Soil Health within Indianapolis Urban Gardens

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Abstract

The growing trend of healthier diets and localized food systems has led to the emergence of many urban farms throughout Indianapolis. Numerous urban neighborhoods have a large number of vacant lots due to urban blight. Thus, increasing access to potentially arable land where high quality produce can be grown for families and communities is of high importance. However, many of these vacant lots, where the majority of Indianapolis' urban farms are located, have industrial or commercial legacies. These postindustrial soils could contain contaminants, like heavy metals, some of which are potentially harmful to humans. Due to compaction, foreign debris and other harmful anthropogenic effects, the soil looses its ability to hold the nutrients water a soil microorganisms needed to sustain plant growth. As a result of this poor soil quality, farmers often have to import soil and use large amounts of fertilizer or compost to ensure viable growing conditions. To isolate imported soil from the possibly contaminated native soil, farms typically lay down around 24 inches of mulch between the native soil and the growing medium. To test if this method is effective in avoiding contaminants and providing healthy soil, we collected four soil samples from six urban farms in the Indianapolis area: two from the growing medium and the two from the native land. Samples were tested for a number of soil health indicators (e.g. organic matter, protein, respiration, phosphorous, potassium, etc.), as well as for concentrations of an array of heavy metals (e.g. zinc, arsenic, and lead). We found wide variation in heavy metal concentrations, though growing medium was significantly lower than the original land. Organic matter, related to soil respiration, was higher in the growing

medium, suggesting increased soil health with compost addition. This research will educate gardeners and general public on soil health within urban gardens. This will help farmers become more efficient with their methodology, as well as alert them to any potential hazards.

Introduction

Wholesome food is an essential element to a healthy lifestyle. However, access to food is an issue that plagues many urban residents. In Indianapolis, the focal city of this study, 36% of residents have impaired access to food and 30% of the adult population is obese (Hostetter, 2012). This limited access to healthy food has resulted in Indianapolis ranking worst among U.S. cities for food deserts (Wittmeyer, 2014). Because 19% of Marion County residents live in extreme poverty (Elliot et al., 2011), they must rely on cheap, easily accessible fatty and calorically dense food to feed their families, as opposed to fresh produce and groceries, which tend to cost more and take longer to prepare. Thus, we see the health issues skewed to the poorer populations of the city.

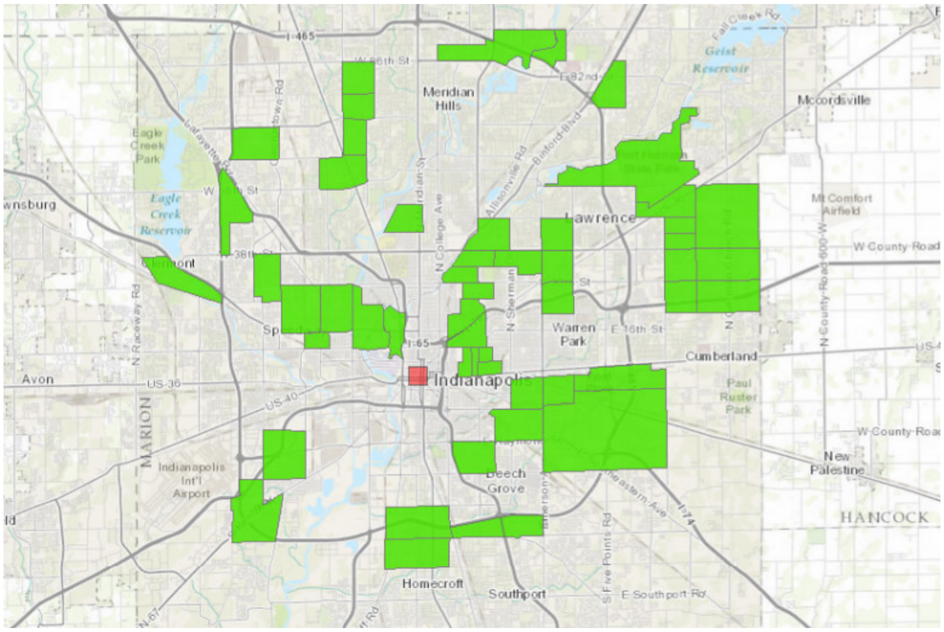


Figure 1: Map of food deserts within Indianapolis. Green areas of the map indicate areas indicated as food deserts (Wittmeyer, 2014).

