Published online July 2, 2018

Effects of Manure History and Nitrogen Fertilizer Rate on Sugar Beet Production in the Northwest US

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Abstract

Past manure applications effects on sugar beet (*Beta vulgaris* L.) production needs to be assessed in the areas where manure applications to crop land are common. A study was conducted in Kimberly, Idaho in 2014 and 2016 to assess the effects of manure application history and N rates on sugar beet production on a Portneuf silt loam (coarse-silty mixed mesic Durixerollic Calciorthid) soil. From 2004 to 2009, manure was applied to plots every 2 years (M1, total application = 60 tons/acre), every year (M2 total application = 106 tons/acre), or no manure (F, commercial fertilizer only). In spring 2014, the manure main plots were split in half with half receiving a commercial fertilizer N rate treatment superimposed on the main plots in 2014 and the other half receiving the superimposed N rate treatments in 2016. In 2014 and 2016, the commercial fertilizer N rates were 0, 30, 56, 77, 100, 141, 180, and 202 lb/acre. The study design was a randomized block split-plot with manure history as the main plot and N rate as the subplot. During both years of the study, N rate did not affect sugar beet yields, but M1 and M2 treatments had higher sugar beet root yields compared to the F treatment. Averaged across all N rates, root yields from both manured treatments were 12 and 36% greater than the F treatment in 2014 and 2016, respectively, although sugar yield was only significantly greater in 2016. Manure applications will impact sugar beet production for several years after manure applications have ceased.

Crop Management

ACCEPTED — Crop, Forage & Turfgrass Management — Peer Reviewed

Core Ideas

- Manure can have a lasting effect on soil fertility and crop production.
- Sugar beet yields are increased on soils with a manure history.
- Sugar beet quality can be decreased under heavy past manure applications.

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Received 17 Nov. 2017.
Accepted 4 Apr. 2018.

Conversions: For unit conversions relevant to this article, see Table A.

Crop Forage Turfgrass Manage.
4:170083. doi:10.2134/cftm2017.11.0083

Effects of Manure and Nitrogen on Sugar Beet

Changes in the dairy industry in the Northwest US. have led to more crop production area receiving manure applications. For example, the number of milk cows in Idaho has increased by approximately 118% in the past two decades (USDA-NASS, 2012). In 2012, there were 578,761 milking cows in Idaho with 71% of these concentrated in the south-central region of Idaho where 15% of US sugar beet production occurs (USDA-NASS, 2012). Most current research-based nutrient management practices and guidelines are based on non-manured systems. There is a need to evaluate nitrogen (N) management practices in production systems that are currently receiving manure applications or have received past manure applications.

Many research studies have evaluated N management for sugar beet production (Adams et al., 1983; Anderson and Peterson, 1988; Carter et

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
Length		
0.304	foot, ft	meter, m
25.4	inch	millimeter, mm (10^{-2} m)
Area		
9.29×10^{-2}	square foot, sq ft	square meter, sq m
Yield and Rate		
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
2.24	ton (2000 lb) per acre, ton/acre	megagram per hectare, Mg/ha

al., 1974, 1976; Halvorson and Hartman, 1975, 1980; Halvorson et al., 1978; Hills and Ulrich, 1976; Hills et al., 1978, 1983; Lamb and Moraghan, 1993; and Stevens et al., 2007; Tarkalson et al., 2012; Tarkalson et al., 2016). These studies often document negative impacts of excessive N on impurities or sugar concentration. However, these studies were conducted in non-manured systems and few were conducted in the Northwestern US Tarkalson et al. (2012 and 2016) were the only studies focused on the sugar beet industry in Idaho and the Northwest US More detailed research is needed to better understand the long-term effects of manure applications on subsequent N fertility status and crop production in arid-irrigated systems in the Northwest US, especially in the areas receiving frequent applications of manure due to animal numbers.

Manure applications have been shown to benefit crop production shortly after application. On soils similar to the soil type in the current study, past research has demonstrated that manure applications improve crop production as a result of factors other than N additions (Robbins et al., 1997). Robbins et al. (1997) found that the year after application of solid dairy manure in the spring and fall at rates of 20 and 41 tons/acre, respectively, restored crop yields on highly eroded soils compared to non-eroded and non-manured soils of the same type. The application of commercial fertilizer on eroded soils did not restore crop yields. Lentz and Lehrsch (2012) looked at N availability to sugar beet from a one-time manure application in three subsequent years after manure treatment. They found that net mineralization of N from the manure increased with manure application rate, and the amount mineralized each year was more predictable with greater manure application rates. The effects of past (greater than 5 years) manure applications on crop productivity need to be evaluated.

