Nitrogen Mineralization in Chernozemic Soils Amended with Manure from Cattle Fed Dried Distillers Grains with Solubles

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Inclusion of dried distillers grain with solubles (DDGS) in cattle diets, coupled with the increasing use of construction and demolition waste (CDW), particularly the wood and drywall fractions as bedding in beef cattle feedlots, may affect nitrogen (N) dynamics when the resulting manure is applied to soil. This laboratory incubation study was conducted to evaluate the mineralization of N in contrasting Chernozemic soils amended with regular manure (RM) from cattle fed a grain-based diet versus manure from cattle fed a diet containing DDGS (DGM). The effect of adding CDW to DGM (DGM_CDW) was also assessed. The soils (a Black Chernozem and a Brown Chernozem) were amended with manure (40 g kg soil⁻¹, dry wt.) and incubated at 15 and 25°C. Nitrogen mineralization in the manure-amended Brown Chernozem exhibited negative net mineralization. In the Black Chernozem, the first-order mineralization rate constant varied among manure treatments and decreased in the order DGM_CDW > DGM > RM. The rate constants were not significantly affected by temperature, but the temperature sensitivity (Q₁₀) of N mineralization was significantly greater for RM (1.0) and DGM (1.3) than DGM_CDW (0.3). The percentages of total organic N mineralized from RM and DGM were greater than that for DGM_CDW, with RM producing the greatest mineralization. This suggests that adding CDW to manure will affect N dynamics by lowering the amount of N mineralized, which may necessitate either applying higher manure rates (and risking excess phosphorus build-up) or supplementing with inorganic fertilizers to minimize N deficiency in receiving crops.

Core Ideas

- Manure from distillers grains with bedding from construction waste had reduced N mineralization.
- Addition of construction waste to manure from distillers grains diet reduced the Q₁₀ of N mineralization.
- Nitrogen mineralization was greater at the higher temperature (25°C) than at 15°C.

The Canadian biofuels industry has recently seen a rapid expansion, producing approximately 1.36 billion L of ethanol in 2010 alone, mostly from corn (Zea mays L.) (64%) and wheat (Triticum aestivum L.) (31%) (USDA FAS, 2010). Concomitant with this expansion has been an increased supply of valuable byproducts, including dried distillers grains with solubles (DDGS), which is a dried mixture of the condensed liquid fraction (solubles) remaining after ethanol extraction and the coarse ethanol-free solids (distillers grains). Approximately 0.26 Tg yr⁻¹ of wheat DDGS was produced by Canadian ethanol plants in 2009 to 2010, with an estimated value of US$51 million (International Grains Council, 2010). Nearly all wheat DDGS is used as an animal feedstuff (FOBI Network, 2013), which provides a concentrated source of nutrients.

The inclusion of DDGS in cattle diets may alter manure properties relative to manure from animals fed regular grain-based diets. This can have implications for manure nutrient release and plant nutrient uptake, as well as the potential for nutrient loss to the environment (Hao et al., 2009). Recent studies have shown higher concentrations of N and phosphorus (P) in manure from cattle fed DDGS.
Manure properties may be further altered by bedding materials used in confined feeding operations. Recently, there has been a growing interest in western Canada in the use of construction and demolition waste (CDW), particularly the wood and drywall fractions, as bedding material in cattle feedlots (Hao et al., 2014). In Canada and the United States, CDW is largely buried in landfills, with little or no effort made to recycle it (Sandler, 2003; Yeheyis et al., 2013). Approximately 9 Tg of CDW are generated annually by the construction industry in Canada, which is composed mainly of wood products, asphalt, drywall, concrete and masonry. Metals, plastics, cardboard and paper, earth and shingles are the other materials that are often present in CDW (Yeheyis et al., 2013). Nitrogen availability has been found to be lower in soils amended with beef cattle manure containing woodchips as compared to barley (Hordeum vulgare L.) straw as bedding (Miller et al., 2009, 2010). While the inclusion of DDGS in cattle diets may improve manure N availability, the use of CDW as bedding in feedlots may conceivably negate this because of the stable C in the woodchip fraction of CDW (Larney et al., 2008; Miller et al., 2010). Alternatively, the drywall fraction of CDW, which is mainly gypsum (calcium sulfate), may be beneficial since it supplies calcium (Ca) and sulfur (S) (Hao et al., 2014).

