

Organic carbon and nitrogen evolution in soil after application of digestates: influence of digestate origin and post-treatment

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Abstract

Anaerobic digestion is a biological treatment process where organic wastes are degraded in anaerobic conditions to produce biogas. Many sources of organic wastes can be treated such as food wastes, industrial organic wastes, animal manures and crop residues. After anaerobic digestion, the residual organic fraction, so-called digestate, can be further used on cropped soils.

After anaerobic digestion, the digestates can be post-treated by phase separation to collect the solid fraction, then additional composting. In this study, 14 digestates from different origins were sampled either directly after anaerobic digestion or after post treatment. The carbon (C) mineralisation and nitrogen (N) evolution (mineral nitrogen evolution in soil and N₂O emission) were measured after application on soil in laboratory controlled conditions.

The digestates remained rather biodegradable with 20 to 75% of organic carbon mineralized after 6 months of incubation. The non-post-treated digestates were the less stabilized and the composted ones the most stabilized. 22% to 88% of total nitrogen was present as mineral NH₄ form in the digestate which means high nitrogen availability but also high risk of NH₄ volatilization. The organic fraction presented C/N ratio varying from 11 to 35, explaining the organization of mineral N after digestate application. Finally the emission factors of N₂O vary from 0.002 to 0.024.

Introduction

Anaerobic digestion is a biological treatment process where organic wastes are degraded in anaerobic conditions to produce biogas used to generate energy and a nutrient rich by-product: the digestate. Digestates are usually characterized by high readily available nitrogen levels [1]; and can be used to partially substitute mineral nitrogen fertilization [2]. However, the possible loss of N through N₂O emission after digestate application may compensate the benefits of mineral N substitution.

Losses of mineral N through NH₄ volatilization may also decrease the value of digestate as fertilizer. The digestates can either be applied directly to land or be post-processed before application; yet, the interaction between post-processing and N availability for plants remains insufficiently understood. It is also important to evaluate the stability of the organic carbon of the digestates to determine whether their application could contribute to carbon storage in soils. On the other hand, the properties of digestates may differ according to the feedstock used in the anaerobic digestion process and the following process they undergo [1].

The objectives of this work were to evaluate the stability of the organic carbon of digestates and to evaluate how potential mineral N availability and N₂O emission were influenced by the origin of the digested wastes and the applied post-process.

Material and methods

Digestates:

Five digestates were sampled in February 2012: two digestates of agricultural origin (AGRI1 and AGRI2), two digestates of source separated biowastes (BIOW) or of household wastes collected after separation of dry and clean packaging (HW) and a digestate of a territorial mixture of wastes (TERR).

The digestates were sampled immediately after anaerobic digestion (raw digestate) or after separation of liquid and solid phase (so-called liquid and solid digestates). In all cases, the raw, solid and liquid digestates were sampled and characterized. Additionally, the solid BIOW was composted. All the digestates were analysed for their main physico-chemical characteristics at IRSTEA Rennes (tab1).

Table 1: Physico-chemical characteristics of the digestates (R: raw; S: solid; L: liquid; C: composted. FM: fresh matter; DM: dry matter)

| | AGRI 1 | | | AGRI 2 | | | BIOW | | | | TERR | | | HW |
|------------------|--------|------|------|--------|------|------|------|------|------|------|------|------|------|------|
| | R | S | L | R | S | L | R | S | L | C | R | S | L | R |
| pH | 8.0 | 9.5 | 8.0 | 7.7 | 9.4 | 7.8 | 7.9 | 8.6 | 8.5 | 8.4 | 8.2 | 9.0 | 8.4 | 8.5 |
| DM (% FM) | 17.4 | 25.4 | 12.2 | 5.5 | 23.0 | 3.8 | 18.1 | 43.7 | 4.8 | 47.5 | 5.0 | 23.9 | 1.6 | 25.5 |
| Total C (% DM) | 27.8 | 31.1 | 28.6 | 50.1 | 40.9 | 41.7 | 33.2 | 36.0 | 41.5 | 22.1 | 52.0 | 33.3 | 61.9 | 32.0 |
| Total N (% DM) | 3.5 | 1.9 | 5.9 | 7.2 | 2.0 | 10.3 | 2.3 | 1.1 | 9.2 | 1.5 | 14.5 | 4.0 | 34.8 | 2.0 |
| mineral N (% DM) | 1.9 | 0.5 | 3.5 | 4.8 | 0.7 | 7.0 | 1.1 | 0.1 | 5.5 | 0.1 | 10.3 | 1.3 | 29.7 | 0.7 |
| organic N (% DM) | 1.6 | 1.4 | 2.5 | 2.4 | 1.3 | 3.3 | 1.2 | 1.0 | 3.7 | 1.4 | 4.3 | 2.6 | 5.2 | 1.2 |

Measurement of carbon mineralization and mineral nitrogen evolution during laboratory incubation:

