Published February 21, 2019

Composted Cattle Manure as a Nitrogen Source for Sugar Beet Production

Bijesh Maharjan* and Gary W. Hergert

ABSTRACT

Nitrogen management is key to achieving profitable sugar beet (*Beta vulgaris* L.) yield and quality. When commercial fertilizer prices increase significantly, producers often consider alternatives, including fresh or composted manure. A 3-yr field trial was conducted in western Nebraska to evaluate the effects of different rates of composted beef (*Bos taurus* L.) manure (CManure), and urea on sugar beet yield, sucrose content, and quality. Sugar beet followed maize (*Zea mays* L.) in 2009 and 2010 and dry bean *(Phaseolus vulgaris* L.) in 2011. Agronomic efficiency (AE) of N applied as CManure or urea was also evaluated in this study. There was a trend for reduced AE with increasing rate of N input. Beet yield response to composted manure rates plateaued at 23.0 Mg ha^{-1} (in 2009–2010) and 13.9 Mg ha^{-1} (in 2011) with corresponding fresh beet yields of 62.2 and 77.9 Mg ha^{-1}. Composted manure treatments at application rates of 18 and 36 Mg ha^{-1} statistically matched what urea rates of 67 and 134 kg N ha^{-1} achieved in terms of beet yield. These findings found no adverse effect of composted manure in beet production and underscore the potential of solely depending on composted manure to meet N requirement in beet production.

Core Ideas

- Composted cattle manure has no detrimental effect on sugar beet root yield or sugar quality.
- Composted cattle manure is a potential nitrogen source for sugar beet production
- Besides a proper N rate, crop stand, and previous crop are also important to maximize beet yield and quality.

Published in Agron. J. 111:917–923 (2019)
doi:10.2134/agronj2018.09.0567
Available freely online through the author-supported open access option

Nitrogen management in sugar beet production can be challenging as both under- and over-application of N can affect yield and quality. Under-application of N reduces root and sucrose yield while over-application results in decreased sucrose content and increased root impurities further reducing sucrose extraction (Carter and Traveller, 1981; Tarkalson et al., 2016). Numerous studies have reported on N fertilizer response and recommendations for sugar beet (Adams et al., 1983; Anderson and Peterson, 1988; Moore et al., 2009; Hergert, 2010).

Before the advent of commercial N fertilizer, manure application was the only means of supplying additional N other than plowing down previous legume crops, and manure rates were commonly 12 to 22 Mg ha^{-1} (Haddock, 1952). The disadvantages of manure application included (i) difficulty in applying a precise rate with older manure spreaders, (ii) determining the timing and amount of N mineralization (Tarkalson et al., 2012), and (iii) salt sensitivity of seedling sugar beet from high manure salt levels (Eghball et al., 2004, Horneck et al., 2007). Consequently, most farmers do not apply manure for sugar beets in the intermountain west production area of the Western Sugar Cooperative (comprised of over 850 sugar beet growers) and the practice is discouraged (Jerry Darnell, personal communication, 2018).

The rapid rise of natural gas prices during 2006 to 2008 contributed to significantly increased N fertilizer prices (USDA ERS, 2018) and that prompted this evaluation of composted manure (CManure) as a potential alternative N source. Cost of fertilizers typically represents 24–30% (or more) of the total variable costs of production (Lu et al., 2000). During times of economic uncertainty and decline, all costs of agricultural production including fertilizers become important and require re-evaluation. As Gareau (2004) suggested in their meta-analysis study, manure-based systems that incur no or minimal cost of purchase and transport can be considerably more profitable than conventional systems.

In their early research, Halvorson and Hartman (1975) showed a positive influence of manure on beet yield and sucrose concentration. However, N availability from manure was not well quantified and was believed to occur too late in the season to improve yield and quality (Lentz and Lehrsch, 2012). In contrast with fresh manure, CManure has lower N content (Irshad et al., 2013) and has lower nutrient availability in the first year of application (Rosen and Bierman, 2018). Mineralization of organic N from composted manure is also reported to be lower than that from fresh manure (Eghball, 2000). These

Univ. of Nebraska-Lincoln, Lincoln, NE 68588. Received 7 Sept. 2018. Accepted 8 Dec. 2018. *Corresponding author (bmaharjan@unl.edu).

Abbreviations: AE, agronomic efficiency; CManure, composted manure; RSY, raw sugar yield; SLM, sugar loss to molasses.

Table 1. Chemical properties of soil (0–20 cm) collected in each spring from the research plots.

Parameter	2009	2010	2011
pH	8.2	7.9	7.9
Organic matter, %	2.0	1.7	1.7
Olsen P, mg kg^{-1}	25	13	18
K, mg kg^{-1}	492	361	433
S, mg kg^{-1}	16.4	13.0	16.8
Zn, mg kg^{-1}	1.7	1.0	1.4
Fe, mg kg^{-1}	6.0	6.8	5.9
Nitrate–N, kg ha^{-1}			
0–20 cm	21.0	18.9	36.0
20–60 cm	24.3	31.7	27.0
60–90 cm	8.7	40.8	9.9
90–120 cm	28.0	25.7	13.5
120–150 cm	68.1	12.1	9.6
Previous crop	Maize	Maize	Dry bean

Table 2. Chemical properties of composted manure that was applied each year.

