Platform Presentation

Project Title:
(S1) Fertilizer Management and Preceding Crop Influence Accumulation of Cadmium in Durum Wheat

Investigator(s):
Cynthia Grant[1], Mario Tenuta[2] , Don Flaten[2], Sébastien Sauvé[3], Shabtai Bittman[4], Sukhdev Malhi[5], Eugene Gawalko[6]
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Summary:
Studies were conducted evaluating effects of management practices on trace element accumulation in crops and soils, with a focus on cadmium (Cd). Field studies were conducted since 2002 at seven locations across the Canadian prairies assessing the impact of monoammonium phosphate fertilizer varying in Cd concentration on Cd concentration in durum wheat (*Triticum turgidum* L.) and flax (*Linum usitatissimum* L.). Phosphorus fertilization increased Cd concentration of both crops even with extremely low fertilizer Cd concentration. Crop Cd concentration increased with Cd level in the P fertilizer and with fertilizer rate. The impact of fertilizer Cd concentration became more apparent with repeated applications over time, with the effect proportional to the total Cd applied. Cadmium concentration in crops and the effect of fertilizer application varied with soil characteristics. The effect of P fertilization and fertilizer Cd concentration on soil solution concentration of Cd, Zn and other trace elements was assessed in growth chamber studies, with chemical analysis of solution samples still in progress.

Concentration and accumulation of Cd was higher and Zn lower in durum wheat grown after canola (*Brassica napus* L.) than after barley (Hordeum vulgare L.) or flax. Field and growth chamber studies showed that factors that influence mycorrhizal association, such as preceding crop, P fertilization and tillage, also influence accumulation of Cd in crops. Continuing studies are assessing whether changes in mycorrhizal colonization will directly influence Cd accumulation and evaluating the effect of root growth on soil solution concentration of trace element.

Cadmium accumulation in crops may be reduced by selection of crop sequence that reduces the availability of Cd to the following crop. However, the risk of Cd accumulation in crops will increase with long-term application of Cd-containing fertilizers. Risk of Cd accumulation can be reduced by reducing the Cd concentration of fertilizer and by improving P use efficiency to minimize fertilizer application rates.

Platform Presentation

Project Title:

(S1) Effect of short- and long-term applications of manure and fertilizer on Cd concentration in sunflower (*Helianthus anuus* L.)

Investigator(s):

Bittman, S.[1], Hunt, D.E.[1], Kowalenko, C.G.[1], Liu, A.[1], Forge, T.A.[1] and Grant, C.A.[2]
Agriculture and Agri-Food Canada, [1]Agassiz, BC and [2]Brandon, MB

Summary:

Reduction of Cd conctrations is important for improving food quality of crops that naturally accumulate Cd, such as sunflowers (*Helianthus anuus* L.). Phtyoavailability of Cd is naturally high in some soils and may be increased by adding P fertilizer. The short term effect of using manure rather than P fertilizer on Cd concentrations in sunflower grains was investigated in a field trial at Agassiz, BC in 2008. This trial investigated the effect of rates of P applied as mineral fertilizer or as liquid dairy manure. The P sources were either broadcast or injected near the seed. Increasing mineral fertilizer P increased Cd concentration in the grain while increasing manure rate decreased Cd concentrations giving a significant rate x nutrient source interaction. Whereas seed of sunflowers grown with 0 or 27 kg ha^{-1} of fertilizer P had Cd concentrations of about 0.85 mg kg^{-1}, applying manure at 163 kg NH_4-N and 56 kg P ha^{-1} (moderately high rate) lowered Cd concentrations to 0.70 mg kg^{-1}. Method of application had no effect on Cd concentration in the seed.

A trial was also conducted to examine the effect of multi-year fertilizer and (dairy) manure applications on Cd concentration of sunflower seed. This trial was conducted in the greenhouse using soil collected from a 14-yr replicated field trial on forage grass. Yields in the greenhouse trial were standardized by applying N and Zn to circumvent the possible effect of dilution on Cd concentrations. Historical P applications increased Cd concentrations in sunflower grain compared to historical unfertilized control from 0.98 to 1.2 mg kg^{-1}, but moderate and high rates of historical manure significantly decreased Cd to 0.67 and 0.46 mg kg^{-1}, respectively. Adding Zn to the sunflower crop had very little effect on crop yield but greatly decreased grain Cd across all historical treatments (from 0.73 to 0.39 mg kg^{-1}), but the reduction appeared to be less for the historical fertilizer treatments than for the historical manure. By combining the effect of Zn and the moderate historical level of manure, Cd levels were decreased from 1.2 to 0.29 mg kg^{-1}.

These studies demonstrate that Cd accumulation in grain can be reduced by growing the crops on previously manured land, by adding manure instead of P fertilizer and by adding Zn. Additional field trials will be conducted in 2009 to support these results.