One mechanism to combat this trend that has been successfully implemented is urban gardening. Urban gardening takes vacant land within cities and transforms them into plots suitable for growing produce. Under adequate conditions, a 10 x 10 meter plot is able to meet the vegetable needs of a family for a year, over the course of a 130 day growing season (Brown & Jameton, 2000). Urban gardening provides a convenient and cost-effective means to wholesome food, as a gardener can produce $240 of food for only $9 of input costs (Brown & Jameton, 2000). Given this data, it is no surprise that urban gardening is increasing in popularity globally, Indianapolis included.

However, urban gardens are commonly built on vacant unused land. This land often has compacted and nutrient poor soils, or is even completely covered through the use of concrete, asphalt, or other anthropogenic structures (Shindelbeck et al., 2008). The exposed land may not contain enough of the essential nutrients needed to support the produce being grown. Deficiencies in phosphorous (P), Potassium (K), Magnesium (Mg), Manganese (Mn), Iron (Fe), and Calcium (Ca) can each lead to stunted growth, among other problems (Wilson et al., 2008). Each of these elements can be supplemented in the soil through the use of fertilizer, composting or even importing healthier soil. Soil health may also be aided through the addition and accumulation of organic material in the soil. The microbes actively break down organic material, releasing the nutrients vital to plant growth into the soil. The organic material also plays a pivotal role in the retention of water and nutrients that are already present in the soil. Each of these techniques are commonly achieved via compost, which provides these benefits in a natural and chemical free process.

In addition to poor nutrient levels, urban environments are also susceptible to heavy metal contamination (Kimpe & Morel, 2000). A study conducted by Wei and Yang found that urban soil had consistently higher levels of heavy metals (Aresenic (As), Lead (Pb), Zinc (Zn), Cadmium (Cd), etc.) than sites that have been primarily used for agriculture (2009). This poses an issue for plants, because at high levels, these metal ions exhibit phytotoxicity by disrupting enzyme function within plants (Nagajyoti et al., 2010). Beyond toxicity to plants, some plants are able to accumulate heavy metals in their leaves, roots and fruits (Cobb et al., 2000). Humans can then consume these metal ions, leading to potentially adverse health effects (Peralta-Videa et al., 2009). In addition to accumulation in the plant tissue, these heavy metals may also be present in higher concentrations on the surface of the soil and plants, leaving gardeners vulnerable to exposure. When considering urban soil viability it is important to look at both nutrient availability and potential contamination, such as heavy metals.

In order to produce larger and safer yields of crops, gardeners have utilized a variety of methods. Among the best practices are ways that isolate the imported soil from the native soil, through the use of wood chips to cover the native soil and creating raised plots where imported soil is used to fill the wood chip-based growing plots (Kessler, 2013). Soils are also commonly supplemented with various organic materials and fertilizers. Despite the importance of knowing the composition of the soil, many gardeners opt to not get the tests that are needed to determine soil viability and health because they are so expensive—upwards of $65 per sample to test for only a portion of the heavy metals mentioned above (Kessler, 2013). To determine whether urban gardening is a viable source of food production, we must first determine if current practices are sufficient in providing the necessary nutrients and isolating any heavy metal contaminants from the growing plots. By examining the effectiveness of current practices, we will see if these best practices provide sustainable and well-structured soil (e.g. macronutrients, micronutrients, protein, organic matter, etc.) for crop production.