Content†	2009	2010	2011
Moisture, %	12.6	9.5	25.4
Organic N, kg	7.4	8.2	5.8
Nitrate–N, kg	1.1	1.2	1.1
Ammonium N, kg	0.2	0.1	0.1
Total N, kg	8.7	9.5	7.0
Available N‡, kg	2.4	2.5	2.1
P as P_2O_5, kg	12.2	14.3	9.0
K as K_2O, kg	12.8	13.3	13.3
S, kg	2.4	2.6	2.2
Zn, kg	0.3	0.3	0.2
Fe, kg	5.5	6.1	4.0

† All properties are expressed per Mg of dry composted manure.

‡ Nitrogen availability in the first year of manure application was estimated by adding up 100% of mineral N and 15% of organic N in manure (Shapiro et al., 2015).

characteristic of CManure might alleviate an issue of N supply late in the season in beet production.

Irrespective of N source, application of N is economical, if the value of the increase in the crop yield due to the quantity of fertilizer added is greater than the cost of fertilizer used (Amanullah et al., 2012). Agronomic efficiency (AE) is a metric that reflects the direct production impact of an applied fertilizer and relates directly to economic return (Cassman et al., 1996).

The objective of this study was to evaluate effects of various rates of CManure and urea on beet yield, sucrose content, and quality. Agronomic efficiency of N applied as CManure or urea was also evaluated in this study.

MATERIALS AND METHODS

This experiment was conducted during the growing seasons of 2009 through 2011 at the Panhandle Research and Extension Center near Scottsbluff, NE (41°56′50.98″N 103°42′11.5″W, elevation 1186 m above sea level). The experiment was conducted at different sites each year, but the sites were adjacent to each other on a Tripp very fine sandy loam (coarse-silty, mixed, superactive, mesic Aridic Haplustolls). The slope ranged from 1 to 3% depending on field location. All sites were under a linear-move sprinkler irrigation system. Irrigation was applied regularly to meet crop water need based on evapotranspiration, precipitation, and change in soil moisture data from a regional weather station (HPRCC, 2011). The experimental sites were sampled in early spring to determine soil characteristics. Each year, six soil cores were taken from the 0–20, 20–60, 60–90, 90–120, and 120–150 cm depths from each replication and composited. Soil samples were dried in ventilated oven at 40°C and 0–20 cm samples were analyzed for standard soil test parameters including nitrate N (NO_3^-–N) (Mulvaney, 1996), pH (Thomas, 1996), organic matter (Nelson and Sommers, 1996), Olsen P (Olsen et al., 1954), sulfate-S (Johnson, 1987), and diethylenetriaminepentaacetic acid (DTPA)-extractable Zn, Fe, Mn, and Cu (Lindsay and Norvell, 1978) (Table 1). Soil samples from other depths were analyzed for NO_3^-–N only.

The experimental design was a randomized complete block with N as the main factor and with six replications. The N treatment included control (no N); urea (46–0-0) at 67 and 134 kg N ha^{-1}; and composted beef cattle manure (CManure) from a local feedlot at 9, 18, and 36 Mg ha^{-1} (dry wt) (Table 2). Compost was created by stockpiling beef cattle feedlot manure during the preceding fall, then using mechanical mixing and aeration about every 3 wk for a total of three turnings to maintain sufficient conditions (including maintaining temperature at 54 to 71°C for a period of minimum 21 d) for good composting (Wortmann and Shapiro, 2012). Urea and CManure were weighed for each plot and spread manually, 1–2 d before the strip-tillage operation. A parabolic shank strip-till machine (Schlagel Manufacturing, Torrington, WY) with a 56 cm spacing was used and shanks were run 20 cm deep. The strip-tillage tilled a narrow slot about 10 cm wide and thus, added treatments were partially incorporated from the single pass of strip tillage implement. A Global Positioning System guidance was used for both strip tilling and sugar beet planting so beet rows were planted right over a strip-tilled area. Sugar beet followed maize (*Zea mays* L.) in 2009 and 2010 and dry bean *(Phaseolus vulgaris* L.) in 2011. Two different Roundup Ready sugar beet varieties were used: Beta-seed B66RR70 in 2009 and 2010 and Beta-seed B69RR2N in 2011. Individual plots were 3.4-m wide (six rows) × 10.7-m long with row width of 56 cm. Planting dates were in late April to early May each year (Fig. 1). A 12-row air planter (Monosem Inc, Edwardsville, KS) was used to plant 138,000 seeds ha^{-1}. Plant stand was counted in late May to late June depending on crop condition as affected by weather events.

For harvest, two interior rows of the six-row plot were harvested with a small two-row beet harvester, weighed, and bagged with labels. For each plot after weighing, a subsample of 15 to 20 beets was taken for tare, sugar loss to molasses (SLM), and sugar concentration analyzed by the Western Sugar factory tare laboratory. Soil samples were collected in 30 cm increments to 150 cm from each plot in 2010 and 2011 to estimate residual nitrate N (NO_3^-–N) after beet harvest.

