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Office of Superfund Remediation and Technology Innovation

Phosphate Amendment Fact Sheet

Glossary of Terms and Acronyms

Amendment: Agents that are added to soil to cause lead to be less soluble or less mobile in soil

Bioaccessibility (oral): Soluble fraction of lead in gastrointestinal fluids; used to estimate RBA

Bioavailability (oral): Fraction of an ingested dose of lead that is absorbed from the gastrointestinal tract

Contaminant: Harmful or hazardous matter introduced into the environment

Co-contaminant: Contaminants commonly found together with lead

Dissolved: made soluble

***In vivo*:** Measured in a living organism (human or animal model)

***In vitro*:** Measured in a test tube

Pb: Lead in any form

Phosphate: A phosphorus-oxygen chemical having the structure PO_4^{3-}

Phosphate Amendment: Any one of a group of soil amending agents that contain phosphate

Pyromorphite: Any one of a group of highly insoluble lead-phosphate minerals (e.g., chloropyromorphite, $Pb_5[PO_4]_3Cl$)

Relative Bioavailability (oral): Ratio of oral bioavailability of lead in soil of that of a highly water soluble form of lead (typically lead acetate)

RBA: Relative bioavailability

What happens when soil containing lead (Pb) is ingested?

Lead (Pb) is a ubiquitous environmental constituent and children are particularly sensitive to the effects of lead. Exposure of children to Pb can cause adverse health outcomes, such as neurocognitive impairment.

Ingested soil and surface dust can be important contributors to elevated blood Pb levels in children exposed to Pb contaminated environments.

Following ingestion of soil contaminated with Pb, Pb is released from soil and dissolved in gastrointestinal fluids. Once the Pb is dissolved, it is absorbed from the gastrointestinal tract into the body. Oral bioavailability measures how much of the ingested Pb is absorbed following ingestion.

The oral bioavailability of Pb is strongly influenced by its solubility in fluids of the gastrointestinal tract and the form of Pb that is ingested.

How is the oral bioavailability of Pb in soil measured?

The oral bioavailability of Pb from soil is measured using *in vivo* bioassays. This type of study is typically performed using juvenile swine. In the swine assay, the oral relative bioavailability (RBA) is used to estimate the bioavailability of Pb in soil. Animal studies to assess the bioavailability of Pb in soil are expensive and time consuming.

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The oral relative bioavailability of Pb can also be estimated using an *in vitro* method which measures Pb bioaccessibility. This is the most common and cost-effective method used to determine the oral relative bioavailability of Pb in soil.

How are soils that are contaminated with Pb treated to reduce (mitigate) risk?

Typically, strategies to mitigate human health risk from exposure to Pb contaminated soil have focused on excavation and removal of the contaminated soil, capping with clean soil, or covering with vegetation.

Soil amendments, agents that are added to soil to cause Pb to be less soluble or less mobile in soil, used in combination with other methods (e.g., removal or containment) have been used to mitigate exposure to soil Pb.

Phosphate amendments are agents that contain phosphate, such as triple super phosphate, rock phosphate, phosphoric acid, and hydroxyapatite (e.g., fish bones). Phosphate amendments have been studied as a means to mitigate risks from exposure to Pb in soils.

How can phosphate amendments affect the oral bioavailability of Pb?

The rationale for amending soils with phosphate is that phosphate will promote formation of highly insoluble Pb species (e.g., pyromorphite minerals) in soil, which will remain insoluble after ingestion and, therefore, decrease oral bioavailability.

Results of *in vitro* and *in vivo* studies provide evidence that amending soils with phosphate can reduce the bioaccessibility and bioavailability of Pb from soil within a certain concentration range of Pb.

How is the effectiveness of phosphate amendments measured?

Laboratory studies have shown that pyromorphite has very low solubility and forms rapidly in soils. However, direct measurements of the bioavailability of pyromorphite in the mammalian gastrointestinal tract have not been reported. Therefore, it is not possible to predict the maximum effectiveness of any phosphate amendment treatment.

