Municipal solid waste compost as a long-term NbS to restore soil fertility and biodiversity in mining contaminated field

Stefania Diquattro[1,2]*, Giovanni Garau[1,2], Maria Vittoria Pinna[1], Matteo Garau[1,2], Simonetta Bagella[2,3], Lia Obinu[1], Andrea Porceddu[1], Pier Paolo Roggero[1,2], Paola Castaldi[1,2]

1 University of Sassari, Department of Agricultural Sciences, Viale Italia 39/a, 07100 Sassari, Italy; 2 University of Sassari, Desertification Research Centre (NRD), 07100 Sassari, Italy; 3 University of Sassari, Department of Chemical, Physical, Mathematical and Natural Sciences, Via Piandanna 4, 07100 Sassari, Italy

Introduction

The restoration of soils contaminated by potentially toxic elements (PTEs) represents one of the major environmental challenges in degraded mining areas. Nature-Based Solutions (NbS) promote the use of natural processes, such as organic amendments or phytoremediation, to enhance soil health, immobilize contaminants, and foster biodiversity. Municipal solid waste compost (MSWC) is an organic amendment derived from the controlled aerobic decomposition of the organic fraction of municipal waste, whose application has gained increasing attention as a NbS, since short-term laboratories studies demonstrated its ability to immobilize PTEs and stimulate biological recovery processes. This study aims to perform a comprehensive field evaluation of the long-term effects of MSWC applied at varying doses to a soil contaminated by PTEs from a former mining site, six years after its incorporation.

Study area

The study area was located at Argentiera ex-mining site (40°44'11 "N, 8°08'52 "E; NW Sardinia, Italy) (Fig. 1), within a mining tailings and waste disposal area historically contaminated with Sb, Zn, Cd and Pb, from centuries of galena, sphalerite, and pyrargyrite extraction.

Fig. 1. Experimental field.
T0: 1-2-3; T1: 4-5-6; T2: 7-8-9; T3: 10-11-12.

Methods

Start and setup: January 2015 on a 2 ha area.

Treatments: 0% (T0), 1.5% (T1), 3.0% (T2), 4.5% (T3) MSWC rates mixed into the top 0–30 cm of soil.

Sampling: Soil samples were analyzed six years later (2021).

Analyses: Soil chemical characterization; Sequential extraction procedure; Enzymatic activities; Microbial C respiration; Bacterial community diversity; Vegetation survey.

Results

Soil chemical improvement after six years soil pH, O.M., DOC and CEC increased (Table 1). The mobility of Cd, Zn, and Sb decreased by 27.1%, 27.8%, and 125%, respectively, while the non-extractable residual fractions of Sb and Pb increased by 7.6% and 4.0% at the highest MSWC dose (Fig. 2, T3).

Soil biochemical improvement after six years, soils treated with MSWC showed higher enzymatic activities: dehydrogenase, β-glucosidase, urease up to 12-, 11-, and 4-fold, respectively, compared with the untreated control T0, indicating enhanced microbial metabolism and nutrient cycling (Fig. 3).

Dose-dependant no significant difference was observed between the different MSWC rates applied, although T3 shows a greater effect on chemical and biochemical parameters (Fig. 4).

Microbial activity: after six years soil microbial C respiration increased 5-fold and Shannon α-diversity index revealed a significant difference (p = 0.002; 0.000; 0.000) in MSWC treated soils than in T0. PICRUST results showed that in T0 mainly biosynthetic pathways were involved, while in the amended soil degradation pathways were enhanced (Fig. 5).

Vegetation surveys 56 plant species recorded, dominated by therophytes (61%), as expected under Mediterranean climate. As identified by SIMPER, there were five main discriminating plant species. The treatment had a positive effect on four of them, *Lotus cytisoides*, *Helichrysum italicum* subsp. *microphyllum*, *Crepis* sp. and *Rumex bucephalophorus* (Fig. 6). Non-metric multidimensional scaling (NMDS) indicated significant differences in plant community composition between T0 and T1-T3 plots (Pperm = 0.012), but not between levels of treatments (T1, T2 and T3) (Fig. 7).

