Phytostabilization as a Tool for Managing Risk of Selenium and Arsenic Exposure from Coal Ash

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PROJECT BACKGROUND

Problem Area Incorporation of Phytostabilization in Risk Management Framework for Legacy Ash Impoundments

Problem Statement

Office of Fossil Energy and Carbon Management (FECM) is interested in examining whether phytostabilization can be used within or in the vicinity of ash impoundments to reduce the mobility/exposure potential of selenium (as selenite and selenate) and arsenic (as arsenite and arsenate).

Proposed Solution

- Evaluate the various plant genera and species that can target either Se or As for stabilization in the soil and map their growth requirements to ash impoundment site parameters.
- Examine whether targeted plant species can be used as sentinels to indicate an elevated risk potential from Se or As present in an ash impoundment.
- Based on the findings from this task, this phytostabilization will be incorporated into the Risk Management Framework that is currently under development by FECM / ERDC.

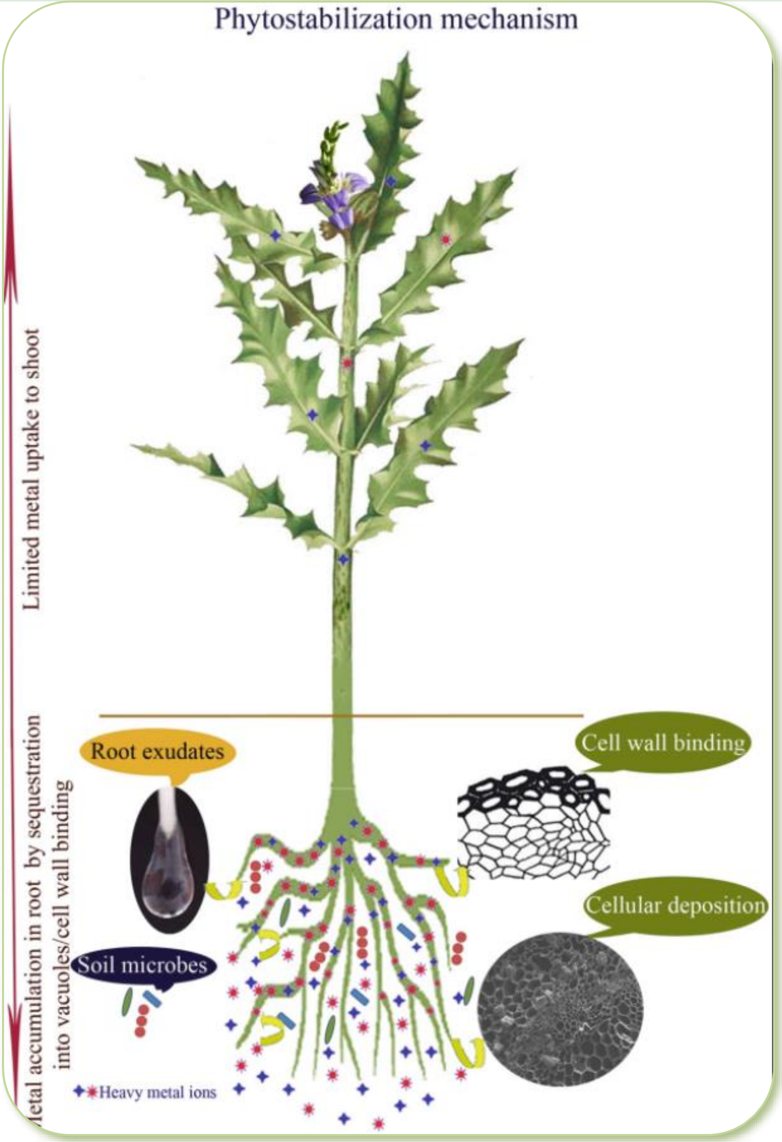


Fig. 2 from Shackira and Puthur, 2019. General mechanisms of phytostabilization of metals

Goal & research questions

Goal

To help stakeholders assess whether the characteristics of their ash impoundment are potentially suitable for successful phytostabilization of Se and As, and if so, which plant species are optimal for inclusion.