Data Analysis

Raw sugar yield (RSY) was calculated as the product of beet yield and sugar concentration corrected for tare. The AE in beet production was calculated as the ratio of beet yield increase (yield in N applied plot minus yield in the control plot) to applied N (CManure or urea N input) (Dobermann and Cassman, 2005). First-year N supply from CManure treatment

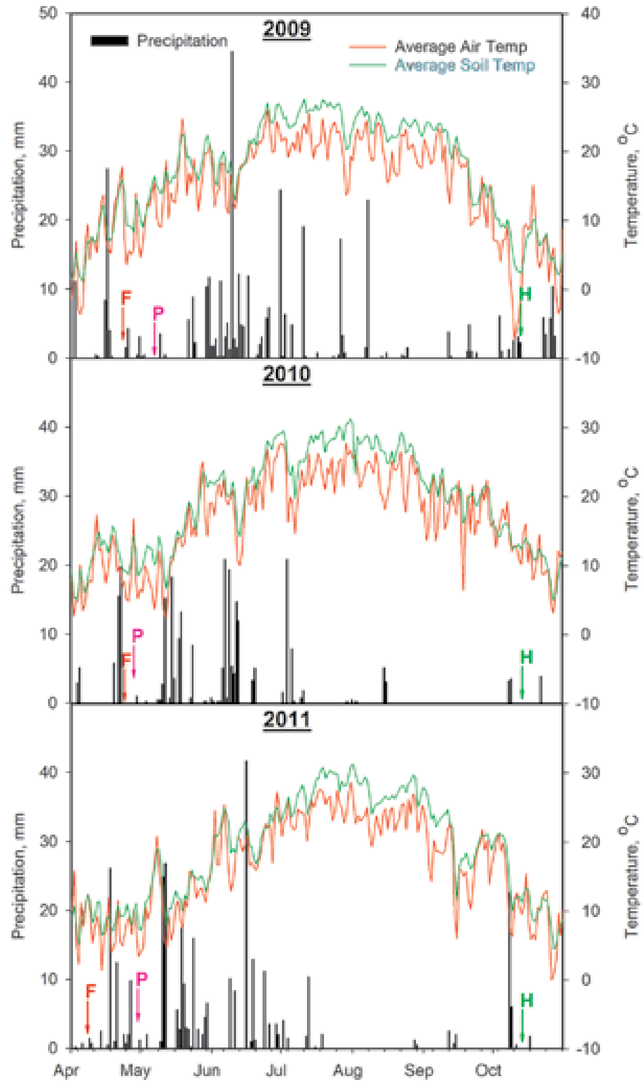

Fig. 1. Daily precipitation, average daily air temperature and average daily soil temperature (at 10 cm depth) during the season in 2009, 2010, and 2011. Colored arrows refer to date of manure/urea application (F), planting (P), and harvest (H).

was estimated assuming availability of 15% of organic N and 100% of inorganic N present in CManure when applied (Shapiro et al., 2015).

Effects of year and N treatment on different response variables were determined using Proc Mixed in SAS (SAS Institute Inc., Cary, NC), with year and N treatment as the fixed effects and block and all interactions of block with other terms as random effects (SAS Institute, 2003; Littell et al., 2006). Year was treated as a fixed effect to evaluate effects of differences in weather between growing seasons. Since the preceding crop was different, dry bean in 2011 versus maize in 2009 and 2010 as were seed varieties, data from 2011 were analyzed separately. Effect of N treatment in 2011 was analyzed using Proc ANOVA in SAS. Response variable means in 2011 were compared against those in 2009 and 2010 separately using *t*-test analysis. Significance criteria of $P < 0.05$ were used unless otherwise mentioned. Quadratic-plateau model in SAS was used to determine agronomic optimum CManure rate for 2009–2010 and 2011 since that model was reported to be better than quadratic model in predicting crop N requirements (Bullock and Bullock, 1994).

RESULTS AND DISCUSSION

Weather

Average air temperatures in the period of 1 April through the end of October were 14.7, 16.7, and 16.4°C in 2009, 2010, and 2011, respectively (Fig. 1). Corresponding average soil temperatures at the 10 cm depth were 17.2, 19.3, and 18.8°C. Except in May, average monthly air and soil temperatures were greater in 2010 compared with 2009 by 2.8 (±1.0) and 2.7°C (±0.6) during April through October. Average monthly air and soil temperatures in 2011 were similar to those in 2010. Total precipitation was 396 mm during Apr.–Oct. 2009. Total precipitation for the same period was 272 mm in 2010 and 346 mm in 2011. Hailstorms caused considerable damage on 10 Jun in 2009 to the crop leaving only ribs and a few leaves. In 2011, there was a light hail in mid-June with no effect on crop vegetative growth.

Agronomic Response

Inter-Annual Variation

Nitrogen recommendations for sugar beet generally accounts for 0–120 cm soil residual NO_3^-–N in spring and in this study, 0–120 cm residual soil NO_3^-–N in spring of 2010 was 117 kg N ha^{-1} compared to 82 kg N ha^{-1} in 2009. If 0–150 cm soil depth was considered, residual soil NO_3^-–N in spring of 2009 was 150 kg N ha^{-1} compared to 129 kg N ha^{-1} in 2010. There was no difference in yield between the 2 yr even after vegetative damage by hail in 2009, which could possibly be explained by the fact that 2009 had greater NO_3^-–N supply from soil when the 150 cm profile is considered (Table 1). In the past, 180 cm deep soil sampling was recommended for sugar beet N management, but 120-cm depth has become a more accepted practice (Hergert, 2012). In 2009 considerable NO_3^-–N was present deeper in the soil profile (Table 1), probably due to high N input in the preceding maize crop. Soil NO_3^-–N deeper than 120 cm is used by sugar beet and is important to quantify when managing N.