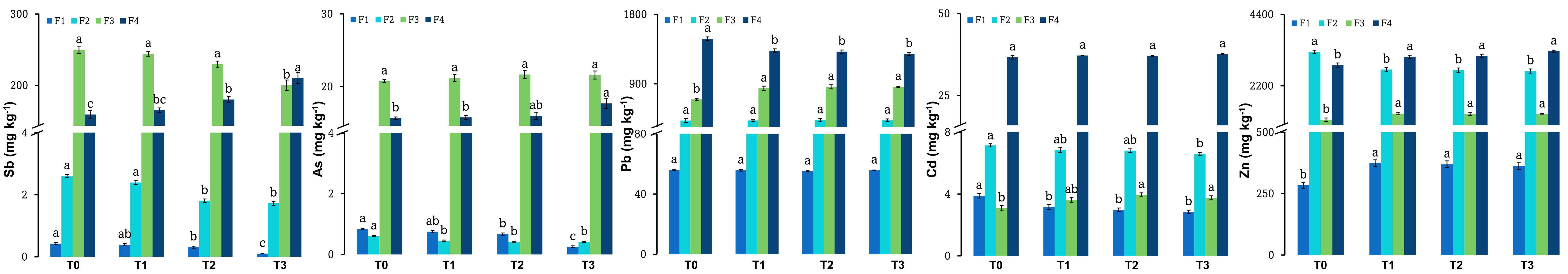

Fig. 2. SEP of Sb and As according Wenzel et al. 2001 (mean ± SE). F1= H_2O; F2= $(NH_4)_2SO_4$; F3= $(NH_4)H_2PO_4$; F4= HNO_3/HCl. SEP of Cd, Pb e Zn according Basta and Gradwohl 2000 (mean ± SE). F1= $Ca(NO_3)_2$; F2= NaOAc; F3= Na_2-EDTA; F4= HNO_3/HCl. For each PTE and fraction, different letters denote statistically differences according to Student's t-test (p<0.05).

Table 1. Selected chemical parameters of T0, T1, T2 and T3 (mean ± SE). Different letters indicate statistically differences according to Tukey (p<0.05).

Soil parameters	T0	T1	T2	T3
pH_{H2O}	6.36 ± 0.20^c	6.63 ± 0.14^b	7.13 ± 0.22^a	7.23 ± 0.21^a
EC (dS·m^{-1})	2.22 ± 0.23^a	0.80 ± 0.15^b	0.44 ± 0.08^c	0.33 ± 0.03^c
P-Olsen (mg·Kg^{-1})	0.33 ± 0.05^b	3.35 ± 0.81^a	4.34 ± 0.24^a	3.48 ± 1.07^a
CEC (cmol$_{(+)}$·Kg^{-1})	4.64 ± 1.10^b	12.8 ± 2.14^a	12.9 ± 0.96^a	13.9 ± 1.90^a
DOC (mg·g^{-1})	0.01 ± 0.00^c	0.03 ± 0.00^b	0.03± 0.00^b	0.05 ± 0.00^a
O.M. (% d.m.)	2.11 ± 0.20^c	2.64 ± 0.40^b	2.78 ± 0.17^b	3.66 ± 0.66^a
Total N (%)	0.11 ± 0.01^b	0.19 ± 0.03^a	0.19 ± 0.02^a	0.16 ± 0.04^a
Total PTEs (mg·kg^{-1})				
As	38.2 ± 3.57^a	34.8 ± [illegible].54^a	35.5 ± 2.70^a	37.3 ± 3.77^a
Cd	50.8 ± 8.52^a	50.5 ± 8.66^a	48.5 ± 8.00^a	40.7 ± 8.97^a
Pb	2664 ± 117^a	2657 ± 92.1^a	2660 ± 226^a	2599 ± 199^a
Sb	416 ± 76.5^a	411 ± 53.7^a	409 ± 36.6^a	411 ± 48.7^a
Zn	7510 ± 821^a	7554 ± 966^a	7569 ± 716^a	7545 ± 860^a

