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Plant available N supply and recalcitrant C from organic soil amendments applied to a clay loam soil have correlations with amendment chemical composition

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ABSTRACT

A 49 week soil incubation study employing 15 recycled organic (RO) wastes was conducted to investigate relations (through Kendall correlation analysis) between plant available nitrogen (PAN) supply and soil recalcitrant carbon (C) parameters with those of the RO waste chemical properties as determined by wet chemistry and spectroscopic methods. The hot water extractable organic C to hot water extractable nitrogen (N) ratio (HWOC:HWN ratio) was often the highest correlating property for mineral N supply (mg mineral N kg dry waste^{-1}), while many of the ^{13}C NMR functional group parameters such as the aromatic C to N ratio, phenyl C to N ratio, and aryl C to carbonyl C ratio were also significantly correlated with mineral N supply. These functional group C properties were significantly correlated with mineral N release in the later phase of the incubation (i.e. 12–49 weeks), while HWOC:HWN ratio was highly correlated with the early period (0–2 weeks) but this period had a dominant influence on the total supply. The fore mentioned ^{13}C NMR functional group properties were also significantly correlated with recalcitrant C, but the fraction of total RO waste C as aromatic C (110–165 ppm) was the parameter most highly correlated with this property. Molecular C component composition had no predictive advantage over functional group data. Future work should focus on narrow classes of organic amendments for predictive correlations.

1. Introduction

Food security is a major challenge for contemporary agriculture, with a need to increase food production by >60% (Bruinsma, 2009) over the next 50 years to feed a projected world population of 9.2 billion people (UN ESA, 2008). One way to lift production is by improving soil quality (Lal, 2010) and this may be achieved through the better utilisation of recycled organic (RO) wastes in agriculture. RO wastes are typically high in organic matter and can have significant reserves of essential plant nutrients (Huang and Lu, 2000; Huntley et al., 1997; Quilty and Cattle, 2011), however their supply of plant available nutrients has proven difficult to predict accurately (Beegle et al., 2008; Eldridge et al., 2008). These difficulties in predicting RO waste plant available nitrogen (N) (PAN) supply which are due partly to their composition variability (Chan et al., 2007) as well as the predominance of N in organic forms, has impeded their full integration into agriculture. Studies in the literature demonstrate that the supply of available N from organic amendments is highly variable even within narrow classes of manure products (Beegle et al., 2008).

It is important to be able to estimate RO waste PAN supply with reasonable precision as an excess supply of nitrate N, because of its mobility in the soil, poses a risk to water quality and human health (Comly, 1945; Donahoe, 1949; Knobeloch et al., 2000), as well as having implications for nitrous oxide emissions and climate change (Dalal et al., 2009, 2010).

A reasonable body of work has accumulated on the relationship between organic material composition and its decomposition and C and N mineralisation, but with little consensus to date. Some studies have

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found significant relationships between N mineralisation rates and such material composition parameters as; C/N ratio (Antil et al., 2009; Delin et al., 2012; Gale et al., 2006; Morvan et al., 2006; Sørensen and Fernández, 2003; Sørensen et al., 2003) and the lignin fibre to N ratio (Browaldh, 1997; Fox et al., 1990; Jedidi et al., 1995; Kumar and Goh, 2003; Rowell et al., 2001; Tian et al., 1995, 1992a; Tremblay et al., 2010; Vahdat et al., 2011) as well as the (lignin + polyphenol)/N ratio (Browaldh, 1997; Constantinides and Fownes, 1994; Handayanto et al., 1994; Handayanto et al., 1995; Mafongoya et al., 1997; Tian et al., 1992b). Fibre analysis determined parameters such as lignin content and the lignin to N ratio have also been found to be highly correlated to the rate of decomposition in some cases (Berendse et al., 1987; Meentemeyer, 1978; Morvan et al., 2006; Puttaso et al., 2011; Tian et al., 1992a). In addition, there have been a number of studies evaluating ^{13}C NMR determined functional group composition and ratios for the prediction of N mineralisation rates for organic amendments and residues (Flavel and Murphy, 2006; Rowell et al., 2001) and many more studies for predicting C mineralisation and decomposition (e.g. Wang et al., 2004).

The primary focus and objective of our study was to determine the amount of N mineralisation and mineral N supply from a broad range of RO wastes applied to a typical agricultural soil and to evaluate how well a selection of RO waste chemical properties correlated with this mineral N supply over time. A secondary objective of this study was to also determine the RO waste contribution to organic C levels in the soil after 12 months incubation, when applied to the soil at a common total N loading rate. Recalcitrant organic C was included in the study since it relates to C residence time in the soil with possible associated implications for soil C sequestration and because it is an inverse measure of the RO waste contribution of labile OC to the soil which has important implications for soil health and function through the provision of substrate and energy for soil microbes. The research hypotheses of our study were; (i) RO waste chemical composition affects the proportion of its organic N mineralised in the soil, (ii) some RO waste chemical composition properties can provide a reliable prediction of mineral N supply from RO wastes applied to the soil under controlled conditions, and (iii) some RO waste chemical composition properties can provide a reliable prediction of recalcitrant C remaining in the soil as a result of RO waste applications to the soil under controlled conditions.

