Sugarbeet Yield and Quality When Substituting Compost or Manure for Conventional Nitrogen Fertilizer

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ABSTRACT

To grow sugarbeet (*Beta vulgaris* L.) profitably, producers must effectively manage added N, whether from inorganic or organic sources. Our objective was to determine if equivalent sugarbeet root and sucrose yields could be achieved when substituting dairy cattle (*Bos* spp.) manure, either composted or stockpiled, for conventional N (urea) fertilizer. First-year treatments at Site A (Parma, ID) included a control (no N), urea (202 kg N ha^{-1}), compost (218 and 435 kg estimated available N ha^{-1}), and manure (140 and 280 kg available N ha^{-1}). Site B (Kimberly, ID) treatments were a control, urea (82 kg N ha^{-1}), compost (81 and 183 kg available N ha^{-1}), and manure (173 and 340 kg available N ha^{-1}). Compost and manure were incorporated into two silt loams, a Greenleaf (fine-silty, mixed superactive mesic Xeric Calciargid) at Parma in fall 2002 and 2003 and a Portneuf (coarse-silty, mixed superactive, mesic Durinodic Xeric Haplocalcid) at Kimberly in fall 2002. Sugarbeet was planted the following spring. Sucrose yield averaged across years and organic N rates at Site A was 12.24 Mg ha^{-1} for urea, 11.88 Mg ha^{-1} for compost, and 11.20 Mg ha^{-1} for manure, all statistically equivalent. Doubling the organic N rates at Site A increased the yield of roots up to 26% and sucrose up to 21%. Applying organic amendments in place of urea affected neither root nor sucrose yields but, at one location, decreased sugarbeet quality, though without hindering sucrose recovery. Sugarbeet producers can use compost or manure to satisfy crop N needs without sacrificing sucrose yield.

Dairy manure, either before or after composting, is readily available in many areas of North America's Intermountain West. In Idaho alone, the approximately 565,000 dairy cattle likely produced 13.2 million Mg of manure in 2014 (Nennich et al., 2005; NASS, 2014). To be sustainable and protect surface water quality by limiting P in runoff, manure application rates should be limited by soil test P levels and, ideally, other parameters (Eghball and Power, 1999; Moore and Ippolito, 2009). In southern Idaho, for example, dairy owners are permitted to apply manure to their fields only at rates based on an interacting set of factors, including soil test P levels, soil P thresholds, water quality concerns, published fertilizer application guides, and crop P uptake (Idaho State Department of Agriculture, 2012). Many dairy producers compost raw manure on-site (Richard, 2005; Bernal et al., 2009). Composting reduces the weight, volume, weed seed viability, and odor of manure to ease handling, improve storage and transport, and increase marketability (Draycott and Christenson, 2003; Larney et al., 2006). On a per unit dry weight basis, composted manure generally contains more stable C compounds and more inorganic N, though less organic N, than raw manure (Eghball et al., 1997; Lehrsch and Kincaid, 2007; Lehrsch et al., 2014). Many dairy producers lack the land base to efficiently, sustainably, and beneficially use the manure and compost produced.

Many farmers know the benefits of applying compost, manure, or both, to their soils. Organic amendments, particularly in the short term, decrease bulk density, increase soil organic carbon, and, at times, increase water holding capacity (Haynes and Naidu, 1998; Edmeades, 2003; Loveland and Webb, 2003; Lentz and Lehrsch, 2014). Compost applications in the long term increase aggregate stability and improve crop agronomic performance by steadily supplying N that has been mineralized from nitrogenous organic compounds in compost (Diacono and Montemurro, 2010). Compost and manure also provide P and K (Chang et al., 1991; Robbins et al., 1997; Eghball, 2002; Eghball et al., 2004), which often increase yield (Mugwira, 1979; Robbins et al., 1997). In addition, the benefits of manure applications often last for several years following application (Lentz et al., 2011), especially on eroded soils.

Some sugarbeet producers hesitate to apply these organic materials to their soils for numerous reasons, including (i) the difficulty in accurately estimating or predicting the amount and timing of the N mineralized from manure and compost (Tarkalson et al., 2012), and (ii) the sensitivity of sugarbeet seedlings to compost- or manure-supplied salt loadings

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Abbreviations: CNS, carbon–nitrogen–sulfur.

(Eghball et al., 2004; Horneck et al., 2007; Moore et al., 2009), particularly if amendments are concentrated near the soil surface in semiarid areas. Other reasons include concerns with ammonia, such as gaseous N losses, odor generation, and seedling toxicity from NH_3 formed when ammonium ions react with hydroxyl anions in calcareous soils (Tisdale and Nelson, 1975) and with the cost and difficulty of transporting and applying amendments. In short, producers must manage organic N sources properly to reap their benefits while avoiding their pitfalls.

Effective N management is essential for the profitable production of sugarbeet (Campbell, 2002; Jaggard et al., 2009; Hergert, 2010). Sugarbeet yield and quality vary with the magnitude and timing of N applications (Carter and Traveller, 1981). Sugarbeet quality is reduced with excessive available N (James, 1971; Tarkalson et al., 2012), particularly late in the season from readily available inorganic N applied mid-season or later (Carter and Traveller, 1981). Such late-season available N, either applied as fertilizer or recently mineralized, may increase root yield but significantly decrease root sucrose concentrations and recoverable sucrose (Halvorson and Hartman, 1975), which reduce the economic returns to a producer. Root yield is inversely related to sucrose concentrations in sugarbeet, frustrating breeders and growers alike worldwide (Campbell, 2002). Also, NO_3–N remaining in the profile after harvest can be leached to degrade groundwater quality (James, 1971; Moore and Ippolito, 2009). Since grower profit margins are small (Campbell, 2002), a producer who applies unnecessary N as urea suffers substantial economic loss in view of the doubling of urea prices since 2004 (USDA-ERS, 2012). Thus, sugarbeet producers might benefit by replacing expensive inorganic with less expensive organic N fertilizer sources if best management practices were in place for their use (Lentz and Lehrsch, 2012).

The effects of compost, manure, or both, on root and sucrose yields of irrigated sugarbeet have been studied, though not widely and but little recently. A fall manure application of 22.4 Mg ha^{-1} repeated every second year for a total of 18 yr produced the greatest sucrose yield, 7.9 Mg ha^{-1} from a root yield of 47.5 Mg ha^{-1} (Halvorson and Hartman, 1975). From their long-term investigation, Halvorson and Hartman (1975) concluded that manure could be successfully used to supply N to produce high-quality sugarbeet. In 38 experiments where both manure and conventional fertilizer were applied to commercial fields in the United Kingdom, Draycott (1969) found that fall manure applications decreased the need for conventional N fertilizer by sugarbeet planted the following spring. With adequate P and K, an average application of 7 Mg dry manure ha^{-1} that provided 67 kg available N ha^{-1} [assuming first-year N mineralization of 400 g N (kg total N)$^{-1}$] increased sucrose yield equivalent to 33.6 kg N ha^{-1} applied as conventional fertilizer (Draycott, 1969). Sucrose yield was not proportional, however, to the total N content of the manures, presumably because of differences in leaching or mineralization.