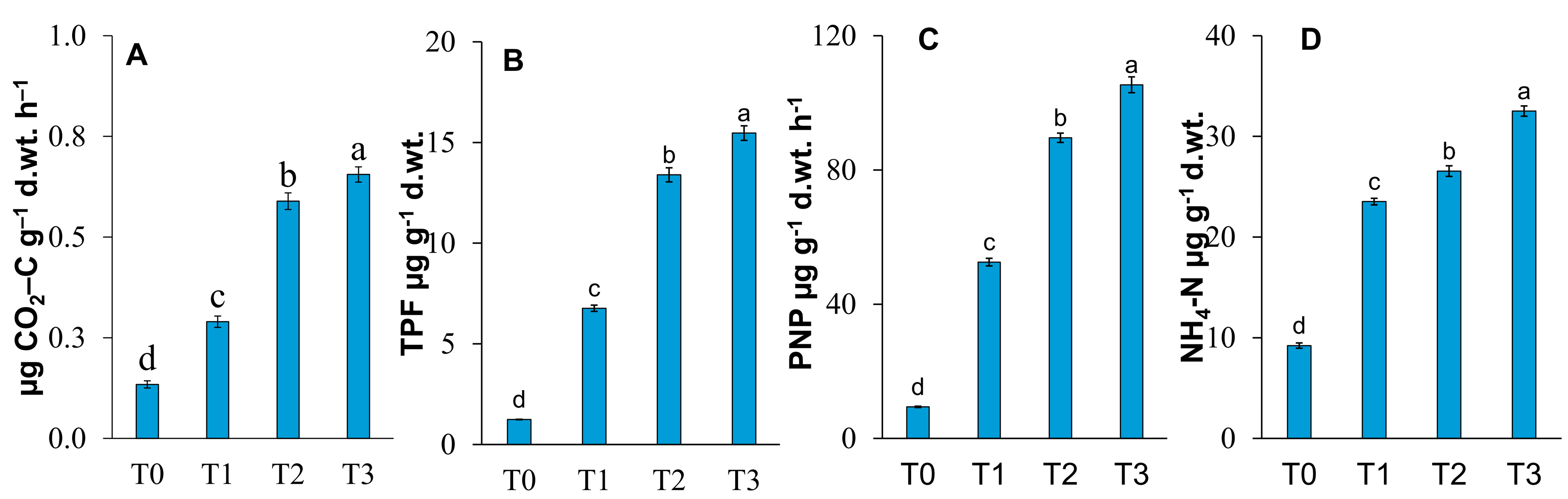

Fig. 3. A) Microbial C respiration, B) DHG C) GLU, D) URE (mean ± SE) of T0 and T1, T2, and T3. Different letters indicate statistically differences according to Tukey (p<0.05).

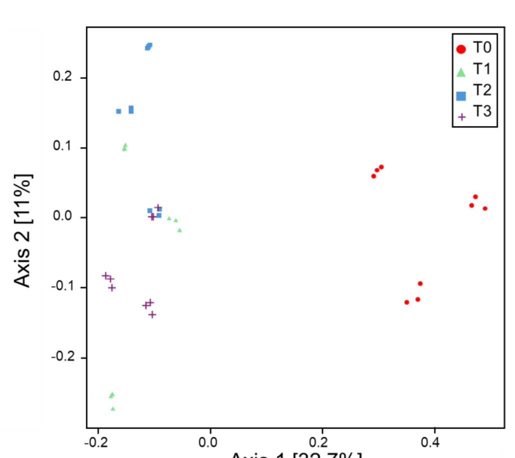

Fig. 4. PCoA of the cumulative sum scaling normalised ASV dataset, based on Bray Curtis dissimilarity metrics.

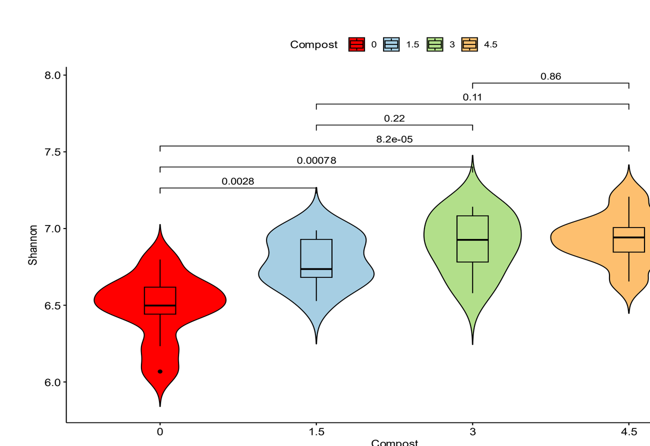

Fig. 5. Shannon α-diversity Index in T0 and T1-T3 soils. The line inside the box represents the median, while the violin plot represents the standard deviation.

