The Effect of Compost on Crop Arsenic Uptake

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ABSTRACT

Urban gardens, such as the Santa-Fe-Right-of-Way, an old railway bed in South Berkeley, sometimes struggle with contaminated soils contaminated with high levels of metals like arsenic. Community gardens often need a short-term, inexpensive method of managing this contamination, and studies have shown that long-term compost applications reduce the amount of arsenic that is taken up into crops. However, I wanted to test whether short-term compost applications had any effect on arsenic uptake. This study showed that short-term compost applications are not an effective method of treating arsenic contamination in soil. The application of compost did not have an effect on the crop uptake of arsenic, and there was not a significant difference in arsenic level between different kinds of crops. Compost is not an effective short-term arsenic immobilizer and while it is easy for communities to use, it should not be used to remediate arsenic in community garden soil contaminated with heavy metals.

KEYWORDS

soil, Berkeley, urban garden, heavy metal, contamination

INTRODUCTION

Urban gardens can help strengthen communities and provide fresh food to community members, but are sometimes contaminated with soil pollutants that are harmful or toxic to people. Urban soils can be contaminated with heavy metals, the most common being lead, arsenic, cadmium and zinc, which could potentially make the food grown in them unsafe to eat due to uptake. One of the most common ways that people unintentionally ingest heavy metals is through contaminated food, either grown in contaminated soil, or watered with contaminated water (Bundschuh et al. 2012). Arsenic, if ingested by humans, can cause many problems, such as cancer, cardiovascular and neurological diseases (Jomova et al. 2011). In order to prevent people from eating arsenic in crops grown in contaminated soil, it is important to know how the arsenic initially enters the plant tissue.

Since soil arsenic can be taken up by plants and accumulate into their tissues, consumption of fruits and vegetables that are grown in contaminated soils should be avoided. In soil and water, arsenic species share an oxidation state similar to phosphorous in soil. Highly soluble species of arsenic are more mobile in water and pose a greater threat to food contamination. Arsenic is taken up into the plant's roots by phosphate receptors, and then either incorporated into cell walls, or distributed throughout the plant via the xylem (Zhao et al. 2009). In general, the fruit of plants grown in contaminated soil has the lowest concentration of heavy metal, while leaves have more and roots have the most (McBride 2013). There can be a difference in the amount of heavy metals taken up by plants based on plant species as well (Abedin et al. 2002). While the Food and Drug Administration (FDA) has not set a limit of arsenic concentration in food, the Food and Agriculture Organization (FAO), has set the maximum daily arsenic intake level at 3 µg arsenic/kg body weight per day and a 0.1 mg arsenic/kg fresh weight vegetable oil guideline (United Nations 2012). In order to avoid human consumption of arsenic, it is important to find the best methods to prevent it from being taken up into plants.

The addition of compost to soils may be a quick and cheap alternative to other lengthy processes, such as bioremediation. Biosolid compost (compost made from treated sewage) added to soil has been shown to reduce arsenic uptake in lettuce and carrots due to immobilization by organic matter (Cao and Ma 2004). Organic matter immobilizes arsenic when complex carbon molecules "tie up" the arsenic, making it harder for plants to take it up into their system.

However, in the same study, the addition of phosphate into the compost greatly increased uptake of arsenic by plants (Cao and Ma 2004). Arsenic ions get "tied up" in complex carbon chains by bonding to the negatively-charged carbon chains with a cation bridge and is no longer able to be absorbed into the plant via water (Smith and Naidu 2009). As soil phosphate levels rise, it displaces arsenic ions from whatever substrate they are bound to, which increases the level of unbound soil arsenic that can then be absorbed by plants (Smith et al. 2002). The addition of compost to contaminated soils does not remove the arsenic from the soil, but it immobilizes it to some extent, which could reduce the amount of arsenic taken up by fruits and vegetables. There is a gap in scientific knowledge about whether short-term applications of compost will reduce the amount of arsenic taken up by edible crops in low-level contaminated soil, and whether or not the crops are safe to eat.

I want to determine the effect of short-term compost applications on crop arsenic uptake in low-level arsenic contaminated soil. I also want to determine if there is a difference of arsenic levels in different tissues of the plants and if these various crops are considered safe for consumption by FAO standards. I hypothesize that the crops grown in soil moderately contaminated with arsenic and amended with compost will uptake less arsenic than crops grown in the same contaminated soil without compost addition. My second hypothesis is that within each treatment group, roots will have the highest concentration of arsenic, followed by stems and leaves, then fruit. Of the crops grown in the compost-treated soil, the arsenic content of the tomato fruits and kale leaves will be below 0.1 mg/kg (the FAO standard); the arsenic level will be higher in the radish roots. Of the crops grown in the non-treated soil, the arsenic level will be below 0.1 mg/kg only for the tomato fruit; the kale leaves and the radish roots will be above the 0.1 mg/kg level.