The objective of this study was to evaluate the response of sugar beet production factors to N in systems that have a history of manure application.

Field Experiment

The study was conducted during the 2014 and 2016 growing seasons at the USDA-ARS Northwest Irrigation and Soils Research Lab in Kimberly, Idiaho on a Portneuf silt loam (coarse-silty mixed superactive, mesic Durixerollic Xeric Haplocalcids). From 2004 to 2009, manure was applied to field plots (10,800 ft^2) either every 2 years (M1) or every year (M2). A no-manure treatment was included and received nutrients via commercial fertilizer based on soil tests and published recommendations (F). Each treatment was replicated three times in a randomized block design. The M1 and M2 treatments received cumulative dry manure at rates of 60 tons/acre and 106 tons/acre, respectively from 2004 to 2009 (Table 1). The manure was scraped dairy manure from an open lot dairy, which is common dairy operation type in Southern Idaho. These application rates represent typical application rates to producer fields. From 2010 to 2013, the entire study area received the same rate of commercial fertilizer based on soil samples and recommendations from the F treatment. The field was planted to a corn (*Zea mays* L.)-barley (*Hordeum vulgare* L.) rotation during the 2010 to 2013 period. The study was arranged in a randomized block split-plot design with manure history as the main plot and N rate as the subplot. In 2014 and 2016, commercial fertilizer N rate treatments were superimposed on top of the past manure treatments (F, M1, and M2). In 2014, each 10,800 ft^2 plot was divided in half. Half of the plot received the N-rate treatments in 2014 and the second half received the N-rate treatments in 2016. The N rates were 0, 30, 56, 77, 100, 141, 180, and 202 lb/acre. In 2014, the half of each plot that was not part of the study received an application of N fertilizer at a rate of 50 lb/acre. During 2015, the entire plot area was planted to barley and received an N application rate of 50 lb/acre.

Prior to N fertilizer application in spring of 2014 and 2016, three soil cores (1.7-inch diameter) in 1-ft increments to a depth of 4 ft were taken in each plot. Soil samples were analyzed for nitrate N (NO_3–N) and ammonium N (NH_4–N) after extraction in 2M KCl (Mulvaney, 1996) using a flow injection analyzer (Lachat Instruments, Loveland, CO) (Table 2). The 0- to 2-ft soil samples were also tested for sodium bicarbonate extractable P and exchangeable K concentrations (Olson et al., 1954) (Table 2).

The study was planted to sugar beet on 12 May 2014 and 5 May 2016 at rate of 316,000 plants/acre with the same variety both years (BTS 21RR25). Fertilizer treatments were applied after planting at the 2 to 4 leaf stage, prior to the start of significant crop N uptake (Amalgamated Sugar Company, 2010), as urea ammonium nitrate [UAN, 32% N] in 2014 and urea

Table 1. Dry solid dairy manure and commercial fertilizer application rates.

Treatment ID	Treatment additions	2004	2005	2006	2007	2008	2009	Total
F	Manure (tons/acre)	0	0	0	0	0	0	0
	Manure C† (tons/acre)	0	0	0	0	0	0	0
	Manure N‡ (lb/acre)	0	0	0	0	0	0	0
	Manure P_2O_5§ (lb/acre)	0	0	0	0	0	0	0
	Fertilizer N (lb/acre)	215	170	0	0	165	215	765
	Fertilizer P_2O_5 (lb/acre)	190	50	0	0	50	190	480
	Total N (lb/acre)	215	170	0	0	165	215	765
M1	Manure (tons/acre)	25	0	15	0	20	0	60
	Manure C (tons/acre)	5	0	3	0	4	0	12
	Manure N (lb/acre)	550	0	334	0	442	0	1326
	Manure P_2O_5 (lb/acre)	75	0	46	0	61	0	181
	Fertilizer N (lb/acre)	160	125	0	0	0	109	394
	Fertilizer P_2O_5 (lb/acre)	0	0	0	0	0	0	0
	Total N (lb/acre)	710	125	334	0	442	109	1720
M2	Manure (tons/acre)	25	15	15	15	20	15	106
	Manure C (tons/acre)	5	3	3	3	4	3	21
	Manure N (lb/acre)	550	334	334	334	442	334	2328
	Manure P_2O_5 (lb/acre)	75	46	46	46	61	46	318
	Fertilizer N (lb/acre)	160	95	0	0	0	0	254
	Fertilizer P_2O_5 (lb/acre)	0	0	0	0	0	0	0
	Total N (lb/acre)	710	429	334	334	442	334	2582

† Manure % C = 20.0% (Based on average manure analysis from study).

‡ Manure % *N* = 1.1% (Based on average manure analysis from study).

