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Carbon and nitrogen mineralization at different salinity levels in Omani low organic matter soils

Khair T.S. Al-Busaidi [a,1], Andreas Buerkert [a], Rainer Georg Joergensen [b,*]

[a] Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, University of Kassel, Steinstr. 19, 37213 Witzenhausen, Germany
[b] Soil Biology and Plant Nutrition, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

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ABSTRACT

A 56-d incubation experiment at 30 °C was carried out to study how salinity affects C and N mineralization of composted dairy manure and date palm straw. A low- and a high-saline soil were amended with (1) manure, (2) manure + low straw, (3) manure + straw, and (4) sole straw. The microbial and fungal biomass contents are very low in Omani soil abandoned for at least 6 years. Straw application revealed a highly significant increase in microbial biomass C, but especially in ergosterol in the low-saline soil. In contrast, straw led only to an increase in ergosterol in the high-saline soil, where only the combined application of manure with straw had significant positive effects on microbial biomass C. In the high-saline soil, the sum of C mineralized reached only 55% of SOC-derived CO_2–C, 65% of manure-derived CO_2–C, and 75% of straw-derived CO_2–C in comparison with the respective treatments of the low-saline soil. The application of straw led always to a net N immobilization, which was markedly stronger in the high- than in the low-saline soil. The increase in salinity by composted cattle manure should be considered if this fertilizer is applied to soils sensitive to changes in salinity.

1. Introduction

In arid regions such as Oman, the soil organic C (SOC) turnover can be considerably altered by farmers' management practices such as addition of organic fertilizers and irrigation, which contrasts the situation in humid climates (Wichern et al., 2004a). This dynamic situation enhances the risk of mismanagement, leading to a rapid breakdown in soil fertility (Powlson et al., 2001), especially if the soils become salt-affected by irrigation with saline groundwater or insufficient drainage (Rietz and Haynes, 2003; Setia et al., 2013). The effects of salinity on soil microorganisms and microbially mediated processes have been increasingly investigated in the past decade (Rietz and Haynes, 2003; Tripathi et al., 2006). However, the dimension and the direction of the effects observed on microbial C and N mineralization, microbial biomass and microbial community structure are not consistent and seem to depend on environmental conditions, such as soil pH, anion composition, texture, and SOC level (Li et al., 2006). At present, our knowledge regarding the function of microbial biomass as a sink and source of plant nutrients in sub-tropical soils is still insufficient, considering the large variety of environmental conditions and management practices observed.

In hyper-arid northern Oman, one of the most important sources of organic fertilizers are N-rich ruminant manures (Siegfried et al., 2011); another important source could be N-poor date palm straw (Ali, 2011; Alkoaik et al., 2011; Ghehsareh et al., 2011). However, the recalcitrance of this material might cause problems in Omani soils, especially when saline, because under these conditions the contribution of saprotrophic fungi to the microbial community is most likely low (Pankhurst et al., 2001; Sardinha et al., 2003). The application of N-rich highly degraded dairy manure usually promotes bacteria, whereas that of N-rich fresh straw promotes fungi (Scheller and Joergensen, 2008). A reduction in the decomposition rate of organic fertilizers in saline soils may increase the risk of N immobilization and thus reduce the supply of inorganic N to plants (Flavel and Murphy, 2006).

Consequently, the central aim of the current incubation experiment was to investigate the following four predictions: (1) The application of fresh date palm straw strongly increases microbial biomass, especially that of saprotrophic fungi. (2) The date palm straw-induced increase in fungal biomass is strongly reduced by salinity. (3) Salinity decreases C mineralization of date palm straw and N mineralization of dairy manure. (4) Salinity increases N immobilization after date palm straw application. Microbial biomass C and N are useful indicators of microbial performance in

* Corresponding author. Tel.: +49 5542 98 1591.
E-mail address: joerge@uni-kassel.de (R.G. Joergensen).
[1] Directorate General of Agriculture & Livestock Research, Plant Production Research Center, Fruit Research Laboratory, Sultanate of Oman.

