ARC – November 9, 2016

Can a Low Dose Selenium Additive Reduce Environmental Risks of Arsenic and Mercury in Old Gold Mine Tailings?

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Project Details

First project to assess Se additives for effect on the mobility, bioaccumulation and toxicity of As and Hg in soil/tailings

- Collaboration - Saint Mary's University (Dynamic Environment & Ecosystem Health Research)/Amec Foster Wheeler Infrastructure and Environment

- Project funded by NSERC Engage (6 months)

Gold mining in Nova Scotia

- 64 gold mining districts in Nova Scotia
- Hg amalgamation - used for gold extraction in the 1800s and early 1900s, prior to the development of cyanidation as a gold recovery method.
- The remaining sand-like substance; tailings typically dumped into low-lying areas or lakes and streams near the mine.

Gold mining in Nova Scotia, cont.

- Approx. 3 million tonnes of tailings were generated in NS between the 1860s and 1940s

- Tailings contain average concentrations of Hg and As **140** and **340** times background levels, respectively posing a threat to **human health** and **the environment**.

- Receiving environments of concern; terrestrial ecosystems, groundwater, wetlands, lakes, rivers, estuaries and re-emissions to air.


HEALTH WARNING
Soils On This Site Contain Arsenic
Keep Off This Site
at the Request of the Medical Officer of Health
NOVA SCOTIA

Toxic mode of action – Hg and As

- Due to high affinity for sulphur and selenium (Se), Hg and As bind to sulfhydryl, thiol and selenocysteine groups of critical proteins, inhibiting their function

- Hg–Se binding affinity is **a million times stronger** (stab. coef. 10^{45}) than Hg–S (cinnabar, HgS) (stab. coef. 10^{39})

- Hg and Se form mercury selenide (inert).

- As and Se *in vivo* formation and biliary excretion of the seleno-bis (*S*-glutathionyl) arsinium ion, $[(GS)_2AsSe]$.

- Hg and As induce selenium deficiency. This deficiency can be replenished if more selenium is provided with As and Hg exposure.

Why selenium to limit risks of Hg and As?

Se appears to be able to limit risks of As and Hg:

- By **limiting bioavailability** and **mobility** in receiving environments
- By **increasing excretion** of these elements from organisms
- By **translocation** of these elements in plants

More on selenium…

The range between Se's essentiality and toxicity is narrow….

- Minimum concentration in soil required if feed crops are to provide animals with adequate amounts of Se: **0.45** mg/kg
- CCME soil guideline value (agricultural/residential/parkland properties):**1** mg Se/kg
- Natural concentrations of Se in Canadian soils range between **0.3-4** mg/kg

Specific research questions for pilot project:

- Do Na_2SeO_3 additions change the toxicity of Hg and As in plants exposed to the soil/tailings?
- Do Na_2SeO_3 additions change the bioaccumulation of Hg and As in earthworms exposed to the soil/tailings?
- What is the most appropriate dose of Na_2SeO_3 additive to prevent Se, Hg and As leaching from the soil/tailings and still avoid toxic side-effects from elevated Se itself?

33 ARSENIC

Arsenic is a highly toxic element commonly used in rat poisons.

As

80 MERCURY

Mercury is a deadly liquid element that causes damage to the nervous system.