In contrast, Jaggard et al. (2009) discounted the contribution of N mineralized from fall-applied manure to produce sugarbeet. They noted that a credit of only 10 kg N ha^{-1} should be allowed to account for N mineralized from nitrogenous organic compounds in the manure. Moore et al. (2009) recommended that compost and manure not be used as the sugarbeet's sole N source due to the amendments' typical pattern of providing mid- to late-season plant-available N from mineralization. Because much of the N mineralized from manure may become available in the latter part of the sugarbeet growing season, some recommend either applying no manure or reducing the inorganic N fertilizer application rate for manure-treated fields (Blumenthal, 2001).

Sugarbeet is an important crop in southern Idaho, generating revenue of nearly $396 million in 2011 (NASS, 2013). Sugarbeet producers and sugar company fieldmen understandably seek to maximize sucrose production from every harvested hectare. Thus, in numerous sugarbeet-producing areas of western North America, an opportunity exists for producers to take advantage of large quantities of an under-used and relatively inexpensive resource, namely organic amendments, to reduce their production costs without decreasing their economic returns. The objective of this study was to determine if compost, manure, or both could be applied to silt loam soils in southern Idaho in place of conventional inorganic N fertilizer to give equivalent root and sucrose yields with similar or better crop quality. At one location, we included treatments designed to test the hypothesis that soluble salts in shallowly incorporated amendments would hinder sugarbeet seedling emergence and subsequent growth and yield.

MATERIALS AND METHODS

Site A

Soils and Amendments. Site A was located at the University of Idaho Research and Extension Center in Parma, ID, with one site-year on each of two fields. Trials were established on separate fields in 2002–2003 and 2003–2004 on a Greenleaf silt loam (Soil Survey Staff, 2010), found on nearly 17,900 ha in southwestern Idaho and southeastern Oregon (NRCS, 2009). Field D-2 (2002–2003) was at 43°48.15′ N, 116°56.56′ W, whereas Field E-5 (2003–2004) was at 43°48.01′ N, 116°56.42′ W, both at an elevation of 705 m. Soil properties are given in Table 1. Initial soil test N samples were collected each fall before amendment application from Field D-2 on 16 Oct. 2002 and from Field E-5 on 24 Nov. 2003. There was less inorganic N (nitrate-N + ammonium-N) but more organic C in Field D-2 than in E-5 (Table 1). Neither field had received any organic N source within the past 10 yr.

Table 1. Properties of two Greenleaf silt loams at Site A and a Portneuf silt loam at Site B.

Soil properties (0- to 0.3-m depth, or as noted)	Site A Field D-2 2002–2003	 Field E-5 2003–2004	Site B 2002–2003
Particle size distribution, g kg^{-1}			
Sand (0.05–2.0 mm)	330	300	140
Silt (0.002–0.05 mm)	600	550	660
Clay (<0.002 mm)	70	150	200
Organic C, g kg^{-1}	6.4	5.5	8.4
pH (aqueous saturated paste)	7.8	7.6	7.1
Electrical conductivity, dS m^{-1}	0.56	0.54	0.8
$CaCO_3$ equivalent, g kg^{-1}	67	42	75
Inorganic N†			
0–0.3 m, mg kg^{-1}	8.1	15.2	10.2
0.3–0.6 m, mg kg^{-1}	7.0	8.8	22.7
0–0.6 m, kg ha^{-1}	60	96	130

† Residual inorganic N (NO_3–N + NH_4–N) in fall before amendment application. Site B data indicates the N present in the control at sugarbeet planting after preirrigation in spring and subsequent preplant rainfall (Lentz et al., 2011).

Table 2. Properties of the compost and manure applied to each site in fall of the year shown. Other than dry matter content, all measurements are on a dry-weight basis.

	Compost			Manure		
	Site A		Site B	Site A		Site B
Property	2002	2003	2002	2002	2003	2002
Total C, g kg^{-1}	282	ND†	163	162	ND	302
Total N, g kg^{-1}	20.5	15.7	14.2	16.0	22.1	18.6
C/N ratio	13.8	ND	11.5	10.1	ND	16.2
Dry matter content, kg kg^{-1}	0.65	0.65	0.74	0.65	0.40	0.60

† ND, not determined.

Manure and compost application rates each year were determined from their total N contents, assuming that the portion of the total N that would be mineralized in the 12 mo following application would be 200 g N (kg total N)$^{-1}$ from compost and 400 g N (kg total N)$^{-1}$ from manure (Eghball and Power, 1999; Richard, 2005). In fall 2002, dried samples of each amendment were ground to pass a 1-mm screen and their total C and N concentrations were determined by dry combustion (Tabatabai and Bremner, 1991) of a 400-mg sample in a vario MAX carbon–nitrogen–sulfur (CNS) analyzer (Elementar, Hanau, Germany). In fall 2003, the total N content of each amendment was determined via the micro-Kjeldahl method with NH_4–N measured colorimetrically (Watson et al., 2003). Dry matter content, being the dry mass as a proportion of the undried mass, was determined by weighing a fresh 1-kg sample before and after drying at 60°C (Hoskins et al., 2003). Compost and manure properties are given in Table 2.

Experimental Design and Treatments. The treatments at Site A (Table 3) were arranged in a randomized complete block design with four replications. Each 12-row plot was 6.7 by 15.2 m. Treatments consisted of a non-N-fertilized control (Cntrl–A), conventional N fertilizer (urea) applied at the University of Idaho's recommended N rate (Gallian et al., 1984) of 202 kg ha^{-1} (Fert–A), two rates of stockpiled solid manure (21.9 and 43.8 Mg ha^{-1}, dry wt.) from dairy cattle replacement heifers (Man1–A and Man2–A, respectively), and two rates (53.1 and 106.1 Mg ha^{-1}, dry wt.) of composted dairy cattle manure, hereafter referred to simply as compost (Com1–A and Com2–A, respectively). Manure excreted from a replacement heifer has about 25% of the total N as that from a lactating cow (ASAE Standards, 2005). The 202-kg N ha^{-1} rate was chosen (i) based on a sugarbeet yield goal of 67.2 Mg ha^{-1} and (ii) after accounting for the 15.1 mg kg^{-1} of inorganic N in the profile in fall 2002 at study initiation (Table 1). The N content of those fall soil samples was used to estimate the spring 2003 N content of the profile. The 202-kg N ha^{-1} rate included 34 kg N ha^{-1} to account for about half of the N immobilized into microbial tissue after we incorporated an estimated 9.0 Mg ha^{-1} of residue on 4 Sept. 2002 from the previous crop of wheat (*Triticum aestivum* L.). All told, the 202-kg N ha^{-1} rate was conservative and appropriate for our study designed to measure sugarbeet response to applied sources of both inorganic and organic N. Two additional treatments included the lower rate of manure (Man1s–A) and compost (Com1s–A) incorporated at half the depth of the other treatments. These shallow incorporation treatments were principally to gauge incorporation effects

Table 3. Treatment descriptions, application rates of bulk amendments (moisture-free basis) and total N, and estimates of the treatments' total N that became available via mineralization the first year.