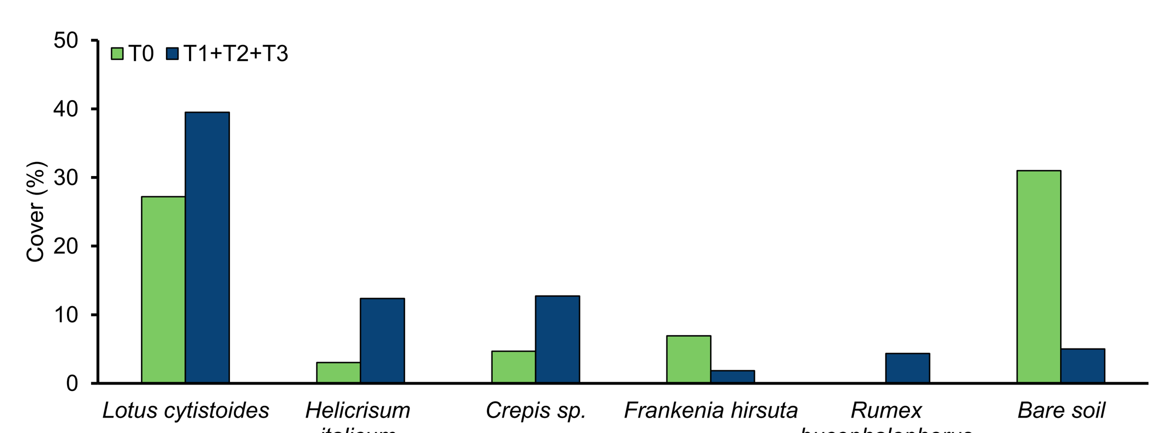

Fig. 6. % cover of the five species contributing at least 5% to the dissimilarity between plant communities according to SIMPER analysis and % of bare soil in T0 and amended soils (T1+T2+T3).

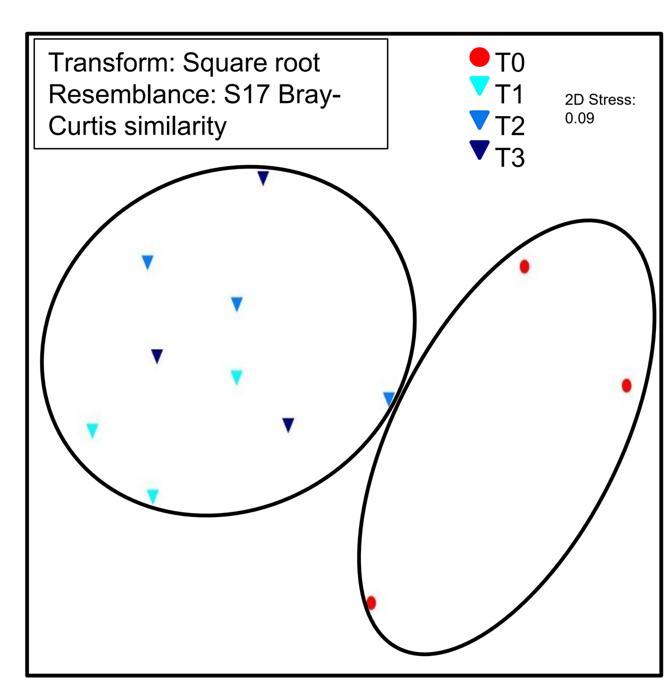

Fig. 7. NMDS of plant community composition in T0 and T1,T2 and T3.

Take home message

MSWC application proved to be sustainable and long-lasting strategy and environmental management approach, enhancing soil functionality as well as promoting plant growth and diversity. These factors are crucial for the complete recovery and securing of PTEs-contaminated site.

Acknowledgments

2nd International Symposium on Biodiversity and Ecosystem Functions under Global Change
12 – 14 November 2025
Alghero (Sardinia – Italy)