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Original article

Synergistic and antagonistic interactions among organic amendments of contrasted stability, nutrient availability and soil organic matter in the regulation of C mineralisation

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A B S T R A C T

Organic amendments to agricultural soils may increase soil organic matter reserves. However, manure amendment may stimulate soil microbial activity and soil organic matter decomposition. The stability of manure and soil organic matter and the availability of nutrients are crucial for the regulation of soil organic matter decomposition. Therefore, we aimed to study the effects of adding stabilised or unstabilised manures combined with mineral nutrients ($N-NO_3$, $P-PO_4$, K and $S-SO_4$) on carbon mineralisation in two agricultural (sandy loam) soils with contrasted organic matter stocks and N availability. These two soils were incubated alone and after adding unstabilised farmyard manure (FYM) or stabilised manure (compost), combined with the addition of mineral nutrients. Mineralisation of C (CO_2 evolution) increased after FYM addition while it decreased after compost addition as compared to the control soils. When mineral nutrients were added to soils amended with FYM, C mineralisation synergistically increased only in soils with low nitrogen availability. In these soils, the addition of nutrients may promote the mobilization of soil C, while in soils with high N availability the synergistic mobilization of C on adding FYM may be reduced. In contrast, the depressed C mineralisation after the addition of compost was little affected by nutrient availability. We suggest that recalcitrant compounds in compost may be stabilised in soil particles and humic substances with little effects of nutrient availability. In contrast, the incorporation of FYM was mainly driven by microbial transformations and affected by nutrient availability. Finally, we conclude that the application of stabilised organic matter may be a good practice for the built up of humus in a wide range of arable lands with particular significance for land reclamation in organic matter depleted soils.

1. Introduction

Soil organic matter (SOM) plays a key role in agricultural systems by improving soil structure and favouring nutrient retention and cycling. Thus, the maintenance or enhancement of soil carbon stocks can be beneficial for crop productivity. In this context, there is a need to identify land management practices that enhance the mean residence time of the SOM pools by increasing resistance against microbial decomposition [1]. It is widely believed that the input of organic matter can enhance SOM stocks [2,3]. However, only a small proportion of the added organic matter can be retained in the soil over the mid-to long-term [3]. The amount of C remaining in the soil after organic amendments is dependent on the quality of the organic sources [4]. While the use of recalcitrant sources of organic matter may favour soil organic carbon (SOC) stocks [5], the addition of labile organic matter may decrease SOC stocks, as it may quickly decompose and stimulate the decomposition of native soil organic matter [6].

The use of stabilised manures such as compost was common in traditional agriculture. Nowadays, compost is mostly used in biodynamic and in some organic farming systems [5]. By contrast, the organic matter applied in most conventional croplands is not stabilised (uncomposted). Stabilised manures play a long-term role in building soil fertility and SOC stocks [7,8], and may contribute to controlling weeds, pests and diseases due to their chemical and

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biological properties [9–11]. The chemical nature of organic C in soils amended with stabilised sources of organic matter have been found to be enriched with recalcitrant components such as lignin and alkyl-C [12]. As these recalcitrant components in the soil environment may also decompose at low rates, it is not clear whether this enrichment will also occur in the long run in soils amended with recalcitrant C. The stabilisation of N forms during composting may reduce N mineralisation rates in soils amended with compost [13,14]. In contrast, N mineralizes more readily in soils amended with unstabilised manures [15]. Consequently, unstabilised manures appear to be more suitable for supplying N to plant and soil microbes in the short-term [16] although this may not always be the case [17] as N could be immobilised by soil microbes. On the other hand, the addition of mineral nutrients can also affect soil microbial processes and thus C and N mineralisation rates [18].

C mineralisation is mediated by soil microorganisms and depends upon the availability of labile sources of C and nutrients. However, it is not clear to what extent the regulation of this process relates to the characteristics of soil organic matter and nutrient availability or to the structure and size of the soil microbial community [19]. The application of fresh and composted organic waste can modify the size, structure and activity of the soil microbes [20]. However, the regulation of C mineralisation could still rely on the availability of labile sources of organic C and nutrients [21].

From a functional point of view, soil microorganisms can be divided into two groups. The first group, known as autochthonous microorganisms (K-strategists), is adapted to the use of recalcitrant sources of C, while the second group, named zymogenous microorganisms (r-strategists), is adapted to the use of more labile organic matter sources [22,23]. According to this distinction, the composition of microbes in soils and manures will depend upon the recalcitrance of the organic C, which in turn will be affected by the amount and quality of the organic input and stocks. The input of labile, easily usable C sources to soils can increase rates of mineralisation of the more recalcitrant native SOM [24,25] and likely results from the impact of labile-C sources on the soil microbial biomass activity and represents a transient increase in the decomposition rate of the protected soil organic matter. Thus, it is very important to find out whether the application of exogenous refractory or labile C compounds in the soil is a key factor in the net storage and sequestration of soil carbon [26]. Alternatively, high soil nutrient availability may reduce soil C mineralisation [27–29]. If this is the case, high nutrient availability may favour the retention of recalcitrant C pools [28].