METHODS

Site preparation

The field site that I conducted this research on is the Santa Fe Right-of-Way, an old railway bed in South Berkeley west of Sacramento St between Derby St. and Ward St. The surrounding community was planning on planting a community orchard, but stopped when they tested the soil and found heavy metals present. The area is heavily contaminated with arsenic

(20-200 ppm As), but I pulled the soil from an area with lower arsenic levels (45 ppm), alongside a polyurethane tunnel that the Pallud lab is using for fern remediation. I used this soil because it mimics the soil quality present in many urban community farms and contains arsenic, the contaminant I am interested in. I got compost from the Berkeley Marina Municipal Compost Program. This compost is made from food scraps and yard waste collected from Berkeley residents and is aerobically processed in the Central Valley. Both the lifted soil and compost I sieved down to 4 mm. I used the sifted soil as the untreated control group's soil. For the compost-amended soil, I mixed 3 parts soil with 1 part compost, by volume. This soil was then put into pots where the plants were to be grown.

Determination of arsenic concentrations and nutrition in soil samples

I found the arsenic levels and nutrition levels in the contaminated soil, compost, and compost-amended contaminated soil. Arsenic levels were measured in triplicate by sending soil samples to Brookside Labs, where the results were reported in ppm. Both the untreated and compost-amended soil had an arsenic level of about 45 ppm, despite the addition of compost. Nutrition was measured in triplicate by UMASS Labs. The nutrition tests included phosphorous, nitrogen, calcium and potassium, measured in µg nutrient per kg sample

Outdoor pot experiment

I conducted an outdoor controlled experiment to determine if treating the soil with compost had an effect on the amount of arsenic taken up by different parts of edible crops. The crops were grown on site, alongside the polythene tunnel. The site was in full sun and sheltered from wind. No pesticides or herbicides were used on the crops, and the only fertilizer used was the compost that was applied to the treatment group. Bugs (usually aphids and cabbage moths) were picked off the plants by hand every time I watered. This was mainly a problem for the kale. Beginning at the end of May 2015, I grew three species of vegetables: kale (*Brassica oleracea*), tomatoes (*Solanumlycopersicum*) and radishes (*Raphanussativus*). These crops were chosen to compare the arsenic uptake in the edible roots, leaves, and fruit of crops. The tomatoes were each grown in their own 9" pots. The kale and the radishes were each grown in 6" pots. There were 12 individual plants grown per crop; 6 in the compost-treated soil, and 6 in the non-treated soil, for a total of 36 individual plants. I constructed around the plants to prevent the crops from being disturbed. Radishes were watered with 400 mL of water, kale with 600 mL, and tomatoes with 1700 mL twice a week. I harvested the crops at the point where they were considered edible, with the last harvest occurring in October 2015. Since it ran through the summer, daily highs averaged 80-85 °F, with a few days at the end of August reaching 90 °F, which caused the radishes to go to seed a bit earlier than they should have. It rained a few times at the end of August, and I adjusted the water schedule accordingly. Tomato fruits, radish roots, and kale leaves were harvested for analysis; radish roots and any part of the kale plant above the ground were considered as one sample. All the tomatoes from one plant were collected and later processed; this was considered to be one sample.

Crop Arsenic Measurement

I found the arsenic levels in the crops grown in both soil treatments by preparing the samples and sending them on Brookside Labs. The plant materials were washed and dried at the Oxford Tract Greenhouse drying room, which is kept at about 90 °F. They were then ground in the Pallud Lab using a coffee grinder. At least 1 g of each sample was then sent to Brookside for arsenic test IB030. Under this test, the sample is digested by EPA method 3050B, and analyzed by method 6010B. There were 6 plants per crop per treatment, for a total of 36 samples taken.

Analysis

Between Treatments

To test if the addition of compost had any effect on the amount of arsenic taken up by the crops, I ran a t-test between two means. For each crop, I compared the average arsenic level between the compost-amended soil and the untreated soil.

Between Crops

To determine if there is a difference among crops of the same treatment, I ran a 1 way ANOVA to compare the mean arsenic level among the three different crops.

