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Classification and assessment models of first year byproducts nitrogen plant-availability from literature data

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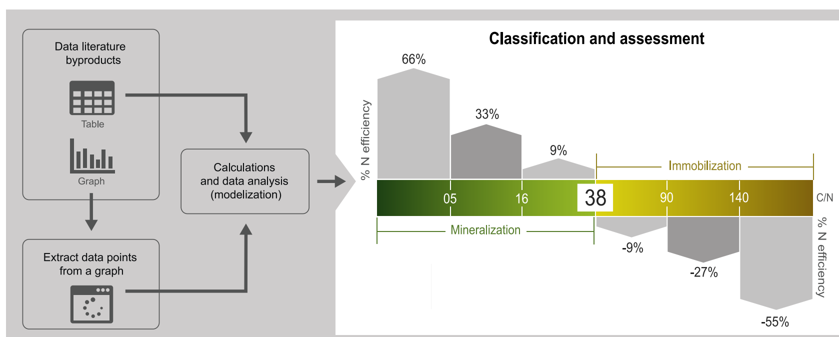
HIGHLIGHTS

- Data from 37 studies were collected to assess byproducts N plant-availability.
- Three models of byproducts N plant-availability based on C/N were developed.
- Byproducts were classified into six categories of N efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

Byproducts can provide an important amount of nutrients for crops and improve soils properties. According to their C/N, nitrogen (N) mineralization or immobilization may be observed after their application onto agricultural land. Therefore, an indicator is needed to assess byproducts N availability for crops. Thirty-seven studies from the scientific literature on N mineralization or immobilization after application to agricultural land under a wide range of climatic and experimental conditions were collected in order to elaborate models assessing non-composted byproducts N availability during the first growing season according to the C/N ratio. Four methods were used to evaluate N availability: incubation, apparent N recovery (ANR), relative N effectiveness (RNE) and fertilizer equivalence (FE). Since ANR was the model most related to C/N ($R^2 = 0.77$), this model was used to define six categories of C/N. Results expressed in terms of FE were converted into RNE values. Although RNE is less precise than ANR, efficiencies of byproducts were expressed in terms of average RNE because it is the most appropriate for fertilization grids. Therefore, depending on C/N of non-composted byproducts, six categories were defined. i) high mineralization: +66% RNE and 5 ≤ C/N, ii) moderate mineralization: +33% RNE and 5 < C/N ≤ 16, iii) low mineralization: +9% RNE and 16 < C/N ≤ 38, iv) low immobilization: −9% RNE and 38 < C/N ≤ 90, v) moderate immobilization: −27% RNE and 90 < C/N ≤ 140, and vi) high immobilization: −55% RNE and C/N > 140.

1. Introduction

In recent decades, large amounts of byproducts are generated by cities and industries, and land application is a frequently used option as organic and nutrient soil amendment when the byproducts are within

Abbreviations: ANR, apparent N recovery; RNE, relative N effectiveness; FE, fertilizer equivalence; C/N, carbon/nitrogen ratio.

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standards for contaminants and pathogens. A better knowledge of nitrogen mineralization capacity and crop benefits from field application of byproducts is needed to improve nutrients use efficiency and avoid excess nutrients losses to the environment. Byproducts can be an important source of essential plant nutrients (e.g. N, P, K) and of organic matter (Lu et al., 2012). Benefits of using byproducts onto agricultural land are reported by many researchers (Douglas et al., 2003; Gutser et al., 2005; Gagnon et al., 2012; N'Dayegamiye, 2006). Unlike mineral fertilizers that contain N readily available for crops, the N supplied with byproducts is present both under inorganic and organic forms (Rigby et al., 2016). The organic nitrogen fraction is available to plants only after mineralization to ammonium (NH_4^+) and nitrate (NO_3^-) by soil microorganisms (Pu et al., 2012).

After field application, mineralization of organic nitrogen depends on a number of factors including the type and organic composition of organic residues (C, N, C/N) (Rigby et al., 2016; Cogger et al., 2004; Er et al., 2004), soil type and properties (Rigby and Smith, 2013; Huang and Chen, 2009), soil temperature and water content (Cabrera et al., 2005), and environmental conditions (Castillo et al., 2010; Pu et al., 2012). The amount of nitrogen available to crops is also influenced by the application rate (Simard et al., 1998), and by the timing and method of application (Castillo et al., 2011; Mulvaney et al., 2010). A recent work by Rigby et al. (2016) gives a summary of factors influencing byproducts N mineralization on agricultural soils.