Phosphorus was somewhat lower in 2010 (Table 1) (13 mg P kg^{-1}) compared to 2009 (25 mg P kg^{-1}) and suggested some P was needed (Hergert, 2012). About 25 kg P ha^{-1} is recommended if the soil Olsen P test is 13 mg kg^{-1} or less. However, comparison of beet yield and sucrose content of the highest urea-N rate and the two higher CManure rates did not show any difference, so P level may not have been limiting. In some cases, soils can be responsive to Zn addition when soil test is <1.0 mg kg^{-1} (Moore et al., 2009) and in this study, soil Zn levels in both 2009 and 2010 were adequate (Hergert, 2012).

Beet yield in 2011 was 76.7 Mg ha^{-1} compared to 61.4 and 56.6 Mg ha^{-1} in 2009 and 2010 respectively (Table 3 and 4). In 2011 fresh beet yield was significantly greater than in 2009 or 2010 (Table 5). Sugar concentration, RSY, and plant stand were higher in 2011 than in previous years. In 2011 SLM was significantly lower than in 2009. The high-yielding year 2011 also had considerably less post-harvest residual NO_3^-–N than 2010 (27.5 kg N ha^{-1} vs. 40.6 kg N ha^{-1}). Lower crop stand and subsequent lower yield in 2010 than in 2011 may have contributed to reduced N uptake, thereby leaving higher residual NO_3^-–N. However, AE in 2011 was not significantly different from 2009 or 2010. In spite of lower 0–150 cm residual soil NO_3^-–N in spring of 2011 (96 kg N ha^{-1}), beet yield in the control plots in 2011 was considerably high (69.3 Mg ha^{-1} compared to 49.4

Table 3. ANOVA results with means for different dependent variables as affected by year, N treatment, and their interaction.†

Source of effects	Beet yield	Sugar	RSY	SLM	Plant stand	AE	Post-harvest soil N‡
	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	%	1000 ha^{-1}	Mg kg^{-1}	kg N ha^{-1}
Year (Y)							
2009	61.4	14.5 b§	8.9	1.4 a	86	0.14	–
2010	56.6	17.6 a	10.0	1.1 b	92	0.27	40.6
Significance	ns¶	***	ns	***	ns	ns	–
N Treatment (N)							
Control	49.4 c	16.1	7.8 b	1.3	87	–	32.9
9 Mg ha^{-1} CManure	56.9 b	16.2	9.2 ab	1.2	88	0.33	41.9
18 Mg ha^{-1} CManure	61.9 ab	15.8	9.7 a	1.2	85	0.28	42.3
36 Mg ha^{-1} CManure	62.2 ab	15.9	9.9 a	1.3	90	0.14	46.1
67 kg urea-N ha^{-1}	59.6 ab	16.0	9.5 a	1.2	92	0.15	40.8
134 kg urea-N ha^{-1}	64.2 a	16.2	10.4 a	1.2	91	0.11	39.4
Significance	**	ns	*	ns	ns	ns	ns
Interaction							
Y × N	ns	ns	ns	ns	ns	ns	–

* Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$.

† RSY, raw sugar yield; SLM, percent sugar loss to molasses; AE, agronomic efficiency estimated by increase in beet yield by N input; CManure, composted manure.

‡ Post-harvest soil samples were collected from 150 cm depth and analyzed for residual nitrate N in 2010 only.

§ Means in columns are presented with mean separation letters (different if significantly different).

¶ ns, not significant

Table 4. ANOVA results with means for different dependent variables as affected by N treatment in 2011.†

Source of effects	Beet yield	Sugar	RSY	SLM	Plant stand	AE	Post-harvest soil N‡
	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	%	1000 ha^{-1}	Mg kg^{-1}	kg N ha^{-1}
N treatment (N)							
Control	69.3	16.2	12.1	1.0	107 bc§	–	28.7
9 Mg ha^{-1} CManure	76.8	17.0	13.1	1.0	120 a	0.41	26.9
18 Mg ha^{-1} CManure	77.5	16.8	13.0	1.0	116 ab	0.22	25.6
36 Mg ha^{-1} CManure	78.3	16.9	13.2	1.0	109 bc	0.12	26.9
67 kg urea–N ha^{-1}	77.1	17.1	13.1	1.0	112 abc	0.12	26.1
134 kg urea–N ha^{-1}	81.1	16.9	13.7	1.1	104 c	0.09	31.0
Significance	ns¶	ns	ns	ns	*	ns	ns
Means	76.7	16.8	13.0	1.0	111	0.19	27.5

* Significant at $P < 0.05$.

† RSY, raw sugar yield; SLM, percent sugar loss to molasses; AE, agronomic efficiency estimated by increase in beet yield by N input; CManure, composted manure.