RESULTS

Between Treatments

The addition of compost to arsenic-contaminated soils did not have a significant effect on the uptake of arsenic into kale, broccoli, and radish plants (Table 1 and Figure 1). I ran a Shapiro-Wilk's test to test for normality and found that the data is normal.

Table 1: Summary of arsenic level means and p-values.

	Mean control As (mg/kg)	**Mean compost As (mg/kg)**	**P-value**
Radish	3.2	2.1	0.36
Kale	1.98	1.97	0.13
Tomato	2.0	2.0	0.32

Between Crops

There is no significant different between mean levels of arsenic in different crop types within the same treatment group (Figure 2). The p-value for the control group was 0.085 and for the compost-amended group was 0.11.

FAO Comparison

I compared the mean levels of arsenic in the crops to the FAO's allowed limit of 0.1 mg arsenic/kg oil (United Nations 2012). Every sample was above this limit. The highest sample above this limit was a radish grown in untreated contaminated soil, and was 2 orders of magnitude above the limit. Most of the samples were only 1 order of magnitude above the limit.

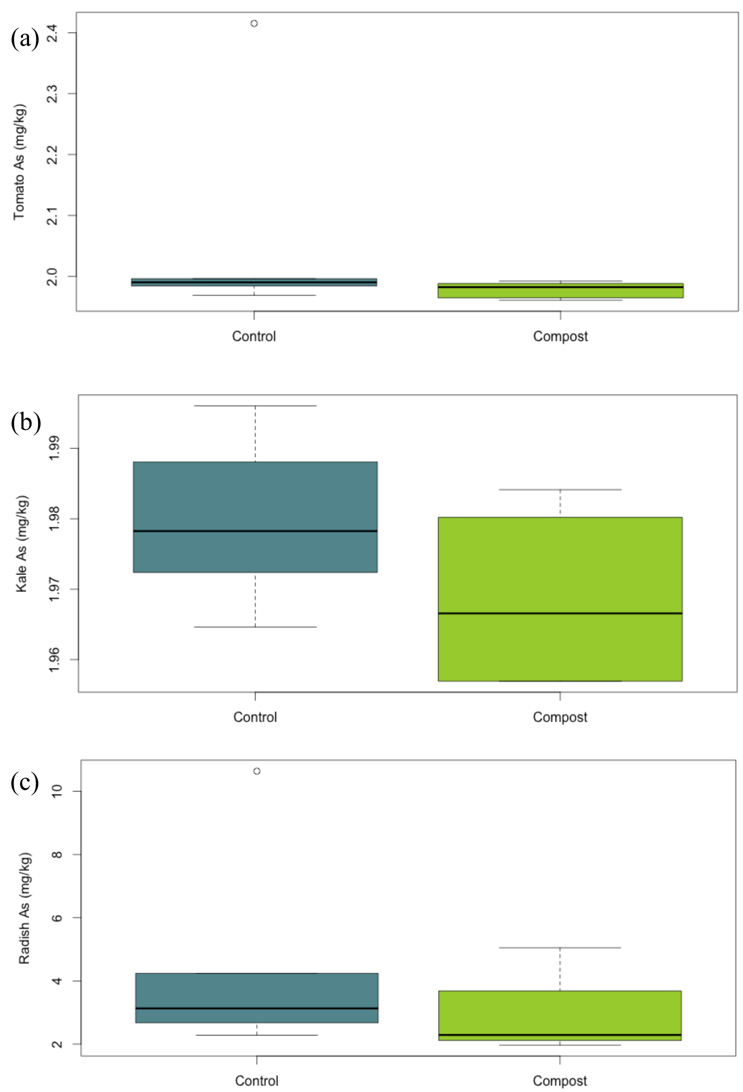

Figure 1: Comparison of arsenic levels between treatments. Box and whisker plot comparison of the levels of arsenic present between different treatment types in Tomato fruit (a), Kale leaves (b), and Radish roots (c).

