg^{-1} difference between roots from the 0 and 33.6 kg ha^{-1} treatments, respectively, contrasts with the 9 g kg^{-1} difference between 30 and 90 DAH associated with roots from the 201.6 kg ha^{-1} treatment (Fig. 1B).

Fertilizer rate had a significant overall impact (Tables 2 and 3) on both sucrose concentration and recoverable sugar per ton. Although differences were not significant for all comparisons, RST decreased with each 33.6 kg ha^{-1} increase in applied nitrogen, ranging

Table 3. Effect of nitrogen fertilizer rate on sucrose concentration, recoverable sugar per ton, invert sugar concentration and respiration rate of roots from the 2011 and 2012 crop with fall applied nitrogen and the 2012 crop with spring applied nitrogen, Crookston, MN, stored for 30 and 90 days after harvest (DAH).

Applied nitrogen	2011 Fall		2012 Fall		2012 Spring		Mean		
	30 DAH	90 DAH	30 DAH	90 DAH	30 DAH	90 DAH	30 DAH	90 DAH	Mean
kg ha^{-1}	*Sucrose, g kg^{-1}*								
0.0	190	181	212	201	193	201	197	194	**196**
33.6	190	187	207	124	205	218	201	176	**188**
67.2	188	183	201	168	208	159	199	170	**184**
100.8	188	187	201	158	205	186	198	177	**188**
134.4	193	204	191	175	199	176	194	185	**190**
168.0	186	181	204	157	194	202	195	180	**188**
201.6	187	152	197	148	198	160	194	153	**174**
Mean	**188**	**182**	**202**	**162**	**200**	**186**	**197**	**177**	**187**
	Recoverable sucrose, kg Mg^{-1}								
0.0	173	166	199	184	178	184	184	178	**181**
33.6	175	171	195	107	191	201	187	160	**174**
67.2	172	166	187	147	194	139	185	151	**171**
100.8	170	169	188	137	189	162	182	156	**169**
134.4	177	187	173	150	183	153	178	163	**167**
168.0	168	162	188	132	175	175	177	156	**167**
201.6	165	128	180	121	179	129	175	126	**150**
Mean	**172**	**164**	**187**	**140**	**193**	**163**	**181**	**156**	**168**
	Invert sugar, g (100 g sucrose)$^{-1}$								
0.0	1.71	2.56	1.02	2.64	1.89	2.68	1.54	2.62	**2.08**
33.6	2.08	2.81	0.98	2.40	1.23	2.36	1.43	2.52	**1.98**
67.2	1.77	1.39	1.27	2.48	1.47	3.21	1.50	2.36	**1.93**
100.8	1.55	2.86	1.17	2.56	0.89	4.26	1.20	3.23	**2.22**
134.4	1.52	1.70	1.54	2.38	1.20	3.46	1.42	2.52	**1.97**
168.0	1.44	1.46	1.01	1.87	1.54	2.68	1.33	2.00	**1.66**
201.6	1.99	8.26	1.29	2.21	1.13	2.22	1.47	4.23	**2.85**
Mean	**1.72**	**3.01**	**1.18**	**2.36**	**1.33**	**2.98**	**1.41**	**2.78**	**2.10**
	Respiration rate, mg CO_2 kg^{-1} hour^{-1}								
0.0	4.47	6.36	5.77	6.46	5.25	5.33	5.16	6.05	**5.61**
33.6	4.38	5.96	4.78	5.40	6.15	6.12	5.10	5.82	**5.46**
67.2	5.24	5.58	5.43	6.89	5.13	6.16	5.26	6.21	**5.74**
100.8	4.76	5.95	5.88	6.13	5.25	7.45	5.30	6.51	**5.90**
134.4	4.71	5.90	5.66	6.01	6.03	6.61	5.47	6.17	**5.82**
168.0	4.69	5.14	5.24	5.17	5.19	6.77	5.04	5.69	**5.37**
201.6	4.99	6.86	5.31	6.40	5.70	5.76	5.33	6.34	**5.84**
Mean	**4.75**	**5.97**	**5.44**	**6.07**	**5.53**	**6.31**	**5.24**	**6.12**	**5.68**

Figure 1. Changes in amino-nitrogen (A), loss to molasses (B), recoverable sucrose (C), sodium (D), potassium (E), and sucrose concentration (F) associated with nitrogen fertilizer rates in sugarbeet roots stored for 30 and 90 days after harvest (DAH). Regression lines are shown for significant relationships, where α = 0.05.



from 181 kg Mg^{-1} when the only nitrogen sources were the residual nitrogen and the starter fertilizer to 150 kg Mg^{-1} when 201.6 kg of additional nitrogen were applied (Table 3). The difference between the average RST 30 DAH and 90 DAH for the fall applied nitrogen in 2012 was 47 kg Mg^{-1}, approximately six times the 8 kg Mg^{-1} difference between RST 30 and 90 DAH for the 2011 crop with the fall applied nitrogen.