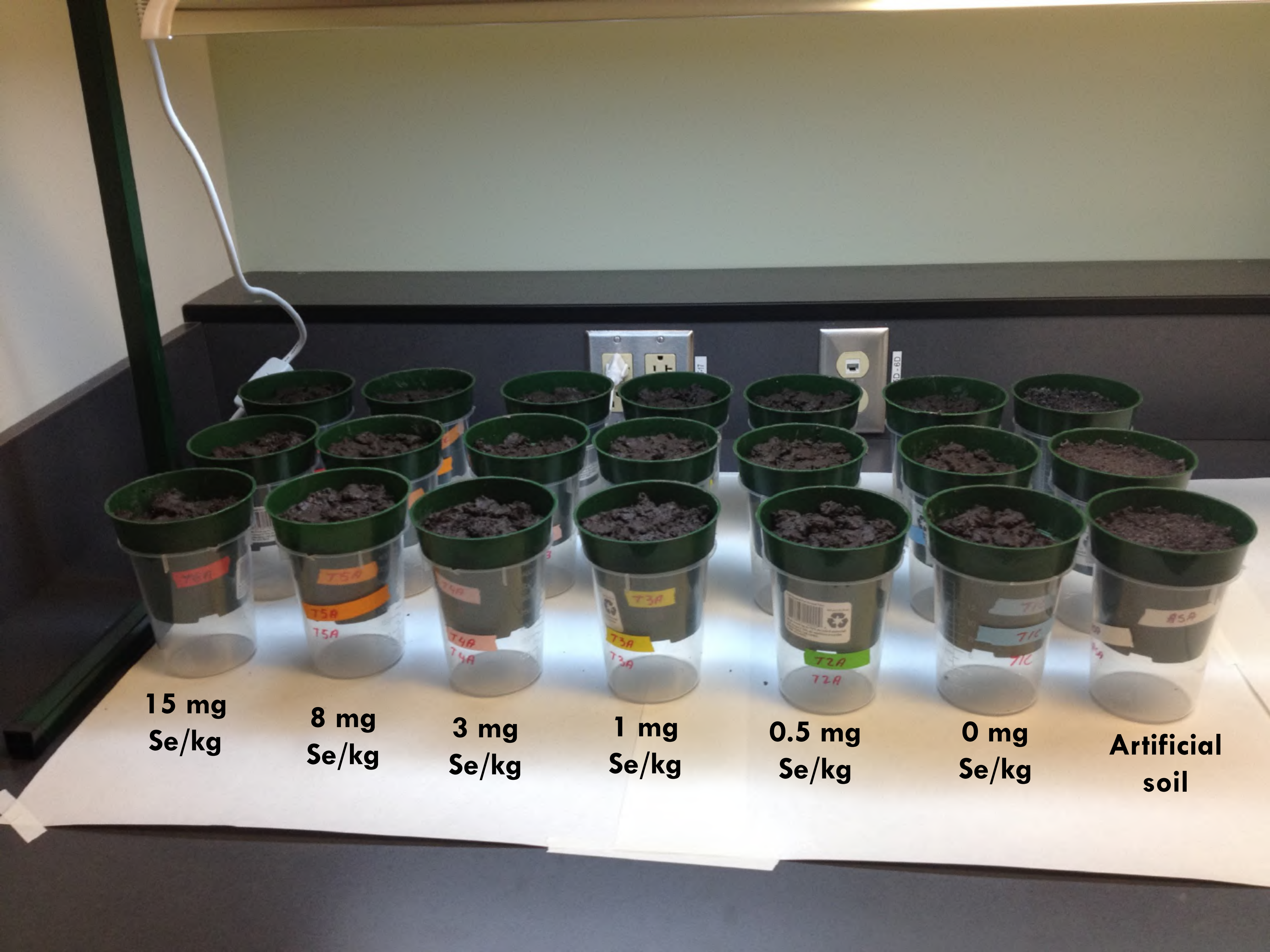
Hg


Se

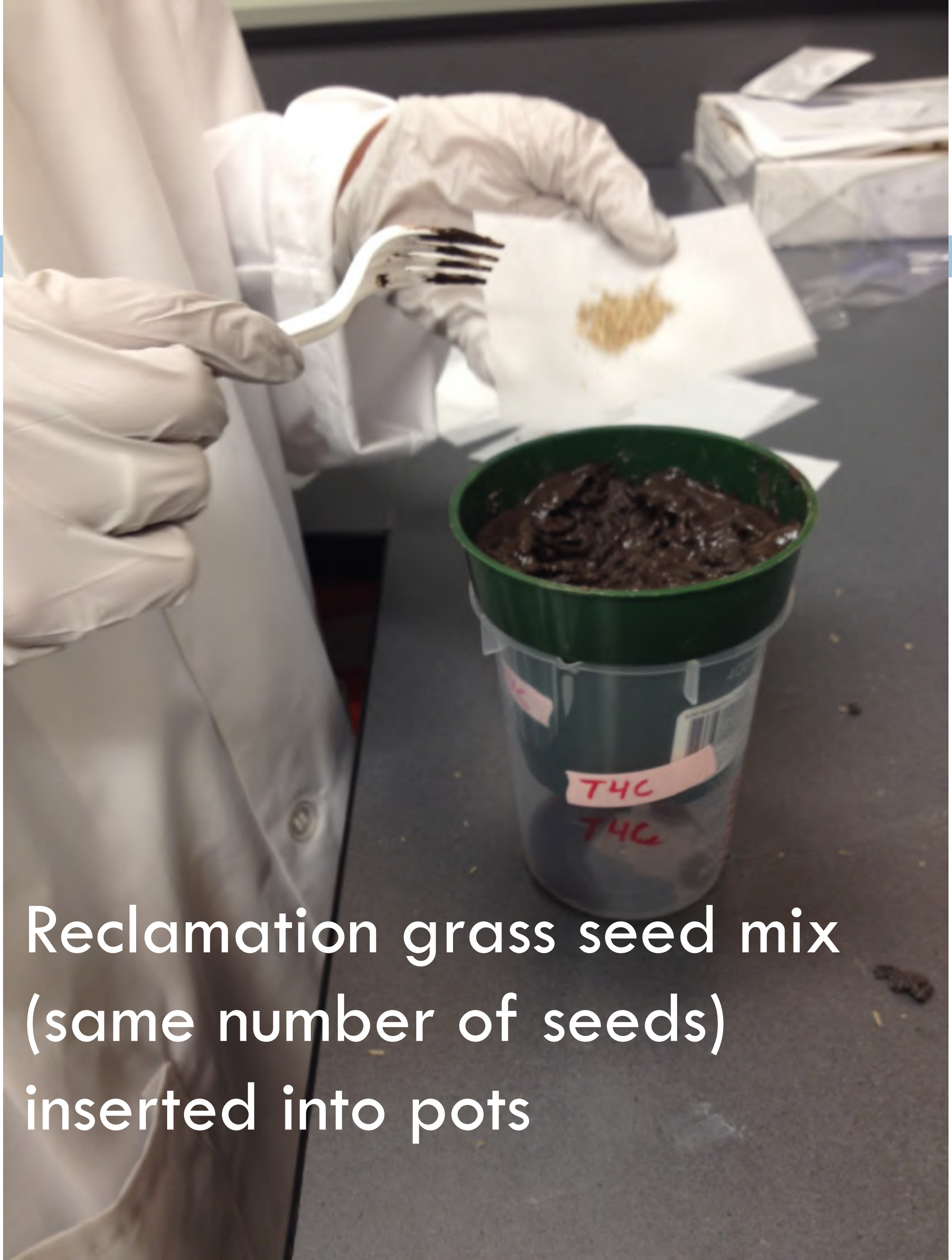
- Site visit, sampling and experimental set-up