Treatment code†	Amendment	Bulk application rate		Depth of incorporation	Total N application rate		Estimated available N‡	
		2003	2004		2003	2004	2003	2004
		Mg ha^{-1}		m	kg ha^{-1}			
Site A								
Cntrl–A	none	0	0	0	0	0	0	0
Fert–A	urea	0.44	0.44	0.05	202	202	202	202
Com1s–A	compost	53.1	64.2	0.05	1089	1008	218	202
Com1–A	compost	53.1	64.2	0.10	1089	1008	218	202
Com2–A	compost	106.1	128.4	0.10	2175	2016	435	403
Man1s–A	manure	21.9	22.8	0.05	350	504	140	202
Man1–A	manure	21.9	22.8	0.10	350	504	140	202
Man2–A	manure	43.8	45.6	0.10	701	1008	280	403
Site B								
Cntrl–B	none	0	–§	0	0	–	0	–
Fert–B	urea	0.18	–	0.07	82	–	82	–
Com1–B	compost	28.4	–	0.10	403	–	81	–
Com2–B	compost	64.3	–	0.10	913	–	183	–
Man1–B	manure	23.3	–	0.10	433	–	173	–
Man2–B	manure	45.7	–	0.10	850	–	340	–

† Cntrl, control; Fert, fertilizer (urea; Com, compost; Man, manure; 1s, Rate 1 shallowly incorporated to 0.05 m; 1, Rate 1 incorporated to 0.10 m; 2, Rate 2 incorporated to 0.10 m; –A, Site A; –B, Site B.

‡ Calculated assuming a first-year mineralization of 200 g N (kg total N)$^{-1}$ from compost and 400 g N (kg total N)$^{-1}$ from manure (Eghball and Power, 1999; Richard, 2005).

§ None.

on sugarbeet emergence. We postulated that the greater level of soluble salts near the seed in the shallow rather than deep treatments would desiccate germinating sugarbeet seeds, thus decreasing emergence.

We sought to apply compost and manure at rates that would supply available N amounts (i) similar to and (ii) twice that of the urea-fertilized treatment in the first year after application. Two samples of compost and two of manure were collected when the amendments were delivered to our field in fall 2002. One sample was analyzed by a local feed testing laboratory within 24 h to determine an initial estimate of its total N content. Each of those resulting total N values was used with assumed mineralization rates to calculate the bulk application rate for that amendment (Table 3). The second of the two samples of each amendment was later analyzed using a CNS analyzer to determine its total N and C contents (Table 2). The total N values from the CNS analysis, deemed to be more definitive in part because they were analyzed in triplicate, were used to calculate the estimated available N of each amendment, given in Table 3. The two measures of the total N in manure differed, however, such that our 2003 bulk application rates missed the available N targets for manure (discussed later). In southern Idaho, typical bulk amendment application rates (dry weight basis) range up to 28 Mg ha^{-1} for compost and 55 Mg ha^{-1} for manure.

Field Operations. The residue from the previous wheat crop was incorporated by disking, followed by rototilling on 1 Oct. 2002. Thereafter, the soil was leveled and firmed using a Groundhog roller harrow (The Parma Co., Parma, ID). All organic amendments were applied by hand to Site A on 6–8 Nov. 2002. After incorporating the organic N sources by rototilling to a depth of either 0.05 or 0.10 m, the soil was again firmed with the roller harrow and tilled with toolbar-mounted shovels to form beds every 0.56 m across the plots on 8 Nov. 2002. These beds remained undisturbed until spring. Based on the soil tests from the previous fall, on 1 Apr. 2003, the entire field was uniformly fertilized with P [as triple superphosphate (calcium dihydrogenphosphate) at a rate of 13.2 kg P ha^{-1}], K (as KCl at 33.5 kg K ha^{-1}), and B (as Solubor at 1.15 kg B ha^{-1}). This preplant fertilizer was applied as a topdressing and then lightly incorporated as the furrows were reestablished with shovels before planting. Three days later, bed tops were removed and sugarbeet was planted to a depth of ~25 mm into moist soil in the bed center. The in-row seed spacing was 79 mm at planting. After thinning by hand in late May 2003, the resulting in-row plant spacing was 160 mm, giving a final population of 111,850 plants ha^{-1}. The acceptable plant populations in the region range from 106,000 to 119,000 plants ha^{-1}, with greater populations preferred within the range. The conventional N treatment was applied as recommended (Anderson and Peterson, 1988; Sullivan et al., 1999) and per standard grower practice in the area, in spring as a split application, either pre-plant broadcast or sidedressed multiple times after sugarbeet stand establishment. To the conventionally fertilized plots only, a broadcast application of 56 kg N ha^{-1} (as urea) was made on 5 May 2003, followed by two sidedress applications of urea: one of 67 kg N ha^{-1} on 4 June and a second of 78 kg N ha^{-1} 13 d later. The sidedressed urea was placed 50 mm below the soil surface and 140 mm from the beet row into the bed shoulder next to the watered furrow. The evapotranspiration requirement of the sugarbeet was met by furrow irrigating the site 15 times in 2003 and 14 times in 2004, using furrows spaced 1.12 m apart and separated by two beds. The sugarbeet crop was managed using locally standard production practices as described by Strausbaugh et al. (2006). Just before harvest, the sugarbeet was mechanically topped, nominally at the lowest leaf scar. Thereafter, the sugarbeet was harvested on 27 Oct. 2003.

The trial was repeated on a different field for the 2003–2004 season, generally using the same or similar field operations and timing as in 2002–2003, with the following exceptions. Straw from the preceding winter wheat crop was incorporated by disking and, on 23 Oct. 2003, subsoiling to 0.5 m twice. The soil was then firmed by roller harrowing. Initial soil test N samples were collected on 24 November. Four days later, since those samples had not yet been analyzed, we applied then incorporated similar rates of amendments as the year before, assuming that the mineral N in the profile would be similar between the first and second year because both fields had similar cropping histories and management. Our assumption proved inaccurate and, as a consequence, the 2004 conventional N rate, which by design had to match the already applied amendments' mineral N, was greater than that recommended (Gallian et al., 1984) by 62 kg N ha^{-1}. Beds were formed on 2 Dec. 2003, 4 d after the amendments had been incorporated by rototilling. With no additional non-N fertilizer applied, sugarbeet was planted the following spring on 1 Apr. 2004. Of the 202 kg N ha^{-1} (as urea) applied in 2004 to the conventional treatment (Fert–A), half of the urea was sidedressed on 14 May and half on 2 June. The post-thinning plant population was 111,850 plants ha^{-1}. Although the sugarbeet harvest was timely in 2003, rainfall and excessively wet soil delayed the 2004 sugarbeet harvest until 22 November.