Poster

Project Title:
(S1) Effects of phosphorus fertilization, tillage and crop sequence on root colonization by arbuscular mycorrhizal fungi and cadmium accumulation in durum wheat

Investigator(s):
Akhter, F.[1], Gao, X.[2], Tenuta, M.[2,3], Flaten, D.N.[2], and Grant, C.A.[4]

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Summary:
Cadmium (Cd) may accumulate in crops to levels that are of concern in human diets. A field study was conducted over three years to determine if arbuscular mycorrhizal (AM) fungal colonization of roots limits Cd concentration and accumulation in crops. Three agricultural management practices known to affect AM fungal colonization of crops were used as treatments to determine impact on Cd concentration in above-ground crop tissue. The treatments includes P fertilization (0 or 13 kg P ha^{-1} as monoammonium phosphate (MAP) containing low Cd as impurities in it), tillage (no-till or conventional), and previous crop (AM fungal dependent flax and non-AM fungal dependent canola). Above ground plant tissue Cd concentration and accumulation were determined four and eight weeks after emergence.

No-till slightly reduced Cd concentration by 11% and accumulation by 19% in above ground tissue of durum wheat ($P < 0.06$ to 0.09) at eight weeks following emergence. Flax rather than canola as a previous crop increased AM fungal root colonization of durum wheat by 56% over the four and eight week post-emergence samplings. Arbuscular mycorrhizal fungal colonization did not seem related to Cd concentration and accumulation in durum wheat above ground tissue. There was a lack of a previous crop effect on Cd concentration and accumulation in above ground tissue as well as insignificant linear relationships between AM fungal colonization and tissue Cd concentration and accumulation.

Poster – Student Competition

Project Title:
(S1) Monoammonium phosphate and preceding crop influence on soil solution Cd availability and plant Cd accumulation

Investigator(s):
Amarakoon, I. D.[1]; Flaten, D. N.[1]; Tenuta, M.[1] and Grant, C. A.[2]
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[2]Agriculture and Agri-Food Canada, Brandon Research Centre, Brandon, MB R7A 5Y3

Summary:
Monoammonium phosphate (MAP) is a common phosphate fertilizer heavily used in agriculture. Commercial MAP contains Cd as an impurity and can increase Cd accumulation in soils and crops by direct Cd addition. Further, the MAP in its purest form (reagent grade) still has the potential to increase plant Cd accumulation, which may due to an increase in Cd availability in soil solution. Preceding crops may alter soil Cd availability by affecting soil chemical characteristics and further influence Cd accumulation in subsequent crops. Crop residue might release Cd during decomposition and increase Cd availability in soil solution, as well. Two growth chamber studies were conducted to investigate the effect of MAP fertilization, crop sequence and crop residue on Cd availability in soil solution and plant Cd accumulation.

In the first experiment, two levels of reagent grade MAP (0 and 80 mg kg^{-1} P) were added to three plant species: (canola (*Brassica napus* L.), durum wheat (*Triticum turgidum* L.) and flax (*Linum usitatissimum* L.)) and a control (unplanted). Soil solution was collected at weekly intervals using soil moisture samplers and is being analyzed for pH, EC, P, Cd and Zn concentrations. Soil attached to root and bulk soils were sampled and are being analyzed for pH, EC, P, DTPA extractable Cd and Zn concentrations. Plant shoot and root samples are being analyzed for P, Cd, Zn and arbuscular mycorrhizal fungi root colonization.

The first phase of the second experiment has been completed. Canola and barley (*Hordeum vulgare* L.) were grown in the initial cycle. Flax and durum wheat will be grown on soil from the two previous crops (soil from canola and soil from barley), with three crop residue treatments (i.e. canola residue, barley residue and no residue addition). Soil solution will be collected at weekly intervals and will be analyzed for pH, EC, P, Cd and Zn concentrations. Soil samples will be analyzed for pH, EC, P, DTPA extractable Cd and Zn concentrations. Shoot and root samples will be analyzed for P, Cd, Zn and arbuscular mycorrhizal root colonization.

Poster

Project Title:
(S1) Impact of crop rotation and crop residue cycling on the cadmium concentration of the subsequent crop in a rotation

Investigator(s):
Eastley, L. M.[1]; Grant, C. A.[2], Flaten D. N.[1], and Tenuta, M.[1]
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Summary:
Crop rotations can affect both the biological and chemical characteristics of the soil, thus affecting cadmium (Cd) availability. The cycling of Cd from decomposing crop residues may also influence Cd availability to the following crop. Two growth chamber studies were conducted to study the effect of crop rotation and Cd cycling from crop residue on the Cd concentration of the succeeding crop in a rotation.

The first experiment included treatments of soil where the previous crop was canola (*Brassica napus* L.) or barley (*Hordeum vulgare* L.) and the application of no straw, canola straw or barley straw, equivalent to 5000 kg residue ha^{-1}. The second experiment involved application of durum wheat straw equivalent to 5000 kg residue ha^{-1}, containing concentrations of Cd ranging from 50 to 217 µg kg^{-1}. In both experiments flax (*Linum usitatissimum* L.) and durum wheat (*Triticum turgidum* L.) were grown as indicator crops in clay loam soil in pots.