WELCOME TO
MONTAGUE GOLD MINES

Mixing of tailing material

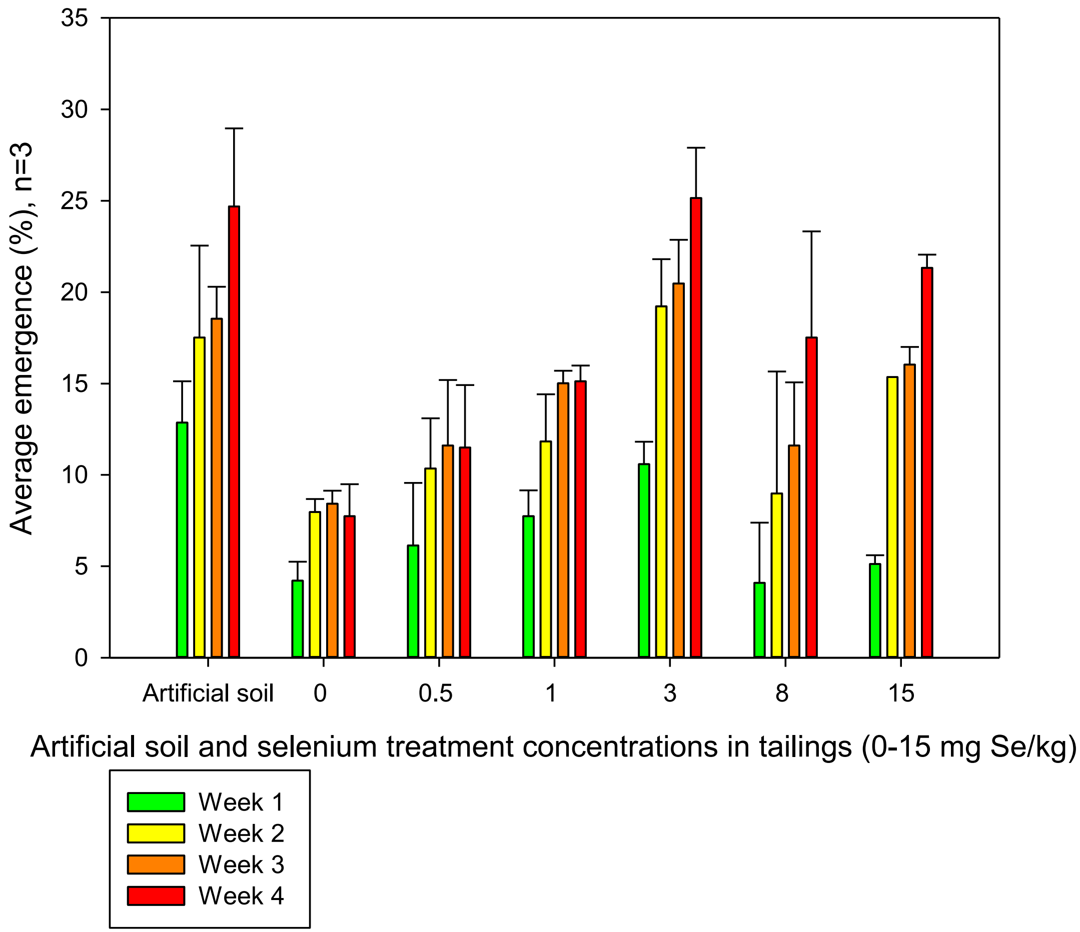

15 mg Se/kg
8 mg Se/kg
3 mg Se/kg
1 mg Se/kg
0.5 mg Se/kg
0 mg Se/kg
Artificial soil