A good understanding of N availability for crop uptake, hence organic N mineralization during the growing season, is critical not only from the perspective of efficiency of fertilizer use, but also to ensure that loss of excess N to the environment is minimized (Zebarth et al., 2009; St. Luce et al., 2011). Nitrogen mineralization reactions in soils typically follow first-order kinetics, with the rate constants and potentially mineralizable N (N\text{m}, a measure of soil mineralizable N concentration) usually derived from long-term incubation studies (Stanford and Smith, 1972; Ellert and Bettany, 1992; Curtin and Campbell, 2008). Others have estimated these parameters using either a double exponential (Bonde and Rosswall, 1987; Gil et al., 2011) or the mixed first-order and zero-order kinetic model (Bonde and Roswall, 1987), suggesting that more than one fraction of soil organic N may be mineralized, each with a unique rate of decomposition (Benbi and Richter, 2002).

To the best of our knowledge, the mineralization of N from DGM mixed with CDW has not been previously characterized. Therefore, the objective of this study was to evaluate the mineralization of N in manure from cattle fed DDGS relative to manure from cattle fed a regular grain-based diet. The study further examined the effects of CDW and temperature on DGM mineralization, and how these vary between two contrasting soils.

**MATERIALS AND METHODS**

**Soil**

Soil samples (0–15 cm layer) were collected using a spade from a Black Chernozem (loam, Typic Haplocryoll) near Olds, Alberta, Canada (113°57′42″ N, 51°43′51″ W) and a Brown Chernozem (sandy clay loam, Aridic Haploboroll) near Cranford, Alberta (112°20′31″ N, 49°45′ 51″ W). These soils belong to the dominant Chernozem group in the cropland areas of Alberta and the western Canadian Prairies. Their regional distribution is spatially correlated with the major climate zonation of the region, with the Brown Chernozems occupying areas of the prairies that have the greatest annual water deficit. During the season immediately preceding soil collection, the Cranford site was cropped to tomatoes (Solanum lycopersicum L.) while the Olds site was cropped to barley in a canola-wheat-barley rotation. The soils were air-dried, passed through a 4-mm mesh sieve, thoroughly mixed to ensure uniformity, and stored at room temperature (23–25°C) until the start of the experiment. Soil subsamples were ground to pass through a 2-mm sieve prior to laboratory analysis. Particle size distribution was determined using the hydrometer method (Kroetsch and Wang, 2008). Soil pH and electrical conductivity (EC) were determined in a 1:2 (w/v) soil/water suspension using a pH and EC meter (Model SP2000, Skalar BV, Breda, Netherlands). Ammonium (NH\text{4}+) N concentration in the soil was measured colorimetrically by the indophenol method following extraction with 2 mol L\text{–1} KCl. Soil nitrate (NO\text{3}) N concentration was measured colorimetrically by the cadmium-reduction method following extraction with 2 mol L\text{–1} KCl. Soil total N (TN) concentration was determined by the macro-Kjeldahl method using an automated Kjeldahl analyzer (Foss Kjeltec 8400, Höganäs, Sweden) following digestion with H\text{2}SO\text{4} and TiO (catalyst), Total carbon (TC) concentration was determined using a CN analyzer (Elementar, Langenselbold, Germany). Total P (TP) concentration was measured with an inductively coupled optical emission spectrometer (Thermo Electron Corporation iCAP 6300, Cambridge, England) following digestion of a 1:10 (w/v) soil/ concentrated HNO\text{3} suspension with a MARS 5 microwave system (CEM Corporation, Matthews, NC).