In both growth chamber experiments, tissue Cd concentration was higher in flax than in durum. In experiment one, Cd concentration in flax tissue increased with the application of canola and barley straw compared to when no straw was applied and both types of straw had similar effects on the Cd concentration in the flax. However, the Cd concentration in durum wheat was not influenced by the application of crop residue. Soil from the canola crop increased the Cd concentration in durum wheat, compared to durum grown on soil from the barley crop. However, the soil from the previous crop of the rotation did not influence Cd concentration in flax. In experiment two, the Cd concentration of flax tissue increased with increasing Cd concentration of the applied durum wheat straw, but durum wheat tissue in the indicator crop was not affected.

These experiments show that Cd concentration in flax, but not durum wheat may be influenced by Cd released from the decomposition of the crop residue, whereas the Cd concentration in durum wheat and not flax may be influenced by soil effects caused by the crop rotation.

Poster

Project Title:
(S1) Dependency of cadmium concentration in flax on colonization by *Glomus intraradices*, cadmium and phosphorus addition to soil

Investigator(s):
Gao, X.[1]; Tenuta, M.[1,2]; Flaten, D.N.[1]; and Grant, C.A.[3]
[1]Department of Soil Science and [2]Canada Research Chair in Applied Soil Ecology, University of Manitoba, Winnipeg, MB, Canada R3T 2N2
[3]Agriculture and Agri-Food Canada, Brandon, MB, Canada R7A 5Y3

Summary:
Excessive cadmium (Cd) concentration in soils and crops represent a potential threat to human health because of its accumulation in food chain. Arbuscular mycorrhizal (AM) fungi are widely distributed in natural and agricultural soils and can affect Cd concentrations in crops. Phosphorus (P) can be a source of Cd and inhibit AM fungi development. A growth chamber study was conducted to investigate the influence of AM fungi on shoot Cd concentrations of flax, as affected by levels of P and Cd addition.

Plants inoculated with *Glomus intraradices* (*Gi*) and uninoculated controls were grown in a pasteurized clay loam soil that had received three rates of added Cd (0, 2.5, and 10 mg kg^{-1}) and two rates of added P (10 and 50 mg kg^{-1}). Flax plants were harvested 8 weeks after germination at late flower stage. Shoot and root dry weight, root colonization by AM fungi and Cd concentration in plant biomass were determined. Root colonization was not affected by Cd addition, but was reduced by the 50 mg kg^{-1} P addition. The shoot concentration of Cd was approximately 25% lower in mycorrhizal compared to non-mycorrhizal plants when Cd was supplied at 0 or 2.5 mg kg^{-1} concentrations and P at 10 mg kg^{-1}. In contrast, shoot Cd concentration and plant Cd uptake increased in mycorrhizal plants when Cd was supplied at 10 mg kg^{-1} concentration.

These results confirmed our hypothesis that the effect of AM fungi on Cd concentration of flax depends upon Cd and P addition rates to soil. The dependency of shoot Cd concentration on *Gi* inoculation at different P and Cd addition rates was not associated with a growth-dilution effect or competition between Cd and Zn. Rather, decreased shoot Cd concentration at low Cd (0 and 2.5 mg kg^{-1}) and P (10 mg kg^{-1}) addition rates seems to have been due to reduced root to shoot Cd translocation in mycorrhizal plants. Our results indicate a benefit of AM fungi in reducing Cd concentration of crop plants is likely if soil Cd and P concentrations are low.

Poster

Project Title:

(S1) Soil solution Cd dynamics and Cd accumulation of durum wheat following phosphate fertilizers containing different levels of Cd

Investigator(s):

Gao, X.[1]; Tenuta, M.[1,2]; Flaten, D.N.[1]; and Grant, C.A.[3]

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Summary:

Reduction of cadmium (Cd) levels is important for improving food quality in crops. One of the major inputs of Cd to agricultural soils is the application of Cd-containing phosphorus (P) fertilizers. Fertilization can influence Cd concentration of crops by direct Cd addition and by indirect effects on soil pH, ionic strength, Zn concentration, rhizosphere chemistry, microbial activity, and plant growth. So far, little is known about the Cd dynamics in soil solution following phosphate fertilizers and the relationship between soil Cd availability and crop Cd uptake and translocation. The objective of this study is to understand the effects of phosphate fertilizer (rate, source and Cd content) on soil solution dynamics of Cd and Cd uptake of durum wheat.