Sample Collection and Analyses. Eight soil samples (0–0.3 and 0.3–0.6 m) were collected from the field on 16 Oct. 2002, then composited by depth to determine the baseline contents of inorganic N, P, K, and other selected micronutrients in the soil at the site.

Before thinning, final stand counts were measured on 19 May 2003, 45 d after planting. Emerged seedlings were counted in 3.05-m portions of two adjacent rows. Stands were reported as emergence, defined as the percentage of planted seeds that emerged. Had 77 seedlings emerged, emergence would have been 100%.

Sugarbeet yield was measured from two locations in each plot at the end of the season. At each location, sugarbeet was harvested from 7.62-m-long portions of two adjacent rows, while ensuring that the rows to the side of those sampled also had adequate stands. One approximately 8.9-kg subsample of harvested sugarbeet from each plot was collected and submitted to the Tare Laboratory of the Amalgamated Sugar Company at Nyssa, OR, for measurements of soil and crown tare, along with the crop quality factors of percentage sucrose, brei conductivity, and brei nitrate. The quality factors were measured as described by Strausbaugh et al. (2009). Conductivity of the brei (finely ground root tissue from the shredding of washed and crowned roots; Campbell, 2002) is a measure of the electrolytes in brei that interfere with the crystallization of sucrose during refining (James, 1971; Campbell, 2002). Two measures of sugarbeet yield were determined: the field sugarbeet yield was measured at harvest and the clean sugarbeet yield was the field yield less both the soil tare and crown tare. The sucrose yield (or estimated recoverable sucrose), on which a grower is paid, was the estimated mass of sucrose extractable from the harvested sugarbeet per unit area. Samples from the 2003–2004 season were collected within a few days, in general, of the dates sampled in the 2002–2003 season.

Statistical Analysis. To test for stable variances, we first regressed the logs of each response variable's within-treatment SDs on the logs of its corresponding treatment means. A resulting nonsignificant linear regression would indicate stable error variances for that variable (Box et al., 1978; Lehrsch and Sojka, 2011). We tested our variances (with $n = 4$ for each treatment) using regression rather than a common normality test because the latter performs poorly for $n < 30$ (Razali and Wah, 2011). The linear regression was significant only for emergence ($P = 0.040$), corrected with an arcsine square root transformation, and for brei nitrate ($P = 0.021$), corrected with a square root transformation. Thereafter, for each variable, we performed a mixed-model ANOVA using the PROC Mixed procedure in SAS (SAS Institute, 2009) with a significance of $P = 0.05$, unless otherwise noted. In the statistical models, the random factor for the Site A analysis was block (field). A grouping option in the ANOVA for sucrose concentration accounted for its significant ($P = 0.005$) heterogeneous variances among treatments. For all significant fixed effects, we separated least-squares means using the Tukey–Kramer multiple comparison test at $P = 0.05$, with letter groupings assigned using software written by Saxton (1998). To gain additional insight into the findings of our study, using the ANOVA we constructed a number of pre-planned, relatively sensitive single-degree-of-freedom contrasts to test for differences among groups of related treatments, averaged across fields. Emergence and brei nitrate means were back-transformed into the original units for presentation.

Site B

Soils and Amendments. Site B was located near the USDA–Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID. The field (42°31.12′ N, 114°22.48′ W, elevation 1196 m a.s.l.) was located on a Portneuf silt loam, found on 117,400 ha in southern Idaho. Soil properties are given in Table 1. The residual inorganic N in the soil, first measured the preceding fall, was decreased by a spring preirrigation and subsequent preplant rainfall. Consequently, the inorganic N in the Portneuf soil measured in the control at sugarbeet planting has been reported in Table 1. The Portneuf soil at Site B contained 1.67-fold more residual inorganic N, on average, than the two Greenleaf soils at Site A. No organic N source had been applied to Site B since 1994.

The experimental methods used at Site B have been described in detail by Lentz et al. (2011). In brief, the amendment rates studied at Site B were established by also assuming that the N mineralized in the first year would be 200 g N (kg total N)$^{-1}$ from compost and 400 g N (kg total N)$^{-1}$ from manure. Of the eight treatments at Site A, we studied six at Site B for 1 yr on noneroded soil (Table 3). The amendment properties at Site B are shown in Table 2 and the application rates of the bulk amendments and estimated available N added are shown in Table 3. Samples were collected with tarps, then weighed when the manure was applied on 10 Oct. 2002 and the compost on 22 Oct. 2002. Subsamples of each were freeze-dried and later analyzed to determine their total C and N contents (Nelson and Sommers, 1996) by combusting a 25-mg sample in a Thermo-Finnigan FlashEA1112 CNS analyzer (CE Elantech, Lakewood, NJ).

Experimental Design and Treatments. Plots were arranged, as at Site A, in a randomized complete block design with four replications. Treatments were a control (which received no N fertilizer; Cntrl–B), a fertilized treatment that received urea at the recommended rate (Fert–B), two compost treatments (Com1–B and Com2–B), and two manure treatments (Man1–B and Man2–B). The compost treatments received sufficient compost to supply the sugarbeet with available N equivalent to about one times and two times the N supplied via the urea that was applied to the fertilized treatment. Manure at a dry rate of 23.3 Mg ha^{-1} was provided by the Man1–B treatment (i. e., manure at Rate 1 applied to Site B, Table 3), a common application rate in the region. It was doubled to provide the Man2–B rate. The same total N was supplied, in general, by the Com1–B and Man1–B treatments and by the Com2–B and Man2–B treatments (Table 3). A sugarbeet yield goal of 76 Mg ha^{-1} resulted in an urea N application rate of 82 kg N ha^{-1} (Table 3), after accounting for the inorganic N content in the 0.6-m profile. The N in the profile was measured in soil samples collected in fall 2002 before the amendments were applied. Each 16-row plot was 9 m wide by 21 m long.