The C/N of organic biosolids is the critical factor controlling the N mineralization process in amended soil (Rigby et al., 2016). The relationship between C/N and N mineralization or immobilization of byproducts is usually reported in the literature (Er et al., 2004; Camberato et al., 2006). For example, Er et al. (2004) report that the effect of C/N on N mineralization is statistically significant and may explain up to 35.3% of the total variability of N mineralization. Parnaudeau et al. (2004) and Jedidi et al. (1995) found that the C/N is strongly correlated with N mineralization. When the C/N is high, the nitrogen is immobilized by soil micro-organisms and, therefore, a reduction of nitrogen plant-availability is observed during the first growing season (Douglas et al., 2003). Since byproducts N is usually present in organic forms, evaluating the mineralizable fraction is necessary to calculate plant-availability and to deduce fertilizer replacement value (Rigby et al., 2016). Commonly used methods to determine organic residues nitrogen availability to crops are: i) laboratory incubation, ii) apparent N recovery (ANR), iii) relative N effectiveness (RNE), iv) fertilizer equivalence (FE), and v) recovery of ^{15}N-labeled methods (Cusick et al., 2006; Muñoz et al., 2004; Motavalli et al., 1989). N availability is often based only on the type of byproducts (e.g. deinking paper sludge, municipals biosolids). Since C/N is routinely obtained by laboratories, researchers often used it as an indicator of organic amendments N availability. Collecting available data on N mineralization from byproducts could help elaborating fertilization guidelines for the end-user. Although nitrogen availability of byproducts has been studied by several authors, these studies focused on specific intervals of the C/N, on different soils and for varying experimental conditions (Rigby and Smith, 2013; Bernal et al., 1998; Nendel et al., 2004). It appears that there are no studies combining the data on available N from multiple studies on a range of N byproducts.

The objective of this study was to develop C/N classification models based on a wide range of literature data to provide farmers and advisors with decision tools to predict potential N availability of municipal and industrial byproducts during the first growing season after field application.

2. Materials and methods

2.1. Literature data

Literature data extraction presented in Fig. 1 is organized according to the type of experiment and the methods used to assess nitrogen availability. Numerical data were obtained either directly from papers, or extracted from graphs using the "Data Thief" software (Tummers, 2006). Most studies were for solid byproducts. Liquid byproducts data results are only from Bramryd (2001), Mantovi et al. (2005) and Rigby and Smith (2013). The solids and liquids byproducts from several different sources (e. g. paper-mill sludge, compost, distillery, slaughterhouse, municipal wastewater) showed wide ranges of chemical, physical and biological properties: up to 40% of organic carbon, C/Ns from 4.0 to 151.5 and pHs from 3.6 to 11.6. For liquid byproducts and those having a C/N from 90 to 140, there were very few data points. The byproducts investigated were produced under various conditions such as aerobic or anaerobic digestion, aerobic or anaerobic mesophilic digestion, thermophilic digestion, lime stabilization, dewatering, air or heat drying and composting. The nitrogen availability in byproducts was assessed using four computation methods (Fig. 1): i) incubation (Model I, Eq. (1), Gale et al., 2006); ii) apparent N recovery (Model II, Eq. (2), Motavalli et al., 1989); iii) relative N effectiveness (Model III, Eq. (3), Muñoz et al., 2004); and iv) fertilizer N equivalence (Model III, Eq. (4), Muñoz et al., 2004). Data in the selected literature were either raw (N uptake, yield and N mineralized) or expressed as percentages (percent of mineralized N, ANR, RNE or FE).

2.2. Incubation method

For the incubation method, there were 27 studies providing 322 observations of N mineralization or immobilization (Table 1). Incubations were performed under varying conditions such as temperature (20 °C to 35 °C), soil water content (23% to 100% of water-holding capacity), aeration (aerobically or anaerobically), incubation period (48 to 217 days), and leaching or non-leaching experiments. In these studies, the amount of mineralized N was calculated by subtracting the mineral N concentration in the unamended control soil from that in the amended soils, and the difference was expressed as the proportion of total N applied (Gale et al., 2006).

$$N_{min}\ (\%) = \frac{N_{treatment} - N_{control}}{N_{applied}} * 100 \quad (1)$$

where: N_{min} (%) is the percentage of nitrogen mineralization during the incubation period; $N_{treatment}$ is the amount of nitrogen mineralization in the amended soil sample at the end of the incubation period; $N_{control}$ is the amount of nitrogen mineralization at the end of the incubation period in the control samples; and $N_{applied}$ is the total amount of N applied.

2.3. Apparent N recovery method (ANR)

For the apparent N recovery method, there were 20 studies providing 205 observations (Table 2). The greenhouse and field experiments were conducted with different crops (corn, wheat, ryegrass, barley, fescue, *Sorghum bicolor*, oat, potatoes, winter wheat, winter barley) under different experimental conditions (temperature, soil water content, soil properties, rainfall). For fodder crops (e.g. ryegrass), there were 2 or 3 cuts. The ANR method compares crop N uptake in the amended treatments with that in the unamended control. This method assumes that the amount of N provided by the soil is the same across plots, and that crop N uptake in the amended plots, in excess of control N uptake, is due solely to the treatment (Muñoz et al., 2004). For inorganic and organic fertilizers, the ANR was either obtained directly from the literature or calculated using the equation of (Motavalli et al., 1989):

$$ANR\ (\%) = \frac{N_{treatment} - N_{control}}{N_{applied}} * 100 \quad (2)$$

where: ANR (%) is the apparent N recovery of organic or inorganic fertilizers; $N_{treatment}$ is the crop N uptake with organic treatments; $N_{control}$ is