§ Manure % P_2O_5 = 0.15% (Book value based on 2007, MWPS, Livestock Waste Facilities Handbook).

Table 2. Selected soil nutrient concentrations of study sites in 2014 and 2016. Bold values are the summed constituents in the 0–4 ft soil profile.

Treatment ID	Nutrient	Soil depth 2014 0–1	1–2	2–3	3–4	0–4	2016 0–1	1–2	2–3	3–4	0–4
		ft									
F	NO_3–N (ppm)	16.1	15.3	2.6	3.8	**9.5**	8.5	7.0	4.8	2.6	**5.7**
	NH_4–N (ppm)	1.9	0.7	0.6	0.5	**0.9**	3.1	4.1	1.9	4.7	**3.5**
	Olsen P_2O_5 (ppm)	10.4	4.2	–	–	–	9.2	3.2	–	–	–
	Inorganic N (lb/acre)	72.0	64.0	12.8	17.2	**166.0**	46.4	44.4	26.8	29.2	**146.8**
M1	NO_3–N (ppm)	17.3	28.0	8.9	7.9	**15.5**	14.0	20.2	16.4	19.8	**17.6**
	NH_4–N (ppm)	1.9	1.2	0.8	0.8	**1.2**	5.2	4.4	3.9	4.4	**4.5**
	Olsen P_2O_5 (ppm)	44.2	34.4	–	–	–	36.8	4.2	–	–	–
	Inorganic N (lb/acre)	76.8	116.8	38.8	34.8	**267.2**	76.8	98.4	81.2	96.8	**353.2**
M2	NO_3–N (ppm)	49.1	86.9	26.3	22.9	**46.3**	22.5	32.7	32.2	16.9	**26.1**
	NH_4–N (ppm)	1.7	0.7	0.5	0.4	**0.8**	5.8	3.1	2.9	4.3	**4.0**
	Olsen P_2O_5 (ppm)	84.2	17.6	–	–	–	245.2	9.1	–	–	–
	Inorganic N (lb/acre)	203.2	350.4	107.2	93.2	**754.0**	113.2	143.2	140.4	84.8	**481.6**

(46% N) in 2016. All treatments were incorporated into the soil immediately after application via sprinkler irrigation (0.75 in. water). All other crop management (herbicide, insecticide, and water management) was conducted as needed based on best management practices.

Prior to harvest, the entire study area was mechanically topped and root counts were obtained in the harvest area from each plot [2 rows (22 in/row) × 40 ft]. Roots were harvested on 7 October 2014, and 12 October 2016 using a plot harvester. Total yield was determined from each plot using a load cell-scale on the plot harvester. From each plot three 8-root samples were obtained and bagged. Two of the samples were sent to the Amalgamated Sugar Inc. tare lab for analysis of percent sugar and quality analysis. Percent sugar was determined by using an Autopol 880 polarimeter (Rudolph Research Analytical, Hackettstown, NJ), a half-normal weight sample dilution, and aluminum sulfate clarification method [ICUMSA Method GS6–3 1994] (Bartens, 2005).

Root electrical conductivity was measured using a Foxboro conductivity meter Model 871EC (Foxboro, Foxboro, MA) and root brei nitrate was measured using a multimeter Model 250 (Denver Instruments, Denver, CO) with Orion probes 900200 and 9300 BNWP (Krackler Scientific, Inc., Albany, NY).

Estimated recoverable sucrose (ERS lb/ton) = [(extraction)(0.01)(gross sucrose lb/acre)]/ (root yield tons/acre),

Where extraction = 250 + {[(1255.2)(conductivity) − (15000) (percent sucrose − 6185)]/[(percent sucrose)(98.66 − [(7.845) (conductivity)])} and gross sucrose = [[(tons/acre)(percent sucrose)](0.01)](2000 lb/ton).

Estimated recoverable sucrose (ERS lb/acre) was calculated as:

ERS lb/acre = ERS lb/ton × root yield tons/acre.

Statistical analysis was conducted separately for each year. Analysis of variance was conducted for manure history and N rate treatment main effects and the interaction for selected production factors (root yield, ERS yield, root sucrose concentration, root brei nitrate concentration, root electrical conductivity) using a split plot design model in Statistix 8.2 (Analytical Software, Tallahassee, FL). For each factor, polynomial contrasts were conducted for N rate main effects to determine significance of linear and quadratic relationships.