This study completed a comprehensive analysis of soil health at some of the urban gardening sites in Indianapolis. Using trends within the data, we hoped to determine the effectiveness of various gardening techniques. In order to do so, we will compare quantifiable soil properties, including protein, respiration, organic matter, extractable potassium, extractable phosphorous, magnesium, iron, manganese, calcium, aluminum, zinc, lead and arsenic in both in-plot (soil being used to grow crops) and out-of-plot (native urban soil). Based on the available knowledge, we expect that there will be an accumulation of heavy metals in the out-of-plot soil because of the prolonged proximity to roads, industrial and retail sites, and other anthropogenic practices. Due to the importation of new and potentially healthy soil, in addition to gardening practices (i.e. placing mulch between soil types, and supplementation of fertilizer and organic matter), we expect to see in-plot levels of nutrients, organic matter, protein and respiration at higher levels than soil samples taken from out-of-plot.

Methods and Materials

Of the more than 20 gardeners contacted, six sites responded and allowed us to test their soil. Sites were sampled during the growing season of 2015. The sites that were sampled were larger and have been established for longer periods of time than what is typically found in urban gardens. Each site, with the exception of one utilized, a similar approach to soil modification. Typically a layer of wood chips, about a foot deep, is applied on top of the native soil in an effort to isolate the imported, in-plot, soil from the out-of-plot soil. Imported soil is then brought in from a variety of sources and is either spread out broadly on top of the layer of wood chips or is placed into raised plots, which also lie on the surface of the wood chips.

Sampling Distribution

In order to get a comprehensive analysis of each site and the differences between in plot and out of plot soils, four samples were taken from each of the six sites. Of the four samples, two were taken from locations inside the plot, while two were taken from outside. Out of plot samples were taken as near to the in plot samples as possible.

Sampling Procedure

For each of the 24 total samples, we utilized guidelines developed by The Cornell University Soil Health Project. At each of the four sampling locations, from each site, ten areas were identified, in order to control for random areas of high or low concentrations. Once these locations were identified, surface debris (e.g. grass, hay, etc.) was removed and not included in the sample. We then dug a circular hole about eight inches deep. Using a spade, we removed a vertical slice of about six inches deep and two inches thick from the side of the hole. The thickness was held constant to prevent the sample from over-representing the shallower or deeper soil. We then placed the 6-inch by 2-inch slice into a clean bucket. We repeated this process for the remaining nine sub-samples. Once all ten sub-samples were collected into the bucket, we thoroughly mixed them together, providing a comprehensive example of either an in-plot or out-of-plot sample. Four cups of soil were then removed and placed into zip-lock plastic bags and labeled with the site, date and description (in-plot or out-of-plot). We repeated this process until we had two complete samples of both in-plot and out-of-plot soils. Once the four samples were collected, they were immediately shipped to Cornell University College of Agriculture & Life Sciences.

The tests conducted at Cornell's nutrient analysis lab measured soil pH, extractable phosphorous and potassium, magnesium, manganese, calcium, iron, autoclave-citrate extractable (ACE) protein, organic matter and respiration. Additional tests were also purchased to screen for the heavy metals cadmium, lead, zinc, and arsenic. These results were then received in the form of a comprehensive and broad overview, which, along with the raw data, was provided to each of the gardeners and used for statistical analyses.

Results

Organic Matter, Protein and Respiration

Organic matter varied significantly across sites, as well as in-plot versus out-of-plot (Fig. 2a & d). Thus, there seemed to be a relationship between the gardening method used and the amount of organic material present in the soil. However, we did not have enough statistical power to determine differences between specific sites. The amount of organic material in-plot was more than three times greater than out-of-plot samples (Fig. 2d). This difference is most likely due to farmer manipulation (e.g. addition of fertilizer, straw, novel soil, etc.), as they have probably increased the amount of organic matter.

Protein followed a similar pattern, although differences were not significant across sites. The amount of protein was about 3 times higher in-plot as opposed to out-of-plot (Fig 2e). Thus, indicating that gardening practices increased the amount of protein present in the soil.