- Plant toxicity tests

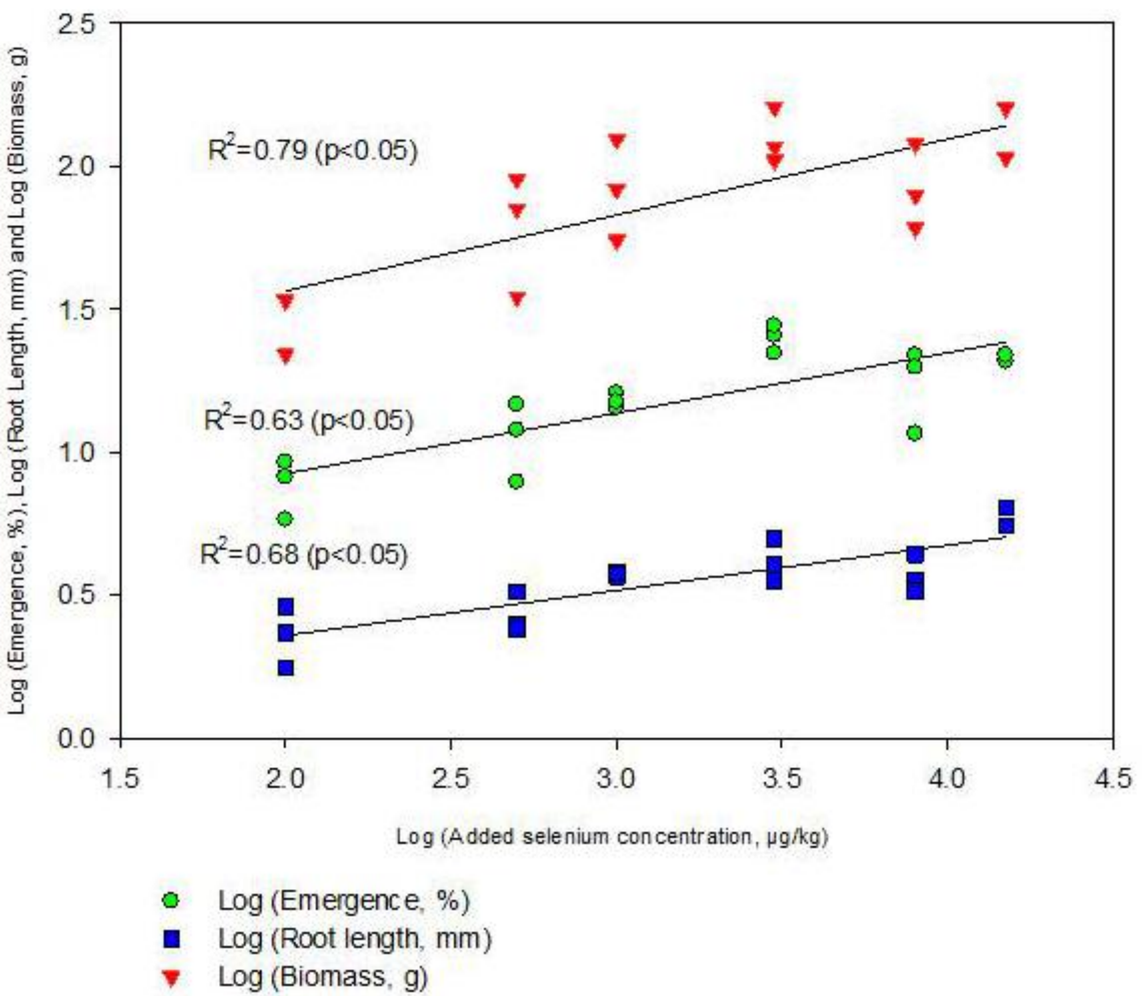


Reclamation grass seed mix (same number of seeds) inserted into pots

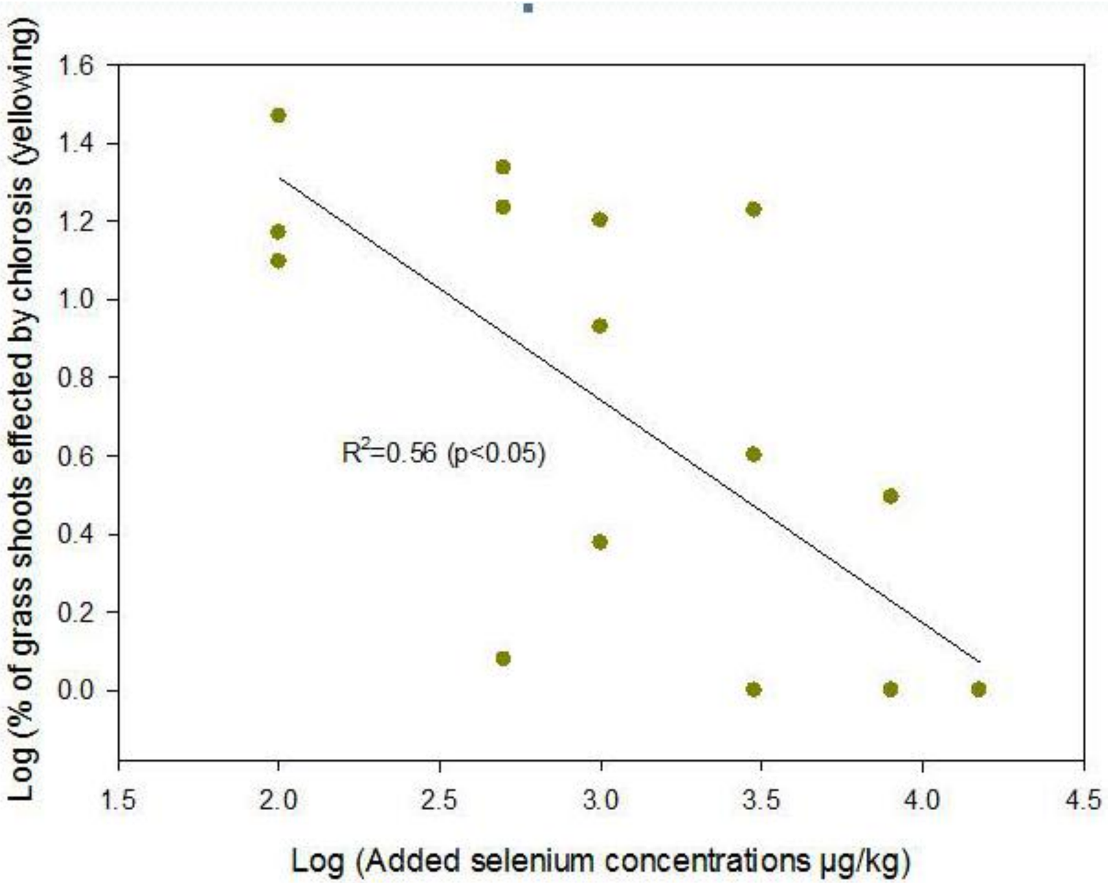