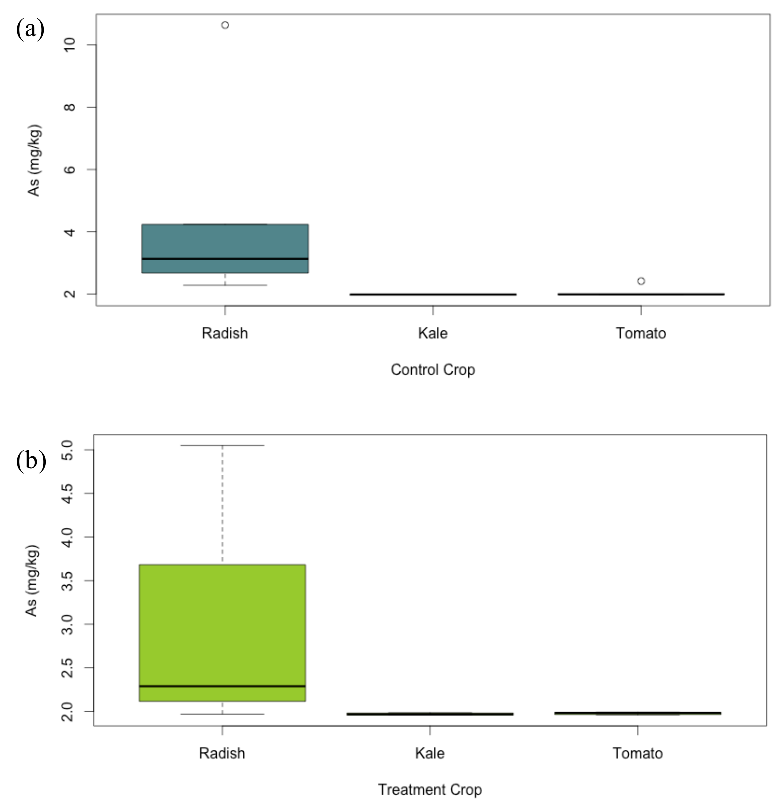

Figure 2: Comparison between control and treatment group. Box and whisker plots compare the arsenic levels present between crop types within the same treatment group. The control group corresponds to (a) and the compost-amended group corresponds to (b).

DISCUSSION

Arsenic uptake by plants

Arsenic is taken up into plants through their roots and accumulates in their tissues. Roots can uptake arsenic from the water or the soil, and then distribute and deposit it into the tissues of the plant (Abedin et al. 2002). In general, the fruit of the crop has the least amount of arsenic, which was a trend that I also noticed with my data. This is very important for urban gardeners to know, as depending on the type of crops they are growing, they could unknowingly reduce or increase the amount of arsenic in their food. Species has also been shown to make a difference in the uptake of arsenic into the crops, but my findings did not support that trend.

Compost effects

Compost has been shown to have an effect on arsenic uptake under long-term conditions, but my data does not support this hypothesis under short-term conditions. If communities were to begin to use compost as a remediation method, they would have to be aware that they would have to remediate for a while before the compost would begin to make a difference in the amount of arsenic taken up by crops. In general, compost is fairly cheap relative to other remediation methods (Tangahu et al. 2011). For example, the City of Berkeley provides free compost at the marina. It is important to note that compost remediation does not remove the arsenic from the soil, it merely keeps it bound to the soil and not available for plants to uptake. If community gardens start to use compost to remediate arsenic, they should keep this in mind, and still take precautions against coming in contact with too much of the soil. This method of arsenic treatment may seem like a tempting remediation option for communities, as it is both cheap and is fairly straightforward to apply. However, it is a stop-gap measure for more permanent remediation and should be used carefully and over the long-term.

Plant tissue effects

While there was no significant difference in the amount of arsenic taken up by different crop species within the same treatment group, there does seem to be a trend of increased arsenic uptake for the root crops. This is an opportunity for more research to gather more data to confirm the trend, if there is one. Other short-term studies have found an increase in the amount of arsenic taken up by root crops compared to other parts of the same plant (McBride 2013). As for how this would affect community gardens, people should be aware that in general, the closer a crop is to the ground, the more likely it is for it to be more contaminated. Communities are recommended to avoid growing root crops, and to thoroughly wash fruits and vegetables that are growing in contaminated areas (Jones et al. 2014).

FAO limits

Since all of the samples that I sent in were above the FAO limit of acceptable arsenic, it is safe to say that none of these crops were nontoxic enough to eat. In addition, for all samples it was higher than the limit by an order of magnitude at least. Communities that are struggling with heavy metal contamination should be extremely careful when attempting to grow crops under these conditions, as even relatively low levels of arsenic in the soil can still produce food that has toxic levels of arsenic. One of the reasons that the FAO limit is set so low is because of the long-term consequences of arsenic consumption. Because arsenic is metabolized by the body and remains there, the most dangerous risk of arsenic exposure is daily exposures over the course of a lifetime (Mitchell 2014). It is unlikely that many communities in urban areas are getting most of their staples in food from community gardens, so it is also unlikely that community members would be eating high quantities of these crops daily. However, the risk still stands that the gradual accumulation of arsenic in the body could do lasting damage, especially to children who eat these crops (Carrizales et al. 2006).