Soil Analysis

During the study years (2014 and 2016), the quantity of inorganic N in the 0- to 4-ft soil depth was between 1.6 and 4.5 times greater in the manured treatments compared to the F treatment even though manure had not been applied for 5 years (Table 2). These differences were directly related with the differences in total N applied with manure from 2004 to 2009 (Table 1). From 2004 to 2009, the M1 and M2 treatments had 2.2 and 3.4 times more total N applied than the F treatment. In a given year, the total N applied with manure was not immediately available; much of the N is in an organic form (67–55% of total N) and must be mineralized over time through microbial activity (MidWest Plan Service, 1993). Data from 2014 and 2016 show that applications conducted 5 to 10 years ago, were still influencing soil N fertility levels. In another study near the same location and on the same soil type, 3 to 6% of the applied manure N (depending on application rate) was mineralized 5 years after application (Lentz and Lehrsch, 2012). Five years after a one-time manure application (no commercial fertilizer applied), Lentz and Lehrsch, (2012) found that manure (average application rates; 10 and 30 tons/acre) increased soil available N (NO_3–N and NH_4–N) in the surface 12 inches by 27% compared to a control plot (no manure or fertilizer). The available N from prior manure application was equivalent to concentration in soil that received annual commercial N fertilizer based on soil test and crop recommendations (average = 24.4 mg/kg).

Bicarbonate extractable P concentrations were greater in the M1 and M2 treatments in 2014 and 2016 (Table 2) even though 480 lb P_2O_5/acre was applied in the F treatment from 2004 to 2009 (Table 1). Measured soil bicarbonate extractable P concentrations varied with time in all treatments. This variability was greatest in soils of the M2 treatment, which had 300% greater extractable P in 2016 than in 2014 (Table 2). Based on published recommendations for sugar beet, in 2014 and 2016, concentrations of extractable P in the M1 and M2 treatments were sufficient. However, soil test P concentrations for the F treatment were considered low to marginal according to University of Idaho fertilizer recommendations for sugar beet (Moore et al., 2009). The recommendations suggested application of 120 to 240 lb P_2O_5/acre depending on the soil lime content. It is not clear why extractable P concentrations were low in the F treatment compared to the manured treatments. It is possible that soil erosion from furrow irrigation prior to 1998, when the linear move sprinkler system was installed, could have decreased soil P concentration in this field and manure applications increased soil P more than P fertilizer. Differences in soil productivity between the top and bottom of fields due to soil erosion have been demonstrated for the same soil type on an adjacent field (Tarkalson and Bjorneberg, 2010).

Sugar Beet Yields and Quality Measurements

Across all treatments in 2014 and 2016, N rate did not affect sugar beet root or ERS yields (Table 3). The lack of yield response to N supply is not uncommon; Tarkalson et al. (2016) found that sugar beet yields from 4 of the 14 study site-years were the same across the ranges of applied N, including no applied N. For four of these site-years, the range of residual soil N in the top three feet of soil was 90 to 160 lb N/acre. Based on research data from this region, on average a total of 180 to 200 lb N/acre (residual soil NO_3–N and NH_4–N, and fertilizer N) of total N is needed to maximize yields (Tarkalson et al., 2017). The remaining N needed from these sites likely came from organic based N that was mineralized during the growing season. In 2014 and 2016, the F treatment had suboptimal available inorganic N (NO_3–N and NH_4–N) in the soil profile to maximize yield, 166 and 147 lb N/acre, respectively (Table 2). The M1 and M2 treatments during both years had sufficient available N to maximize yield (Table 2). In this study, the lack of root yield response from the F treatment during both years was likely caused by in-season N mineralization. Spring soil sampling protocols do not predict mineralization rates, thus it can be common to have sites that do not respond to added N even when soil tests recommend N additions. These data highlights the need for additional research to better predict in-season N mineralization.

Across N rates, the M1 and M2 treatments had greater sugar beet root yields compared to the F treatment. The M1 and M2 treatments did not have different root yields. In 2014 and 2016, averaged across all N rates, root yields from both manured treatments were 12 and 36% greater than the F treatment, respectively (Fig. 1 and Fig. 2). The greater root yield

Table 3. Probability values (*P* > F) from analysis of variance for measured yield related factors during the two study years. Bolded probability values are significant at the *P* = 0.05 level.

Year	Source	df†	Root Yield	ERS‡	Sucrose	Brei Nitrate	Conductivity
2014	Manure (M)	2	**0.034**	0.109	**0.017**	**0.015**	**0.010**
	N Rate (N)	7	0.887	0.815	0.430	0.430	0.981
	M × N	14	0.157	0.053	0.054	0.054	0.676
	N Linear	1	0.797	0.205	0.085	0.245	0.589
	N Quadratic	1	0.217	0.732	0.327	0.762	0.990
2016	Manure (M)	2	**0.010**	**0.025**	0.079	**0.017**	0.475
	N Rate (N)	7	0.246	0.767	0.480	0.609	0.311
	M × N	14	0.496	0.736	0.294	0.598	0.513
	N Linear	1	0.263	0.744	0.419	0.076	0.222
	N Quadratic	1	0.062	0.577	0.658	0.799	0.403

† Degrees of freedom.