Research Questions

1) *Can phytostabilization be used within or in the vicinity of ash impoundments to reduce the mobility/exposure potential of selenium (as selenite and selenate) and arsenic (as arsenite and arsenate), and how?*

2) *Can targeted plant species be used as sentinels to indicate an elevated risk potential from Se or As present in an ash impoundment, and how?*

PHYTOSTABILIZATION BACKGROUND

- Less invasive, low-cost phytotechnology that uses plants for stabilization of contaminants in soils.
- Used to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or further entry into the food chain.
- Plants can immobilize heavy metals in soil through:
  - Sorption by roots,
  - Precipitation,
  - Complexation or metal valence reduction in the rhizosphere

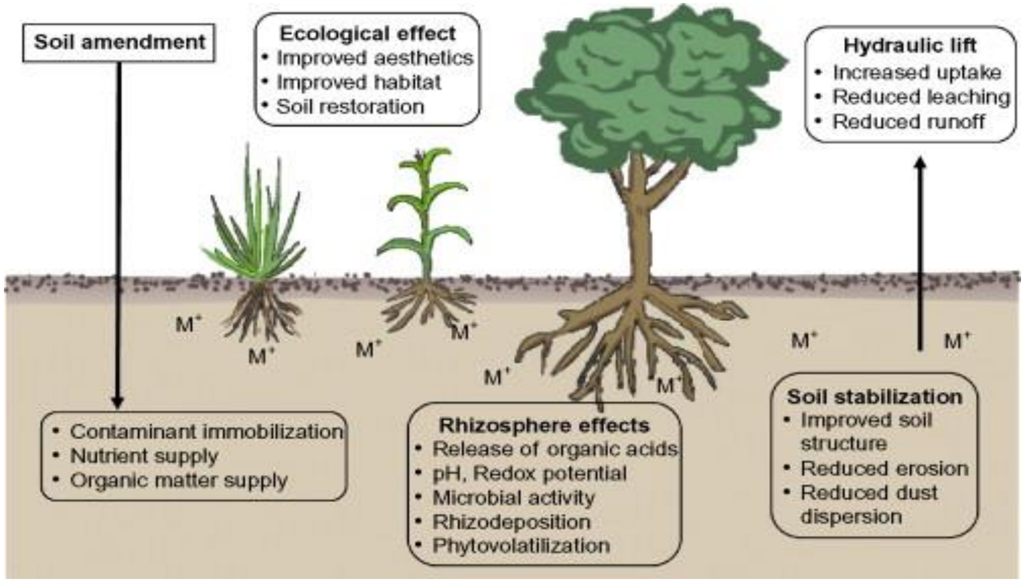


Fig 1 from Bolan et al., 2011. Schematic diagram illustrating the potential action of phytostabilization on contaminants in soil.

Phytostabilization pros & cons

Table 1. Major advantages and disadvantages of phytostabilization technique (Shackira and Puthur, 2019)

Sl no.	Advantages	Limitations
1	Disposal of polluted biomass is not required	The contaminants remain in place
2	Effective immobilization reduces leaching and bioavailability of toxic metal ions	It is useful at sites with shallow contamination but is less effective at sites with contamination at greater soil depth
3	The presence of plants with dense root systems reduces soil erosion	The vegetation and soil may require long-term maintenance to prevent re-release of the contaminants and future leaching
4	Does not destroy or remove soil organic matter, soil microorganisms, and soil texture	Vegetation may require extensive fertilization or soil modification using amendments
5	It has a lower cost and is less disruptive than other, more vigorous soil remedial technologies	Contaminant stabilization might be due primarily to the effects of soil amendments, with plants only contributing to stabilization by decreasing the amount of water moving through the soil
6	Revegetation enhances ecosystem restoration and renders the site aesthetically pleasing	The root zone, root exudates, contaminants, and soil amendments must be monitored to prevent an increase in metal solubility and leaching
7	Vegetation provides physical stability to the soil	Plants that accumulate heavy metals in the roots and in the root zone typically are effective at depths of up to 24 inches