**Manure**

Two types of beef cattle (British cross heifers) manure were collected by scraping from the pen floor of a feedlot at the Agriculture and Agri-Food Canada Research and Development Centre in Lethbridge, Alberta, Canada. Regular manure (RM) was collected from cattle fed a finishing grain-based diet consisting of 85% barley grain, 10% barley silage, and 5% mineral supplement to provide trace minerals, vitamins and monensin. This diet is typical of that used in western Canadian feedlots (Hao et al., 2009). Manure (DGM) was also collected from cattle fed a diet composed of 45% barley grain, 40% wheat DDGS, and 10% silage along with 5% of the same mineral supplement as in the grain-based diet. An additional manure treatment (DGM\text{CDW}) was prepared by mixing DGM with CDW (a mixture of drywall and woodchips, mainly waste from new housing construction in southern Alberta) in a 5:1 ratio (w/w) to attain a C to N ratio less than 20:1. Studies have shown that positive N mineralization from manure after application to soil occurs when manure C to N ratio is less than 20:1 (Beauchamp and Paul, 1989; Qian and Schoenau, 2002). Manure samples were analyzed for pH, total N, total C, NH\text{4}–N, and NO\text{3}–N according to the methods of the American Public Health Association, American Water Works Association, and Water Environment Federation (APHA, 2005). Initial soil and manure properties are presented in Table 1.
Table 1. Initial properties of soils and organic amendments used for the incubation study.

<table>
<thead>
<tr>
<th>Property†</th>
<th>Black Chernozem</th>
<th>Brown Chernozem</th>
<th>RM‡</th>
<th>DGM</th>
<th>DGMCDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.6</td>
<td>7.2</td>
<td>8.7</td>
<td>8.6</td>
<td>8.4</td>
</tr>
<tr>
<td>EC, dS m⁻¹</td>
<td>0.5</td>
<td>0.3</td>
<td>6.5</td>
<td>7.7</td>
<td>8.0</td>
</tr>
<tr>
<td>NO₃⁻-N, mg kg⁻¹</td>
<td>8.8</td>
<td>16.4</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>NH₄⁺-N, mg kg⁻¹</td>
<td>18.9</td>
<td>19.2</td>
<td>1564</td>
<td>1566</td>
<td>2262</td>
</tr>
<tr>
<td>Soluble P, mg kg⁻¹</td>
<td>–</td>
<td>–</td>
<td>40</td>
<td>82</td>
<td>29</td>
</tr>
<tr>
<td>PO₄³⁻-P, mg kg⁻¹</td>
<td>38</td>
<td>31</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total C, g kg⁻¹</td>
<td>50</td>
<td>21</td>
<td>106</td>
<td>114</td>
<td>111</td>
</tr>
<tr>
<td>Total N, g kg⁻¹</td>
<td>4.7</td>
<td>2.0</td>
<td>6.8</td>
<td>9.2</td>
<td>8.4</td>
</tr>
<tr>
<td>Total organic N, g kg⁻¹</td>
<td>–</td>
<td>–</td>
<td>5.3</td>
<td>7.6</td>
<td>6.2</td>
</tr>
<tr>
<td>C to N ratio</td>
<td>11</td>
<td>11</td>
<td>16</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Total P, g kg⁻¹</td>
<td>0.8</td>
<td>0.6</td>
<td>1.7</td>
<td>2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Dry matter content, kg kg⁻¹</td>
<td>–</td>
<td>–</td>
<td>0.27</td>
<td>0.30</td>
<td>0.38</td>
</tr>
<tr>
<td>Clay, g kg⁻¹</td>
<td>201</td>
<td>232</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Silt, g kg⁻¹</td>
<td>314</td>
<td>278</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sand, g kg⁻¹</td>
<td>485</td>
<td>491</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

† All chemical analyses expressed on a dry weight basis.
‡ RM, manure from cattle fed a regular grain diet; DGM, manure from cattle fed a diet containing dried distillers grains; DGMCDW, DGM mixed with construction and demolition waste (CDW).