‡ Estimated recoverable sucrose.

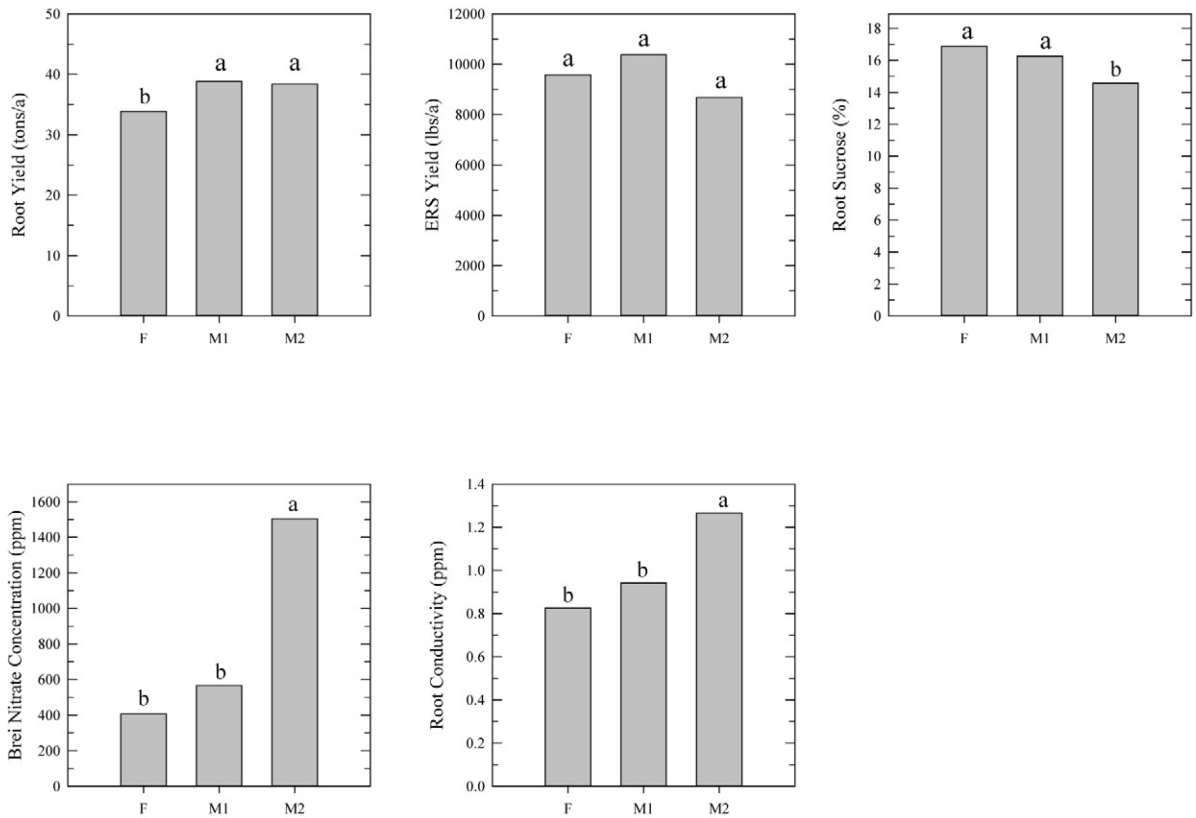

Fig. 1. Selected root factors in 2014. Values are averaged over N rate. Columns with the same letter are not significantly different. ERS = Estimated recoverable sucrose.

difference in 2016 was likely exasperated by a hail storm that occurred in June. The hail reduced the plant leaf area more in the non-manured treatment than in the manured treatments (Fig. 3, no data observation). During both years of the study, manured plots had greater leaf area early in the season compared to the non-manured plots (Fig. 3).

