Assessment of arsenic phytotoxicity of a contaminated Ferrosol using radish.

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Abstract
Arsenic (As) contaminated soil presents a potential risk to human and environmental health, especially when As contaminated sites are redeveloped for residential purposes. State Environmental Planning Policy 'No 55 – Remediation of Land' requires planning authorities to consider land contamination when assessing development applications. This study's aim was to directly assess As phytotoxicity and soil availability using a quick growing, common residential garden vegetable. The results of this study may be used to inform a review of the adequacy of the current phytotoxicity investigation level (PIL), 20mg Total As kg^{-1} soil. A phytotoxicity trial growing long scarlet radish (*Raphanus sativus*) revealed no significant difference in root elongation in soils contaminated with 10, 86, 169, 244, 315 and 656mg As kg^{-1}. The current PIL of 20mg kg^{-1} is excessive in this Ferrosol and remediation to the health investigation level (HIL) of 100mg kg^{-1} would be sufficient. The PIL should be specific to the remediation site and based on plant availability of As.

Key Words
contamination arsenic phytotoxicity Ferrosol remediation radish.

Introduction

Arsenic (As) based pesticides, used extensively in the early to mid 1900s, have caused contamination in excess of 1000mg As kg^{-1} at some sites throughout Australia (Smith *et al.* 1998). Many of these highly contaminated sites are decommissioned livestock dip sites and cropped areas such as abandoned banana farms. Some of these contaminated lands are adjacent to population growth areas and as such, there is significant pressure to redevelop this agricultural land for residential use. In New South Wales (NSW), State Environmental Planning Policy No 55 – Remediation of Land, (SEPP 55) (DUAP 1998), requires planning authorities to consider land contamination as a land use constraint and the redetermination of appropriate actions to be undertaken as part of the redevelopment.

Current guidelines for As site contamination assessment are based on Total As concentration. This is consistent with the National Environment Protection Measures (NEPM) for As. After testing the soil, a remediation action plan (RAP) is normally formulated to rehabilitate the contaminated site as part of the conditions of any redevelopment approval. Normally, the remediation target levels for residual soil As employ a health investigation level (HIL e.g. 100 mg As kg^{-1} for residential areas) and a phytotoxicity investigation level (PIL e.g. 20 mg As kg^{-1}) (NSW EPA 1998). The HIL is based on significant research and forms part of the Australia wide NEPM. However, a soil PIL at 20 mg As kg^{-1} is a value that may change significantly with the soil type and properties (pH, clay content and type, organic matter, iron and aluminium oxides, phosphate-sorptive characteristics) and plant species (As sensitivity, preferred uptake and accumulation characteristics).

As such, a single soil Total As concentration alone is an inappropriate indicator for assessing phytotoxic impacts at contaminated sites. In order to improve the assessment of As phototoxicity in soil, a direct plant based measure of soil As availability for any soil type is needed.

A phytotoxicity procedure already exists for assessment of potting mixes (Standards Australia 2002. *AS 3743 - Potting Mixes*). Using this procedure, a series of trials were undertaken to test the application in the assessment of the level of As phytotoxicity of a contaminated soil. This procedure tests the toxicity of potting mixes by germinating the seed of an indicator plant (usually Radish, *Raphanus sativus*), incubating the germinated seed for five days and measuring the length of the radicle in comparison with those grown in a known non-toxic potting mix. This is a simple trial that takes approximately five days to complete and yields a direct measurement of the toxic effects on seed germination and root extension.

The aim of this study was to assess As phytotoxicity of a Ferrosol for the purpose of remediation of a site by identifying the impact of soil As concentration on the germination of plants by growing radish (*Raphanus sativus*).

Methods

Soil site characteristics

The soil for testing was taken from a proposed redevelopment site at Bilambil heights on the North Coast of NSW. The predominant soil type was a Ferrosol. The soils were red-brown with a light to medium clay texture. Six soil samples were recovered and tested for Total As. The Total As concentrations were; 10mg kg-$^{-1}$, 86mg kg^{-1}, 169mg kg^{-1}, 244mg kg^{-1}, 315mg kg^{-1} and 656mg kg^{-1}.

Germination Trial

The experimental trials were undertaken in two steps: a test procedure to validate the impact of soil As on plant root development and a direct test of the validated procedure on the trial site soils.