Experimental Design and Setup

The experimental design was a randomized complete block with a split-plot treatment layout consisting of temperature (15 and 25°C, replicated three times) as the main plot and factorial combinations of the two soils and four amendment treatments (RM, DGM, DGMCDW, and a non-amended control) as the subplot. The temperatures were selected to closely mimic the mean daily soil temperatures at the 10-cm depth early in the spring and during the summer months, respectively.

Each organic amendment was thoroughly mixed with 30 g of air-dry soil to give a rate of 40 g kg⁻¹ soil⁻¹. The manure rate approximates a field application rate of 60 Mg ha⁻¹ for irrigated cereals (Benke et al., 2010).

Leaching column setup followed the technique described by Campbell et al. (1993). Briefly, PVC conduit pipes (2.5 cm i.d. by 15 cm length) were sealed at the base with a perforated #5 stopper (30 g of quartz sand and packed into leaching columns to attain the bulk densities mentioned above. A glass-wool pad (~5 mm) thin layer of bug screen mesh was placed on the end of the stopper (15 cm length) were sealed at the base with a perforated #5 stopper. Deionized water was added to the soil weekly to replenish any moisture lost through evaporation. Leachates collected at each sampling day were immediately stored in a freezer at −19°C and analyzed within a week for inorganic N (NH₄⁺-N + NO₃⁻-N) concentration using a SAN++ segmented flow analyzer (Skalar BV, Breda, Netherlands).

Calculations and Statistical Analysis

Net N mineralization for amended soil, measured as soil inorganic N concentration at time t and corrected for mineralization in the unamended soil and for initial soil inorganic N concentration, was calculated from the cumulative amounts of leached N (NH₄⁺-N + NO₃⁻-N) as follows:

\[
N_{min(t)} = \frac{[IIN_A(t) - IIN_A(0)] - [IIN_C(t) - IIN_C(0)]}{CaSO_4 \cdot 0.002 \text{ mol L}^{-1} MgSO_4 \cdot 0.005 \text{ mol L}^{-1} Ca(H_2HPO_4)_2 \cdot 0.0025 \text{ mol L}^{-1} K_2SO_4} \text{(Curtin and Campbell, 2008)}
\]

where \(N_{min(t)}\) (mg kg⁻¹) is the net mineralized N concentration at sampling time t (d); \(IN_A(t)\) (mg kg⁻¹) is the amendment-derived inorganic N concentration at sampling time t; \(IN_A(0)\) (mg kg⁻¹) is the inorganic N concentration in the amended soil at the start of the experiment \(t = 0\); \(IN_C(t)\) (mg kg⁻¹) is the inorganic N concentration in the unamended soil at time t; and \(IN_C(0)\) (mg kg⁻¹) is the inorganic N concentration at \(t = 0\).

Cumulative net N mineralized (%Nmin), or the percentage of manure organic N (%Norg) mineralized between the start of the experiment and time t, was calculated as:

\[
%N_{min} = \frac{N_{min(t)} \times N_{org}}{100} \times 100 \text{[2]}
\]