Project Status

- Literature review (Web of Science, Google Scholar, ad hoc searches) yielded **~185 papers** related to As and Se phytoremediation.
- Currently sorting / selecting relevant papers related to phytostabilization of As and Se. Extracting information on:
  - **Plant species**
    - Terrestrial (e.g., metallophytes-metal tolerant plants)
    - Aquatic (freshwater, halophyte, etc.)
  - **Contaminant / type of substrate** (e.g., acid mine waste, coal combustion residues, etc.)
  - **Media types** (e.g., soil, water, and sediment)
  - **Geographic region** where studied
  - **Climatic conditions** (e.g., arid vs semi-arid)
  - **Growth requirements** (e.g., amendments, inoculations)

Criteria for Phytostabilization of As and Se

To effectively stabilize heavy metals in soil, literature suggests the following features in determining plant species:

1. Plants should be **tolerant** to the soil conditions.
2. Plants must **grow quickly** to set up a ground cover.
3. Plants should have **dense rooting** systems.
4. Plants must be **easy to establish** and to maintain under field conditions.
5. Plants must have a relatively **long life** or be able to **self-propagate**.

Aided phytostabilization:

"The rate of phytostabilization can be amplified when used in combination with certain soil amendments which facilitate trace metal immobilization in the soil."

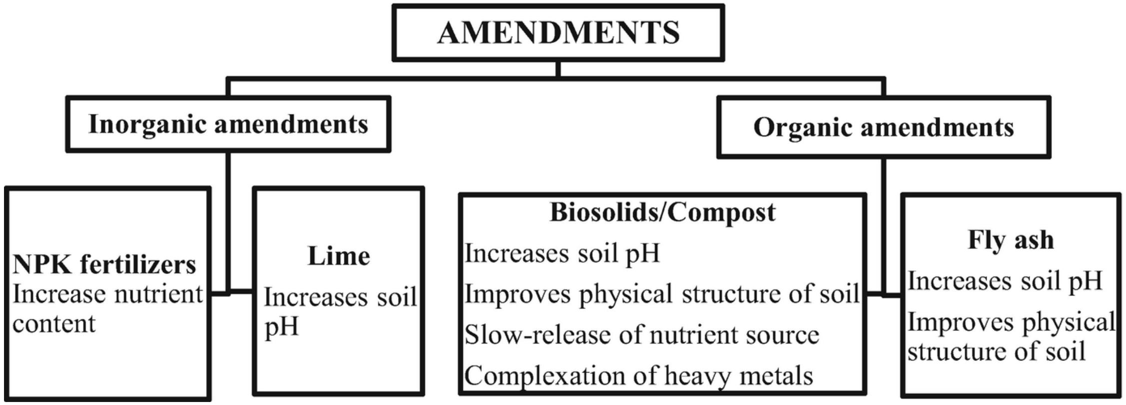


Figure 1 from Shackira and Puthur 2019. Various organic and inorganic amendments used for increasing the rate of immobilization of toxic metal ions in the phytostabilization process.

Preliminary Findings

- The success of a phytomanagement plan that includes phytostabilization also depends on careful selection of appropriate plant species suitable to site conditions, such as:
  - Climatic conditions
  - Varying levels of contamination (e.g., field/treatment size)
  - Media types (e.g., soil, water, and sediment)
  - Chemical properties (e.g., pH, salinity, metal levels, and contaminant types)
  - Applied amendments particular to the site conditions

- Although phytostabilization has become more widely accepted, further research is still needed concerning the testing of new amendments and the selection of tolerant plant species for the process, especially as it relates to coal ash impoundments.