The validation trial tested the germination and root extension of an As contaminated washed sand. The sand was treated with sodium arsenite to yield total sand As concentrations of; 0mg kg^{-1}, 100mg kg^{-1}, 200mg kg^{-1}, 300mg kg^{-1}, 500mg kg^{-1} and 800mg kg^{-1}. The sand was put into small pots and used a randomised complete block design with the six treatments and three replications. The phytotoxicity trial used *long scarlet* radish. Ten seeds were placed in each pot and moistened. The pots were then kept moist for five days and the radish harvested and the length of each radicle measured.

The soil test adopted a randomised complete block design using six treatments (soil As of 10mg kg-$^{-1}$, 86mg kg^{-1}, 169mg kg^{-1}, 244mg kg^{-1}, 315mg kg^{-1} and 656mg kg^{-1}) with three replications. The soil treatment of 10mg kg^{-1} As was selected as the control treatment. Natural As concentrations in soil are usually less than 15mg kg^{-1} (Walsh *et al.* 1977). The initial soil moisture content was estimated for each soil sample. The gravimetric moisture content was then calculated and used to determine the amount of water required per gram of soil to reach field capacity. Soil samples were air-dried, ground and put through a 2mm sieve to eliminate structural variance and ensure maximum soil to root contact. The soils were then placed in pots, wet to field capacity, with each pot planted with ten *long scarlet* radish seeds. The pots were kept moist for five days and then the radish harvested and the length of each radicle measured.

Statistical Analysis

All statistical analysis was assessed using the 0.05 (α) level of significance for difference and only the resultant $R^2 > 0.70$ were reported. A t test on root length was conducted assuming equal and unequal differences to determine any significant difference in root elongation in the trial.

Results

Arsenic dosed-sand

The trial method was ratified using washed sand dosed with sodium arsenite in which bioavailability was uninhibited by any sorptive components. The addition of increasing concentrations of As^{iii} caused a significant decrease in root elongation. A statistical summary of t test on root length is shown in Table 1. A root elongation response curve is shown in Figure 1. The results for radish grown in dosed sand confirmed the viability of the test method. The validation trial shows a strong response to the addition to As to the sand. The initial test indicates that radish should respond to soil As by reducing radicle extension.

Arsenic contaminated soil

In terms of root elongation, no significant difference was observed in soils contaminated with up to 656mg As kg^{-1}, except for radish seedlings grown in soil containing 169mg As kg^{-1} compared with those grown in soil containing 244mg As kg^{-1} (where significant difference was noted). A summary of the t test on root length is shown in Table 2.

Table 1. Summary of t test on root elongation in six sand samples of validation trial (* 0.05, ^ 0.01).

	Equal variances							
	mg As kg^{-1}		0	100	200	300	500	800
		Mean root length (mm)	27	11	7	3	2	0
Unequal variances	0	27		**^8.926**	**^10.774**	**^12.848**	**^14.210**	**^15.684**
	100	11	**^8.926**		**^3.711**	**^7.789**	**^11.208**	**^16.099**
	200	7	**^10.774**	**^3.711**		**^3.912**	**^6.493**	**^10.273**
	300	3	**^12.848**	**^7.789**	**^3.912**		1.934	**^5.048**
	500	2	**^14.210**	**^11.208**	**^6.493**	1.934		**^4.273**
	800	0	**^15.684**	**^16.099**	**^10.273**	**^5.048**	**^4.273**	