Field Operations. The entire site was sown with spring wheat in mid-August 2002 to provide cover and to lessen weed growth. Seven weeks later, without being harvested, the ~0.15-m-tall wheat was killed with glyphosate [*N*-(phosphonomethyl)glycine, in the form of its isopropylamine salt] at an acid equivalent rate of 1.04 kg a.i. ha^{-1}, then incorporated as a green manure by disking and roller harrowing. Studying the same site, Lentz et al. (2011) measured in situ net N mineralization from green manured but otherwise unamended soil from incorporation to sugarbeet planting in May 2003. Their measurement was the net effect of N mineralization, denitrification, and immobilization exclusive of leaching and plant uptake. Based on the 10 mg N kg^{-1} soil in the uppermost 0.30 m that they measured, the wheat green manure contributed about 40 kg N ha^{-1} to the N requirement of the 2003 sugarbeet. In fall 2002, after manure was applied with a commercial spreader truck, compost was applied in 4 to 7 passes of a 9-Mg truck equipped with a calibrated rotary spreader. Thereafter, both amendments were incorporated by disking to the 0.1-m depth on 24 Oct. 2002. Five days later, urea was applied by hand to the appropriate plots and the entire field was sprayed with the selective pre-emergence herbicide cycloate (*S*-ethyl cyclohexyl(ethyl)thiocarbamate) at a rate of 4.49 kg a.i. ha^{-1}. All materials were then immediately incorporated with a roller harrow. The field was subsequently tilled to form beds every 0.56 m across the plots to prepare for sugarbeet planting the following spring. After preirrigating in late April, sugarbeet was planted at a nominal 19-mm depth into each bed on 21 May 2003. After thinning by hand on 7 to 8 July, the resulting in-row plant spacing was 150 mm, resulting in a final population of 119,300 plants ha^{-1}. The site was irrigated with sprinklers every 3 to 7 d throughout the season to satisfy the evapotranspiration needs of the sugarbeet. Sugarbeet yield from each plot was determined on 14 Oct. 2003. Unlike Site A, the trial at Site B was not repeated for a second year.

Sample Collection and Analyses. Final stands were measured on 17 June 2003, 27 d after planting. Fully emerged seedlings were counted in 7.6-m-long portions of two rows. If 200 seedlings had emerged from the monitored portions of the rows, emergence would have been 100% at Site B.

Table 4. Treatment, field, and contrast effects on sugarbeet response variables for Site A.

	ANOVA $P > F$						
		Root yield					
Source of variation	Emergence	Field	Clean	Sucrose concentration	Brei nitrate	Brei conductivity	Sucrose yield
Treatment†	0.49	***	***	*	***	***	***
Field	***	**	**	***	***	0.47	*
Treatment × field	0.45	0.51	0.58	0.59	0.28	0.18	0.79
Contrasts‡							
Shallow vs. deep	0.64	0.68	0.72	0.93	0.07	*	0.97
Fert–A vs. Com1&2	0.75	0.66	0.83	0.78	**	***	0.54
Fert–A vs. Man1&2	0.63	0.12	0.21	0.31	**	***	0.08
Com_All vs. Man_All	0.93	**	**	0.79	0.75	0.09	**
Com1_both vs. Com2–A	0.37	**	**	0.06	0.23	0.51	*
Man1_both vs. Man2–A	0.25	***	***	0.06	*	0.15	***

* Significant at the $P = 0.05$ level.

** Significant at the $P = 0.01$ level.

*** Significant at the $P = 0.001$ level.

† Coded as: Cntrl, control; Fert, fertilizer (urea); Com, compost; Man, manure; 1s, Rate 1 shallowly incorporated to 0.05 m; 1, Rate 1 incorporated to 0.10 m; 2, Rate 2 incorporated to 0.10 m; –A, Site A.

‡ shallow = Com1s–A + Man1s–A; deep = Com1–A + Man1–A; Com1&2 = Com1–A + Com2–A; Man1&2 = Man1–A + Man2–A; Com_All = Com1s–A + Com1–A + Com2–A; Man_All = Man1s–A + Man1–A + Man2–A; Com1_both = Com1s–A + Com1–A; Man1_both = Man1s–A + Man1–A.

Sugarbeet yield was measured at Site B on 14 Oct. 2003 using the procedure described earlier for Site A, in general. The lone exception was that two subsamples, one from each of the yield samples collected from the two locations in each plot, were delivered to the Tare Laboratory of the Amalgamated Sugar Company, Paul, ID, for quality analysis. Yield and quality factors for each plot at Site B were calculated as the arithmetic average of the values measured on the two subsamples.

Statistical Analysis. Data collected at Site B were analyzed using the same procedures, in general, as those described earlier for the Site A data. Block was the only random factor in the statistical model for Site B, however. The LSD (Little and Hills, 1978) was used to indicate experimental variability.

RESULTS AND DISCUSSION

Site A

Our attempts to apply compost and manure at rates which, in the first year after application, provided (i) a similar, and (ii) twice the amount of available N as that supplied by the urea-fertilized treatment were not successful. When the compost and manure were delivered in fall 2002, two samples of each were collected and analyzed: the first by a testing laboratory that fall and the second using a CNS analyzer (Elementar, Hanau, Germany) some months later. The CNS measurement of the total N in the manure was, unfortunately, less than the testing laboratory's initial estimate, resulting in the manure treatments' available N being less than our 2003 targets (Table 3). The available N values for compost treatments, in contrast, were close to our targets. Consequently, the available N rates for the three compost treatments at Site A exceeded those of their companion manure treatments by approximately 1.55-fold in 2003. The available N rates for the treatments at Site A in 2004 were as planned (Table 3).

With the exception of emergence, treatments as a main effect influenced every variable measured at Site A (Table 4). All variables except brei conductivity differed between fields. The preplanned, single-degree-of-freedom contrasts best summarized the findings of our experiment because of the structure in our treatments. For sucrose concentration and yield and brei nitrate and conductivity, data for the deeply incorporated rates of each amendment were pooled across rates since rates within amendments were similar. For root yield, the effect of the urea-fertilized treatment was similar to each rate of compost and to each rate of manure, except the shallowly incorporated manure rate. Although rates within amendments differed, the facts that (i) each deeply incorporated rate was similar to the urea treatment and (ii) the contrasts were planned before analyzing the data were deemed sufficient justification to consider the deeply incorporated low and high rates of each amendment as a class when discussing our findings in summary form. Considering the low and high rates of each amendment as a class also enabled us to test a third rate, in essence an average of the low and high rates of each amendment, by pooling variances. Among the contrasts, brei nitrate and conductivity differed between the fertilized treatment and (i) the two deeper incorporated compost treatments as a class (Com1&2 = Com1–A + Com2–A), and (ii) the two deeper incorporated manure treatments as a class (Man1&2 = Man1–A + Man2–A). Yields of roots and sucrose responded differently to compost than to manure, when considering all rates of each as a class. Furthermore, increasing the organic amendment rate affected the yields of roots and sucrose when the two low rates of each amendment (as a class) were compared with their respective high rates.

Treatment Effects

Depth of Incorporation. Incorporating organics at shallow depths appeared to exacerbate the effect of low estimated available N (hereafter termed available N) on sugarbeet yield. In the case where the Com1s–A and Com1–A treatments resulted in similar amounts of available N as Fert–A (Table 3), all three produced similar sugarbeet root and sucrose yields (Table 5). Conversely, when the available N in the Man1s–A and Man1–A treatments was less than that of Fert–A (Table 3), root and sucrose yields were lower than those in Fert–A only for the Man1s–A treatment (Table 5). This suggests that a portion of potentially available N in the Man1s–A treatment was not used by the sugarbeet. We speculate that near-surface water relations were the likely cause. On the one hand, microbial

Table 5. Treatment, field, and contrast effects on sugarbeet response variables for Site A. Field means are averaged across treatments, whereas treatment and contrast means are averaged across fields.