Emergence of grass seedlings each week



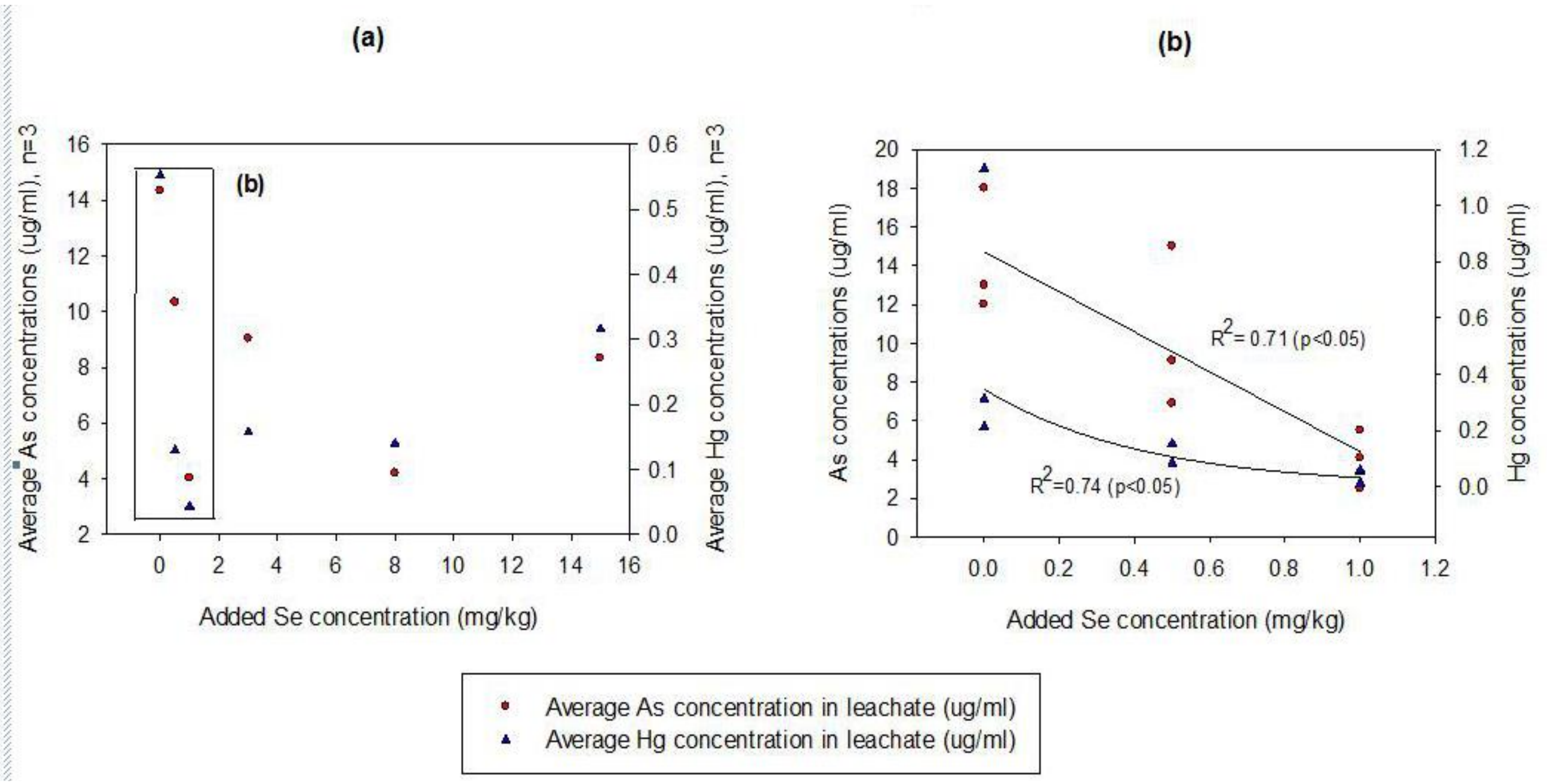
Plant parameters (biomass, emergence and root length) vs added selenium