In 2016, the M1 and M2 treatments had greater ERS yields than the F treatment (Table 3 and Fig. 2). However, there were no differences in ERS yields among all past manure treatments in 2014. The M2 treatment also had decreased root sucrose concentration in 2014. The decreased sucrose concentration was likely due to increased beet root impurities resulting from increased available N in the soil. The impurity (brei nitrate and root electrical conductivity) measurements were greater in the M2 treatment compared to the F treatment in 2014. In 2016, the effect of increased soil available N on sucrose concentration did not exist (Fig. 2). Although soil available N was greater in both 2014 and 2016 in the manured treatments compared to the F treatment, the timing of N mineralization, especially in the manured treatments, was likely different during the growing season,

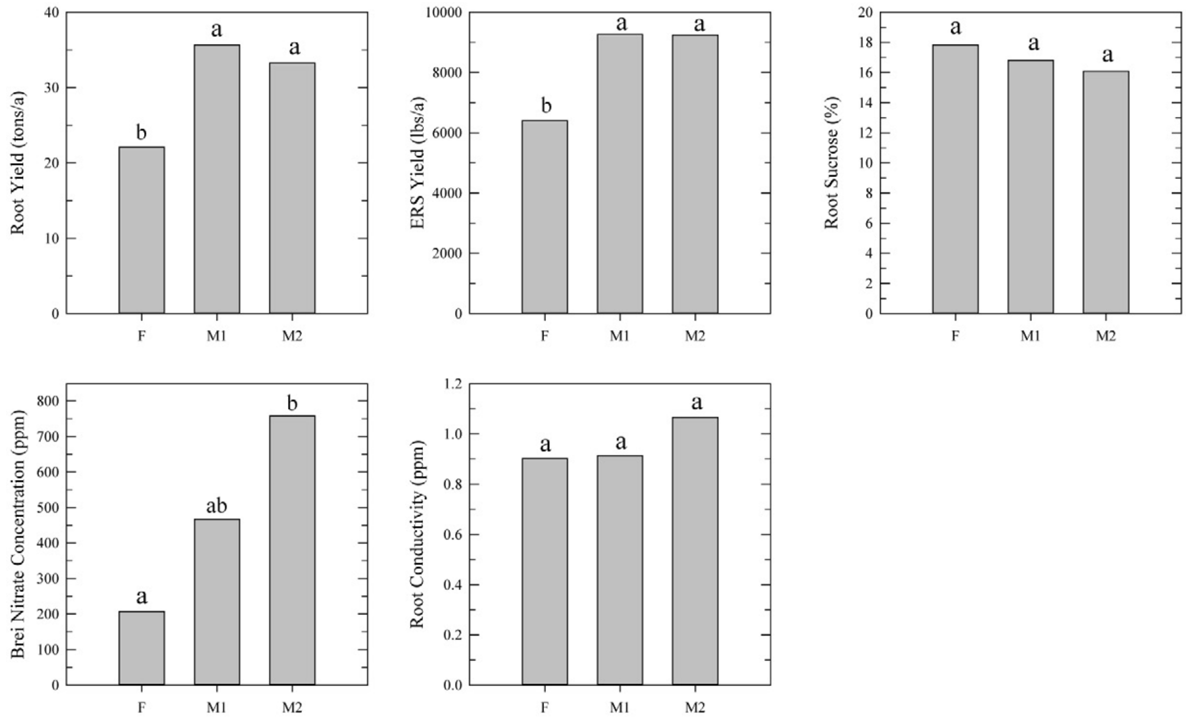

Fig. 2. Selected root factors in 2016. Values are averaged over N rate. Columns with the same letter are not significantly different. ERS = Estimated recoverable sucrose.

Fig. 3. Sugar beet early in the 2017 growing season at the research site.

resulting in differences in soil N effects on sugar beet quality and sucrose concentration. Soil N mineralization can vary substantially as a function of both time of year and from year to year (Fig. 4). Specifically, Lentz et al. (2011) showed that manure treatments generally had greater N mineralization in late summer than fertilized plots even 3 yr after manure application (Fig. 4). Furthermore, when manure is applied, the effect of time on soil N mineralization also differs as a

