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Short-Term Response of Soil Microbial Biomass to Different Chabazite Zeolite Amendments

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ABSTRACT

Zeolitites (ZTs) are rocks containing more than 50% of zeolite minerals and are known to be a suitable material for agricultural purposes by improving soil physicochemical properties and nitrogen (N) use efficiency. However, little is known about their effects on soil microbial biomass. This study aimed to evaluate short-term effects of different chabazite-rich ZT (CHAZT) amendments on soil microbial biomass and activity. A silty-clay agricultural soil was amended in three different ways, including the addition of natural (5% and 15%) and NH_4^+-enriched (10%) CHAZT. Soil dissolved organic carbon (C), total dissolved N, NH_4^+, NO_3^-, NO_2^-, microbial biomass C and N, and ergosterol were measured periodically over 16 d in a laboratory incubation. To verify the microbial immobilization of the N derived from NH_4^+-enriched CHAZT, a high ^{15}N source was used for enriching the mineral to measure the microbial biomass $\delta^{15}N$ signature. An increase in the ergosterol content was observed in the soil amended with 5% natural CHAZT. However, no similar result was observed in the soil amended with 15% natural CHAZT, suggesting that the fungal biomass was favored at a lower CHAZT application rate. In the soil amended with NH_4^+-enriched CHAZT, microbial biomass N was related to NO_3^- production over time and inversely related to NH_4^+, suggesting high nitrification process. Isotopic measurements on microbial biomass confirmed immediate assimilation of N derived from NH_4^+-enriched CHAZT. These results suggested that the NH_4^+-enriched CHAZT used in this study supplied an immediately available N pool to the microbial biomass.

Key Words: ergosterol, microbial biomass $\delta^{15}N$, natural zeolite, NH_4^+-enriched zeolite, nitrification, slow-release fertilizer

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INTRODUCTION

The application of organic and inorganic amendments has been recognized as a possible method for improving soil physicochemical properties and fertility (Waltz *et al*., 2003; Lima *et al*., 2009; Colombani *et al*., 2014). Among them, natural zeolite-bearing rocks are known to be a suitable material for agricultural purposes owing to their very high cation exchange capacity (CEC), reversible dehydration, and molecular sieving properties (Reháková *et al*., 2004; Passaglia, 2008; Misaelides, 2011). Zeolites are aluminosilicates with an open three-dimensional framework, which delimits channels and cavities where different kinds of polar and non-polar molecules can be exchanged, involving both inorganic and organic compounds, with a particular affinity to NH_4^+ (Reháková *et al*., 2004). Furthermore, zeolites can be easily modified from their natural state by enrichment processes, which cause the adsorption of specific cations, *e.g.*, NH_4^+ and Na^+ (Dittert *et al*., 1998; Leggo, 2000; Faccini *et al*., 2015).

Since natural chabazite (CHA) zeolites are less abundant than clinoptilolites worldwide (Passaglia, 2008), the latter have been investigated in the majority of agricultural and environmental studies. Chabazite zeolites are commonly found in volcanoclastic deposits, especially in the Italian Peninsula, where many quarries are exploiting zeolite-rich tuffs for the production of construction bricks (Passaglia, 2008). These tuffs are generally dominated by potassium (K)-rich CHA, and

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thus can be classified as zeolitites (ZT) with a high zeolite content (> 50%) (Galli and Passaglia, 2011). During the cutting process of these construction bricks, a high amount of zeolite-rich material remains unused, constituting a waste for the quarry. However, it is an interesting and precious granular by-product, which can be used for many purposes, including the use as a soil amendment as demonstrated by the ZeoLIFE project, European Union (LIFE10 ENV/IT/000321) (Ferretti *et al.*, 2017a).

