Soil Biology & Biochemistry 65 (2013) 144–157

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Increased nitrogen availability in soil after repeated compost applications: Use of the PASTIS model to separate short and long-term effects

Maha Chalhoub [a], Patricia Garnier [a], Yves Coquet [b], Bruno Mary [c], François Lafolie [d], Sabine Houot [a,*]

[a] INRA, UMR 1091 INRA-AgroParisTech Environnement et Grandes Cultures, F-78850 Thiverval Grignon, France
[b] AgroParisTech, UMR 1091 INRA-AgroParisTech Environnement et Grandes Cultures, F-78850 Thiverval Grignon, France
[c] INRA, US 1158 Agro-Impact, F-02000 Barenton Bugny, France
[d] INRA, UMR1114 INRA-UAPV EMMAH, F-84914 Avignon, France

A R T I C L E I N F O

Article history:
Received 17 October 2012
Received in revised form
19 May 2013
Accepted 20 May 2013
Available online 10 June 2013

Keywords:
Nitrogen mineralisation
Compost
PASTIS model
Long-term
Organic matter stability
Field experiment

A B S T R A C T

Regular application of composts on cropped soils has been shown to restore soil organic matter contents. The effect of repeated applications of three urban composts on the nitrogen (N) dynamics in a cropped loamy soil was compared to farmyard manure application and a control receiving no amendment. Each amendment application brought on average 250–400 kg ha^{-1} of total N. After five applications, total organic N increased in amended soils from 9 to 27% compared to control and the increase of soil organic N corresponded to 32–79% of total N brought by the amendments. The PASTIS model was used to describe the N balance in the soil-plant system during the 2 years after a sixth amendment application and provided correct predictions of N dynamics in cropped plots. The N availability increased in all treatments receiving organic amendments. The N availability in the soils amended with urban composts or manure was predominantly driven by the biodegradability of the organic amendments, their mineral N content and by the cropping conditions. Composts with high biodegradability exhibited higher proportion of N recovery by plants (21% for the municipal solid waste compost) during the year following their application, while more stabilised composts (biowaste compost, co-compost of sludge and green wastes) increased the N availability mainly through the increase of soil organic N content and mineralisation after several compost applications (6–8% of the soil organic N increase). Mature composts behaved comparably to FYM, except that for FYM very little N from the last application was available. Regular compost applications equivalent to 200 kg N ha^{-1} every other year could increase N availability for crops of 50–70 kg N ha^{-1} over the 2 years of the crop rotation. However, the most stabilised composts led to a higher crop N recovery but also to potential higher amounts of leached N compared to less mature composts.

1. Introduction

The recycling of urban composts on cropped soils has been shown to restore soil organic matter contents (Peltre et al., 2012). The related increase of organic nitrogen (N) affects the N dynamics in soil. The progressive release of mineralised N from both soil and compost organic forms makes the assessment of N availability for crops difficult and raises the environmental risks of groundwater contamination related to leaching of an excessive or unbalanced supply of nutrients (Mamo et al., 1999). To improve the uptake of N by crops and reduce N losses through leaching remains a challenge (Singh et al., 2001). The N availability in composts depends on the stability of their organic matter, thus on compost maturity and on their physico-chemical characteristics. The carbon to nitrogen ratio (C/N) has been discussed as a relevant indicator of compost maturity (Cooperband et al., 2003) and has been commonly used to predict N availability. Composts with high C/N ratio (>15) often limit N availability due to immobilisation of N in the soil (Amlinger et al., 2003; Gutser et al., 2005). The N dynamics in soil after compost incorporation can also be affected by environmental conditions (e.g., soil type, climate) and management practices (e.g., rate and frequency of compost application, crop

* Corresponding author. Tel.: +33 130815401; fax: +33 130815396.
E-mail address: sabine.houot@grignon.inra.fr (S. Houot).

0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.05.023

rotation, etc), which makes the comparison of separate experiments difficult (Mamo et al., 1999; Wolkowski, 2003; Hartl and Erhart, 2005; Gutser et al., 2005). Long-term experiments contribute to a better understanding of the effect of repeated compost applications on N dynamics and N release from accumulated organic matter (Amlinger et al., 2003; Gutser et al., 2005). Modelling is a powerful tool to understand the complex interactions between agricultural practices and N dynamics in the soil–plant–water system and predict the potential environmental impacts such as N leaching after compost application (Gerke et al., 1999; Cabrera et al., 2005; Bruun et al., 2006).

Our study investigated the performance of different types of urban composts at increasing soil organic N and N availability for crops. The potential contamination of groundwater through mineral N leaching was also evaluated. The N dynamics after compost application was simulated with the soil–plant model PASTIS (Garnier et al., 2003), based on data from a long-term field trial in which the different urban composts were compared. The use of the PASTIS model made possible the distinction of the N fluxes that would have been impossible to measure at the field scale. The first objective was to investigate how the repeated applications of the composts increased the N availability for crops in soil and to distinguish between the short term direct effect related to the last compost application, and the longer term, related to the repeated previous applications and increased soil organic nitrogen stocks. The second objective was to relate the differences in N availability to the compost organic matter stabilities and chemical characteristics.