Source of variation	Emergence	Root yield		Sucrose concentration	Brei nitrate	Brei conductivity	Sucrose yield
		Field	Clean				
	%	Mg ha^{-1}		%	mg L^{-1}	dS m^{-1}	Mg ha^{-1}
Treatment†							
Cntrl–A	76.6	54.4 e‡	50.5 e	18.4 a	47 c	0.60 b	8.08 d
Fert–A	80.6	87.1 abc	78.6 abc	18.0 ab	65 bc	0.60 b	12.24 ab
Com1s–A	85.9	84.0 abc	76.7 abc	17.9 ab	134 ab	0.76 a	11.55 abc
Com1–A	82.7	77.1 bcd	71.0 bcd	18.3 ab	96 abc	0.71 a	11.06 abc
Com2–A	81.0	93.4 a	84.6 a	17.7 ab	143 a	0.75 a	12.71 a
Man1s–A	84.2	68.5 de	62.9 de	18.3 ab	117 ab	0.72 a	9.75 cd
Man1–A	84.7	72.7 cd	66.4 cd	17.9 ab	89 abc	0.68 ab	10.28 bc
Man2–A	80.1	89.0 ab	81.7 ab	17.5 b	154 a	0.74 a	12.11 ab
Field							
D-2	74.8 b	68.1 b	62.0 b	18.7 a	66 b	0.70	9.98 b
E-5	88.3 a	88.5 a	81.1 a	17.3 b	148 a	0.69	11.97 a
Contrast§							
Shallow vs.	85.1	76.2	69.8	18.1	126	0.74 a	10.65
Deep	83.7	74.9	68.7	18.1	93	0.69 b	10.67
Fert–A vs.	80.6	87.1	78.6	18.0	65 b	0.60 b	12.24
Com1&2	81.8	85.3	77.8	18.0	120 a	0.73 a	11.88
Fert–A vs.	80.6	87.1	78.6	18.0	65 b	0.60 b	12.24
Man1&2	82.4	80.8	74.0	17.7	122 a	0.71 a	11.20
Com_All vs.	83.2	84.8 a	77.4 a	17.9	124	0.74	11.77 a
Man_All	83.0	76.7 b	70.3 b	17.9	120	0.71	10.72 b
Com1_both vs.	84.3	80.5 b	73.8 b	18.1	115	0.73	11.31 b
Com2–A	81.0	93.4 a	84.6 a	17.7	143	0.75	12.71 a
Man1_both vs.	84.4	70.6 b	64.6 b	18.1	103 b	0.70	10.02 b
Man2–A	80.1	89.0 a	81.7 a	17.5	154 a	0.74	12.11 a

† Cntrl, control; Fert, fertilizer (urea); Com, compost; Man, manure; 1s, Rate 1 shallowly incorporated to 0.05 m; 1, Rate 1 incorporated to 0.10 m; 2, Rate 2 incorporated to 0.10 m; –A, Site A.

‡ For a given response variable, treatment, field, or contrast means followed by a common letter were not significantly different according to the Tukey test at $P = 0.05$. Letters are not shown if the means did not differ.

§ Shallow = Com1s–A + Man1s–A; Deep = Com1–A + Man1–A; Fert = Fert–A; Com1&2 = Com1–A + Com2–A; Man1&2 = Man1–A + Man2–A; Com_All = Com1s–A + Com1–A + Com2–A; Man_All = Man1s–A + Man1–A + Man2–A; Com1_both = Com1s–A + Com1–A; Man1_both = Man1s–A + Man1–A.

activity may have been limited in the dry soil at shallow depths (Ippolito et al., 2007), thus reducing N mineralization rates. Had mineralized N been present, irrigation water could have transported it to the root zone, thus increasing uptake. On the other hand, mineralized N from the shallowly incorporated manure may have been positionally unavailable in the dry soil near the surface, particularly in every second never-irrigated furrow, as was discussed by Lehrsch et al. (2000 and 2001). In either case, mineralized N as nitrate would not have been transported into the subsurface root zone where it would have been taken up by the sugarbeet, which is very efficient at acquiring N (Tarkalson et al., 2012). The soil was observed to be darker in color where organically amended than otherwise. Before canopy closure, darker soil surfaces would have absorbed more solar radiation (not measured), resulting in more near-surface soil water being lost to evaporation.

Fertilizer and Organic Amendment Differences. Yields of roots and sucrose were similar between Cntrl–A and Man1s–A (Table 5), probably because of the low available N in the latter, as discussed earlier. In all other cases, sugarbeet root yield and sucrose yield were greater than those in Cntrl–A for the remaining fertilizer treatments, whether organic or inorganic or shallowly or deeply incorporated. On the other hand, the sucrose concentration of the Cntrl–A treatment was greatest in magnitude, though not statistically greatest, among all fertilized treatments at Site A (Table 5). Notably, this greatest sucrose concentration occurred where root yield was least (Table 5). Sugarbeet sucrose concentrations are known to be inversely proportional to yield (Campbell, 2002). Sucrose concentrations tended to decrease as the application rate of each organic amendment increased (Table 5), as was noted by Halvorson and Hartman (1975).

Organic amendments increased mean sugarbeet brei nitrate concentration by nearly twofold and mean brei conductivity by 1.2-fold, compared with conventional fertilizer [see the contrasts in Table 5 between Fert–A and either the Com1&2 class (being Com1–A + Com2–A) or the Man1&2 class]. These increases were not always significant when individual treatments were compared, as there was much variation among replicates. Since rates within amendments were similar (Table 5), data have been pooled for these contrasts. The amendments' soluble salts (not measured) were apparently taken up by the growing sugarbeet in sufficient quantities to increase the electrolytes in the brei. The finding that sugarbeet quality decreased (i.e., conductivity increased) with compost or manure confirms the findings of Lentz and Lehrsch (2012) and is important because increased brei conductivity potentially can decrease recoverable sucrose yield and, in turn, economic returns to a producer. Though sugarbeet quality decreased, it was still equal to or better than the 2003–2004 average in the immediate region (D. Searle, The Amalgamated Sugar Co., Nampa, ID, personal communication, 2013). Though brei nitrates were also increased by the Com1&2 and Man1&2 classes relative to the Fert–A treatment (Table 5), their brei nitrate concentrations were still less than half the upper limit (250 mg L^{-1}) established by the Amalgamated Sugar Company to maintain acceptable sucrose concentrations in the harvested sugarbeet (Kerbs, 2005). The increased brei nitrates reveal that, late in the growing season, more available N was taken up from the organically amended than from the urea-fertilized plots. Though the organic amendment applications decreased sugarbeet quality, they did not always significantly decrease recoverable sucrose yield. In fact, the sugarbeet grown at Site A in our experiment had an overall 2-y average sucrose concentration of 18% (Table 5), 1.14-fold greater than the 2003–2004 average in the district (D. Searle, The Amalgamated Sugar Co., Nampa, ID, personal communication, 2013).