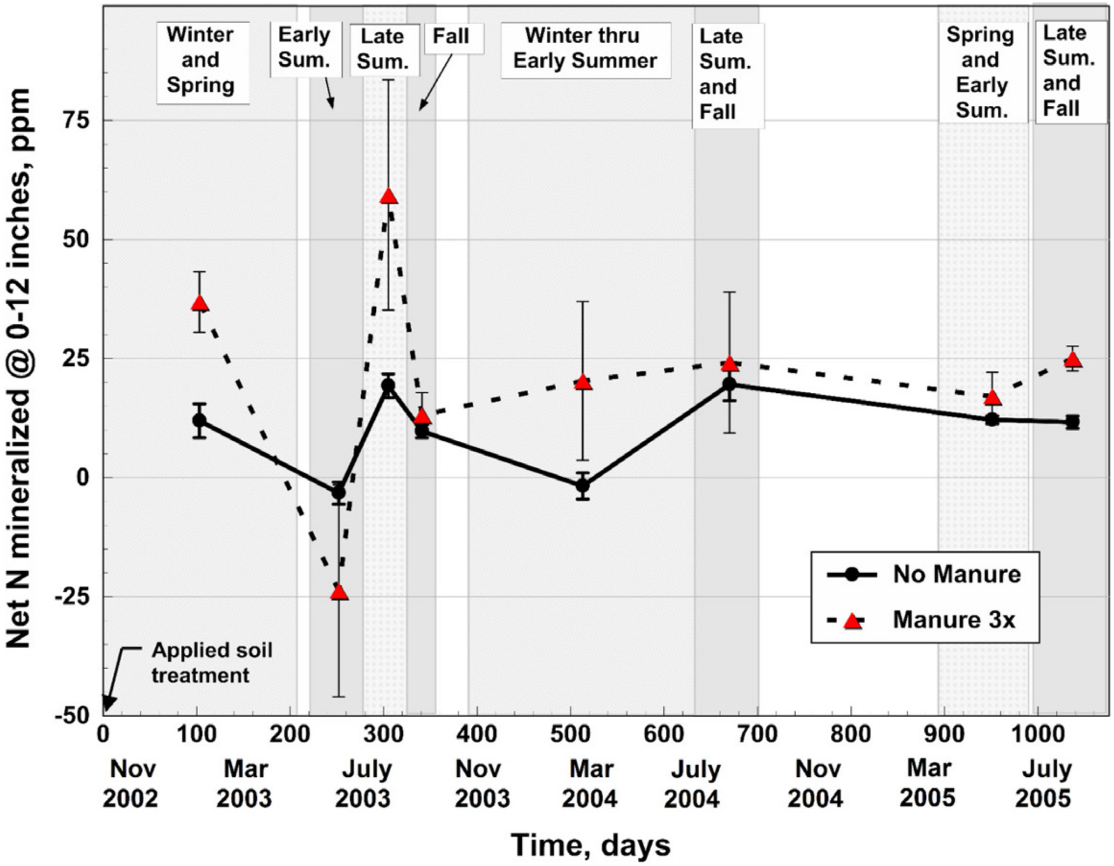

Fig. 4. The net N mineralized at 0-to-12-inch soil depths for defined periods from Oct. 2002 through Oct. 2005. Values are means for two N-source treatments: No Manure, including no amendment or mineral fertilizer only (n = 16); and a single 29.7 ton/acre (dry wt.) dairy manure treatment applied on Day 0 (n = 4). Each leg of the error bars represents one standard error of the mean (n = 48). Back panels in the figure identify the measurement interval used for each data point. (Lentz et al., 2011).

function of soil depth (Fig. 5). The addition of organic N, like manure, to soil/production systems can drastically change the N cycle, complicating the prediction of crop available N and thus commercial fertilizer N recommendations. A better understanding of mineralization during the growing season will be important to improve N management.

Brei nitrate is a measure of N related impurities in sugar beet roots that can result in reduced sucrose concentration and decreased sucrose extraction efficiency. The Amalgamated Sugar Company Sugar beet Growers Guide Book states that sucrose concentration decreases by approximately 0.5% for every 100 ppm brei nitrate, and above average sucrose concentrations are likely at brei nitrate concentration below 200 ppm (Amalgamated Sugar Company, 2010). High brei nitrate levels indicate that excessive N was available during the growing season. Root electrical conductivity measurements often mirror brei nitrate concentrations as a result of the effect of nitrate concentrations on electrical conductivity. In 2014 and 2016, brei nitrate concentration was greatest in the M2 treatment. This was expected since the M2 treatment had the greatest available N in the spring. The reason elevated brei nitrate concentrations in 2016 did not affect sucrose concentrations and ERS yield is likely due to other factors influencing both nitrate and sucrose concentrations. For example, King and Tarkalson (2017) found that growing season temperatures likely influence sugar beet sucrose concentrations

Improved P fertility could be partially responsible for the greater root yields in the manured treatments compared to the F treatment. Improved crop yields and crop quality have been observed due to organic material applications to soils (Granstedt and Kjellenberg, 1997). Yield improvements from organic matter additions were often greater in soils with lower organic matter concentrations. The research site and soil (Portneuf silt loam) in our study has as history of furrow irrigation. Furrow irrigation is known to remove top soil, and the organic matter and nutrients contained in the topsoil, from the inflow end of fields (Trout, 1996). Carter et al. (1985) found that crop yield was reduced up to 25% on eroded, inflow ends of furrow irrigated fields. Robbins et al. (1997) determined that manure could improve dry bean (*Phaseolus vulgaris* L.) yield on exposed subsoil equal to that of conventionally fertilized topsoil. Tarkalson and Bjorneberg (2010) found that a field near the study location containing a Portneuf silt loam soil, had differences in soil organic matter from soil erosion in the top 8 inches of soil between the top end (1.0% organic matter) and bottom