‡ Post-harvest soil samples were collected from 150 cm depth and analyzed for residual nitrate–N.

§ Means in columns are presented with mean separation letters (different if significantly different).

¶ ns, not significant.

Table 5. The *t*-test results (*p*-values) comparing means of different variables in 2011 against 2009 and 2010.

Variable	2009	2010
Beet yield	< 0.0001	< 0.0001
Sugar concentration	< 0.0001	< 0.0001
Raw sugar yield	< 0.0001	< 0.0001
Sugar loss to molasses	< 0.0001	0.06
Plant stand	< 0.0001	< 0.0001
Agronomic efficiency	0.72	0.07
Post-harvest residual nitrate–N	na†	< 0.0001

† na, not available.

in 2009–2010). As a result, AE in 2011 was not significantly greater than in 2009 or 2010 in spite of greater yield in fertilized plots that year. Another contrasting factor in 2011 was that beet followed dry edible beans while in 2009 and 2010, beet followed maize. Quality and amount of crop residue and its effects on soil microbial processes, residue decomposition, and soil mineralization are some factors that can affect subsequent crops (Sawyer and Mallarino, 2017). Our result aligns with Jacobs et al. (2018) that demonstrated that sugar beet following grain pea had lower N requirement, and subsequently higher N use efficiency compared to sugar beet following silage maize.

Treatment Effect

Overall mean beet yield and RSY were significantly affected by N treatment in 2009 and 2010. Beet yields with CManure or urea treatments were greater compared to the control. Beet yield was also significantly greater with 134 kg urea-N ha^{-1} compared to 9 Mg ha^{-1} CManure treatment. There was a trend for greater yield with 134 kg urea-N ha^{-1} compared to 67 kg urea-N ha^{-1} ($P = 0.18$). All N treatments, except for 9 Mg ha^{-1} CManure, had significantly greater RSY than the control treatment. Plant stand, SLM, and sugar concentration did not vary by N treatment.

The AE did not statistically differ by N treatment at $P = 0.05$ (Table 3). However, there was a trend for reduced AE with

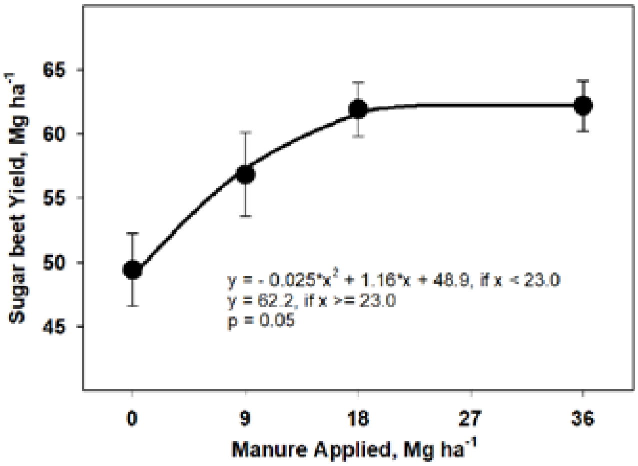

Fig. 2. Means (standard error) of sugar beet yield at different manure rates in 2009 and 2010 combined and their quadratic-plateau regression.

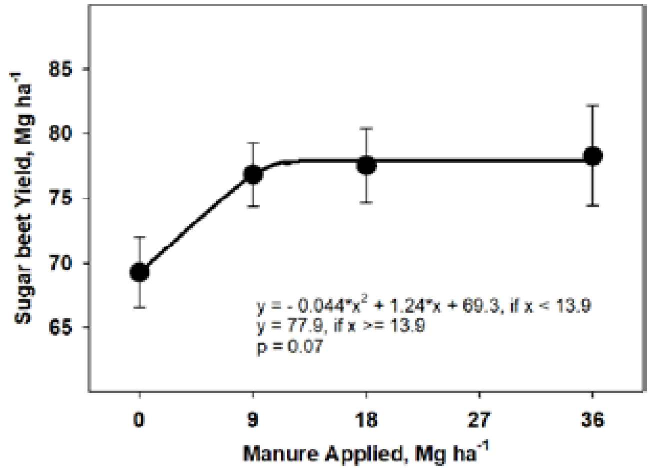

Fig. 3. Means (standard error) of sugar beet yield at different manure rates in 2011 and their quadratic-plateau regression.

increasing rate of N input. This observation aligns with the law of diminishing returns to applied N fertilizer where successive increments in yield due to successive equal increments in fertilizer tend to form the terms of a decreasing geometric series (Spillman, 1923). The AE with the 9 Mg ha^{-1} CManure treatment was higher than with the N treatments of 134 kg urea-N ha^{-1} (at $P = 0.07$), 67 kg urea-N ha^{-1} (at $P = 0.14$), and 36 Mg ha^{-1} CManure (at $P = 0.12$). When only CManure treatments were considered, yield response to CManure rates averaged across 2 yr plateaued at 23 Mg ha^{-1} with corresponding beet yield of 62.2 Mg ha^{-1} at $P = 0.05$ (Fig. 2).