Although the same patterns between sites and plots present in the protein and organic matter were also visible with respiration, soil respiration was not shown to be significantly different at either the site or plot level (Fig. 2). The lack of significance is mostly likely a result of low sample size and statistical power, where some analytes (e.g. protein and organic matter) were able to overcome this with very large differences.

Soil Nutrients

Soil nutrients followed a similar pattern to that found for organic matter and respiration, which was to be expected, because the compost used to introduce organic matter is likely high in nutrients as well. The concentrations of nutrients across all sites differed, but were only significant for magnesium and manganese (Fig. 3c & e). Sites C and F were significantly higher than site A in manganese (Fig. 3c & e). However, there failed to be significant differences between individual sites for magnesium.

The interesting and most relevant data is between in and out-of-plot. For each nutrient, the in-plot samples were significantly higher than those taken out-of-plot (Fig 3 f-j). In phosphorous' case, an element widely supplemented in fertilizer, it was well above ten-fold higher (Fig. 3f). The amount of extractable phosphorous in-plot was near 200ppm despite the optimum level for plant growth being in the range of 15-20ppm (Fig 3f).

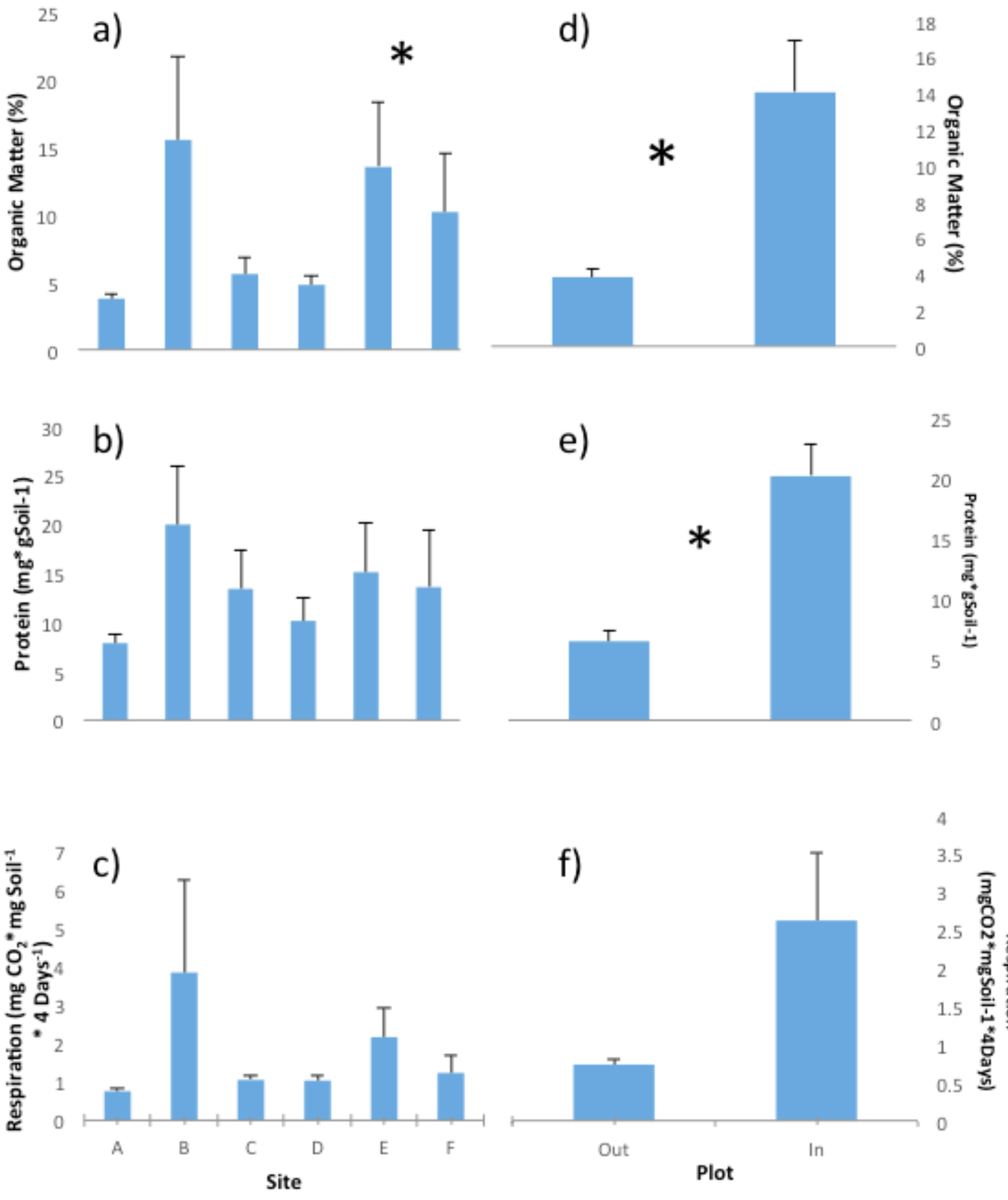
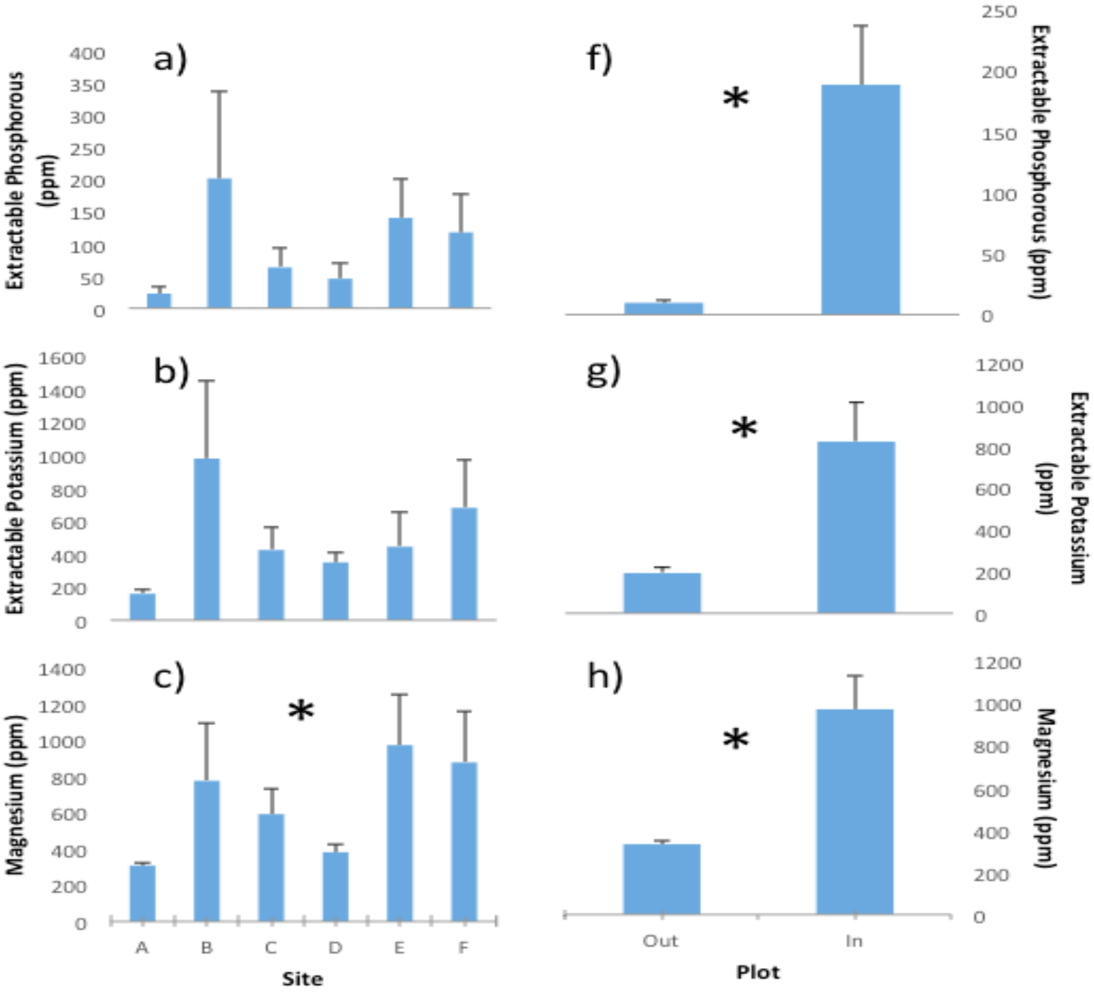