Our research presented here represents one of the first studies to bring all of these attributes together (i.e. parameters derived from ^{13}C NMR, fibre analysis and standard wet chemistry) to evaluate their relative importance in accounting for the variation that exists in mineralised N between a diverse range of organic materials applied to agricultural soil. In addition to many of the standard characterisations of organic materials this study also includes evaluations of novel properties such as the modelled molecular C components and their ratios (Eldridge et al., 2013) and hot water extractable C and N (Sparling et al., 1998).

To the best of our knowledge, this study is also one of the first to employ the more appropriate Kendall correlation analysis to assess the relative importance of variants in explaining the variation in C and N mineralisation properties observed for the RO wastes where the relationships are often non-linear. This contrasts with the more common and sometimes erroneous use of the Pearson correlation analysis with its inherent assumption of a linear relationship.

2. Materials and methods

2.1. Selection and processing of RO wastes and soil for study

The 15 RO wastes characterised in this study were selected on the basis of them being largely representative of a broad cross section of the major RO wastes generated around urban centres such as the Sydney basin and recycled for use in agriculture (Table 1). They represent a range of manures (sewage biosolids, swine manure, dairy cow manure, broiler litter), composts including source separated green waste compost (garden organics) and Nitro-humus® compost (composted mixture of garden organics and processed sewage biosolids), as well as controversial composts such as municipal solid waste (MSW) compost from unsorted domestic waste: and animal manure composts such as composted broiler litter and blended cow manure compost. In addition, the wastes also included rendered animal carcase waste (blood and bone meal), and high C/N ratio mulch materials (pinewood shavings, wheat straw) and biochars (green waste char and poultry manure char—pyrolysis at 450 °C).

All samples were dried to a constant mass at 40 °C and chopped up with a plant grinder to <4 mm for storage and use in a subsequent 49 week soil incubation study. A representative 1 kg subsample of each material was finely ground to <2 mm with a plant grinder for chemical analysis, and a 100 g subsample of this was then taken and further ground to a fine flour (<0.5 mm) with a puck mill grinder for ^{13}C NMR analysis.

The incubation soil was a silty clay loam topsoil with hard setting properties and low levels of organic matter from a Yellow Chromosol/Kandosol intergrade soil type (Isbell, 1996) [Lixisol (FAO, 2006)]. It was selected because it represented one of the major agricultural soil types of the Sydney Basin. The soil was sampled from the top 0–10 cm layer of soil at the site located near Camden south west of Sydney (150° 42′ 32″ E, 34°05′ 45.6″ S) by collecting more than 40 randomly located individual 1 kg spade full samples of soil to provide a 40 kg sample of moist soil for processing. The soil was then gently pushed through a 2 mm diameter sieve with any visible plant material and gravels being

Table 1
Recycled organic wastes and their basic chemistry.

Organic Waste	pHw	EC	Total OC (Dumas)	Total N (Dumas)	NH_4^+-N	NO_3^--N	C/N ratio
	pH units	dS/m	%	%	mg kg^{-1}	mg kg^{-1}	
Biosolids (GB)	5.9	4.9	31.72	4.90	2900	3.2	6.5
Cow manure—dairy (FCM)	8.5	5.6	36.20	2.94	26	4.1	12.3
Swine manure (FSM)	7.1	8.6	39.25	2.99	1300	1.8	13.1
Blood and bone (BB)	7.2	2.1	35.96	8.25	91	<0.2	4.4
Broiler litter (BL)	7.2	12	38.74	3.94	3200	650	9.8
Composted broiler litter (CBL)	7.1	11	36.02	3.95	4300	21	9.1
Dynamic lifter ® (DL)	6.5	17	30.57	3.45	6000	55	8.9
Composted cow manure—feedlot (PCM)	7.8	11	29.32	2.26	1000	8.6	13.0
Green waste compost (GCo)	7.3	2.9	26.24	1.27	26	4.5	20.7
Nitrohumus compost (NHCo)	6.7	3.0	24.14	1.34	300	400	18.0
MSW compost (MSW)	6.9	5.5	31.22	2.03	1100	2.7	15.4
Green waste char (GCh)	5.9	0.06	65.55	0.15	13	<0.2	432.4
Poultry Manure char (PMCh)	10	4.6	34.90[a]	2.22	3.5	<0.2	15.7
Pinewood shavings (PS)	4.7	0.77	46.37	0.11	11	<0.2	418.3
Wheat straw (WhS)	5.1	5.0	41.97	0.83	60	22	50.7

[a] Factoring out 18 g kg^{-1} carbonate C content.