A growth chamber study was conducted to evaluate the effects of Cd concentration in phosphate fertilizer on soil solution dynamics of Cd and Cd uptake in durum wheat (*Triticum turgidum* L). Treatments consisted of three different P fertilizers (which contain 3.4, 75.2, 231 mg Cd kg^{-1}, respectively) at three rates (20 and 40 and 80 mg kg^{-1}) plus a control (no P fertilization) in four replicates. Soil solution samples were collected at week interval by soil moisture sampler and determined for pH and P, Cd and Zn concentrations. Above ground plant biomass and root were harvested eight weeks after emergence and Cd, P and Zn concentrations in plant biomass were determined. Results showed that plant biomass, Cd concentration and accumulation in crops increased with phosphate fertilization rate. At each application rate, however, Cd concentration and acculation were not affected by phosphate fertilizer types even though use of the high Cd containing fertilizer tended to produce less plant dry biomass than the low containing fertilizer. Analysis on the soil solution is underway, which will help to understand the mechanisms by which P fertilizer increases Cd availability to crops. The current results indicate that use of low-Cd fertilizers and a suitable application rate should be recommended to decrease Cd accumulation in crops.

Poster

Project Title:
(S1) Dependency of cadmium concentration in flax on colonization by *Glomus intraradices*, cadmium and phosphorus addition to soil

Investigator(s):
Gao, X.[1]; Tenuta, M.[1,2]; Flaten, D.N.[1]; and Grant, C.A.[3]
[1]Department of Soil Science and [2]Canada Research Chair in Applied Soil Ecology, University of Manitoba, Winnipeg, MB, Canada R3T 2N2
[3]Agriculture and Agri-Food Canada, Brandon, MB, Canada R7A 5Y3

Summary:
Excessive cadmium (Cd) concentration in soils and crops represent a potential threat to human health because of its accumulation in food chains. Arbuscular mycorrhizal (AM) fungi are widely distributed in natural and agricultural soils and may affect Cd concentrations in crops. Phosphorus (P) can be a source of Cd and inhibit AM fungi development. A growth chamber study was conducted to investigate the influence of AM fungi on shoot Cd concentrations of flax, as affected by levels of P and Cd addition.

Plants inoculated with *Glomus intraradices* (*Gi*) and uninoculated controls were grown in a pasteurized, clay loam soil, that had received three rates of added Cd (0, 2.5, and 10 mg kg^{-1}) and two rates of added P (10 and 50 mg kg^{-1}). Flax plants were harvested 8 weeks after germination at late flower stage. Shoot and root dry weight, root colonization by AM fungi and Cd concentration in plant biomass were determined. Root colonization was not affected by Cd addition, but was reduced by the 50 mg kg^{-1} P addition. The shoot concentration of Cd was approximately 25% lower in mycorrhizal compared to non-mycorrhizal plants when Cd was supplied at 0 or 2.5 mg kg^{-1} concentrations and P at 10 mg kg^{-1}. In contrast, shoot Cd concentration and plant Cd uptake increased in mycorrhizal plants when Cd was supplied at 10 mg kg^{-1} concentration.

These results confirmed our hypothesis that the effect of AM fungi on Cd concentration of flax depends upon Cd and P addition rates to soil. The dependency of shoot Cd concentration on *Gi* inoculation at different P and Cd addition rates was not associated with a growth-dilution effect or competition between Cd and Zn. Rather, decreased shoot Cd concentration at low Cd (0 and 2.5 mg kg^{-1}) and P (10 mg kg^{-1}) addition rates seems to have been due to reduced root to shoot Cd translocation in mycorrhizal plants. Our results indicate a benefit of AM fungi in reducing Cd concentration of crop plants is likely if soil Cd and P concentrations are low.

Poster

Project Title:
(S2) Factors affecting trace element concentration in the edible parts of vegetables grown in urban gardens.

Investigator(s):
Foucher, E. and Hendershot, W.

Summary:
Trace element uptake and accumulation in plant tissues is determined by soil physico-chemical properties and plant physiological properties and processes. The objective of this poster is to present the results of a field experiment conducted in 2007 using a general linear model to outline the effect of different soil and plant variables on the concentration of trace element in plant tissues. During this experiment, six different vegetables were grown in 22 urban gardens in Montreal. The following variables were included the general linear model: soil HNO_3 , EDTA and $CaCl_2$ extractable trace element content (for 18 elements); soil pH; percent soil organic matter; soil phosphorus content and plant growth rate in grams per day. Growth rate reflects many physiological responses as well as differences in plant age, health and physiological stage. Competition for uptake between elements, such as the antagonistic effect of Zn on Cd uptake, has also been considered as a plant factor. The general model that was tested is:

$$log\mathrm{M}_{\mathrm{Plant}} = a + b \cdot log\mathrm{M}_{\mathrm{soil}} + c \cdot \mathrm{pH} + d \cdot log(\text{soil property}) + e \cdot log(\text{plant factor})$$

