COST AND PERFORMANCE REPORT

Phytoremediation at the Twin Cities Army Ammunition Plant
Minneapolis-St. Paul, Minnesota

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EPA

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Background Information

The Twin Cities Army Ammunition Plant (TCAAP) is a 2,370-acre facility located in Arden Hills, Minnesota, approximately 10 miles north of Minneapolis-St. Paul, Minnesota.

The TCAAP was used for the production and storage of small arms ammunition, related materials, fuzes, and artillery shell materials. The facility also provided proof testing of small arms ammunition and the storage and handling of strategic and critical raw materials for other government agencies. In 1981, studies indicated that contaminated groundwater from the TCAAP was migrating into the Minneapolis-St. Paul metropolitan groundwater supply. A number of sites within TCAAP were contributing to groundwater and soil contamination including former landfills, impoundments, burning and burial grounds, ammunition testing and disposal sites, industrial operations buildings, and sewer system discharges. The primary groundwater contaminants were volatile organic compounds (VOCs). The primary soil contaminants were ammunition-related heavy metals (copper, lead, and mercury), followed by VOCs and polychlorinated biphenyls (PCBs).

The phytoremediation demonstration was conducted at areas within Sites C and 129-3 at the TCAAP. Site C was historically used for many purposes including burning production materials and decontamination equipment contaminated with explosives. Analytical data of composite soil samples from areas in Site C indicate the presence of heavy metals, particularly, lead, arsenic, antimony, beryllium, and thallium. Site 129-3 contained pits that were believed to have contained contaminated wastewater from a lead styphanate production facility constructed in December 1971. Elevated concentrations of barium, chromium, lead, and antimony have been found in the soils at Site 129-3. The general characteristics of the climate and soil matrix at Sites C and 129-3, including concentrations of metal contaminants, are presented in Table 1.

The Environmental Security Technology Certification Program (ESTCP) funded the phytoextraction field demonstration at TCAAP to determine its effectiveness in removing heavy metals from soils. The project was executed under a partnering agreement among the U.S. Army Environmental Center (USAEC), Tennessee Valley Authority (TVA), TCAAP, and the U.S. Army's Industrial

Table 1. General Characteristics of Climate and Soil Matrices at Sites C and 129-3

Parameter	Value
Climate conditions	• Continental • Less than ideal for growing crops; can have early/late frosts • Average annual precipitation rate of 28.6 inches • Average annual temperature of 49.6°F
Soil type	• Site C: peat, underlain by fine sand and sandy clay • Site 129-3: fine- to medium-grained sand
Depth to water table	• Site C: 2 to 6 feet below surface • Site 129-3: 140 to 200 feet below surface
Metal contaminants	• Site C: average of 2610 ppm Pb in surface soil • Site 129-3: average of 358 ppm Pb in surface soil

Source: USAEC, 1999

Operations Command (IOC). A two-year field demonstration (1998 and 1999) was funded in fiscal year 1998. This case study reports results from the first year's (1998) field demonstration.

Technology Description and System Design

The primary objective of the field demonstration was to determine if phytoextraction is a technically and economically feasible means of reducing lead contamination from near-surface soils. Sites C and 129-3 at the TCAAP were selected for this demonstration based on the following factors:

- Soil lead concentration: Site C had a moderate contamination level (average of 2610 ppm of lead in the first six inches of soil), while Site 129-3 had a low contamination level (average of 358 ppm lead).

- Forms of lead: Metallic debris (bullet jackets and copper scrap) was present in the soil at Site C and would provide a perspective on the impact of metallic particulates on remediation efforts.

- Matrix characteristics: The soils at TCAAP are highly sandy and provided an opportunity to observe the potential for leaching.

- Groundwater characteristics: The depth of the water tables varied at the TCAAP sites, providing opportunities to examine its effect on the technology. At Site C, the water table is two to six feet below ground surface, while at Site 129-3 the water table is estimated to be 140 to 200 feet below ground surface.

- Growing season: The growing season in Minnesota is short thus providing an opportunity to examine operational feasibility in less than ideal climatic conditions.

The field demonstration was conducted at two 0.2-acre plots, one at Site C and another at Site 129-3. The two sites were prepared by clearing, fencing, and plowing the areas, and installing an irrigation system. Two crops were grown on each site. The first crop was corn and the second was white mustard. These crops were selected based on previous optimization studies conducted by the USAEC and TVA. Amendments were added to the soil in order to aid in the solubilization and uptake of the lead. The soil amendments included acetic acid and EDTA. Acetic acid temporarily increases soil acidity and, thereby, solubilizes lead in the soil out of the solid phase and into the solution phase. EDTA is a chelate which complexes with lead and enhances its solubility in an aqueous solution (USAEC, 1999). Each crop was harvested and smelted.