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saline soils (Muhammad et al., 2008; Sardinha et al., 2003; Tripathi et al., 2006). The fungi-specific membrane component ergosterol has been successfully used as a biomarker for fungal biomass in many soils (Joergensen and Wichern, 2008), also in saline environments (Sardinha et al., 2003; Wichern et al., 2004a), but never in irrigated saline Omani soils.

2. Material and methods

2.1. Soils, organic amendments and layout of experiment

Two soils, a high-saline sandy saline and low-saline sandy loam were sampled with from two sites of the agricultural research station at Rumais (23°41′ 15 N, 57°59′ 1 E, 4 m ASL) in south Al-Batinah, Oman. At 0–20 cm depth, 72 random samples from different locations of the sites were taken using an auger to form one compound sample. The two sites had no vegetation for more than 6 years. The high-saline soil was used as irrigated arable land before. The mean (1983–2010) annual temperature is 27.0 °C and the mean annual precipitation is 109 mm, ranging from 10 to 341 mm per year. The soils were air-dried and sieved (<2 mm). Sub-samples of dried soil material were homogenized in a ball mill and analyzed in triplicate prior to the incubation experiment. The soils are similar in the contents of clay and soil organic C, but differed in all other properties (Table 1). Aged (2 years) composted cow manure was obtained from a factory in Oman. Fresh date palm straw was obtained from Rumais, chopped to 5 mm pieces. The organic amendments were air-dried, milled and analyzed in quadruplicate (Table 2).

A 1600 g (on an oven dry basis) sample of each soil was placed into a plastic container, covered with plastic bags, rewetted to 45% water holding capacity and pre-incubated for 7 days at 30 °C. Thereafter, the soils were mixed with dairy manure compost and date palm straw according to the following treatments: (T1) non-amended control, (T2) sole composted dairy manure (3.6 mg C g^{-1} soil), (T3) composted dairy manure (3.6 mg C g^{-1} soil) + low date palm straw (0.59 mg C g^{-1} soil), (T4) composted dairy manure (3.6 mg C g^{-1} soil) + date palm straw (1.76 mg C g^{-1} soil), and (T5) sole date palm straw (1.76 mg C g^{-1} soil). All treatments were placed in sealed 1500 ml glass jars (400 g soil per jar), and incubated for 8 weeks at 30 °C in the dark as a completely randomized design with four replicates. All treatments were kept at 50% water holding capacity throughout the incubation period.

2.2. Analysis of soils and organic amendments

The pH values were measured in water, using a substrate to water ratio of 1–2.5 for the two soils and of 1–10 for two organic amendments. Electrical conductivity (EC) was estimated using a substrate to water ratio of 1–10 for soil and organic amendments, which was converted to EC values in a saturation extract (EC_e). Inorganic N in the initial soil samples, organic amendments, and in the final samples at the end of the incubation were measured in 10 g samples, extracted for 30 min at 200 rev min^{-1} with 0.5 M K_2SO_4, filtered (hw3, Sartorius Stedim Biotech, Göttingen, Germany), followed by ammonia (NH_4^+) and nitrate (NO_3^-) quantification by photometric detection (Evolution II, Alliance Instrument, Salzburg, Austria). Total C and total N in soils and organic amendments were determined after combustion, using a Vario Max CN analyzer (Elementar, Hanau, Germany). Carbonates in the bulk soil were destroyed by 10% HCl and washed away with water prior to analysis of C and N. Carbonate was measured gas-volumetrically after the addition of 10% HCl (Chapman and Pratt, 1961). Soil textural analysis was carried out after pre-treatment with H_2O_2, HCl, and suspension in sodium polyphosphate using a combined sieving and pipette method (Chapman and Pratt, 1961). In the organic amendments, total P was measured by photo-spectrometry (U-2000, Hitachi, Tokyo, Japan) and total K was measured by flame photometry (Laboratory Instrument 543, Lexington, USA), after combustion at combustion at 550 °C and dissolving the ash in 20 ml conc. HCl (Chapman and Pratt, 1961). Lignin, cellulose and ADF analysis were according to the modified procedure of van Soest et al. (1991).