The use of EDTA or $CaCl_2$ extractable trace element content showed no or little advantages as compared to the use of the total HNO_3 content. Simple regression between soil and plant content yielded few significant results, stressing the importance of including other variables in the model. Due to the low range of pH covered by the database, the effect of pH on trace element uptake was generally non-significant except for Mn, Pb and Sr in lettuce. Soil phosphorus was shown to greatly reduce the availability of Pb in chard and Cd in lettuce, chard and radish. The percent soil organic matter seems to alternatively increase or decreased trace element availability to leafy vegetable depending on the element and plant species for Cd, Ce, Cu and V. Zinc antagonistic effect on Cd uptake has been observed in lettuce, chard and radish. Finally, the growth rate was shown to be a significant variable for Al, Ce, Cr, Pb and V in chard; Ce, Cu and Zn in broccoli; Pb and Sr in lettuce, and Cu in radish. The faster and the larger the plants have grown, the smaller were the concentrations in the edible parts. The importance of the growth rate on trace element uptake and accumulation shows that plant physiological factors and processes cannot be ignored when working with plants grown in the field.

Poster

Project Title:
(S2 and S5) Effects of transpiration and soil solution chemistry on plant trace element uptake.

Investigators:
[1]Hendershot, W.H., [2]Macfie, S.M., and [2]Sharma, P.

[1] Natural Resource Sciences, McGill University, Montréal, QC
[2] Biology, University of Western Ontario, London, ON

Summary:
While vegetables grown in contaminated soils may pose a health risk to human consumers, the actual amounts of each trace element (TE) that accumulate in the edible tissues depend both on soil properties and on plant species. This project aims at determining the functional relationships between TE content in edible plants and the TE content in soil, TE content and speciation in soil solution as well as volume and rate of transpiration. This second phase of a large collaborative 'urban garden' project was initiated in the spring of 2008 and is based on a series of growth chamber experiments. To date, lettuce and radish have been grown in six different soils with varying degrees of contamination. The transpiration rates of the plants have been manipulated by growing the plants under each of two relative humidity levels (40% and 60%), and the growth rate and amount of water transpired by each plant have been monitored daily. During the 28-day growth period, soil solution was collected twice and analyzed for pH, dissolved organic carbon, as well as for Ag, As, Ba, Cd, Ce, Co, Cr, Cu, Lu, Mn, Mo, Ni, Pb, Pt, Rb, Se, Sr, Tl, V, Y and Zn using ICP-MS. After harvest, the plant tissues (root and shoot) were acid digested and these tissues will also be analyzed for TE content as above. Commonly measured soil properties and different TE fractions are also being analyzed. The experiment will be repeated for barley (with the addition of TE content of the seeds), and all three vegetables will be grown at a third RH level.

Transpiration rates did vary with relative humidity but the magnitude of difference between plants grown at 40% RH and 60% RH varied depending on soil type and plant species. In general, transpiration rates were higher in radish than in lettuce, and the difference in transpiration rates for plants grown at 40% RH as compared to 60% RH were greater for radish than for lettuce. The next steps in the project include evaluation of the relationship between growth rate and transpiration rate as well as analysis of the functional relationships between metal accumulation in plant tissues the chemistries of the soil and soil solution. These data will allow assessment of the amount and identity of TEs accessible to the plant from the soil solution, and will determine the effect of transpiration on the translocation of metal within the plant.

Poster

Project Title:
(S2) The effect of organic matter on the bioavailability of metals in urban garden soils.

Investigator(s):
Murray, H. and Macfie, S.M.

Summary:
Among urban gardeners compost is often proposed as a suitable material for vitalizing the soil. In addition, compost amendments are believed to immobilize metals thereby reducing ecotoxicity. In this study, the effect of compost amendments on metal bioavailability were measured in order to assess the need to include organic matter (OM) when setting guidelines for urban garden soils. Metal accumulation and distribution among organs (root, leaf and pod) of *Phaseolus vulgaris* (green bean) were determined using ICP-AES for plants grown in five soils at soil:compost ratios of 10:0 (unamended), 10:1 (low OM) and 10:3 (high OM). All soils were analyzed for metal content, pH, conductivity, particle size and OM content. Contamination levels of metals measured in soil and vegetable samples were used to calculate bioconcentration factors (BCF) and hazard quotients (HQ).

The results indicated that compost amendment had a significant effect on metal uptake. Where soil metal concentration was below 1000 mg/kg, addition of OM at the highest level resulted in increased total metal uptake by the plant. Above 1000 mg/kg total metal in the soil, addition of OM had no effect on metal accumulation in the beans. Generally, the BCFs were highest for beans grown in contaminated soils treated with high OM. Some HQs exceeded the threshold value of 1, the majority of which were for beans grown at the high OM treatment. The largest potential risk was associated with the ingestion of beans grown in high OM soils with the most hazardous element being Pb. Even in soils considered uncontaminated by Pb under the current guidelines, the HQs exceeded the threshold value of 1. On the other hand, soils considered contaminated by Zn did not have corresponding HQs greater than 1, suggesting beans grown in these soils do not pose a human health risk for Zn. Overall, the analyses of the health risk confirmed that consumption of vegetables grown in contaminated soils may pose an unacceptable risk to urban gardeners. The addition of compost at high levels increases this risk, suggesting OM mobilizes rather than immobilizes metals. These results reinforce the need to include soil characteristics, specifically OM, when setting threshold criteria for metal content of urban garden soils.