Technology Performance

Results from the first year's demonstration were not as good as expected, exhibiting less than anticipated biomass yields and lead uptake in the harvested plant material. The first crop, corn, yielded 2.1 to 3.6 tons of corn stover per acre. (Corn stover is corn prior to grain production.) These yields were low as compared to the anticipated yield of 6.0 tons per acre. High biomass yields (in conjunction with uptake concentrations) are important since it determines the mass of lead that can be removed during each planting. Poor yields were attributed to agronomically low producing soils at the site and the presence of other soil contaminants. Lead concentrations in the harvested corn averaged 0.65% and 0.13% dry weight for Sites C and 129-3, respectively. These results were lower than anticipated based on the 0.85% removal obtained during a prior greenhouse study. (USAEC, 1999)

The second crop, white mustard, yielded 1.9 to 2.1 tons of white mustard per acre of land in those areas of the plot where white mustard grew. However, on a per plot basis, the total yields for Site C were half of this value since the white mustard grew in only about 50% of the plot area. In the areas where plants grew, the yields produced were comparable to the expected yield of 2 tons per acre of mustard. Lead uptake concentrations in the harvested white mustard biomass were very low. Average lead concentrations were 0.083% and 0.034% dry weight for Sites C and 129-3, respectively, as compared to anticipated concentrations of 1.5% obtained during greenhouse studies. (USAEC , 1999)

The following factors were implicated in the low lead uptake levels:

- A shallow white mustard rooting system. The limited rooting pattern of the white mustard may have been due to carryover EDTA and water-soluble lead from the previous corn amendment application. The shallow rooting pattern could also have been caused by overwatering in total amount or frequency, possibly due to excessive rainfall.

- Migration of lead after the corn harvest. Lead may have migrated downward to varying extents in the soil due to solubilization by EDTA and subsequent tillage/irrigation cycles before white mustard was planted. A portion of the lead could have moved below the shallow rooting zone of the white mustard but could still be present in significant concentrations in the top 24 inches of the soil.

- Problems with the drip delivery system. The drip delivery system used for applying EDTA to the white mustard did not rapidly saturate the soil and required an extensive time for application. This inhibited the movement of a constant volume of water-soluble lead to the plant roots during the period when the plants were continuously exposed to EDTA. EDTA is toxic to plants at these concentrations and the prolonged exposure to EDTA may have killed the white mustard plants before they could take up significant amounts of lead.

- Damage due to other contaminants. Other contaminants in the soil, such as beryllium and thallium, may have impacted plant growth and function.

Technology Cost

As part of this demonstration, USAEC developed a preliminary cost estimate for a typical phytoextraction project. For cost estimating purposes, the following conditions were assumed: (1) there would be a shortened growing season (northern U.S. location), (2) two crops would be grown per year (one corn and one white mustard), (3) sub-optimal soil conditions would exist for plant growth, (4) the soil lead level would be about 2,500 ppm (moderate contamination level), and (5) five years of remediation would be required to meet the regulatory standard.

Based on these assumptions, it was estimated that a typical phytoextraction project would cost about $30.34 per cubic yard of soil per year, or about $153 per cubic yard of soil over the entire life of the project. Literature data obtained by the TVA indicated that phytoremediation generally costs between $25 and $127 per cubic yard. When comparing these figures with TVA's preliminary estimate of $30.34 per cubic yard of soil per year, USAEC concluded that the preliminary estimate was reasonable given that growing conditions at the TCAAP were unfavorable and that phytoremediation projects are speculated to last one to five years. (USAEC, 1999)

Summary of Observations and Lessons Learned

Observations from the 1998 field demonstration were used to refine the demonstration planned for the 1999 growing season. The changes made to improve performance include:

- Use of alternate mustard varieties. The white mustard used in this study was subsequently found to be sensitive to other contaminants such as thallium. The sensitivity of the chosen species to exotic constituents in a soil may present a challenge from a species selection perspective. In this application, this problem was not recognized until after the end of the season. The use of an alternative mustard species with a greater tolerance for soil conditions and higher biomass yields is being considered.

- The use of higher fertilizer rates to encourage greater biomass.

- Varying the irrigation scheme to encourage rooting and growth. Since an extensive and dense root pattern is critical to metal uptake, irrigation strategies that promote root growth will be investigated and implemented.

- Alternate amendment delivery systems. Amendment delivery impacted both the migration of lead and the health of the plants. Alternate amendment delivery systems, such as subterranean drip systems or higher delivery rate drip systems, will be considered.

- Deep tilling. Downward migration of lead and other metal contaminants after plantings may mobilize contaminants beyond the reach of the root system. Deep tilling after crop harvesting can bring migrated metals back into the near surface samples and within reach of the root system.

- Alternate EDTA degradation methods. Residual EDTA may build up in the soil and impact plant productivity of subsequent plantings. Alternate EDTA degradation processes are being investigated.

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References

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