In 2011, there was no N treatment effect on any measured variables except for plant stand. No N treatment effect on beet yield could have been due to differences in plant stand. The highest urea-N rate treatment had the lowest of all plant stands (Table 4). Urea fertilization is sometimes reported to reduce crop stand depending on soil moisture conditions (Grant et al., 2016). However, in this study in 2011, the field was irrigated 6 d after planting and it also received 5 cm precipitation 2 d after that irrigation event. Therefore, low crop stand in the highest urea–N rate treatment was most likely not due to any adverse effect of urea. Beet yield response to CManure rates plateaued at 13.9 Mg ha^{-1} with corresponding beet yield of 77.9 Mg ha^{-1} at $P = 0.07$ (Fig. 3). This was a high-yielding year compared to previous years, probably due to favorable weather, improved variety, potentially considerable N credits from previous leguminous crop, and better crop stand.

There is a concern when growing sugar beet in fields that receive fresh manure and it is discouraged (Davis and Westfall, 2010) because N availability from the manure is not well quantified and is believed to occur too late in the season to improve yield and quality (Lentz and Lehrsch, 2012). This is particularly important for sugar beet production as beet yield, sugar, and impurity are sensitive to both insufficient N and excess soil N. This concern with using manure in sugar beet production may be well founded; however, there are reports that suggest that sugar beet can be grown successfully in manured fields. Halvorson and Hartman (1975) showed a positive influence of barnyard manure on beet yield and sucrose concentration in their early research. Highest RSY (7.9 Mg ha^{-1}) accompanied by root yields of 47.5 Mg ha^{-1} was obtained with 22.4 Mg ha^{-1} of manure in that study. Lentz et al. (2011) also reported that peak net N mineralization in (stockpiled dairy) manure-amended, irrigated soils coincided with maximum N uptake by beet, and first-year manure applications as high as 20 Mg ha^{-1} had no significant adverse effect on beet yield or quality.

Agronomic optimum CManure application rate in 2009–2010 (23.0 Mg ha^{-1}) was a little higher than optimal fresh manure rates in above-mentioned studies. It is a known fact that CManure has lower N content compared to fresh manure (Irshad et al., 2013) and therefore, more is needed to meet crop N need. However, CManure has its own advantages over fresh manure including reduced viable weed seeds, various pathogens, and less soluble N prone to loss (Rosen and Bierman, 2018). In this study, CManure treatments at application rates of 18 and 36 Mg ha^{-1} statistically matched what urea rates of 67 and 134 kg N ha^{-1} achieved in terms of beet yield in all 3 yr. These findings underscore the potential of solely depending on CManure to meet N requirement in beet production. When commercial N fertilizer prices are very high compared to sugar price, CManure may be an economic alternative, provided that cost and transport of CManure are lower than commercial N.

However, it is important to acknowledge some caveats concerning composted or fresh manure management in cropping systems. Efficient use of manure as fertilizer can be undermined by nutrient imbalances in manure, variability in manure sources, and difficulties in estimating nutrient availability (Sawyer and Mallarino, 2016). Manure management is most likely to be profitable if there is minimal cost associated with purchase and/or transport. Potential loss from N applied above the optimum rate can also have environmental implications.

In this study, first-year N availability from applied CManure was estimated to facilitate evaluation of beet yield response to various N rates irrespective of N source. When beet yield response to N from urea and CManure was analyzed for 3 yr separately, the fit to a quadratic-plateau model was statistically significant in all 3 yr at $P < 0.05$ (Fig. 4). In 2009 and 2010, beet yield plateaued at 58 kg N ha^{-1} with corresponding yields of 63.7 Mg ha^{-1} in 2009 and 60.4 Mg ha^{-1} in 2010. In 2011, agronomic optimum beet yield was 78.5 Mg ha^{-1} at 32.4 kg N ha^{-1}. The higher yield with lower N rate in 2011 underscores an opportunity and need