Poster

Project Title:
(S2) Application of a root TBLM to predict copper phytotoxicity in 14-day old barley seedlings.

Investigator(s):
Schwertfeger, D. and Hendershot, W.
Natural Resource Sciences, McGill University
dina.schwertfeger@mail.mcgill.ca

Summary:
Semi-mechanistic models, such as the biotic ligand model (BLM), have been successful in predicting metal bioavailability in aquatic environments. There is much interest in applying the BLM to the terrestrial environment. However, the heterogeneous and multi-phase nature of soil complicates metal speciation and presents a stumbling block for the validation of the TBLM. While chemical speciation computer programs assist with the complex iterative calculations of equilibrium chemistry, their efficacy relies on the use of meaningful and environmentally relevant *input data* and *model parameters*.

We present an approach for applying a root TBLM to predict Cu toxicity in *Hordeum vulgare* (barley) seedlings grown in pots of laboratory spiked test soil. Copper-spiked test soils were leached after the metal addition in order to minimize artifacts associated with traditional soil spiking methods. A plant growth experiment was conducted in growth chambers whereby germinated barley seedlings were cultivated in the Cu-spiked soil for 14 days. Samples of the soil solution were obtained on Day 12 by leaching test pots under suction and analyzed for dissolved metal content, DOC, pH, EC and major cations. Visual MINTEQ 2.53 was used to speciate the soil solution and estimate binding to the root ligand. A 2-site root TBLM developed by Wu (2007) to describe the inhibition of root growth of *Pisum sativum* (pea) seedlings exposed to various trace metals in hydroponic culture was used. Preliminary results are presented which compare the ability of the root TBLM to predict Cu phytotoxicity, with other estimates of soil Cu bioavailability (i.e. free Cu^{2+}, root tissue-Cu).

Poster

Project Title:
(S2) Integrating research results into predictive models to describe the movement of trace elements from soil to edible plants

Principal Investigator(s):
William Hendershot, McGill University
Yonghong Wu and William Hendershot
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Summary:
The accumulation of trace metals by edible plants may pose a risk to human health through food chain transfer. Earlier studies within the Soil and Plants theme have accumulated valuable data on the behavior of different components of the soil-plant system. We are trying to integrate these data to formulate a conceptual framework to model the movement of trace elements from soil to plants. The aim is to provide an improved model to relate steady state metal concentration in the different parts of plants to commonly measured soil properties

Data are being collected from published literature and solicited from collaborators. Metal uptake studies are surveyed and included in our dataset for modeling if reliable values of metal concentration in different parts of the plants are present; if soil properties (e.g. pH, SOM, CEC, and major ions) that most likely to control metal bioavailability are measured and present; if they are well controlled studies where other sources of metal contamination (e.g. atmosphere deposition) can be reasonably identified and excluded; if a wide selection of crops are studied and the crops are grown in the same corresponding soil environment, so that interpretation of the relative transfer factors among different species can be made.

Three modeling approaches have been identified. The first uses simple regression models to relate metal uptake to commonly measured soil properties, such as total metal concentration, soil pH, SOM, and DOC. The second is based on the free ion activity model (FIAM). The tissue content of metals in plants is related to free ion activities in the soil solution or soil pore water. The free ion activities are calculated using either the regression equations developed by Sauve et al (1998) or the non-ideal competitive adsorption (NICA) model implemented in Visual Minteq. The third uses the terrestrial biotic ligand model (TBLM) where metal-root binding constants are derived from measured root cation exchange capacity, binding strength of proton and other major cations, and root metal loadings that lead to a given degree of root growth inhibition.

The distribution of metals in different parts of a plant is physiologically controlled by different plant species. In addition, trace metal uptake is influenced by the transpiration flux that plays an important role in trace metal movement from the soil to the root and further to the edible parts. Therefore, we also look for input from experts on plant physiology to improve the modeling of metal transfer within the plants where transpiration kinetics and plant physiologic factors could be integrated.

Poster

Project Title:
(S3) Terrestrial Biotic Ligand Model for Cadmium Accumulation in Soybean

Investigator(s):
Arthur, Lindsay[1], Edward Berkelaar[2], and Beverley Hale[3]

[1]Ontario Ministry of Agriculture, Food and Rural Affairs, Guelph, ON, [2]Redeemer University College, Hamilton, ON, and [3]University of Guelph, Guelph, ON

Summary:
Of all the trace metals in the environment, cadmium (Cd) poses the greatest concern to terrestrial food safety. The accumulation of Cd in crops is not a straightforward outcome of the Cd level in soil. There are several other soil characteristics that have previously played an important role in determining Cd accumulation in crops. The degree of importance of each of the soil characteristics is heavily dependent on genetics, with crop species, and cultivars within species demonstrating significant differences in Cd accumulation.