Compost and Manure Differences. Compared to a class consisting of the three manure treatments, Man_All (Man1s–A + Man1–A + Man2–A), the three compost treatments as a class, Com_All (Com1s–A + Com1–A + Com 2–A), increased sugarbeet yield (Table 5). These increases were due, at least in part, to the greater available N from the compost than manure, at least for the 2003 sugarbeet growing season (Table 3). The greater N available with compost, however, did not decrease that class's sucrose concentration, as often occurs (Campbell, 2002) and, as a consequence, resulted in nearly 1.10-fold more recoverable sucrose than with manure: 11.77 Mg ha^{-1} for compost vs. 10.72 Mg ha^{-1} for manure (Table 5).

Contrasts were also used to test for differences between rates of compost and manure. Compared with the Com1s–A and Com1–A treatments as a class (Com1_both), the Com2–A treatment increased root and sucrose yields (Table 5). These increases probably resulted from the greater available N in the Com2–A treatment than that in the Com1s–A and Com1–A treatments (Table 3). This doubling of the compost application rate increased sugarbeet root yield by approximately 1.15-fold and sucrose yield by 1.12-fold (Table 5). Manure rate effects were similar, in general, to compost rate effects on sugarbeet responses. Compared with the Man1s–A and Man1–A treatments as a class (Man1_both), the Man2–A treatment also increased yields of sugarbeet by 1.26-fold and sucrose by 1.21-fold (Table 5). The N uptake by sugarbeet tops, roots, and whole plants was similar between the inorganic N and deeper incorporated organic N treatments (data to be reported in a manuscript in preparation). This finding of similar uptake shows that where organic amendments had been incorporated to a depth of 0.10 m, sufficient organic N had been mineralized to meet the N requirements of the sugarbeet while sustaining root and sucrose yields (Table 5). This is a significant benefit of great interest to producers who use compost, manure, or both to satisfy the N needs of their crops.

All in all, doubling the N available from compost or from manure decisively altered sugarbeet responses for 2 yr at Site A, increasing root yield by one-fifth and sucrose yield by one-sixth, on average. Not all was gain, however. Increasing the manure rate by a factor of two (contrast Man1_both with Man2–A) increased brei nitrate by nearly 50%, indicative of greater late-season available N in the more heavily manured plots. Though increases in brei nitrate decrease sugarbeet quality, the calculation by the sugar company of estimated sucrose yield was based solely on brei conductivity rather than a combination of brei nitrate and conductivity.

Field Effects

Some of the sugarbeet response variables differed from one field to the other (Table 5). Sugarbeet seedling emergence was 88.3% in Field E-5, 1.18-fold greater than that in Field D-2. Temperature differences from field to field may have been responsible, at least in part. The mean monthly air temperature in April, the first month after seeding, was 2.4°C greater for Field E-5 (2004) than Field D-2 (2003). Warmer air temperatures may have increased soil temperatures at the 25-mm seeding depth (not measured) that probably hastened both germination and seedling emergence. In addition to emergence, root yield was ~1.30-fold greater in Field E-5 than in D-2 (Table 5). Late in the 2003 growing season, we noted that sugarbeet root crowns had protruded farther above the soil surface in Field D-2 than was typically seen in nearby sugarbeet production fields, suggesting that compaction in the upper profile influenced root system development and thereby N uptake and yield. This compaction was quantified by hand in fall 2003 before sugarbeet harvest by measuring soil strength (Lowery and Morrison, 2002) using the cone index (CI), the ratio of the force required to push a metal cone through the soil to the basal area of the cone (ASAE Standards, 1999). Two root-restrictive layers were detected in Field D-2, one ranging from depths of 0.10 to 0.14 m (centered at 0.11 m) and a second present at 0.24 m and below (Fig. 1). These

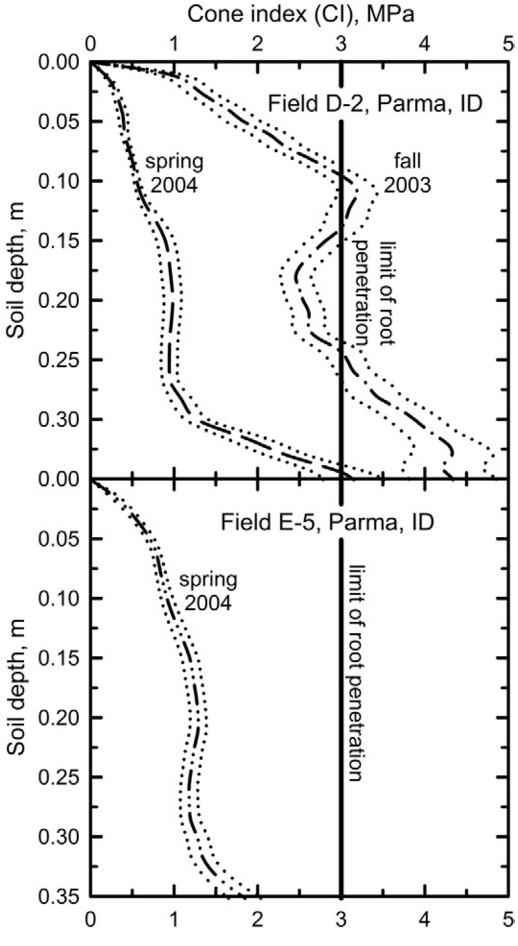

Fig. 1. Soil strength, as cone index (CI), with depth measured in fall 2003 before fall subsoiling and in spring 2004 on Field D-2 at Parma, ID. Also shown is the soil strength profile measured on Field E-5 in spring 2004 (fall 2004 data not available). Data have been averaged across treatments. Means (*n* = 32) are shown with 95% confidence intervals.

restrictive layers physically limited rooting, thus restricting both N and water uptake from deeper portions of the profile, as well as storage root penetration, development, and enlargement (Smith, 2001). Having discovered this compaction, following sugarbeet harvest we subsoiled Field D-2 (as well as Field E-5, which was to be used for the second year) to a depth of 0.3 m before planting winter wheat. Cone index measurements collected the following spring revealed the effectiveness of our subsurface tillage in alleviating compaction in Field D-2 and eliminating compaction, had any been present, in Field E-5 (Fig. 1). Compaction in Field D-2 in 2003 affected rooting and possibly microbially mediated mineralization, so that the sugarbeet could not take full advantage of the added then mineralized organic N, residual inorganic N, or both. Compaction at a particular soil depth could have decreased mineralization deeper in the profile by (i) impeding downward water flow, thus decreasing soil water contents, and (ii) preventing or hindering rooting, thus decreasing the root-exudate carbon supplied to microbes (Subba Rao, 1999), thereby decreasing microbial activity. Lentz et al. (2011) documented significant net N mineralization below 0.24 m in calcareous, organically amended silt loam profiles in the region. In the current study, sugarbeet whole-plant N uptake was 179.6 kg ha^{-1} from subsoiled Field E-5, 1.21-fold greater (significant at $P < 0.05$) than that from compacted Field D-2 (data to be reported later elsewhere). This undetected compaction illustrates how soil factors other than amendment application rates can influence the availability of nutrients from field to field and year to year. The subsurface compaction in Field D-2 may also have impeded downward water flow, leading to transient saturated areas, microsite denitrification, and N being lost as nitrous oxide. All told, compaction and consequent limited rooting, that reduced N uptake, and possibly increased N loss during the sugarbeet growing season were likely responsible for the decreased yields of field roots, clean roots, and sucrose from Field D-2 relative to E-5 (Table 5). Brei nitrate more than doubled from Field D-2 to E-5 (Table 5), reflecting late season N uptake by the sugarbeet root systems, which were probably growing deeper into the subsoiled profile of Field E-5.