The use of different kinds of natural and enriched ZTs as a soil amendment has been studied extensively in terms of modification of the soil physicochemical characteristics (Passaglia, 2008; Colombani *et al.*, 2015, 2016), reduced N leaching, increased N use efficiency, increased water use efficiency, and improved crop yield (Reháková *et al.*, 2004; Sepaskhah and Barzegar, 2010; De Campos Bernardi *et al.*, 2013; Gholamhoseini *et al.*, 2013; Li *et al.*, 2013; Di Giuseppe *et al.*, 2016). Some studies have defined NH_4^+-enriched ZT as a slow-release fertilizer, where NH_4^+ is released slowly over time and becomes available for plant uptake, thus reducing potential N losses (Barbarick and Pirela, 1984; Lewis *et al.*, 1984; Dwairi, 1998). Except for a few studies such as Mühlbachová and Šimon (2003), the effects of ZT amendments on the soil microbial biomass (MB) are mostly unexplored. Concerning amendments with NH_4^+-enriched ZT, Leggo (2000) carried out an investigation of plant growth in an organo-zeolitic substrate and observed an increase in NO_3^- after the use of natural clinoptilolite enriched by composting with poultry manure. He concluded that the Ca^{2+} present in the soil solution has probably been exchanged with the NH_4^+ adsorbed by the zeolites, making it immediately available to nitrifier microorganisms. However, this outcome is contradictory to the view of NH_4^+-enriched ZT as a slow-release fertilizer. To the best of our knowledge, no studies exists on the effects of natural and NH_4^+-enriched CHA-rich ZT (CHAZT) amendments on soil MB.

The present study aimed to investigate the effects of different typologies of CHAZT amendments on soil MB and C-N dynamics over a short-term period. To this end, this study was designed to simulate the conditions occurring in the ZeoLIFE experimental field (ZeoLIFE project), an ongoing field-scale experimentation, in which natural and NH_4^+-enriched CHAZTs are being tested at the field scale (Ferretti *et al.*, 2017a). We hypothesized that: i) amendments with CHAZT at natural state will reduce N availability to soil MB in a short-term period owing to their high CEC and NH_4^+ affinity, thus favoring the development of fungi rather than bacteria due to the lower nutrient requirement of fungi (McGill *et al.*, 1981; Strickland and Rousk, 2010) and ii) NH_4^+-enriched CHAZT, acting as a slow-release fertilizer once added to soil, will not affect soil MB in the short-term period.

MATERIALS AND METHODS

Soil sampling

Soil samples were collected during spring 2015 from the ZeoLIFE project experimental field, consisting of a 6-ha agricultural field where different CHAZT amendments are being tested since 2012. The field is located in the Po River Delta Plain near Codigoro Town in Ferrara Province, Italy (44°50′33″ N, 12°05′40″ E), and lays on clayey-silty soil of alluvial origin classified as Calcaric Gleyic Cambisol (Di Giuseppe *et al.*, 2014; IUSS Working Group WRB, 2014). The experimental field has been subdivided into different plots (0.5–1.5 ha) in which both natural and NH_4^+-enriched CHAZTs have been applied in various amounts (5–15 kg m^{-2}). Soil samples for this study were collected from an unamended parcel from the top 0.3-m depth layer and amended with different types of CHAZTs in the laboratory immediately before the beginning of the experiment in order to reproduce the short-term effects of zeolite application. Approximately 5 kg soil was brought to the laboratory immediately after sampling, sieved to < 5 mm and air-dried. Main soil characteristics are given in Table I, and soil mineralogical composition has been reported in Malferrari *et al.* (2013). The soil is mainly characterized by quartz, illite, chlorite, K-feldspar, plagioclase, calcite and amorphous residues, thus lacking of clay minerals with very high CEC (*e.g.*, smectite).

TABLE I

Basic properties of the soil used in this study

Property[a]	Value
pH	7.6 ± 0.2[b]
EC (mS cm^{-1})	1.0 ± 0.1
$CaCO_3$ (g kg^{-1})	64.5 ± 3.5
CEC (mmol kg^{-1})	325 ± 1
TN (g kg^{-1})	2.33 ± 0.31
TOC (g kg^{-1})	22.76 ± 3.20
TOC/TN ratio	9.76 ± 0.34
Bulk density (kg m^{-3})	1 247 ± 81

[a] EC = electrical conductivity; CEC = cation exchange capacity; TN = total N; TOC = total organic C.
[b] Means ± standard deviations (n = 3).

Natural and NH_4^+-enriched CHAZTs used

The ZTs used in the present study are a bypro-