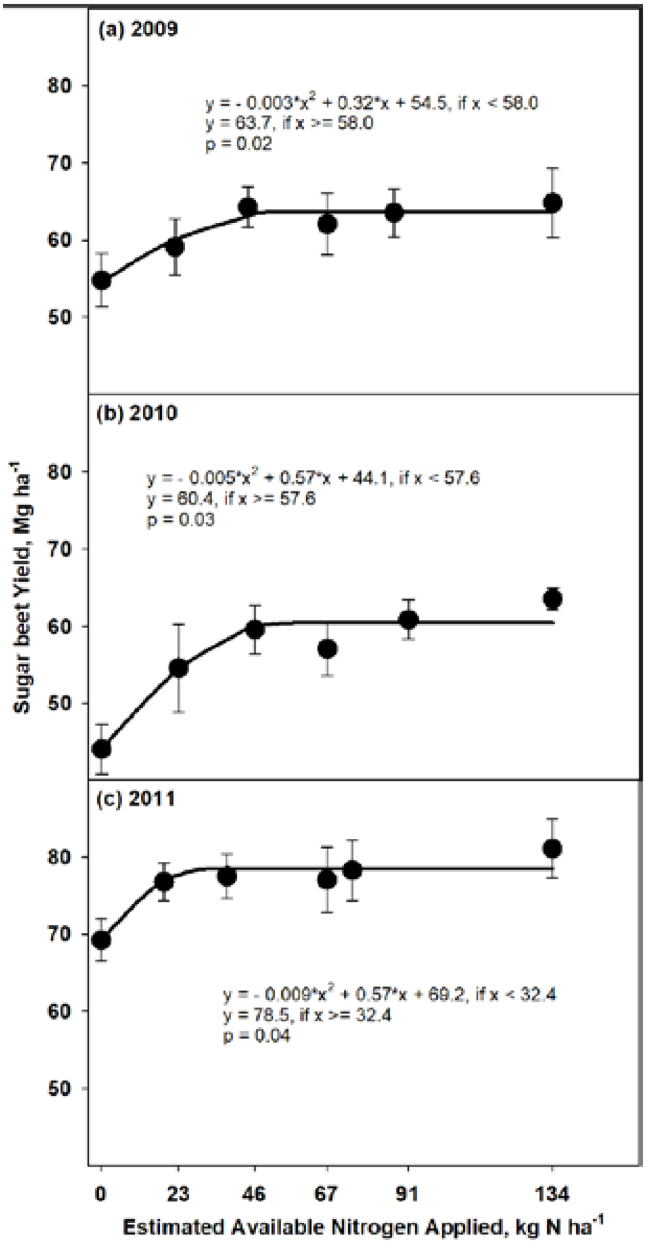

Fig. 4. Means (standard error) of sugar beet yield at different N rates in (a) 2009, (b) 2010, and (c) 2011 and their quadratic-plateau regression. Nitrogen from composted manure treatments were estimated assuming 100% N available from inorganic forms and 15% from organic N in the first year of manure application each year.

to explore improved beet varieties, strive for better crop stand, and consideration for leguminous crop in rotation.

CONCLUSION

This study shows that composted cattle manure produced yields comparable to urea N. The composted manure had no detrimental effects on sugar beet stand, beet yield, RSY, or impurities and thus can be a viable N source for production. Further research is needed to evaluate economic and environmental aspects of CManure management in beet production. The year when sugar beet followed dry beans and had optimal stand, beet and sugar yield were very high; this suggests that a proper N rate, stand, and previous crop are all important to maximize yield and quality.

ACKNOWLEDGMENT

We sincerely thank Western Sugar's Joint Research Committee forfunding this project.

REFERENCES

Adams, R.M., P.J. Farris, and A.D. Halvorson. 1983. Sugar beet N fertilization and economic optima: Recoverable sucrose vs. root yield. Agron. J. 75:173–176. doi:10.2134/agronj1983.00021962007500020004x

Amanullah, M.A., L.K. Almas, A. Jan, Z. Shah, H. Rahman, and S.K. Khalil. 2012. Agronomic efficiency and profitability of p-fertilizers applied at different planting densities of maize in northwest Pakistan. J. Plant Nutr. 35:331–341. doi:10.1080/01904167.2012.639916

Anderson, F.N., and G.A. Peterson. 1988. Effect of incrementing nitrogen application on sucrose yield of sugarbeet. Agron. J. 80:709–712. doi:10.2134/agronj1988.00021962008000050002x

Bullock, D.G., and D.S. Bullock. 1994. Quadratic and quadratic-plus-plateau models for predicting optimal nitrogen rate of corn: A comparison. Agron. J. 86:191–195. doi:10.2134/agronj1994.00021962008600010033x

Carter, J.N., and D.J. Traveller. 1981. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. Agron. J. 73:665–671. doi:10.2134/agronj1981.00021962007300040023x

Cassman, K.G., G.C. Gines, M.A. Dizon, M.I. Samson, and J.M. Alcantar. 1996. Nitrogen use efficiency in tropical lowland rice systems: Contribution from indigenous and applied nitrogen. Field Crops Res. 47:1–12. doi:10.1016/0378-4290(95)00101-8

Davis, J.G., and D.G. Westfall. 2010. Fertilizing sugar beets. Colorado State University Cooperative Extension fact sheet no. 0.542. Colorado State University, Fort Collins, CO.

Dobermann, A., and K.G. Cassman. 2005. Cereal area and nitrogen use efficiency are drivers of future nitrogen fertilizer consumption. Sci China. 48:745–758.

Eghball, B. 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci. Soc. Am. J. 64:2024–2030. doi:10.2136/sssaj2000.6462024x

Eghball, B., D. Ginting, and J.E. Gilley. 2004. Residual effects of manure and compost applications on corn production and soil properties. Agron. J. 96:442–447. doi:10.2134/agronj2004.4420

Gareau, S.E. 2004. Analysis of plant nutrient management strategies: Conventional and alternative approaches. Agric. Human Values 21:347–353. doi:10.1007/s10460-003-1221-7

Grant, C.A., D. McLaren, R.B. Irvine, and S.D. Duguid. 2016. Nitrogen source and placement effects on stand density, pasmo severity, seed yield, and quality of no-till flax. Can. J. Plant Sci. 96:34–47. doi:10.1139/cjps-2014-0425

Halvorson, A.D., and G.P. Hartman. 1975. Long-term nitrogen rates and sources influence sugarbeet yield and quality. Agron. J. 67:389–393. doi:10.2134/agronj1975.00021962006700030027x

Haddock, J.L. 1952. The nitrogen requirement of sugar beets. Am. Soc. Sugar Beet Tech. 17:159–165.