Table 1
Basic physical and chemical properties of the two soils from Oman used in the 8-week incubation experiment, ± one standard deviation ($n = 3$).

	Low-saline soil	High-saline soil
Soil pH	8.5 ± 0.0	7.9 ± 0.0
EC_e (dS m^{-1})	5.0 ± 0.2	45.1 ± 6.8
Sand (%)	54.0 ± 1.4	84.0 ± 1.0
Silt (%)	36.5 ± 2.1	5.7 ± 0.6
Clay (%)	9.5 ± 0.7	9.7 ± 0.6
Carbonate (%)	35.2 ± 0.1	36.2 ± 1.4
Soil organic C (mg g^{-1} soil)	4.2 ± 0.3	1.9 ± 0.1
Soil organic N (mg g^{-1} soil)	0.43 ± 0.02	0.18 ± 0.01
Soil organic C/N	9.7 ± 0.3	11.0 ± 1.0
Extractable NH_4–N (μg g^{-1} soil)	0.59 ± 0.02	2.03 ± 0.15
Extractable NO_3–N (μg g^{-1} soil)	5.2 ± 0.1	86.2 ± 3.0

Table 2
Basic chemical properties of composted dairy cow manure and date palm straw used in the 8-week incubation experiment with two soils from Oman, ± one standard deviation ($n = 3$).

	Composted manure	Date palm straw
pH	8.4 ± 0.1	5.3 ± 0.1
EC_e (dS m^{-1})	64.8 ± 3.1	3.5 ± 0.2
Total C (mg kg^{-1})	240 ± 8	521 ± 8
Total N (mg kg^{-1})	18.0 ± 4.1	4.1 ± 0.2
Total C/N	13.9 ± 3.4	128.7 ± 5.1
Total P (mg kg^{-1})	6.2 ± 4.0	0.33 ± 0.05
Total K (mg kg^{-1})	24.8 ± 1.7	8.0 ± 0.0
Extractable NH_4–N (μg kg^{-1})	2.9 ± 0.2	4.3 ± 0.1
Extractable NO_3–N (μg kg^{-1})	2650 ± 135	19.2 ± 2.2
Lignin (mg kg^{-1})	146 ± 14	85 ± 36
Cellulose (mg kg^{-1})	289 ± 56	450 ± 64
Acid detergent fiber (mg kg^{-1})	435 ± 42	534 ± 39

2.3. Soil microbial biomass and activity

Microbial biomass C (Vance et al., 1987) and microbial biomass N (Brookes et al., 1985) were estimated by fumigation-extraction. Organic C and total N in the 0.5 M K_2SO_4 extracts was measured using an automatic analyzer (Dimatoc 100 + Dima N, Dimatec, Essen, Germany). Microbial biomass C was calculated as E_C/k_{EC}, where E_C = (organic C extracted from fumigated soils) − (organic C extracted from non-fumigated soils) and k_{EC} = 0.45 (Wu et al., 1990). Microbial biomass N was calculated as E_N/k_{EC}, where E_N = (total N extracted from fumigated soils) − (total N extracted from non-fumigated soils) and k_{EN} = 0.54 (Brookes et al., 1985). The fungal cell-membrane component ergosterol was extracted from 2 g soil with 100 ml ethanol by oscillated shaking at 250 rev min^{-1} for 30 min according to Djajakirana et al. (1996). Ergosterol was determined by reversed-phase HPLC with 100% methanol as the mobile phase and detected at a wavelength of 282 nm. Soil respiration was weekly measured as CO_2–C, where test tubes containing 30 ml 0.5 M NaOH, placed at the bottom of 1500 ml jars. The trapped CO_2 was back-titrated with 0.5 M HCl after addition of 0.5 M $BaCl_2$ solution (Anderson, 1982).