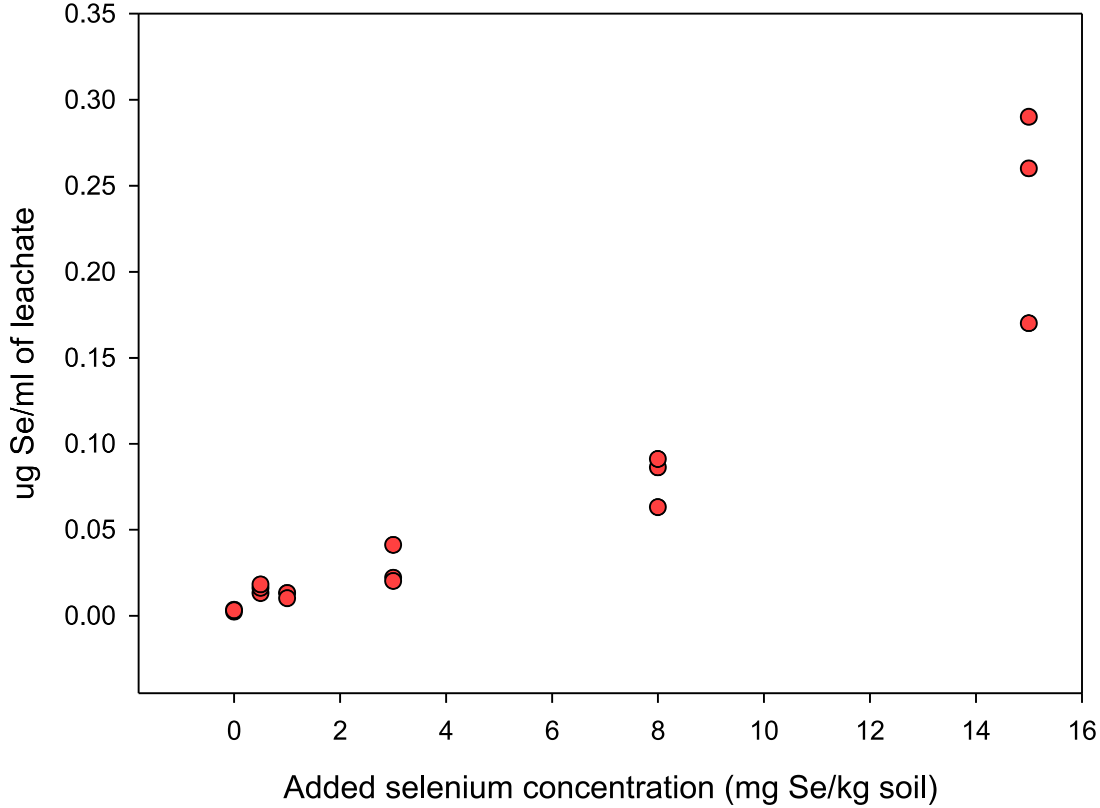
Grass shoots (%) effected by chlorosis (yellowing) in selenium treated material



- Leachate – analysis of dissolved concentrations of As, Hg and Se (**a**) Average concentration of As and Hg in leachate for each Se treatment concentration (n=3). The graph within the square is expanded to (**b**) to show the detail for trends between treatments 0 mg-1 mg Se/kg.