The organic carbon mineralization and mineral N evolution were measured during six months incubation of a mixture of the equivalent of 90g of dry soil and 10g of fresh undried digestate, in controlled laboratory conditions at 28°C and a constant humidity equivalent to 85% of field capacity. All the incubations were run in four replicates. The CO₂ was trapped in 10 mL of 0.5 N sodium hydroxide periodically replaced and analysed by colorimetry on a continuous flow analyser (SKALAR the Netherlands). The mineral nitrogen was periodically extracted with 400 mL of 1 M potassium chloride during 1 hour. The mineral N was analysed in the supernatant by colorimetry on a continuous flow analyser (SKALAR the Netherlands). All jars were opened at the sampling dates for C-CO₂ ensuring the incubation to be run under aerobic conditions.

N₂O emission

During 3 months, we measured the N₂O emissions: in triplicate cylinders of 15cm diameter, 1.7kg of soil was mixed with enough digestate to provide the equivalent of 170kg N.ha⁻¹. 2 control treatments were added: soil alone and soil+urea+ammonitrate (UAN). The samples were saturated with water to promote N₂O production by denitrification process. The cylinders were kept at 20°C and constant humidity. Regular measurements of N₂O fluxes were performed by keeping the cylinders for 2minutes each one in a sealed incubator connected to a gas analyser with high performance spectrometer (QCL).

Results and discussion

Carbon mineralization

The less stabilized digestate was the liquid AGRI2 with 73% of carbon remaining easily biodegradable (tab2), followed by the raw TERR with 64% of organic carbon biodegradable. The two digestates issued of household wastes, except the liquid BIOW, were more stabilized with only 22 to 32% of organic carbon easily biodegradable. The different levels of stability can probably be explained by the origin and composition of the digestates but not with the digestion time that was less important for the BIOW than for the digestates of agricultural origin for example.

The phase separation generated two different products with uneven levels of biodegradability. The liquid phases were more biodegradable than the solid phases and even than the raw digestates (tab2).

The post-processing by composting increased the stability of the organic matter of digestate with only 22% of carbon easily biodegradable in the BIOW compost.

After anaerobic digestion, the solid phase contained the stabilized organic matter, the liquid phases remaining highly biodegradable. The organic matter has been stabilized during anaerobic digestion [3]; these results confirm also that post-processing (by phase separation and composting) provides a more stable product that can be used in agriculture [4, 5].

Table 2: Easily biodegradable C and available N from digestates after six months of incubation

| | AGRI 1 | | | AGRI 2 | | | BIOW | | | | TERR | | | HW |
|--|--------|----|----|--------|-----|----|------|----|-----|----|------|----|-----|----|
| | R | S | L | R | S | L | R | S | L | C | R | S | L | R |
| easily biodegradable C (%totalC) | 51 | 50 | 49 | 54 | 44 | 73 | 31 | 28 | 53 | 22 | 64 | 40 | 147 | 32 |
| available N (% Ntot) | 71 | 13 | 51 | 81 | 60 | 71 | 64 | 11 | 69 | 16 | 49 | 47 | 75 | 41 |
| available N (% initial N-NH ₄) | 95 | 49 | 89 | 98 | 100 | 82 | 91 | 57 | 100 | 72 | 70 | 77 | 58 | 71 |
| available N (kg N/ton DM) | 23 | 5 | 29 | 50 | 11 | 65 | 12 | 1 | 58 | 2 | 78 | 17 | 194 | 7 |

Nitrogen evolution

All digestates were characterized by high contents of ammonium. The high contents of mineral N confirmed the possible use of anaerobic digestates as mineral fertilizers [2].

During the first two weeks of incubation, the ammonium (NH₄) contents decreased because of nitrification and the nitrate increases were equivalent to NH₄ decrease leading to a rather constant total mineral N during the incubation (Fig. 1a). In some cases, the total mineral N tended to decrease, either because of partial volatilization of NH₃ or because of mineral N organization related to the decomposition of the organic fraction of the digestate (Fig. 1b).

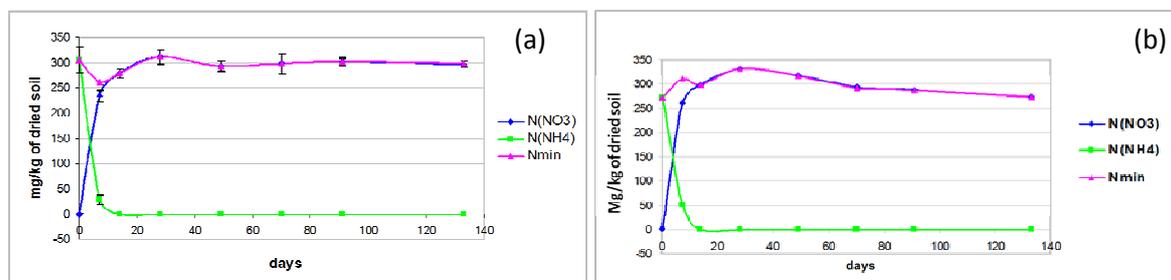


Figure1: Mineral nitrogen evolution during soil-digestate incubation

In all cases, the mineralization of organic N was very slow and in most cases we observed organization of N (fig2) except with the liquid AGRI1 and the HW. When organization was observed, it started soon after the starting of the incubation and remained till the last days of the incubation where positive mineralization was observed again. The available N in the end of the experimentation varied from 1 to 194kgN/ton dried matter, depending on the digestate; the liquid digestates had higher levels of available N than the raw and the solid ones.