Three kinetic models that are commonly used to describe N mineralization in soils (Table 2) were fitted to \(N_{min(t)}\) and
%N_{\text{min}}\) using the NLIN procedure in SAS version 9.4 (SAS Institute, 2014). Model fits were compared using the corrected Akaike’s Information Criterion (AIC_C; Motulsky and Christopolous, 2003). The mixed first-order and zero-order kinetic model (Eq. [3]), which had the lowest AIC_C, was selected as the most suitable for describing N mineralization kinetics for the Black Chernozem:

\[
N_{\text{min}/t} = N_0 [1 - \exp(-k_1 t)] + k_0 t
\]

where \(N_0\) is potentially mineralizable N concentration (mg N kg soil^{-1}); \(k_1\) is the first-order mineralization rate constant (d^{-1}) of the easily degradable organic N fraction; and \(k_0\) is the zero-order mineralization rate constant of the resistant N fraction (mg kg^{-1} d^{-1}). Model parameter estimates were compared using their 95% confidence intervals. The mixed first-order and zero-order model includes parameters for N released from both the resistant and the easily mineralizable organic fractions. Nitrogen mineralization from the resistant fraction ensures continued N release after the active fraction is depleted, which precludes the identification of a single substrate pool or ensures continued N release after the active fraction is depleted, fraction. Nitrogen mineralization from the resistant fraction varied with manure type. Model fits for the hyperbolic, and the parabolic kinetic models with respect to describing N mineralization kinetics in compost-amended soils. The effect of temperature on the mixed first-order and zero-order model varied with manure type. For example, in the study by Gil et al. (2011), the mixed first-order and zero-order model outperformed the simple exponential, the double exponential, the hyperbolic, and the parabolic kinetic models with respect to describing N mineralization kinetics in compost-amended soils. The effect of temperature on the mixed first-order and zero-order model varied with manure type. Model fits for the two temperatures differed significantly for DGM but not for RM (Fig. 1). For DGM, \(N_0\) was greater (\(P < 0.001\)) at 25°C (209 mg kg soil^{-1}) than at 15°C (142 mg kg soil^{-1}).

Potentially mineralizable N concentration differed significantly between RM and DGM (\(P = 0.003\)) and between temperatures (\(P = 0.004\)) (Table 3), reflecting differences in organic N concentration between these manures. Averaged across temperatures, \(N_0\) was 27% greater for RM (235 mg kg soil^{-1}) than DGM (172 mg kg soil^{-1}). Averaged across amendments, \(N_0\) was greater at 25°C (234 mg kg soil^{-1}) than at 15°C (172 mg kg soil^{-1}).

RESULTS AND DISCUSSION

Nitrogen Mineralization Kinetics in the Black Chernozem

Nitrogen mineralization kinetics in the Black Chernozem followed the mixed first-order and zero-order model for all amendments at both temperatures, except for DGM_{CDW} for which the model failed to converge. This is consistent with previous studies (e.g., Dou et al., 1996; Haer and Benbi, 2003; Gil et al., 2011), which demonstrated the superiority of the mixed first-order and zero-order model compared with other N mineralization kinetic models tested in the studies. For example, in the study by Gil et al. (2011), the mixed first-order and zero-order model outperformed the simple exponential, the double exponential, the hyperbolic, and the parabolic kinetic models with respect to describing N mineralization kinetics in compost-amended soils. The effect of temperature on the mixed first-order and zero-order model varied with manure type. Model fits for the two temperatures differed significantly for DGM but not for RM (Fig. 1). For DGM, \(N_0\) was greater (\(P < 0.001\)) at 25°C (209 mg kg soil^{-1}) than at 15°C (142 mg kg soil^{-1}).

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For the Black Chernozem only, the temperature sensitivity coefficient \(Q_{10}\), the factor by which the mineralization rate increased or decreased when the temperature was raised by 10°C for each amendment was calculated separately for each replicate as:

\[
Q_{10} = \left(\frac{K_2}{K_1}\right)^{\frac{10}{\left(T_T - T_a\right)}}
\]
effect on the two rate constants. The larger $k_1$ for DGM indicates that the easily decomposable organic N pool was mineralized more rapidly for DGM than RM. By comparison, the large resistant N pool was mineralized at a lower rate ($k_0$) for DGM than for RM.