This research will develop a Terrestrial Biotic Ligand Model (TBLM) to predict the accumulation of Cd into soybeans, following the principles demonstrated by Di Toro et al. (2001). Its intent is to support the development of government standards and guidelines for Cd in agricultural soils, and provide producers with information on agronomic practices that will reduce the uptake of Cd into crops.

Four cultivars, two of which have previously shown to accumulate Cd at low levels, and the other two at high levels, were assessed at two Ontario sites during year one and five Ontario sites, during year two. Soils were analyzed for factors previously known to influence Cd bioavailability to soybean roots: total and extractable Cd and Ca, Zn, Mg, Cl, soil pH and organic matter with each site being classified as per their soil type.

Year one and two confirmed heritable and relative differences among cultivars in Cd accumulation in beans, as relative differences persisted regardless of soil characteristics. The degree of accumulation of all cultivars at each site was not consistently determined by total and available Cd in the soil at each site; with pH playing a significant role which is complexed by a relationship with anions, competing cations, organic and inorganic ligands present in the soil.

Poster

Project Title:
(S3) Using ion-specific microelectrodes to measure the width of the boundary layer surrounding roots of plants exposed to cadmium and thallium.

Investigator(s):
Harskamp, James[1], Mike J. O'Donnell[2], and Edward Berkelaar[1]
[1]Redeemer University College, Hamilton, ON, and [2]McMaster University, Hamilton, ON

Summary:
Trace elements such as cadmium (Cd) and thallium (Tl) can accumulate in crop species, resulting in human exposure to Cd and Tl. The area through which ions diffuse towards the root tip is described as the boundary layer, and diffusion through this layer may be the rate limiting step in the uptake of ions by plants. The goal of this research is to accurately describe the width of the boundary layer surrounding spring canola and durum wheat roots exposed to Cd^{2+} and Tl^{+}.

Microelectrodes were pulled with a tip approximately 3-5 :m in width and filled with the appropriate ionophore cocktail and backfill solution depending on the element being measured. Cd microelectrodes are described in the literature, but a Tl^{+} microelectrode had to be developed and tested. To do this, 25 different ionophore cocktails were made in nitrophenyl octyl ether by varying the proportions of ionophore and lipophilic salt. Spring canola and durum wheat were germinated in Petri dishes in the dark and were transferred to a modified Hoagland's solution after two to three days. Flux was measured using plants that were four to seven days old. Prior to exposure, plants were twice desorbed in 50 :L $Ca(NO_3)_2$ solution before exposure. Exposure solutions contained 50 :M $Ca(NO_3)_2$ and 1 or 5 :M Cd^{2+}, with or without EDTA or citrate to increase the amount of complexed Cd in the solution. Ion flux was calculated from ion concentration gradients that were measured by positioning the microelectrode tip at two points within the boundary layer.

Flux of Cd to wheat and canola roots was highest about 600 :m behind the root tip. No flux was observed to root hairs. In the region of highest uptake, the boundary layer for Cd^{2+} in both spring canola and durum wheat was 500-600 :m wide in the absence of EDTA and was reduced by 20% when EDTA was present in the exposure solution. There was no change in boundary layer when Cd^{2+} was buffered with citrate. The Tl^{+} microelectrode was successfully able to measure 5 uM Tl^{+}. Future work will involve improving the Tl^{+} microelectrodes lifespan, as well was determining the boundary layer of Tl^{+} for spring canola and durum wheat.

Poster – Student Competition

Project Title:
(S3) The influence of competing ions on Tl accumulation by durum wheat and spring canola grown in soil

Investigator(s):
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Summary:
One of the main routes of exposure for trace elements like thallium (Tl) is through ingested plants and foodstuff. Previous hydroponic studies have indicated that Tl is readily accumulated by plants and that Tl and potassium (K) compete with one another for accumulation and translocation within plants. The current study looked at uptake of Tl from soil and considered the effect of competition between Tl and K on accumulation and translocation within durum wheat and spring canola grown in an amended field soil for one growing season.

Homogenized soil was separated into eight containers and amended with four concentrations of Tl (background, or background plus 0.1, 0.5, or 1 ppm) with or without additional K (background or background plus 150 ppm). The soils were allowed to age for a month before they were potted and seeded with spring canola (*Brassica napus* var 'Hyola 401') or durum wheat (*Triticum turgidum* cv 'Kyle'). Plants were watered with deionized water and a dilute fertilizer solution without added K throughout the summer. Canola was harvested at four life-stages while wheat was harvested at two life-stages, with the final harvest for both cultivars occurring at crop maturity. The plant samples were separated into roots, shoots, and fruits (if applicable) and were analyzed for total Tl and K. Additionally, the soils were analyzed for the total and bio-available concentrations of Tl and K.