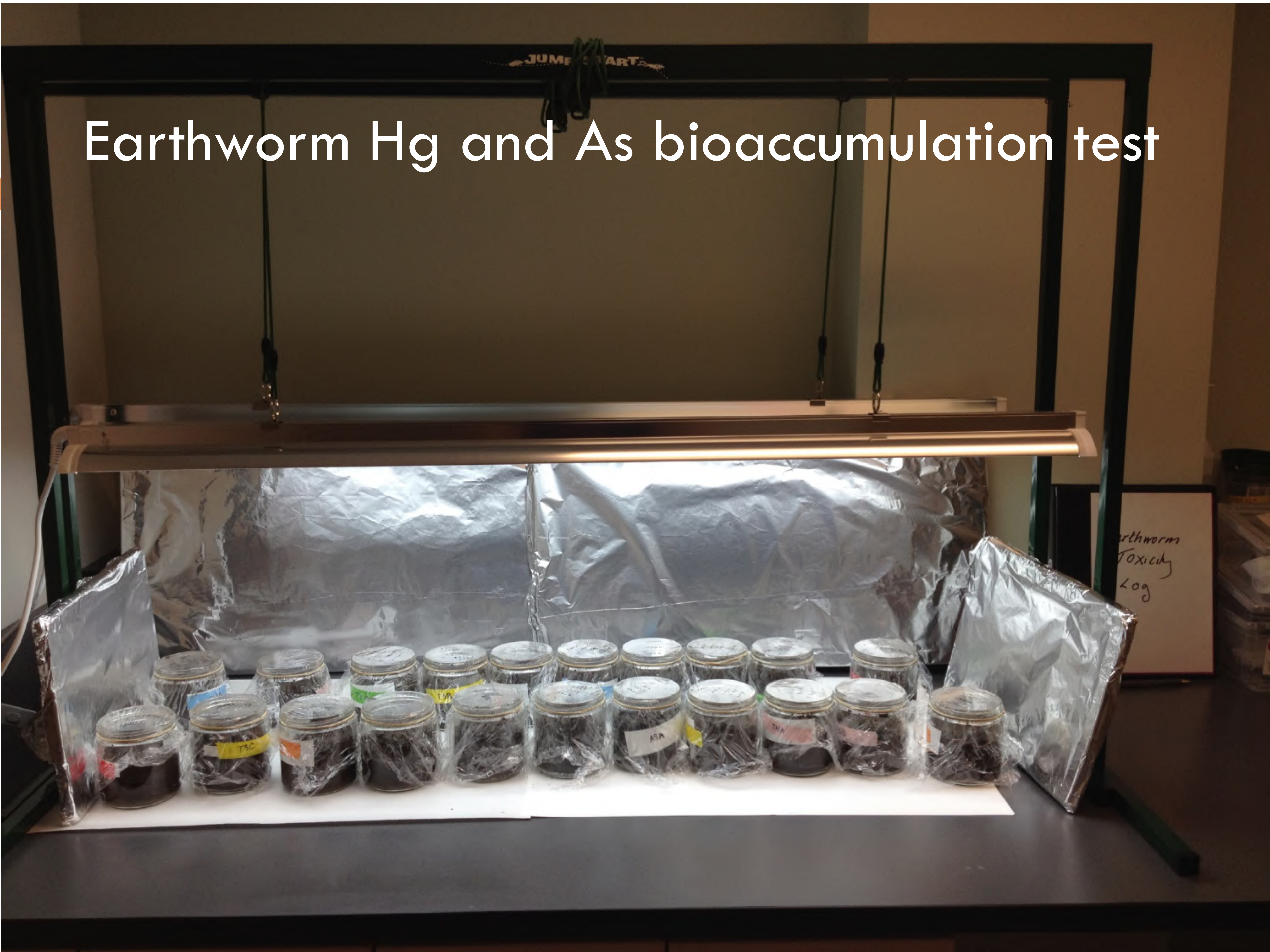
Concentration of Se in leachates (ug/ml) in comparison with concentrations of added selenium to the tailing material (mg Se/kg)