These results suggest that it is the mineralizable N pool ($N_0$) which is temperature dependent instead of the rate constants ($k_0$ and $k_1$). This corroborates findings by MacDonald et al. (1995), who observed no temperature effect on the first order rate constant in a 32-wk incubation study utilizing surface soils from a hardwood forest, but observed an increase in the mineralizable N pool as the temperature was increased from 5 to 25°C. The authors attributed the increase in the mineralizable N pool with increasing temperature to a shift in the microbial community, changes in the biochemical composition of the fraction mineralized, and/or changes in transport processes such as diffusion. However, other studies have shown temperature dependency of rate constants (Ellert and Bettany, 1992; Sierra, 1997; Dessureault-Rompré et al., 2010).

In the Black Chernozem, temporal changes in $%N_{\text{min}}$ followed first-order kinetics for all amendments at both temperatures (Fig. 2). However, temperature effects on the first-order rate constant ($k_1$) varied with amendment, as indicated by an amendment × temperature interaction (Table 4; $P = 0.001$). For $DGM_{\text{CDW}}$, $k_1$ was significantly greater at 15°C (0.18 d$^{-1}$) than at 25°C (0.04 d$^{-1}$), but there were no significant differences in $k_1$ between the two temperatures for RM (mean = 0.009 d$^{-1}$) and DGM (0.02 d$^{-1}$) (Fig. 3). At 15°C, $k_1$ was significantly greater for $DGM_{\text{CDW}}$ (0.18 d$^{-1}$) than RM (0.009 d$^{-1}$) and DGM

### Table 3. Amendment and temperature effects on mixed first-order and zero-order kinetic model parameters for net N mineralization ($N_{\text{min}}$) in a manure-amended Black Chernozem.

<table>
<thead>
<tr>
<th>Effect</th>
<th>$N_0$†</th>
<th>$k_0$‡</th>
<th>$k_1$§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amendment ¶</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DGM</td>
<td>172b††</td>
<td>0.74b</td>
<td>0.10a</td>
</tr>
<tr>
<td>RM</td>
<td>235a</td>
<td>1.80a</td>
<td>0.04b</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C</td>
<td>172b</td>
<td>1.20a</td>
<td>0.08a</td>
</tr>
<tr>
<td>25°C</td>
<td>234a</td>
<td>1.11a</td>
<td>0.05a</td>
</tr>
</tbody>
</table>

| $P$-value |        |        |        |
| Amendment (A) | 0.003 | <0.001 | 0.001  |
| Temperature (T) | 0.004 | 0.45   | 0.25   |
| $A \times T$ | 0.1   | 0.53   | 0.12   |

† $N_0$, potentially mineralizable N.
‡ $k_0$, zero-order mineralization rate constant.
§ $k_1$, first-order mineralization rate constant.
¶ DGM, manure from cattle fed a diet containing dried distillers grains; RM, manure from cattle fed a regular grain diet.
†† Means within columns followed by the same lowercase letter are not significantly different at the 0.05 probability level according to the Tukey multiple comparison procedure.
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(0.02 d−1) but did not differ significantly between RM and DGM. At 25°C, DGM CDW also had the largest $k_1$ (0.05 d−1), which was significantly greater than that for RM (0.009 d−1), while $k_1$ was also significantly greater for DGM (0.03 d−1) than RM at this temperature. The larger $k_1$ for DGM and DGM CDW at 25°C further indicates that the easily decomposable organic N pool was mineralized more rapidly than RM.

Potentially mineralizable N concentration (% of initial organic N concentration) differed significantly among amendments ($P < 0.001$) and between temperatures ($P = 0.03$) (Table 4). Averaged across temperatures, $N_0$ was significantly greater for RM (14%) than DGM (4.2%) and DGM CDW (1.9%) and greater for DGM than DGM CDW.

Cumulative N mineralization concentration ($N_{\text{min}}$) on Day 245 was greater ($P < 0.001$) for RM (670 mg kg−1) than for DGM CDW (135 mg kg−1) and DGM (352 mg kg−1) (Table 5). This is consistent with the greater $N_{\text{min}}$ observed for RM than for DGM and DGM CDW.