Phosphorous

Highly charged particles in the soil, such as phosphorous, can displace the arsenic from the soil it is bound to, freeing the arsenic and allowing more of it to be taken up into the plant (Smith et al. 2002). My compost had an unusually high level of phosphorous (Figure A1), so this trend may have had an effect on the uptake of arsenic in my study. The high amount of phosphate may have displaced any arsenic that had bonded with the compost, making it more mobile and more likely to be taken up by the crops. However, it is difficult to quantify how much of an effect, if at all, this interaction had on arsenic uptake. The high phosphate levels present in the compost could explain why the arsenic uptake levels were so high in the treated group.

Short-term compost usage

Short-term application of compost is not comparable to long-term compost application in reducing arsenic uptake. The short-term application of compost reduced the amount of arsenic in the crops by 0.01 mg As/ kg sample for kale, 1.1 mg/kg for radishes, and 0 mg/kg for tomatoes. This is a non-significant amount and is not a viable option for community gardens. In terms of practicality, this is one of the more accessible options for communities trying to grow crops in contaminated soil. Compost is both cheap and easy to obtain, and only requires a one-time application before planting. This method of compost application would have to be used over a longer period of time than one growing season to make a difference in arsenic uptake, via gradual dilution of the arsenic and arsenic uptake kinetics over time. Communities should be very careful if they choose to use compost with the intent of remediation, as it may not have the huge effect that they are expecting. This is not a viable long-term solution, as the arsenic is still present in the soil, but long-term compost addition it is a fairly straightforward stopgap method that would allow communities to grow their own food as safely as possible given the circumstances.

Limitations

My study may have been small, but it was focused correctly for community gardens in Berkeley. Most of the arsenic concentrations in Berkeley are fairly low, which is good, because my findings cannot be extrapolated to higher arsenic levels. My study matched the limitations imposed on community gardens in Berkeley and other industrial brownfields. I had a limited number of replications available to me. I would have liked more but I was limited by my funding. I also should have measured the weight of the collected crops before drying, but did not think to do so. This would have allowed me to compare the amount of arsenic in the crops against the FAO level of acceptable arsenic, using the fresh crop level, rather than extrapolating from dried crop weight. There was also an unanticipated high level of phosphorous in the compost which was unexpected and potentially had effects on the results.

CONCLUSIONS

Future directions

There are many different variations of the same experiment that could be run to explore different facets of my experiment. The same study could be run again but with a larger sample size in order to be more statistically significant. In order to see if the phosphorous made any difference whatsoever, I could run the same study but with low-phosphate compost. Probably the most useful option would be to see if compost still has the same effect with higher arsenic level and what magnitude of difference it makes.

Broader implications

The applications for the findings of this study are very broad, but they could be easily misconstrued or incorrectly used by communities struggling with arsenic contamination. Communities struggling with heavy metal contamination would have more tools at their disposal to deal with the metals if compost application was a viable remediation method. Adding compost could help with temporary remediation efforts that are easy to use and accessible for the community. However, there are some potential drawbacks to using this method. For one, if it is used without first testing the soil to measure the amount of contaminant in it, people might still be eating unsafe arsenic levels, or putting more faith into the compost treatment than it really warrants. If used incorrectly, it could potentially harm the safety of others. Short-term compost application is not a viable method of temporary arsenic remediation.

ACKNOWLEDGEMENTS

A great thanks to my mentor, Celine Pallud, who let me use her lab, her field site and offered me great advice and guidance. Thanks to Sarick Matzen who helped me design and implement my research. Thanks to the ESPM 175 team, Tina Mendez, Kurt Spreyer, Anne Murray and Abby Cochran for their guidance and valuable advice. Thanks to the SPUR funding group for the opportunity to conduct my own research over the summer of 2015. Also thanks to a cat named July 7th, who loved me forever after I gave her half of my ham sandwich at the field site.

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APPENDIX A: Soil Nutrition

	Mean Phosphate (µg/kg)	**Phosphate Classification**	**Mean Lead (µg/kg)**
Compost	579.4	Above optimum	0.3
Compost/Soil	111.9	Above optimum	18.5
Soil	17.0	Above optimum	37.9

Figure A1: Results of the UMASS soil nutrition test. Mean phosphate and lead are reported in µg element per kg soil sample. Phosphate classification is based on the optimum level of nutrients in the soil for growing plants, based on New England soil. The optimum range is 4-14 µg/kg. Mean lead was classified as less than or greater than 22 µg/kg.