Figure 2. Protein, organic matter and respiration quantities in urban agriculture soils. Four cores were taken from each site (panels a-c), while 12 core samples make up each of the in and out of growing plot data sets (panels e-f). Figs. 2a-c represent levels of respiration, organic matter and protein vary sites. Fig 2d-f represent levels of respiration, organic matter and protein vary between in and out of growing plot samples. Differences in concentrations between plot locations and sites were analyzed using ANOVA; asterisks indicate mean values are significantly different ($p<0.05$).

Potassium was also much higher than its suggested range inside the plots. The recommended level is from 90-120ppm, yet in plot concentrations were closer to 800ppm of extractable potassium (Fig. 3g). Potassium is another common element that is found in very high concentrations within fertilizer.

Magnesium, iron and manganese were each significantly higher within the plot as well. When combined, our results clearly illustrate high nutrient levels in the soil being used to grow the crops. Levels of nutrients were very low for the out-of-plot, in most cases, falling below recommended levels.



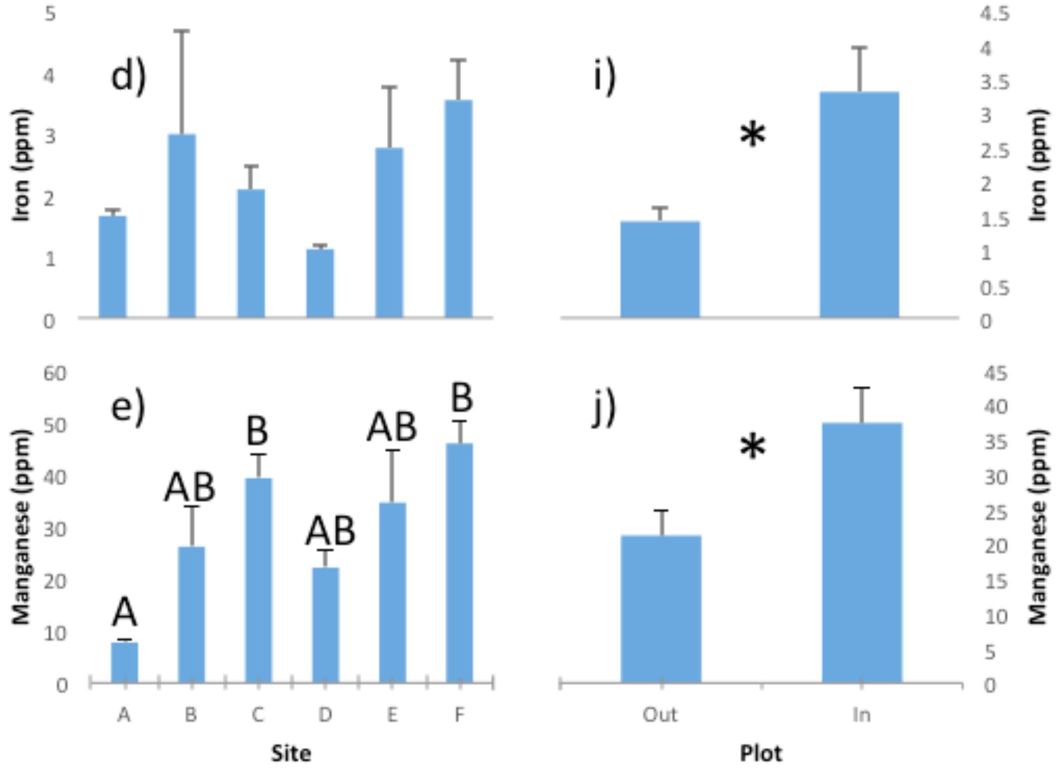


Figure 3. Soil nutrient concentrations in urban agriculture soils. Four cores were taken from each site (panels a-e), while 12 core samples make up each of the in and out of growing plot data sets (panels f-j). Figs. 3a-e represent concentrations of extractable phosphorous, extractable potassium, magnesium, iron and manganese across sites. Figs. 3f-j represent concentrations of extractable phosphorous, extractable potassium, magnesium, iron and manganese in in-plot versus out-of-plot samples. Differences in concentrations between plot locations and sites were analyzed using ANOVA; asterisks indicate mean values are significantly different ($p<0.05$). Posthoc pairwise comparisons between sites were analyzed using Tukey's HSD; values with different letters are significantly different ($p<0.05$).