- Worm Hg and As bioaccumulation test

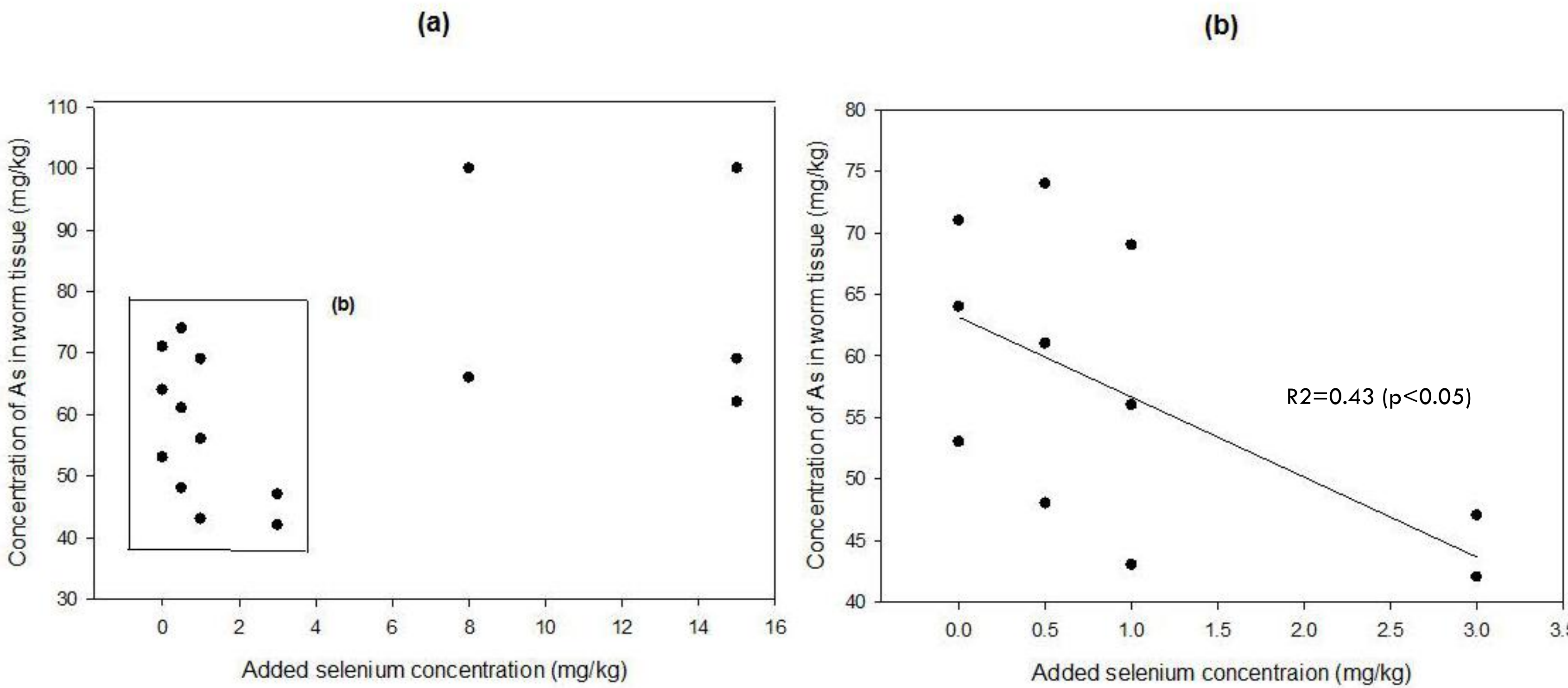

Earthworm species: *E. andrei*

Earthworm Hg and As bioaccumulation test



Segmental swelling and blisters on worms in untreated tailing material

(a) shows accumulated As concentrations in worm tissue (mg/kg) after 8 days in relation to added selenium concentrations (mg/kg) in the tailing material. The graph within the square is expanded in **(b)** to show details for selenium treatment concentrations between 0-3 mg/kg



Concentrations of Hg and As in the tailing material of the different treatments

Sample ID	ASA	ASB	ASC	T1A	T1B	T1C	T2A	T2B	T2C	T3A	T3B	T3C	T4A	T4B	T4C	T5A	T5B	T5C	T6A	T6B	T6C	CCME*
Added Se (mg/kg)	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1	3	3	3	8	8	8	15	15	15	1 (2.9)
Se (mg/kg)	0.4	0.3	0.3	0.8	0.3	0.3	1.7	1.7	1.3	1.8	1.6	2.0	3.5	3.3	3.9	8.5	7.9	9.1	15	15	16	
Hg (mg/kg)	0.02	0.01	0.03	78	50	28	84	42	79	87	175	76	38	73	51	96	100	57	46	84	175	6.6 (50)
As (mg/kg)	2.5	<2.0	<2.0	1100	1200	1600	1300	1100	1100	1200	1100	1000	1000	1100	1300	1600	1100	1100	1500	1100	1400	12 (12)

*CCME guideline for residential/parkland properties. Guideline for industrial sites has been provided in parenthesis

Hg concentrations in worm tissue vs added Se in tailings

- Despite thorough mixing, concentration of Hg was different in the different treatments and replicates confounding the effects of the selenium treatments on Hg accumulation in worms

- When different Hg tailings concentrations were accounted for in a multiple regression, Hg concentration in worm tissue was significantly decreased with increasing Se treatment concentrations ($R^2=0.40$, $p<0.05$)

Conclusions of study

- Na_2SeO_3 additions **decreased toxicity** of the arsenic and mercury in the tailing material to grass.
- Although confounded by different [Hg] in the different treatments, sodium selenite additions **significantly limited** [Hg] accumulated in earthworms.
- [As] in the worms were also negatively related to the [Na_2SeO_3]-up to 3 mg Se/kg. With higher [Na_2SeO_3], [As] in worms increased again.
- Leachate [Hg] and [As] from the Se-treated tailing material decreased drastically in the 1 mg Se/kg treatment, by **94%** and **71%** respectively.
- [Se] in the leachate increased from an average of 3 ug Se/L (in non-treated tailings) to an average of 10 ug Se/L (in the 1 mg Se/kg tailing material).

Potential future research directions

- Potential effects of Se treatments in receiving water bodies
- Other potential cost effective Se additives
- Se/As/Hg solid phase and aqueous phase speciation.
- Controlled field trials/mesocosms to assess effectiveness of Se additive under field conditions. Is more than one application needed over time?
- Se additions as a way to improve revegetation of the sites (research currently underway)

Questions/Comments?

For more information, refer to:

- Chapman, E., Berry, J., Robinson, J., Campbell, L.M., 2016. Can a low dose selenium (Se) additive reduce environmental and health risks of mercury (Hg) and arsenic (As) in old goldmine tailings? Water Air and Soil Pollution 227:216, 1-17.

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