The results indicate that the [Tl] in plant tissue depended on soil [Tl] (higher soil [Tl] resulted in higher tissue [Tl]), plant species (canola contained higher [Tl] than wheat), lifestage (tissues had higher [Tl] in harvest 1 than in later harvests) and soil [K] (high soil [K] resulted in higher tissue [Tl], especially in canola). The effect of K is contrary to what was seen in hydroponic studies, where higher [K] in the exposure solution resulted in lower tissue [Tl], suggesting that K competes with Tl for binding sites in both plant roots (reducing Tl uptake) and in soils (increasing Tl availability). Furthermore, the distribution of Tl among tissues differed between wheat and canola; for wheat, more Tl was found in roots than shoots or grain while in canola, higher [Tl] was found in shoots than in seeds or roots. This suggests that the mechanism responsible for translocating Tl to seeds from the rest of the plant is species dependent.

In terms of risk assessment, these results suggest that the possibility of accumulating Tl within the edible portions of wheat plants is very low, while canola readily accumulates Tl in

seeds. Furthermore, they indicate that when generating models to predict the [Tl] in plant tissue, the soil [Tl] and [K] as well as the plant species are all important parameters to consider.

Poster

Project Title:
(S3) The effect of transpiration on thallium and selenium accumulation by durum wheat and spring canola.

Investigator(s):
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Summary:
The primary route of human exposure to thallium (Tl) and selenium (Se) is via consumption of plants, but models to predict plant uptake of these elements are not well developed. The impact of soil chemistry, variation among plant species and varieties, and perhaps factors that influence the rate of transpiration by plants need to be determined. In this study, the importance on transpiration in Tl and Se accumulation by durum wheat (*Triticum turgidum*) and spring canola (*Brassica napus*) was investigated.

Wheat and canola were exposed to 0, 0.1, 1, or 10 µM Tl(I) (Tl^{+}) or Se (SeO_4^{2-} or SeO_3^{2-}) in solution culture. Exposure occurred in chambers at either high or low humidity and transpiration was determined by weighing to determine the amount of water lost. Plants were harvested after either 9 hours of dark or 24 hours of dark and light. Roots and shoots were separated, dried, and analyzed for Tl or Se.

Transpiration rates were higher for plants exposed in chambers with lower humidity. Concentrations of Tl in the shoots increased with increasing transpiration rate for both species, but the correlation was significant only for canola plants exposed to 10 µM in the dark and all Tl concentrations in the light, and for wheat plants exposed to 0.1 µM Tl in the dark and light. The effect of transpiration on translocation of Se was dependent on both plant species and Se speciation. In wheat, the rate of transpiration effected translocation of selenate but not selenite, while for canola the opposite was found. Measurements of mass flow may be useful in predicting Tl and Se accumulation, and models to predict element concentrations in above-ground parts of plants may be improved by including mass flow.

Poster

Project Title:
(S5) The effect of organic matter on the bioavailability of metals in urban garden soils.

Investigator(s):
Murray, H and Macfie, SM.

Summary:
Among urban gardeners compost is often proposed as a suitable material for vitalizing the soil. In addition, compost amendments are believed to immobilize metals thereby reducing ecotoxicity. In this study, the effect of compost amendments on metal bioavailability were measured in order to assess the need to include organic matter (OM) when setting guidelines for urban garden soils. Metal accumulation and distribution among organs (root, leaf and pod) of *Phaseolus vulgaris* (green bean) were determined using ICP-AES for plants grown in five soils at soil:compost ratios of 10:0 (unamended), 10:1 (low OM) and 10:3 (high OM). All soils were analyzed for metal content, pH, conductivity, particle size and OM content. Contamination levels of metals measured in soil and vegetable samples were used to calculate bioconcentration factors (BCF) and hazard quotients (HQ).

The results indicated that compost amendment had a significant effect on metal uptake. Where soil metal concentration was below 1000 mg/kg, addition of OM at the highest level resulted in increased total metal uptake by the plant. Above 1000 mg/kg total metal in the soil, addition of OM had no effect on metal accumulation in the beans. Generally, the BCFs were highest for beans grown in contaminated soils treated with high OM. Some HQs exceeded the threshold value of 1, the majority of which were for beans grown at the high OM treatment. The largest potential risk was associated with the ingestion of beans grown in high OM soils with the most hazardous element being Pb. Even in soils considered uncontaminated by Pb under the current guidelines, the HQs exceeded the threshold value of 1. On the other hand, soils considered contaminated by Zn did not have corresponding HQs greater than 1, suggesting beans grown in these soils do not pose a human health risk for Zn. Overall, the analyses of the health risk confirmed that consumption of vegetables grown in contaminated soils may pose an unacceptable risk to urban gardeners. The addition of compost at high levels increases this risk, suggesting OM mobilizes rather than immobilizes metals. These results reinforce the need to include soil characteristics, specifically OM, when setting threshold criteria for metal content of urban garden soils.