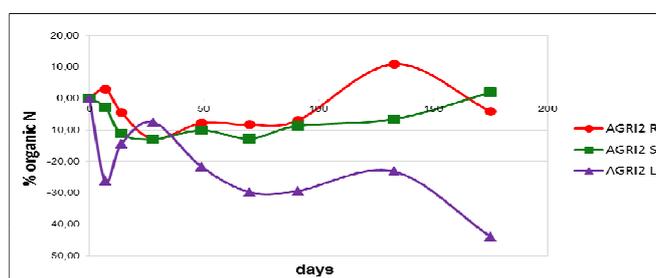


Figure2: Dynamic of organic nitrogen mineralization during soil incubation for the 3 digestates AGRI2

The N organization can be explained by the remaining of highly biodegradable carbon in the digestates that accelerated the multiplication of soil microorganisms that used the available N (mineral N) to ensure their functioning.

Nitrous oxide emissions

During the three months of incubation we observed high levels of nitrous oxide emissions of the digestates compared to the mineral fertilizer (UAN), especially the raw agricultural digestates (tab3). These levels differed among the digestates, depending on the origin and especially on the state of this one (raw, solid or liquid).

Table 3: N₂O emission factors of digestates (N-N₂O/total N applied)

| | Agri 1 | | | Agri 2 | | | TERR | | | UAN |
|----------------------------------|--------|-------|-------|--------|-------|-------|-------|-------|-------|-------|
| | R | S | L | R | S | L | R | S | L | |
| N ₂ O emission factor | 0.024 | 0.006 | 0.003 | 0.011 | 0.002 | 0.004 | 0.008 | 0.006 | 0.004 | 0.003 |

The raw digestates of agricultural origin (AGRI1 and AGRI2) presented the highest factors of N₂O emissions compared to the other digestates and the mineral fertilizer.

It seemed that phase separation decreased the N₂O emissions since N₂O emission factors were much lower after spreading of liquid or solid digestates compared to non-separated digestates (raw

digestate). The example of AGRI2 is presented in figure 3. This pointed out the interest of phase separation in decreasing the environmental impacts of these products after their application on soil, especially for the liquid phase that presents a high fertilizing value with a low emission factor of N₂O.

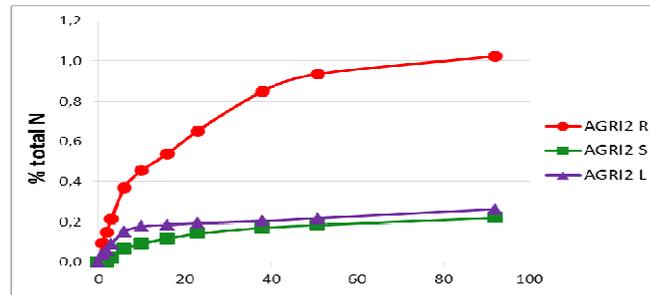


Figure 3: N₂O emissions

Conclusion and perspectives

The results obtained in this study showed that the biological stability of digestates depended on their origin and digestion process. Post-treatments through phase separation separated a still biodegradable fraction from a more stabilized one and composting increased the solid digestate stability. This may lead that the application of such digestates on soil can be used to increase the stock of soil carbon. However the solid and composted digestates had the lowest proportions of available N.

On the contrary, the raw and liquid digestates were rich in mineral nitrogen. In fact, except for the HW and BIOW raw digestates, these products provided from 23 to 194 kg mineral N/ton DM to the soil, thus confirming the high fertilizing value of these products and the possibility of substitution of mineral fertilizers by anaerobic digestates. The entire available N apparently came from the mineral fraction of the digestates (tab2), with a fast nitrification of the initial ammonium content. Apparently organic N mineralization was rather low and even led to transitory organisation into the microbial biomass, explained by the high levels of carbon and C/organic N ratio in these products. Thus it will be very important to prevent ammonia volatilization after application of digestates on soils in order to preserve the available N.

Once applied on soil, the raw digestates led to relatively high factors of N₂O emissions that post-processing by phase separation decreased. Anaerobic digestion followed by phase separation can accordingly provide solid stabilized products that can be used mainly as organic amendments with rather low availability of N and liquid phases that can be used as substitute for mineral N fertilizer with similar environmental impacts than mineral N fertilizer.

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Acknowledgments

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