Sustainable In Situ Bioremediation with Hardwood Mulch Bioborings. A Nature-Based Approach for Reductive Dechlorination.

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INTRODUCTION

Enhanced Reductive Dechlorination (ERD) is a well-known technology for managing both contamination sources and plumes of chlorinated aliphatic compounds in groundwater. Interest continues to grow regarding the use of hardwood mulch as a nature-based, low-capital-cost option for in-situ ERD applications. Hardwood mulch may serve as a slow-release electron donor, and helps to maintain reductive redox conditions in the aquifer, which support the anaerobic dehalogenation of the chlorinated solvents. Hardwood mulch is a cheap and often locally available material, a secondary product of the wood processing industry, (e.g. landscaping, biofilters) and its use as bioremediation amendment may help improve the economic viability, circularity and environmental sustainability of a remediation project.

OBJECTIVES

A laboratory bench-scale and field pilot test was carried out at a dismissed industrial Site, with groundwater contamination by chlorinated ethenes (mostly cis-DCE and TCE in concentrations up to 1000s µg/L), to test the use of hardwood mulch as an electron donor for in situ ERD.

After installing a P&T system near the downgradient Site boundary as per the Public Authority's request, ERM has considered in situ bioremediation options to treat the contamination source, with the ultimate goal of shutting down the existing hydraulic barrier, associated with intensive O&M activities and a high energy demand.

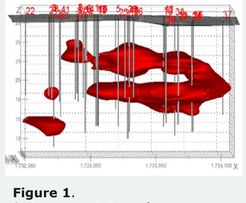


Figure 1.
3-D representation of contamination source, from MIP investigation data.

METHODS | Laboratory bench-scale study

A laboratory treatability test was carried out to assess potential for complete reductive dechlorination of the site contaminants with the following amendments:

- Hardwood mulch
- Hardwood mulch + iron filings
- Commercial electron donor
- Commercial electron donor + commercial ZVI product
- All batches were additioned with a commercial bioaugmentation inoculum
- Blank, duplicate and sterile batches were also prepared for higher scientific soundness

A batch experiment was carried out for approx. 4 months, involving:

- Chemical analysis of pH, redox potential, anions, metals, chlorinated solvents, ethylene, methane
- Microbiological analysis of Dehalococcoides mcartyi species (rDNA) and associate reductive dehalogenases (tceA, bcvA, vcrA) (via qPCR), Sulfate- and Nitrate Reducing Bacteria (via MPN test).

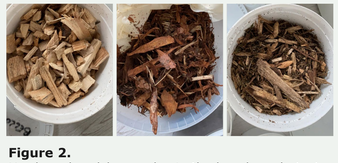


Figure 2.
Hardwood mulch samples in the bench-scale test.

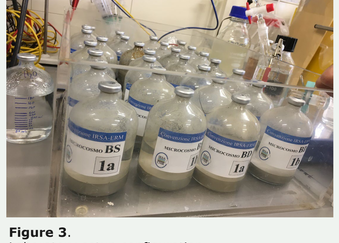


Figure 3.
Laboratory setup configuration.

METHODS | Field pilot test

Based on the bench-scale results, a pilot test was conducted at the Site to evaluate application of hardwood mulch in a large-diameter bioboring configuration, within the area most impacted by chlorinated solvents.
A total of 6, 800 mm-diameter bioborings were installed up to 10 m b.g.l. in an indoor area, and filled with a mixture of locally available hardwood mulch, silica and carbonatic gravel, water, and a commercial bioaugmentation mix.
The pilot test area was completed with a monitoring network including multi-level monitoring wells, soil gas samples.

