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Potential nitrogen mineralization, plant utilization efficiency and soil CO_2 emissions following the addition of anaerobic digested slurries

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ABSTRACT

The liquid (LS) and solid fraction (SS) of a biogas slurry from dedicated crops, the composted solid fraction (CSS) and a municipal solid waste compost (MSWC) were compared in a soil incubation at 200 mg N kg^{-1}, to assess CO_2 emissions and potential C and N mineralization. Products were also compared for nitrogen apparent recovery fraction (ARF) in a pot trial with Italian ryegrass. LS showed the highest C mineralization (63.6%), soil mineral N (>100 mg kg^{-1}), and ARF (50.3%). SS showed 21.6% C mineralization, slight N immobilization (23.6 mg kg^{-1}) and 7.3% ARF. In CSS, a 5.1% C mineralization in soil added to 26.3% C loss during composting, resulting in 31.4% overall C loss. Moreover, composting SS to CSS curbed the emission from 4210 to 1100 mg CO_2 kg^{-1} soil, still double than the reference MSWC (507 mg CO_2 kg^{-1} soil). Despite high mineralization of supplied carbon, LS emitted less CO_2 than SS: 936 mg CO_2 kg^{-1} soil. It appears, therefore, that LS acts as a source of easily available nitrogen, while SS plays the role of an amendment with some limitations due to soil N immobilization. CSS mitigates N immobilization, but the composting process determines relevant CO_2 losses to the atmosphere.

1. Introduction

In the latest years, ever increasing attention to the waste management chain and to the control of energy consumption has promoted the use of renewable sources for energy production. As indicated by the European directive 2009/28/EC [1], this represents an important strategy to reduce greenhouse gas emissions, to comply with the Kyoto Protocol and subsequent international greenhouse gas (GHG) legislation. The EU aims at reducing the amount of landfilled organic waste, in order to save soil areas and reduce landfill contribution to climate change in terms of GHG emissions. Composting and more recently anaerobic digestion represent effective ways to reduce the amount of organic wastes to be properly disposed, curbing potential CO_2 and CH_4 emissions through processing under controlled conditions. Anaerobic digestion can successfully be used for biogas production; this process is strongly supported by many governments as a means to decrease global CO_2 emissions [2]. In this frame, the number of composting and biogas plants has increased in the last decades in the EU and in Italy. Agricultural and animal by-products (crop, market and transformation residues; animal manure and slurries) are valuable feedstocks for the production of biogas, ultimately of methane (CH_4). In recent

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years, dedicated crops have increased in importance for biogas production, even if they are limited to 15% of the total farm crop production, in order to reduce the competition for land with food crops [1,3]. Within the European Union, biogas production increased six-fold from 1990 to 2005 [4] and reached 7.5 million tons of oil equivalents in 2008 [5]. In Italy, there were 672 operating plants and 76 under construction, as of 2010 [6]. Following this great increase of anaerobic digestion plants, a great amount of biogas residues are becoming available.

It is widely recognized that the reintegration of treated (digested, composted or both) organic wastes into the soil, as an alternative to land filling, is a potential solution of the waste management problem that can preserve soil fertility [7,8]; these products are valuable sources of nutrients for plants and contribute to maintain the soil organic matter status [9]. In literature, many are the researches focussing on the nutrition capacity of biogas sludges [7,9,10], or evaluating the potential GHG emission after soil incorporation [11], and the mineral nitrogen availability after soil incorporation [9–11]. Conversely, few informations are available about the course of soil mineral nitrogen, N plant recovery and soil CO_2 emission after the application of a biogas slurry as it is or following composting. To study these aspects, in vivo pot trials and soil incubation tests are generally carried out. For the N recovery study, Italian ryegrass (*Lolium multiflorum*) appears to be one of the most suitable candidates since is a fast growing species, showing a high N requirement over multiple cuts in a limited (3–4 months) time frame [9].

To address the open issues concerning C and N soil dynamics following slurry incorporation and the effects on plant nutrition, soil incubation and plant growth experiments were set up. To this aim, a biogas slurry mechanically separated into the liquid and the solid (fibrous) fraction was collected from an anaerobic digestion plant; part of the solid fraction was composted and all these products were compared with a reference municipal solid waste compost and with no product addition in a soil incubation, to assess potential nitrogen mineralization and CO_2 emissions. In parallel to this, the same treatments were compared in a pot trial to assess plant nitrogen recovery. In the latter experiment, a chemical fertilizer (Urea) was added as a reference.