Site B

Treatments had no effect ($P > 0.15$) on sugarbeet emergence, yields, or quality factors at Site B. The lack of responses at Site B may have been because there was 1.67-fold more residual inorganic N in the Site B profile than in the Site A profiles (Table 1), thereby making the sugarbeet less dependent on and less responsive to added N, whatever its source, at Site B than A. Sugarbeet grown in soil profiles with a high level of residual inorganic N seldom respond to added N (Tarkalson et al., 2012).

Contrasts revealed that compost and manure, when each was averaged across rates, produced sugarbeet yield and quality similar to those of conventional urea fertilizer at Site B (Table 6), as was found for yield at Site A (Table 5). The results at Site B also reveal that no ill effects on yield or crop quality occurred even when manure at rates exceeding those of Site A was applied to the soil profile of Site B, which contained more residual inorganic N than Site A. At Site B when compost supplied about half the available N as manure at each rate (Table 3), yield was similar whether compost or manure was applied (Table 6). These findings suggest that N was used more efficiently from compost than manure for increasing yield, at least in the near term. Alternatively, (i) early-season N immobilization may have been greater in manure- than compost-treated soil or (ii) relatively more residual soil N may have been taken up by the sugarbeet growing in the compost than manure plots, resulting in similar yield among amendments. Also at Site B (Table 6), impurities did not increase and sucrose yield did not decrease when three of four organic amendment treatments supplied more available N than the 82 kg N ha^{-1} supplied by conventional inorganic

Table 6. Treatment and contrast effects on sugarbeet response variables for Site B.

Source of variation	Emergence	Root yield		Sucrose concentration	Brei nitrate	Brei conductivity	Sucrose yield
		Field	Clean				
	%	Mg ha^{-1}		%	mg L^{-1}	dS m^{-1}	Mg ha^{-1}
Treatment†							
Cntrl–B	36.4	56.3	49.5	15.6	715	1.07	6.18
Fert–B	32.6	59.0	52.3	16.2	527	1.02	6.86
Com1–B	31.1	54.6	49.2	15.9	554	1.11	6.25
Com2–B	30.3	56.3	50.0	16.1	654	1.03	6.55
Man1–B	32.6	62.1	55.6	15.9	540	1.04	7.21
Man2–B	31.6	50.8	45.8	15.4	652	1.13	5.59
LSD (0.05)‡	9.7	11.1	10.0	0.8	168	0.11	1.49
Contrast§							
Fert–B vs.	32.6	59.0	52.3	16.2	527	1.02	6.86
Com1&2	30.7	55.4	49.6	16.0	604	1.07	6.40
Fert–B vs.	32.6	59.0	52.3	16.2	527	1.02	6.86
Man1&2	32.1	56.5	50.7	15.6	596	1.08	6.40
Com1&2 vs.	30.7	55.4	49.6	16.0	604	1.07	6.40
Man1&2	32.1	56.5	50.7	15.6	596	1.08	6.40

† Cntrl, control; Fert, fertilizer (urea); Com, compost; Man, manure; 1, Rate 1 incorporated to 0.10 m; 2, Rate 2 incorporated to 0.10 m; –B, Site B

‡ The LSD at $P = 0.05$, correctly used only to compare adjacent means when ranked by magnitude (Little and Hills, 1978), is shown solely to quantify variability since treatment effects were not significant ($P > 0.15$).

§ Com1&2 = Com1–B + Com2–B; Man1&2 = Man1–B + Man2–B.

N fertilizer (Table 3). This finding reveals that, contrary to popular belief (Carter and Traveller, 1981), sucrose yield does not always decrease when organic amendments provide more available N than is recommended. More research is clearly needed on sugarbeet N uptake, recovery, and use efficiency where organic N sources are applied.

Overall, brei nitrate and conductivity were greater, whereas sucrose yield was lower at Site B (Table 6) than at Site A (Table 5). The initial 1.67-fold greater soil inorganic N contents at Site B than A were probably responsible, at least in part, for the increased impurities that decreased sucrose recovery at Site B relative to Site A (James, 1971; Halvorson and Hartman, 1975). This finding underscores the need for producers to account for or, better yet, minimize soil residual N before planting sugarbeet.

CONCLUSIONS

1. Applying dairy manure or composted dairy manure in lieu of urea produced equivalent sugarbeet root and sucrose yields.
2. At one of two locations, brei nitrates and conductivity increased, decreasing crop quality, when either of the organic N sources was substituted for urea. Despite the decrease, organically treated sugarbeet crop quality equaled or exceeded that of nearby growers, most of whom applied inorganic N.
3. Equivalent root and sucrose yields reveal that sufficient organic N had been mineralized from compost or manure to meet sugarbeet N requirements. Thus sugarbeet producers can use either compost or manure to satisfy their crops' N needs without sacrificing sucrose yield or economic return.
4. Comparing organic N sources only, 2-yr average root and sucrose yields were greater for compost than for manure at one site.
5. Incorporating organic amendments at equal rates to a depth of 0.05 rather than 0.10 m affected neither seedling emergence nor the yields of roots or sucrose but increased brei conductivity, when one considered compost and manure collectively as a class.
6. Doubling the organic application rates increased sugarbeet root yield by 15 to 26% and sucrose yield by 12 to 21% at Site A, on average.
7. At one of two sites, sucrose yield did not decrease nor did root impurities increase where we applied compost or manure at rates that supplied available N in excess of that recommended.
8. The variability in sugarbeet brei nitrate concentration and conductivity among our replications suggests that factors other than the type and rate of organic applications influenced these sugarbeet quality parameters. More research is needed to determine how organic amendments influence sugarbeet quality.
9. Producers who use compost or manure to fertilize sugarbeet should: (i) account for residual soil inorganic N at planting and know the N content of the organic source, then tailor their application rates accordingly and (ii) ensure that the availability of N mineralized from the organic source will not be affected by other controllable factors, such as soil compaction or low soil water content.

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