Our results for $N_{\text{min}}$ are within the range reported by Chiyoka et al. (2014) for a Black Chernozem that received fresh beef cattle feedlot manure. The lower $N_{\text{min}}$ with DGM CDW than DGM could possibly be due to the more recalcitrant C or higher lignin content of the woodchip fraction of the CDW, which could have resulted in greater N immobilization when DGM CDW was applied (Miller et al., 2009, 2010). The differences in $N_{\text{min}}$ between DGM and DGM CDW could also possibly be due to the dilution effect resulting from mixing the CDW with DGM before it was applied to soil on a weight basis. The addition of CDW increased the manure C to N ratio from 12:1 for DGM to 13:1 for DGM CDW. Other studies have reported lower N mineralization at C to N ratios of less than 15:1 (Qian and Schoenau, 2002; Helgason et al., 2007). Miller et al. (2009, 2010) have reported slow N mineralization rates in soils that received organic amendments with high C to N ratios (greater than 25:1) or high recalcitrant C contents from woodchip bedding. This suggests that a greater proportion of the organic N in DGM and RM will be readily converted to plant available forms (NH$_4$–N) while lower amounts will be available with the application of DGM CDW.

The temperature sensitivity, $Q_{10}$, of mineralization varied among amendments ($P = 0.01$) and was significantly lower for DGM CDW (0.3) than RM (1.0) and DGM (1.3) (Table 4). These results indicate that the N mineralization rate of RM and, to a lesser extent, DGM, is not affected by temperature within the range of temperatures tested, and that the addition of CDW to DGM results in a decrease in the mineralization rate when the temperature is increased by 10°C. The $Q_{10}$ values for RM...
and DGM fall within the range of values reported by Whalen et al. (2001) for a Dark Brown Chernozem in which beef cattle manure was applied. The authors reported that the N mineralization rate did not double in response to a 10°C increase in temperature (Q10).

The lower Q10 for DGM CDW could be partly due to the high C to N ratio and high recalcitrant C content of the wood-chip fraction of CDW, which is more resistant to decomposition. Studies have shown that Q10 will vary depending on soil characteristics such as pH, texture, and water content, which influence microbial activity, coupled with the quantity and quality of the substrate that is being mineralized (Kirschbaum, 1995; Dessureault-Rompré et al., 2010).

Mineralized Nitrogen Concentration in a Brown Chernozem

All organic amendments resulted in net immobilization (Nmin < 0) in the Brown Chernozem on all sampling days, except on Day 14 when a spike was observed for DGM (Table 5; Fig. 4). Averaged across temperatures and incubation times, %Nmin was lower for DGM than RM, whereas there was no significant difference between DGMCDW and the other two amendments. The negative mineralization observed in the manure-amended Brown Chernozem has previously been reported for a Dark Chernozem amended with cattle manure (Chiyoka et al., 2014). They attributed the greater immobilization in the amended soil to the lower initial inorganic N concentration and organic C of the Dark Brown compared to the Black Chernozem. In the present study, the Brown Chernozem had lower concentrations of total C and total N than the Black Chernozem, which may explain the observed apparent immobilization. It is also likely that the 60% water-filled pore space maintained during incubation may have produced enough anaerobic conditions to cause some denitrification in the Brown Chernozem (Sierra, 1997; Drury et al., 2003; Coyne, 2008). However, other studies have reported that denitrification is favored when the soil water content is high, such as 70 to 100% water-filled pore space (Linn and Doran, 1984; Weier et al., 1993). Nonetheless, our results suggest that manure N may not be readily available for crop uptake.