The relatively high invert sugar concentration [8.26 g (100 g S)$^{-1}$]

for the 90 DAH samples from the 201.6 kg ha^{-1} nitrogen treatment in 2011 (Table 3) appears to be an anomaly. The fact that all four replicates of this treatment had relatively high invert sugar concentrations and samples are analyzed in the laboratory in a random order complicate explaining the unusually high values associated with this particular combination of fertilizer rate, environment, and DAH. If the 201.6 kg ha^{-1} fertilizer rate in 2011 is excluded, the average increase in invert sugar concentration during the 60 days between sampling dates was 1.13 g (100 g $S)^{-1}$.

Nitrogen application rate did not have a significant effect upon postharvest respiration rate (Tables 2 and 3). However, respiration rate increased from 5.24 mg CO_2 kg^{-1} h^{-1} 30 DAH to 6.12 mg CO_2 kg^{-1} h^{-1} 90 DAH; a 17% increase during the 60 days in storage. With only three environments, there was not a clear distinction between the effect of time of fertilizer application and differences due to crop year. The average respiration rate for the 2012 crop with fall applied nitrogen (5.75 mg CO_2 kg^{-1} h^{-1}) was not significantly different (LSD = 0.45 mg CO_2 kg^{-1} h^{-1}) from either the 2012 crop with spring applied nitrogen (5.92 mg CO_2 kg^{-1} h^{-1}) or the 2011 crop with fall applied nitrogen (5.36 mg CO_2 kg^{-1} h^{-1}).

DISCUSSION

Increasing the available soil nitrogen not only increased the initial amino-nitrogen concentration but also accelerated the increase of amino-nitrogen during storage. Regression analysis indicated that when averaged over the three environments, the difference between amino-nitrogen concentrations 30 and 90 DAH increased by 100 ppm for each additional 53.4 kg ha^{-1} of nitrogen fertilizer ($r^2 = 0.89$). The LSD's from the analysis of variance did not detect significant differences among the fertilizer-rate means for sodium or potassium concentration. However, single degree contrasts indicated a significant linear response to fertilizer rate for both sodium and potassium. Furthermore, Spearman' rank correlation coefficients between amino-nitrogen concentration and sodium and potassium concentration of fertilizer-rate means were identical in magnitude ($r_s = |0.86|$, $P = 0.01$); however, the correlation between amino-nitrogen and sodium concentration was positive (Fig. 1D), whereas, the correlation between amino-nitrogen and potassium concentration was negative (Fig. 1E). Hence, the negative impact of an increase in sodium concentration on LTM in response to increases in nitrogen fertilizer would be minimized by the positive impact of a reduced potassium concentration. Consequently, the LTM values follow a pattern similar to that observed for amino-nitrogen concentration; not only did an increase in fertilizer rate increase the average LTM, the difference between roots stored 30 d and roots stored 90 d increased by 1 g kg^{-1} in response to each additional 35.1 kg ha^{-1} of nitrogen ($r^2 = 0.81$). Based upon averages that included all three environments and both storage intervals, each additional 43.2 kg ha^{-1} of nitrogen fertilizer reduced recoverable sugar by 5 kg Mg^{-1} ($r^2 = 0.77$). Changes in recoverable sugar per ton associated with nitrogen fertilizer rate (Fig. 1C) appear to be more closely related to changes in LTM (Fig. 1B) than to corresponding changes in sucrose concentration (Fig. 1F).

Nitrogen fertilizer rate did not have a significant effect on postharvest respiration rate or invert sugar concentration. However, respiration rates increased 0.88 mg CO_2 kg^{-1} h^{-1} ($CI_{0.95}$ = 0.61 to 1.14 mg CO_2 kg-1 h-1) between 30 DAH and 90 DAH and invert sugar concentrations increased 1.37 g (100 g $S)^{-1}$ ($CI_{0.95}$ = 1.02 – 1.72 g (100 g $S)^{-1}$) during the 60 days between observations.

The significant DAH X environment interaction for amino-nitrogen, potassium, LTM, sucrose, and RST indicates that the magnitude of the changes that occur in these variables during storage depends upon conditions during the growing season. This report is based upon samples from a single location that were stored under standardized constant conditions and, as such, the results should be considered preliminary until confirmed by addition studies or observations based upon factory extraction data. However, it does provide further evidence of the importance of nitrogen management in producing a quality crop. To obtain optimum economic returns, the quality considerations highlighted in this report must be balanced with the impact of nitrogen fertilizer on root yield.

ACKNOWLEDGEMENTS

We thank Nyle Jonason, Joe Thompson, John Eide, and Jeff Nelson for technical assistance and American Crystal Sugar Co. for providing a portion of the funds for this research. Trade, firm, or corporate names are mentioned to disclose information that may be of interest to the reader. Such use does not constitute an endorsement by the Agricultural Research Service of any product to the exclusion of others that may be equally suitable or superior. USDA is an equal opportunity provider and employer.