2. Materials and methods

2.1. Soil and amendments

The soil used for the pot trial and incubations was collected from a field in the experimental station of the University of Bologna at Cadriano (Bologna, Italy; 44°33′ N, 11°21′ E, 32 m a.s.l.), at the 0–0.2 m depth. The soil was air-dried, then the aliquot for the pot trial was crushed at 5 mm and homogenised, while the aliquot for soil incubation was ground at 2 mm and analyzed. The following physical–chemical traits were assessed: pH (H_2O 1:2.5), 7.95; particle-size distribution, 24% sand, 47% silt, 29% clay; total organic carbon (TOC), 6.12 mg g^{-1}; total kjeldahl nitrogen (TKN), 0.93 mg g^{-1}; C/N, 6.58; P – Olsen [12], 113 mg kg^{-1} as P_2O_5; exchangeable K [13], 174 mg kg^{-1} as K_2O.

The biogas slurry was collected from a local biogas plant after 62 days of wet fermentation at 50 °C. The slurry was mechanically separated (screw-press) into the liquid (LS) and solid slurry (SS) fractions. An aliquot of about 80 L of SS was composted over 60 d in a 0.5 m × 0.5 m × 1 m (250 L) polystyrene box (composter) provided with a metal grid at 10 cm from the bottom. The aeration was ensured by forced-air ventilation through a pipe inserted in the polystyrene between the bottom and the grid, at a flow rate of 250 mL min^{-1}. The active phase of composting lasted 21 d under continuous aeration: the organic material reached 26 °C after 3 d from the beginning, and the mesophilic stage was 5–6 d long; the compost never reached a proper thermophilic range. During the active phase, the mass was hand-mixed four times (i.e., about every five days). The maturation phase lasted for an additional 30 days at 25 ± 2 °C in a climatic chamber. During this period, the mass was hand-mixed every other week. A composted solid slurry (CSS) was finally obtained. At the beginning and at the end of the composting process the mass was weighed and sampled to determine the total solids, the TOC content and the consequent reduction in the carbon content during stabilization. In parallel to this, two kg of a 90-day old municipal solid waste compost (MSWC) were collected from a local composting plant and sieved at 8 mm. All fresh products (LS, SS, CSS and MSWC) were analyzed for pH, electric conductivity (EC; H_2O 1:10), NH_4^+-N, NO_3^--N and moisture content. Then the solid products were air-dried and ground at 2 mm, in order to reduce the particle-size effect in the incubation and plant growth experiment. Air-dried ground samples were then analyzed for the main physical–chemical parameters. On the three air-dried products and on LS, moisture content was determined on 5 g of samples at 105 ± 2 °C until constant weight (48 h), the volatile solid (VS) content was determined on the total solids (TS) at 550 °C for 4 h; TOC was determined by the dichromate oxidation method; TKN by the Kjeldahl method after hot H_2SO_4 digestion; NH_4^+-N and NO_3^--N were extracted on 10 g of sample with 100 mL of 2 M KCl for 2 h at 120 reciprocations per minute (rpm) in a horizontal shaker; the solution was filtered on Whatman (#42) and analyzed by means of an Autoanalyzer Technicon II, Bran + Luebbe. The total nutrients and heavy metals contents were determined by ICP (Inductively Coupled Plasma-OES, Spectro Arcos, Ametek,) on 2 g of samples after hot digestion with 65% HNO_3. Main physical–chemical characteristics of organic products are reported in Tables 1 and 2.

2.2. Soil incubation experiments

The air-dried, ground soil was pre-incubated at 60% of water holding capacity (WHC) for 4 weeks at 25 °C in the dark, being weekly mixed prior to setting up two separate C and N incubation experiments. To test nitrogen mineralization, 200 g of pre-incubated soil were placed in 500 mL plastic vessels, then the four products (LS, SS, CSS and MSWC) were added at the rate of 200 mg kg^{-1} of TKN. Four replicates of each treatment were set up in a completely randomized block design in addition to an unfertilized control, totalling 20 vessels. These were incubated in the dark for 112 days at 25 °C; during the incubation soil moisture was checked every 2–3 days by weighing and restored at 60% WHC whenever needed, drop by