Hergert, G.W. 2010. Sugar beet fertilization. Sugar Tech 12:256–266. doi:10.1007/s12355-010-0037-1

Hergert, G.W. 2012. Sugarbeet nutrient management. NebGuide G1249. University of Nebraska Extension, Lincoln, NE.

Horneck, D.A., J.W. Ellsworth, B.G. Hopkins, D.M. Sullivan, and R.G. Stevens. 2007. Managing salt-affected soils for crop production. Pacific Northwest Ext. Publ. PNW 601-E. Extension Service, Oregon State Univ. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20788/pnw601-e.pdf (accessed 1 May 2018).

HPRCC. 2011. High Plains Regional Climate Center. https://hprcc.unl.edu/ (accessed June 2009).

Irshad, M., A.E. Eneji, Z.Hussain, and M. Ashraf. 2013. Chemical characterization of fresh and composted livestock manures. J. Soil Sci. Plant Nutr. 13:115–121.

Jacobs, A., H.J. Koch, and B. Marlander. 2018. Preceding crops influence agronomic efficiency in sugar beet cultivation. Agron. Sustain. Dev. 38:5. doi:10.1007/s13593-017-0469-z

Johnson, G.V. 1987. Sulfate: Sampling testing, and calibration. In: J.R. Brown, editor, Soil testing: Sampling correlation, calibration and interpretation. SSSA Spec. Publ. 21. SSSA, Madison, WI. p. 89–96.

Lentz, R.D., and G.A. Lehrsch. 2012. Nitrogen availability and uptake by sugarbeet in years following a manure application. Int J Agr. doi:10.1155/2012/120429

Lentz, R.D., G.A. Lehrsch, B. Brown, J. Johnson-Maynard, and A.B. Leytem. 2011. Dairy manure nitrogen availability in eroded and noneroded soil for sugar beet followed by small grains. Agron. J. 103:628–643. doi:10.2134/agronj2010.0409

Lindsay, W.L., and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42:421–428. doi:10.2136/sssaj1978.03615995004200030009x

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models. 2nd ed. SAS Inst., Cary, NC.

Lu, Y.C., K.B. Watkins, J.R. Teasdale, and A.A. Abdul-Baki. 2000. Cover crop in sustainable food production. J. Sustain. Agric. 18(4):27–37.

Moore, A., J. Stark, B. Brown, and B. Hopkins. 2009. Southern Idaho fertilizer guide: Sugar beets. CIS 1174. University of Idaho Extension, Moscow, ID.

Mulvaney, R.L. 1996. Nitrogen–inorganic forms. In: D.L. Sparks, editor, Methods of soil analysis, part 3: Chemical methods. Wisc. Soil Science Society of America, Madison, WI. p. 1123–1184.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon and organic matter. In: D.L. Sparks, editor, Methods of soil analysis, part 3: Chemical methods. Wisc. Soil Science Society of America, Madison, WI. p. 961–1010.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate (USDA Cir. No. 939). U.S. Gov. Print. Office, Washington, DC.

Rosen, C.J., and P.M. Bierman. 2018. Using manure and compost as nutrient sources for fruit and vegetable crops. University of Minnesota Extension. https://www.extension.umn.edu/garden/fruit-vegetable/using-manure-and-compost/ (accessed 21 July 2018).

SAS Institute. 2003. SAS System for Windows, release 9.1. SAS Inst., Cary, NC.

Sawyer, J., and A.P. Mallarino. 2016. Using manure nutrients for crop production. Iowa State University Extension and Outreach. https://store.extension.iastate.edu/product/Using-Manure-Nutrients-for-Crop-Production (accessed on 15 May 2018).

Sawyer, J., and A. Mallarino. 2017. Nitrogen considerations with dry conditions in 2017. https://crops.extension.iastate.edu/cropnews/2017/08/nitrogen-considerations-dry-conditions-2017 (accessed 15 Mar. 2018).

Shapiro, C.A., L. Johnson, A.M. Schmidt, and R. K. Koelsch. 2015. Determining crop available nutrients from manure. Nebguide G1335. University of Nebraska Extension, Lincoln, NE.

Spillman, W.J. 1923. Application of the law of diminishing returns to some fertilizer and feed data. J. Farm Econ. 5(1):36–52. doi:10.2307/1230266

Tarkalson, D. D., D. L. Bjorneberg, S. Camp, G. Dean, D. Elison, and P. Foot. 2016. Improving nitrogen management in Pacific Northwest sugarbeet production. J Sug Res. 53:14–36.

Tarkalson, D.D., D.L.Z. Bjorneberg, and A. Moore. 2012. Effects of tillage system and nitrogen supply on sugarbeet production. J. Surg. Res. 49:79–102.

Thomas, G.W. 1996. Soil pH and soil acidity. In: D.L. Sparks, editor, Methods of soil analysis, part 3: Chemical methods. Soil Sci Soc Am J, Madison, WI. p. 491–516.

USDA ERS. 2018. U.S. Fertilizer use and price. USDA Economic Research Service. http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx#.U9vJ8WPQrps (accessed 1 May 2018).

Wortmann, C., and C. Shapiro. 2012. Composting manure and other organic materials. Nebguide G1315. University of Nebraska Extension, Lincoln, NE.