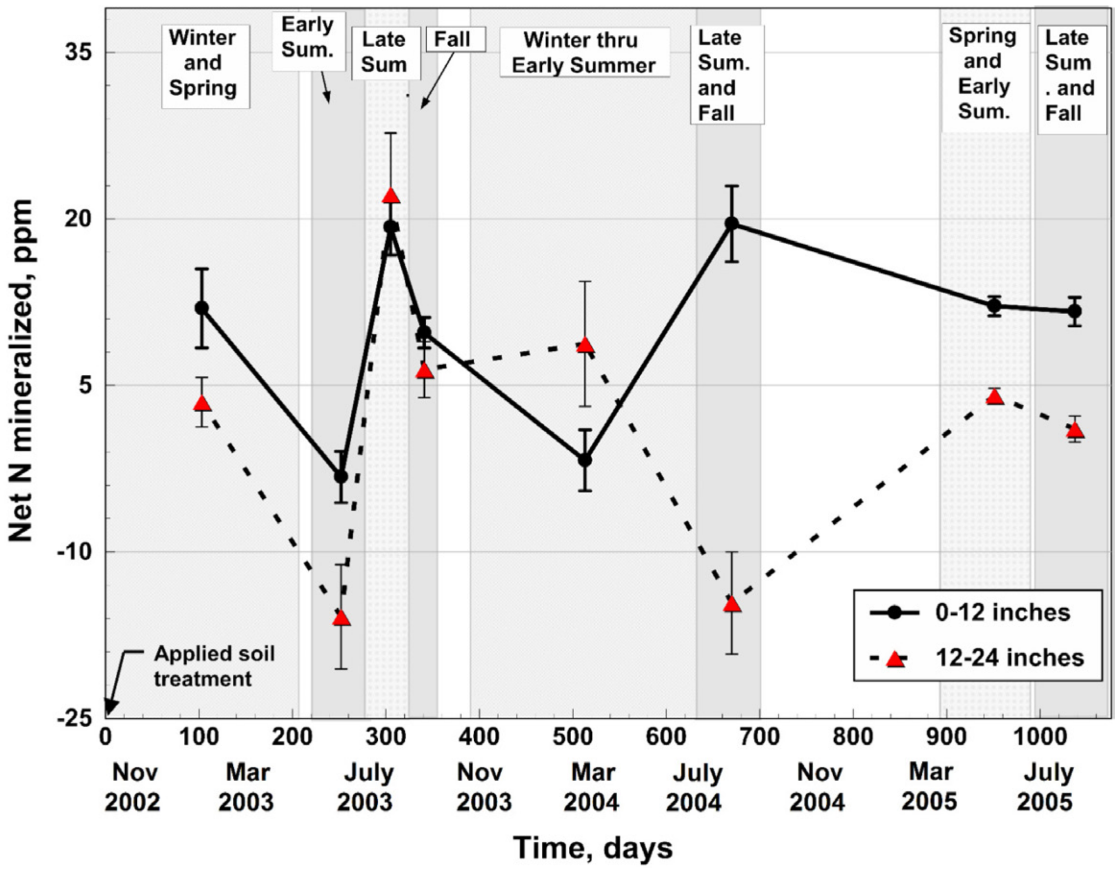

Fig. 5. The net N mineralized at 0-to-12-inch and 12-to-24-inch soil depths for defined periods from Oct. 2002 through Oct. 2005. Values are averaged across several N-source treatments (including no additions, compost, and manure amendments). Each leg of the error bars represents one standard error of the mean (n = 48). Back panels in the figure identify the measurement interval used for each data point. (Lentz et al., 2011).

end of the field (1.8% organic matter). Tarkalson and Bjorneberg (2010) found that commercial N and P applications increased corn grain yields at the top of the field but not at the bottom. The accumulation of soil C and nutrients at the bottom end of the field likely resulted in the lack of yield response to added N and P. The location of the current study was at the inflow end of the field when it was furrow irrigated prior to 1998.

Conclusions

Typical manure application rates led to increased soil inorganic N concentrations 5 to 7 yr after manure applications compared to non-manured systems under conventional fertilizer management. Sugar beet grown in soil with past manure applications had greater root yields compared to sugar beet grown with only fertilizer. These differences in root yield were associated with factors not related to N fertility. However, past manure applications and the associated effects on N cycling can continue to affect sugar beet quality. The long-term effect of manure applications on soil fertility/crop production and environmental impact needs continued evaluation to improve production, environmental protection, and economics of impacted agroecosystems.

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