LITERATURE CITED

Bernhardson, D. 2009. Sugarbeet storage techniques developed by American Crystal Sugar Company, Moorhead, Minnesota, USA. Int. Sugar J. 111:628-631.

Blumenthal, J.M. 2001. Fertilizing sugarbeet. p. 75-80. In: R.G. Wilson (ed.) Sugarbeet Production Guide. University of Nebraska Extension Service. EC01-156.

Bohn, K., 1998. Nitrogenous compounds. Section 2.1.4.2, p. 138-150. In: P.W. van der Poel, H. Schiweck, and T.K. Schwartz (eds.). Sugar Technology. Verlag Dr. Albert Bartens, Berlin.

Bugbee, W.M. 1977. Storage rot of sugarbeet. USDA-Agricultural Research Service. ARS-NC-56. 17 p.

Bugbee, W.M. 1982. Storage rot of sugar beet. Plant Disease 66: 871-873.

Campbell, L.G., K.K Fugate, and W.S. Niehaus. 2011. Fusarium yellows affects postharvest respiration rate and sucrose concentration in sugarbeet. J. Sugar Beet Res. 48: 17-39.

Campbell, L.G., and K.L. Klotz. 2006. Storage. p. 387-408. In: A.P Draycott (ed.) Sugar Beet, Blackwell Publishing, Inc., Oxford.

Carlson, J. 2007. Beet sugar factory operations and how agricultural practices influence their efficiency. Sugarbeet Grower (July/August): 16-20.

Carmer, S.G., W.E. Nyquist, and W.M. Walker. 1989. Least significant differences for combined analyses of experiments with two- or three-factor treatment designs. Agron. J. 81: 665-672.

Dexter, S.T., M.G. Frakes, and G. Nichol. 1966. The effect of low, medium, and high nitrogen fertilizer rates on the storage of sugar beet roots at high and low temperatures. J. Am. Soc. Sugar Beet Technol. 14:147-159.

Draycott, A.P., and D.R. Christenson. 2003. Nutrients for Sugar Beet Production: Soil Plant Relationships. CABI Publishing, Cambridge, MA. 242 p.

Hilde, D.J., S. Bass, R.W. Levos, and R.L. Ellingson. 1983. Grower practices system promotes beet quality in the Red River Valley. J. Am. Soc. Sugar Beet Technol. 22: 73-88.

International Commission on Uniform Methods of Sugar Analysis. 2007. Method GS6-5, Determination of α-amino nitrogen by the copper method ('Blue number'). Verlag Dr. Albert Bartens, KG, Berlin.

Khan, M. (ed.). 2015. 2015 Sugarbeet Production Guide. Coop. Ext. Serv., North Dakota State Univ., Fargo, ND. A1698. 96 p.

Klotz, K.K., and L.G. Campbell. 2009. Postharvest deterioration of sugar beet. p. 92-94. In: R.M. Harveson, L.E. Hanson, and G.L. Hein (ed.) Compendium of beet diseases and pests, 2nd edition. APS Press, Madison, WI.

Klotz, K.K., and D.N. Martins. 2007. Microplate assay for rapid determination of sucrose, glucose, fructose, and raffinose. J. Sugar Beet Res. 44: 169-170.

Martin, S.S., J.A. Narum, and K.H. Chambers. 2001a. Sugarbeet biochemical quality changes during factory storage. Part I. Sugars. J. Sugar Beet Res. 38: 35-53.

Martin, S.S., J.A. Narum, and K.H. Chambers. 2001b. Sugarbeet biochemical quality changes during factory storage. Part II. Non-sugars. J. Sugar Beet Res. 38: 173-188.

McGinnis, R.A. 1982. Analysis of sucrose content. p. 67-76. In: R.A. McGinnis (ed.) Beet Sugar Technology, 3rd ed. Beet Sugar Development Foundation, Denver, CO.

Milford, G.F., and D.J. Watson. 1971. Effect or nitrogen on the growth and sugar content of sugar-beet. Ann. Bot. 35: 287-300.

Stevanato, P., C. Zavalloni, R. Marchetti, M. Bertaggai, M. Saccomani, J.M. McGrath, L.W. Panella, and E. Biancardi. 2010. Relationship between subsoil nitrogen availability and sugarbeet processing quality. Agron. J. 102: 17-22.

Stout, M. 1961. A new look at some nitrogen relationships affecting the quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 11: 388-398.

Tungland. B.C., R.E. Watkins, and P –V. Schmidt. 1998. Section 5.4, p. 267-289. In: P.W. van der Poel, H. Schiweck, and T.K. Schwartz (eds.). Sugar Technology. Verlag Dr. Albert Bartens, Berlin.

Van Eerd, L.L., K.A. Congreves, and J.W. Zandstra. 2012. Sugar beet (*Beta vulgaris* L.) storage quality in large outdoor piles is impacted by pile management but not by nitrogen fertilizer or cultivar. Can. J. Plant Sci. 92: 129-139.