Soil organic matter (SOM) retention may depend on the quality of organic C pools and on the availability of nutrients. In this study we have selected two agricultural soils, one low organic matter soil with high mineralizable N and one high organic matter soil with low mineralizable N. In this context, we hypothesized that the addition of unstabilised organic matter sources would greatly enhance microbial activity and, as a result, transiently increase C mineralisation, particularly when microbial activity is not limited by nutrients. In contrast, the addition of stabilised sources would not enhance microbial activity and thus, in this case, C mineralisation will be less dependent from nutrient availability. The aims of this study are to investigate the effects of adding stabilised and unstabilised manures combined with mineral nutrients on C mineralisation and on the size and activity of the microbial biomass in two agricultural soils with contrasted organic matter stocks and N availability.

2. Material and methods

2.1. Characterization of soils and manures

Soil samples were obtained from two arable systems in Central Catalonia (NE Spain, high organic matter soil: Latitude = 41° 42′ 19.92″N, Longitude = 1° 50′ 14.94″E; low organic matter soil: Latitude = 41° 42′ 49.28″N, Longitude = 1° 47′ 38.73″E). The local climate is Mediterranean with a mean annual temperature of 14.1^{O}C and mean annual precipitation of 551.1 mm. Both soils are coarse-textured (sandy loam) and are classified as *Calcic regosols*. The physical and chemical characteristics of the studied soils are shown in Table 1. At sampling time, the high organic matter soil (HOM) had been fertilised only with composted dairy manures for at least the last 10 years. The low organic matter (LOM) soil had been amended with labile organic matter sources, such as swine slurry and some fresh poultry manure over the last decade. These soils show much higher mineralizable N than the HOM soil (Table 1). Yearly exogenous organic C and N inputs to the studied soils are presented in Table 2. Eight soil samples (0–10 cm) were obtained from each field with a volumetric auger and were bulked to one sample per field. Soils were stored at 4 °C in dark conditions and sieved (4 mm) to minimize the breaking of aggregates prior to incubation and analyses.

From a local farm in the area, we collected a sample of farmyard manure that was composted for more than six months (stabilised manure; Compost) and fresh farmyard manure that was obtained directly from the top layer of the sheep stable (unstabilised farmyard manure; FYM). Both organic amendments were air-dried and then ground in a MM400 Mixer Mill (Retsch) to reduce the heterogeneity and to ensure its incorporation into the soil sample prior to lab incubation. The chemical properties of manures are shown in Table 3. Total C and N from the organic amendments and soils were determined in a Carlo Erba NA-1500 elemental analyser. Soil organic carbon was determined by $K_2Cr_2O_7$ oxidation [30] and soil organic N was calculated by the difference between total soil nitrogen and soil inorganic N. Mineral nitrogen was extracted with 2 M KCl (1:5 soil:extractant ratio). Nitrate was determined by ultraviolet spectrometry at 220 and 275 nm [31]. Ammonium N was determined in the filtrates by the phenate method and quantified at 640 nm using a CECIL (CE7200; Cecil Instruments) spectrophotometer [32]. Mineralised N was determined as the difference in mineral N before and after the 33-day incubation of soils (see below). Cation exchange capacity was determined by extracting exchange cations with $BaCl_2$ and triethanolamine (TEA) at pH 8.1 [33].

2.2. Sample preparation and incubation

To avoid disturbance effects (i.e. soil storage), all soils were pre-incubated for 12 days and then they were either amended or not. Soils amended with manures were enriched with 4 mg C g^{-1} of dry

Table 1
Chemical, biological and physical soil properties of high organic matter and low organic matter topsoil samples (0–10 cm).

	High organic matter soil	Low organic matter soil
Organic C (%)	2.49	1.23
Carbonates (%)	4.12	4.26
Organic N (%)	0.19	0.15
C/N	12.90	8.20
pH	7.59	7.79
Mineralised N (mg kg^{-1})[a]	9.54 ± 2.13	21.96 ± 2.76
K (cmolq kg^{-1})	1.36	1.25
Ca (cmolq kg^{-1})	6.57	4.6
Mg (cmolq kg^{-1})	1.24	1.24
Na (cmolq kg^{-1})	0.04	0.07
CEC (cmolq kg^{-1})	9.22	7.16
Texture (% clay/silt/sand)	19/15/66	15/14/71

[a] Mineralised N after a 33-day incubation.