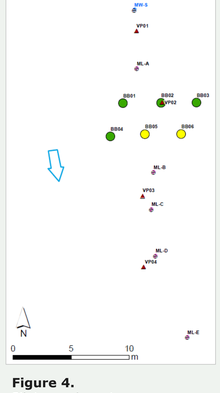


Figure 4.
Pilot area layout

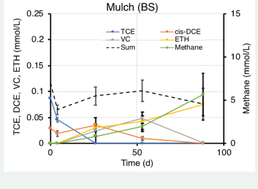
A monitoring program was conducted for approximately 6 months involving:

- Microbiological monitoring with passive samplers
- Groundwater level and field parameters monitoring
- Groundwater sampling from multi-level monitoring wells, and analysis of anions, metals, chlorinated solvents, ethylene, methane
- Soil gas and ambient air sampling and field monitoring
- Conservative tracer test

Figure 5.
Amendment mixing

Figure 6.
Bioboring filling

RESULTS | Laboratory bench-scale study



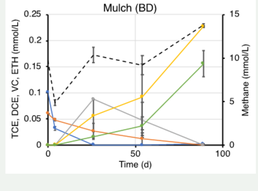


Figure 7.
Chemical analysis in superficial soil and groundwater samples (BS), and deep samples (BD).

- Total conversion of chlorinated ethenes to ethylene
- Complete dechlorination of TCE in 88 days
- Transitory accumulation of VC, completely depleted at day 88
- Significant dissolved methane production, up to 150 mg/L

The chemical analysis trend showed that the microcosms amended with hardwood mulch achieved the complete dechlorination of the site contaminants, with lower methane generation compared to the microcosms amended with commercial electron donors.

RESULTS | Field pilot test

- Following the installation of the bioborings, all physical and geochemical parameters of the aquifer show the existence of favorable conditions for reductive dichlorination (low DO and negative Redox potential) up to 15 m downgradient the pilot area.
- The microbiological analysis show that bioaugmentation of the mulch bioborings has caused a significant increase in the concentration of specific bacterial strains involved in the reductive dechlorination of the site contaminants.
- Dissolved concentration of Chloride, Methane and Iron has increased compared to the baseline monitoring, suggesting that the reductive biodegradation process has started. Competitive electron acceptors such as Nitrate and Sulfate have been depleted in the aquifer.
- A shift in relative groundwater composition has been observed from a higher abundance of parent chlorinated compounds, to degradation products, with Ethene measured in concentrations above 100 ug/L in downgradient monitoring wells 5 months after mulch installation.

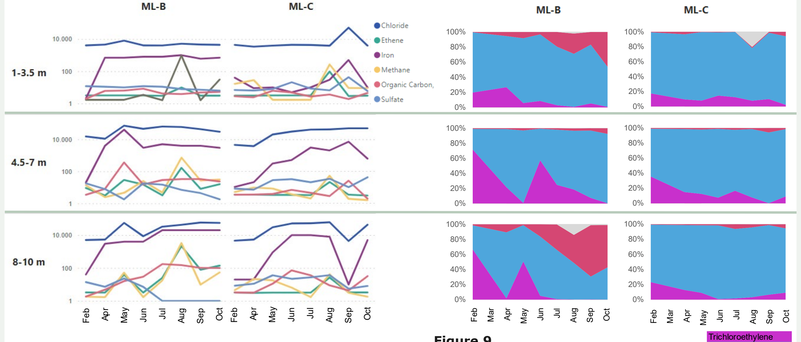


Figure 8.
Dissolved inorganic and organic parameters (µg/L)

Figure 9.
Molar composition of chlorinated ethenes (% mmol/L)

CONCLUSIONS & FUTURE DIRECTIONS

The groundwater monitoring results after bioboring installation provided proof of concept that in situ reductive dechlorination could be achieved in the aquifer with the application of hardwood mulch. However, due to the high baseline chlorinated compounds concentrations in the pilot test area, the extent of the biological reductive process triggered by the tested amendment was believed to be limited. For the following full-scale phase of the project, ERM has proposed to install several bioboring lines perpendicular to gw flow direction, and increase the availability of electron donors in the aquifer by (i) decreasing the spacing between bioborings and (ii) add some commercial Emulsified Vegetable Oil-based product in the amendment mixture in the most impacted zones of the contamination source.

REFERENCES

Masut, E.; Battaglia, A.; Ferioli, L.; Legnani, A.; Cruz Viggi, C.; Tucci, M.; Resitano, M.; Milani, A.; de Laurentiis, C.; Matturro, B.; et al. A Microcosm Treatability Study for EvaluatingWood Mulch-Based Amendments as Electron Donors for Trichloroethene (TCE) Reductive Dechlorination. Water 2021, 13, 1949. https://doi.org/10.3390/w13141949