Table 2. Example of Potential Plant Candidates for Phytostabilization of As and Se in Coal Combustion Residues Over 20 Years

Plant Division / Group	Plant Species	Metal	Site of Stabilization	References
Gymnosperms / Coniferous	*Pinus taeda*	Various metals including As and Se	Coal ash	SRNL Report (2002)
Angiosperms / Grasses	*Phragmites australis and Typha latifolia*	Se	Constructed Wetland	Azaizeh et al. (2006)
Angiosperms / Grasses	*Prosopis juliflora*), *Acacia greggi*), *Buchloe dactyloides*, *Festuca arizonica*, (*Atriplex lentiformis*), *Cercocarpus montanus*	As	Mine tailings	Solis-Dominquez et al. (2012); Dradrach et al. (2020)
Angiosperms / Flowers	*Cistus ladanifer* L.	As	Mine tailings	Santos et al. (2016)
Angiosperms / Crop	*Brassica juncea*	As and Se	Fly ash	Monei et al. (2020)

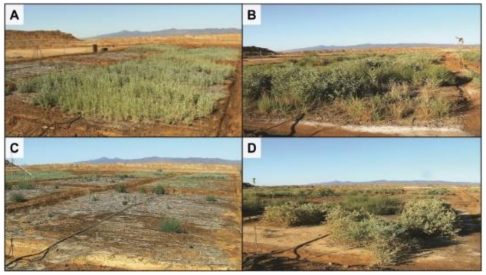


Fig. 3 from Gil-Loaiza et al., 2016. Phytostabilization of mine tailings using compost-assisted direct planting: Translating greenhouse results to the field

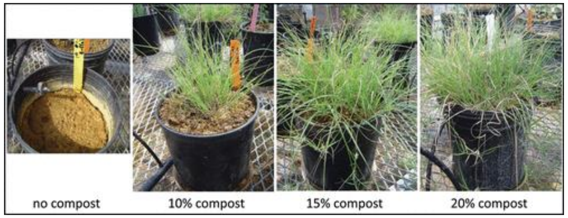


Fig. 1 from Solis-Dominguez et al., 2012. Response of Key Soil Parameters during Compost-Assisted Phytostabilization in Extremely Acidic Tailings: Effect of Plant Species

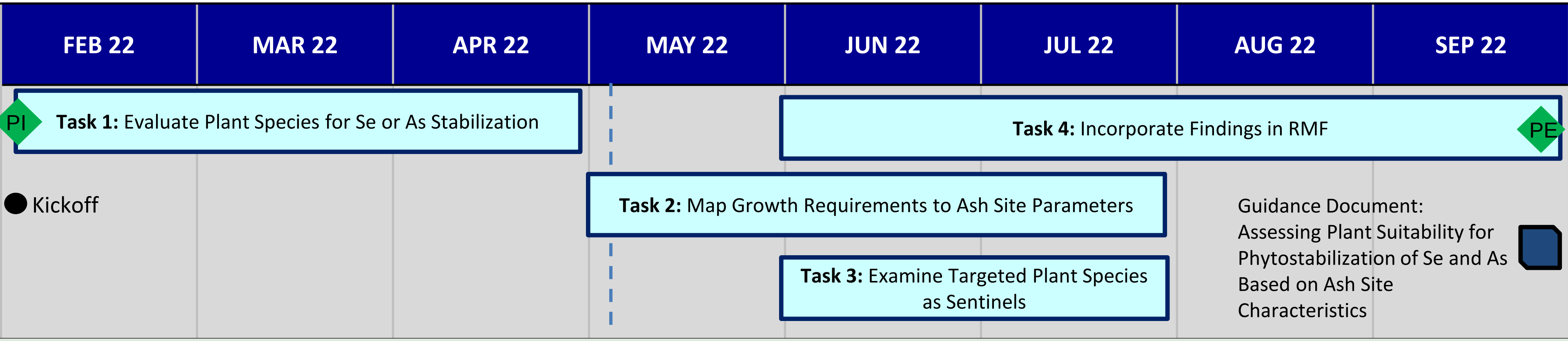
TIMELINE

Next Steps

- Continue detailed analysis of bibliography and categorization by plant characteristics/traits listed in Slide 6 to evaluate plant species for As and Se phytostabilization.
- Once the plant species list/literature review is complete, we still must determine which species are appropriate/suitable based on growth requirements and physical and chemical properties of coal ash impoundments.

Deliverables

- Oral presentation at FY22 FECM Spring R&D project review meeting-emissions control program.
- Guidance Document: *Assessing Plant Suitability for Phytostabilization of Se and As Based on Ash Site Characteristics*



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Questions

Thank You☺