### Table 5. Amendment, temperature, and incubation time effects on cumulative net N mineralized in Black and Brown Chernozems.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Nmin on Day 245†</th>
<th>Nmin‡</th>
<th>%Nmin§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg kg soil⁻¹</td>
<td>mg kg soil⁻¹</td>
<td>%</td>
</tr>
<tr>
<td>Black Chernozem</td>
<td>Brown Chernozem</td>
<td>Brown Chernozem</td>
<td></td>
</tr>
<tr>
<td>Amendment°F</td>
<td>Amendment°F</td>
<td>Amendment°F</td>
<td>Amendment°F</td>
</tr>
<tr>
<td>DGM</td>
<td>352b††</td>
<td>-208a</td>
<td>-2.72a</td>
</tr>
<tr>
<td>DGMCDW</td>
<td>135c</td>
<td>-208a</td>
<td>-3.38ab</td>
</tr>
<tr>
<td>RM</td>
<td>670a</td>
<td>-182a</td>
<td>-3.48b</td>
</tr>
<tr>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
</tr>
<tr>
<td>15°C</td>
<td>362a</td>
<td>-198a</td>
<td>-3.16a</td>
</tr>
<tr>
<td>25°C</td>
<td>409a</td>
<td>-201a</td>
<td>-3.22a</td>
</tr>
</tbody>
</table>

† Nmin on Day 245, cumulative net mineralized N at the end of the incubation on Day 245.
‡ Ncumulative mineralized N from N sources in a Brown Chernozem.
§ %Nmin, cumulative net mineralized N from manure organic N expressed as a percentage of the organic N applied with the manure in a Brown Chernozem.
°F DGM, manure from cattle fed a diet containing dried distillers grains; DGMCDW, DGM mixed with construction and demolition waste (CDW); RM, manure from cattle fed a regular grain diet.
†† Means within columns followed by the same lowercase letter are not significantly different at the 0.05 probability level according to the Tukey multiple comparison procedure.

Fig. 4. Cumulative N mineralized as a percentage of initial organic N concentration (%Nmin) of beef cattle manure applied to a Brown Chernozem during a 240-d incubation period.
when applied to the Brown Chernozem under the conditions of the present study. A greenhouse bioassay in which five growth cycles of canola were grown in the same soils amended with the same amendments (DGM, DGMCDW and RM) also showed negative mineralization ($N_{\text{min}} < 0$) in the Brown Chernozem (Agomoh et al., 2017). Nitrogen uptake was consistently lower for all amendments in the Brown Chernozem compared with the Black Chernozem even though the Brown Chernozem had a greater initial inorganic N concentration. Additional research is needed to further elucidate the factors limiting N mineralization from organic N sources applied to the Brown Chernozem and to determine the optimum moisture content for N mineralization in this soil.

**CONCLUSIONS**

The N mineralization pattern of manure differed between the Black Chernozem and the Brown Chernozem, with the Brown Chernozem exhibiting negative net mineralization (i.e., net immobilization) throughout the entire incubation period, whereas net mineralization occurred in the Black Chernozem. Nitrogen mineralization in the DGM-amended and RM-amended Black Chernozem followed mixed first-order and zero-order kinetics while the cumulative net N mineralized expressed as a percentage of initial organic N concentration ($\%N_{\text{min}}$) followed first-order kinetics. In general, cumulative N mineralization was greater in the RM-amended than the DGM-amended Black Chernozem. More organic N was mineralized from RM and DGM at the higher temperature than the lower temperature, a reflection of greater microbial activity at the higher temperature. However, the mineralization rate constants were not affected by temperature. The rate constant for the easily mineralizable N pool was greater for DGM than RM, whereas the rate of N mineralization for the slowly mineralizable N pool was greater for RM. Addition of CDW to DGM resulted in a decrease in N release compared with DGM and RM in the amended Black Chernozem. In addition, the $Q_{10}$ coefficient (temperature sensitivity) decreased from 1.31 to 0.30 with the addition of CDW in this soil.

**REFERENCES**