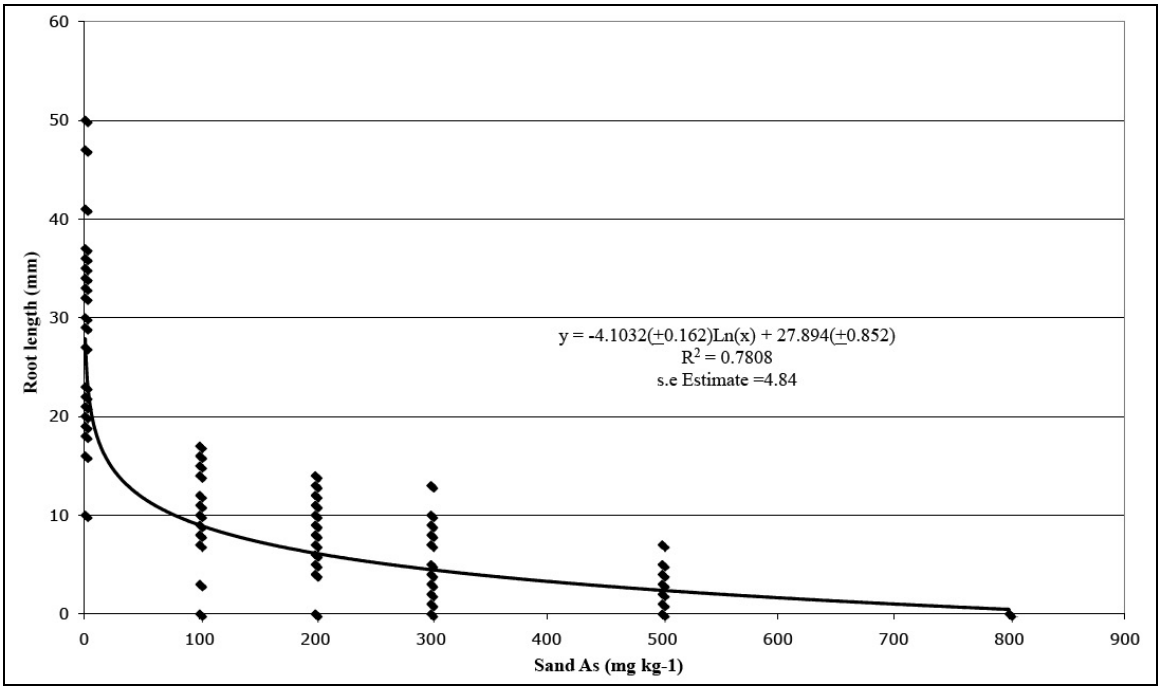

Figure 1. Root elongation with increasing sand arsenic concentration.

Table 2. Statistical summary of t test on root elongation in six Ferrosol soil samples following a phytotoxicity trial (* 0.05^ 0.01).

	Equal variances							
	mg As kg^{-1}		10	86	169	244	315	656
		Mean root length (mm)	83	87	82	93	92	87
Unequal variances	10	83		-0.566	0.156	-1.652	-1.520	-0.677
	86	87	-0.566		0.765	1.346	-1.183	-0.146
	169	82	0.156	0.811		1.884	-1.748	-0.915
	244	93	-1.669	1.346	***2.040**		0.163	1.018
	315	92	-1.536	-1.185	-1.890	0.163		-0.879
	656	87	-0.673	-0.155	-0.913	1.109	-0.955	

Discussion

The validation trial demonstrates the root extension of radish in sand is significantly affected by soil As especially when the As is readily available. The initial trial used similar soil Total As concentrations as those found on the contaminated Ferrosol and indicate that if the soil As was available to the plant, root extension would be reduced. The repetition of the trial method using the contaminated Ferrosol demonstrated that germination of radish was uninhibited by soil As and that the Total As concentrations of this soil are not phytotoxic to radish. The Ferrosol at this location was well drained, aerobic and exhibited pH's ranging from 5.5 to 6.4. Additionally, the clay component of this Ferrosol would include As sorptive components such as iron and aluminium oxides, hydroxides and oxyhydroxides. The presence of these compounds would be restricting the soil-plant availability of As (Masscheleyn *et al.* 1991). The As is strongly sorbed to the soil matrix.

While soil analysis showed concentrations of Total As greatly exceeding the HIL of 100mg As kg^{-1}, the phytotoxicity trial revealed that the As is not available to plants. In this context, the current PIL of 20mg As kg^{-1} is excessive at this site and remediation to the HIL is sufficient.

Conclusion

This direct method of determining phytotoxicity is both time and cost effective and may be applied to any soil type to assess As phytotoxicity at contaminated sites. A simple, rapid method such as this represents a suitable alternative to laboratory analysis and estimates of As availability based on soil properties such as pH and mineralogy. This method should be used to determine site-specific remediation values for other soil contaminants and for framing appropriate management measures to control soil contamination concentrations. Further work is required to assess the plant accumulation of As on sites that have been identified as not being phytotoxic.

References

DUAP (1998) State Environmental Planning Policy 55 – Remediation of Land. (Department of Urban Affairs and Planning: Sydney)

Masscheleyn PH, Delaune RD, Patrick Jr WH (1991) Effect of redox potential and pH on arsenic speciation and solubility in a contaminated soil. *Environmental Science & Technology* **25,** 1414-1418.

NSW EPA (1998) *Guidelines for the NSW Site Auditor Scheme*.

Smith E, Naidu R, Alston AM (1998) Arsenic in the Soil Environment: A Review. *Advances in Agronomy* **64,** 149-195.

Standards Australia (2002) *AS 3743 - Potting Mixes*. (Standards Association of Australia: Homebush, NSW).

Walsh LM, Sumner ME, Dennis RK (1977) Occurrence and Distribution of Arsenic in Soils and Plants. *Environmental Health Perspectives* **19,** 67-71.