2. Materials and methods

2.1. Field experiment

A long-term field experiment located in Feucherolles (Yvelines, France) has been conducted since 1998 to characterise the benefits and potential environmental impacts of urban waste composts (Houot et al., 2002). Three different composts have been evaluated (Table 1): (i) a biowaste compost (BIO) resulting from the co-composting of green wastes and the source-separated organic fraction of municipal wastes; (ii) a municipal solid waste compost (MSW) made from mechanically separated organic fractions after selective collection of dry and clean packaging; and (iii) a co-compost of green wastes, wood chips and sewage sludge (GWS). The composting processes have been summarised in Table 1 and have been detailed in Annabi et al. (2007). The 3 composts were compared to farmyard manure (FYM), as a reference amendment, and to a control treatment without organic application (CONT). The soil was a silt loam Glossic Luvisol (FAO classification) and the main physico-chemical characteristics are described in Table 1S of the supporting information. The field experiment included 4 replicate blocks of the 5 organic treatments randomly distributed within each block. All plots (10 m $\times$ 45 m) were separated by 6-m-wide cropped bands and the blocks by 25-m-high cropped bands to avoid contamination between treatments during application. All treatments received additional mineral N fertilisation calculated on the potential N balance in the treatments (solutions of urea and ammonium nitrate, containing 39% nitrogen). The field was cropped with a winter wheat (*Triticum aestivum* L.) – corn maize (*Zea mays* L.) rotation. Composts and manure were applied on the wheat stubbles in early September of 1998, 2000, 2002, 2004 and 2006. In 2007, barley (*Hordeum vulgare* L.) was sown instead of maize, due to the presence of maize rootworm (*Diabrotica virgifera*). Additional organic application was performed in September 2007 on the barley stubble. All organic amendments were applied based on the same C rate, with an average of 4 Mg organic C ha^{-1} at each application (Table 1). The doses were 2–3 times larger than usually applied by the farmers. The organic amendments were incorporated to a depth of 14 cm by chisel ploughing the day after application. The N–NH_4 losses through ammonia (NH_3) volatilisation within the first 24 h after amendment application were measured using field-based wind tunnel trials in 1998, 2002, 2004 and 2006. These losses reached on average 4, 16, 18 and 53% of the N–NH_4 applied for BIO, GWS, MSW and FYM, respectively. The soil was ploughed every year in mid-October to mid-November to a depth of 30 cm with a four-furrow mouldboard plough.

Table 1
Physico-chemical and biochemical characteristics of organic amendments applied in September 2007 (mean of 3 replicates); information on the composting processes.

		GWS	MSW	BIO	FYM
Amount applied, Mg dw ha^{-1}[a]		16.6 (±2.9)	10.5 (±2.3)	16.2 (±5.1)	13.3 (±2.8)
Dry matter, g kg^{-1} fw		592.0 (±7.1)	454.6 (±1.9)	648.5 (±8.4)	356.4 (±14.5)
OC, g kg^{-1} dw		238.3 (±3.8) a*	359.3 (±6.4) c	228.7 (±5.0) a	274.7 (±4.2) b
ON, g kg^{-1} dw		21.3 (±0.5) bc	14.7 (±0.7) a	21.7 (±0.2) c	20.0 (±0.7) b
C/N		11.2 (±0.4) a	24.5 (±1.4) c	10.5 (±0.3) a	13.8 (±0.3) b
Mineral N[b], g kg^{-1} dw		4.0 (±0.2) c	7.0 (±0.1) d	3.3 (±0.1) b	1.4 (±0.0) a
Estimated volatilized N[c], g kg^{-1} dw		0.7	1.2	0.1	0.7
pH (in H_2O)		7.4 (±0.0) ab	7.0 (±0.4) a	7.6 (±0.0) b	9.3 (±0.0) c
Potentially Mineralized Carbon[d]	% Corg	16	56	10	15
Soluble fraction	% Corg	55	35	46	63
	C/N	7	13	7	11
Hemicellulose-like fraction	% Corg	4	7	8	0
	C/N	17	10	8	0
Cellulose-like fraction	%Corg	20	45	15	17
	C/N	28	53	17	48
Lignin-like fraction	%Corg	21	14	31	20
	C/N	18	27	18	14
Composting process					
Fermentation phase, days		42	30	35	
Maturation phase, days		90	0	60	

*Different letters between amendments for the same variable indicate significant differences at 5%.
[a] fw, fresh weight; dw, dry weight; OC, organic carbon content; ON, organic nitrogen content; C/N, organic C to organic N ratio.
[b] Mineral N was mainly N–NH_4 in amendments.
[c] N–NH_4 losses through ammonia (NH_3) volatilization within the first 24 h after amendment application. The volatilized N was measured in the field experiment.
[d] The excess mineralized carbon after 91 days in the soil–organic amendment mixtures was expressed as a percentage of the amendment organic C applied during incubation (after subtracting mineralized C of the control treatment).