Animal bioassays can be used to determine the RBA of Pb from soils treated with soil amendments. Currently, this is the method recommended by EPA.

At this time, use of *in vitro*, bioaccessibility methods to predict the relative bioavailability of Pb from phosphate-amended soils is not recommended. Although a large number of *in vitro* studies have evaluated the effect of phosphate soil amendments on soil Pb bioaccessibility, the relationship between bioaccessibility and RBA has not been rigorously established for soils amended with phosphate. The U.S. EPA is currently conducting

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research to develop *in vitro* methods that could be used to estimate the RBA of Pb in phosphate amended soils.

What factors may influence the effectiveness of phosphate amendments?

If other metals, such as iron (Fe), aluminum (Al), and manganese (Mn), are present in soil, they may react with phosphate amendments. This may decrease the amount of phosphate available to react with Pb to form pyromorphite

The pH level of soil may influence the chemical form of Pb in soil. Certain forms of Pb do not easily react with phosphate to form pyromorphite.

Water in soil is necessary to transport phosphate amendments through the soil and sustain the formation of pyromorphite. If phosphate amendments are applied to soils that have low water content, pyromorphite formation may be reduced.

There is very little information about long-term stability of pyromorphite or the environmental conditions that could cause it to break down and release soluble Pb into soil.

What happens to other metals when phosphate amendments are applied to soils?

In many instances, Pb-contaminated soils also contain other co-contaminants of concern, such as antimony (Sb), arsenic (As), cadmium (Cd), vanadium (V), and zinc (Zn).

Investigations of effects of phosphate amendments on co-contaminated soils are limited and studies have not examined the bioavailability of co-contaminants.

Studies have shown that phosphate amendments may cause co-contaminants, such as As, to be released from soil and to enhance mobility of these contaminants within soil. Enhanced mobility may cause co-contaminants to migrate to ground or surface water or be more available for uptake into plants.

High soil content of organic matter can reduce formation of pyromorphite.

It is unknown if increased mobility of co-contaminant mobility results in an increase in co-contaminant bioavailability.

Are there other concerns about using phosphate amendments?

Phosphate amendments may migrate to and contaminate areas off the application area.

If applied in excess, phosphate amendments may run off the application area and contaminate ground or surface water.

How should phosphate amendments be used for soil remediation?

Formation of pyromorphite in soil from the site should be demonstrated.

Results of *in vitro* and *in vivo* studies show that amending soils with phosphate reduced

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bioaccessibility and bioavailability of Pb from soil. However, these studies cannot be used to predict how well phosphate amendments will work at a specific site. Therefore, plans to amend soils with phosphate need to include assessment of site-specific efficacy to reduce Pb bioavailability.

Phosphate amendments should be used in combination with other methods, such as re-vegetation, raised garden beds, or gravel.

The long-term effectiveness of the phosphate amendment should be established to determine if repeated applications are necessary to maintain reduced bioavailability.

What are research needs for use of phosphate amendments?

Research needs for assessment of efficacy of phosphate amendments on bioavailability include the following:

- Measurement of the bioavailability of pyromorphite in a suitable animal model and/or human clinical study;
- Development of an *in vitro* bioaccessibility assay that reliably predicts *in vivo* bioavailability of Pb in phosphate-amended soils;
- Additional studies of efficacy of specific amendments in a variety of settings where Pb contamination is an issue and cannot be feasibly remediated by removal (e.g., urban gardens);
- Studies to determine effects of phosphate amendments on the mobility and bioavailability of important co-contaminants (e.g., As); and
- Studies to determine duration of efficacy and requirements for repeated amendments.

Reference:

Scheckel, K.G., Diamond, G., Maddaloni, M., Partridge, C., Serda, S., Miller, B.W., Klotzbach, J. and Burgess, M. 2013. Amending soils with phosphate as means to mitigate soil lead hazard: A critical review of the state of the science. *J. Toxicol. Environ. Health B* 16(6): 337–380.