Calcium

Calcium provided an interesting contrast that did not follow the same pattern seen by the other nutrients. Calcium levels were found to be highest at site F, but lowest at site A, which is similar to the concentrations of manganese. Beyond that however, the other sites were unpredictable. Even more significantly, calcium is the only nutrient that did not differ between in-plot and out-of-plot samples (Fig 4).

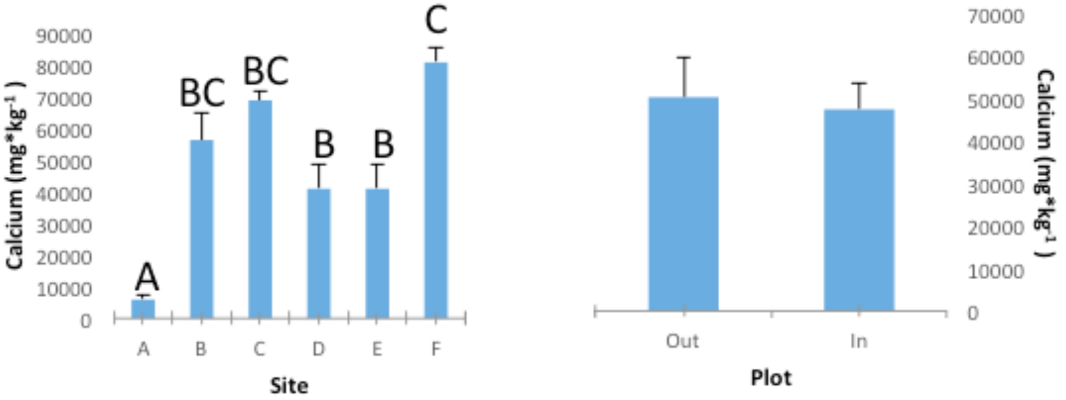


Figure 4. Calcium concentrations in urban agriculture soils. Four cores were taken from each site (a), while 12 core samples make up each of the in and out of bed data sets (b). Fig. 4a represents levels of calcium across sites. Fig 4b represents concentrations of calcium in versus out of growing plot samples. Differences in concentrations between plot locations and sites were analyzed using ANOVA; asterisks indicate mean values are significantly different ($p<0.05$). Posthoc pairwise comparisons between sites were analyzed using Tukey's HSD; values with different letters are significantly different ($p<0.05$).

Aluminum

Aluminum, a heavy metal, was found to be in fairly high concentrations in all sites, when total aluminum was measures. As a result, the pattern does not match that seen with the other heavy metals (Fig. 6). Total aluminum was found to be highest at site A and the lowest at site F (Fig. 5). Yet, when in-plot versus out-of-plot analyses were conducted, out-of-plot samples were higher, though not significant at the current sample size.

Zinc

Zinc begins the pattern that we will see throughout the remaining data. It seems as though, across site, site B is higher than the others (Fig. 6e). The difference is not significantly higher than any of the other individual sites. The relationship between in and out-of-plot is significant, with out-of-plot containing higher levels of zinc (Fig. 6d).

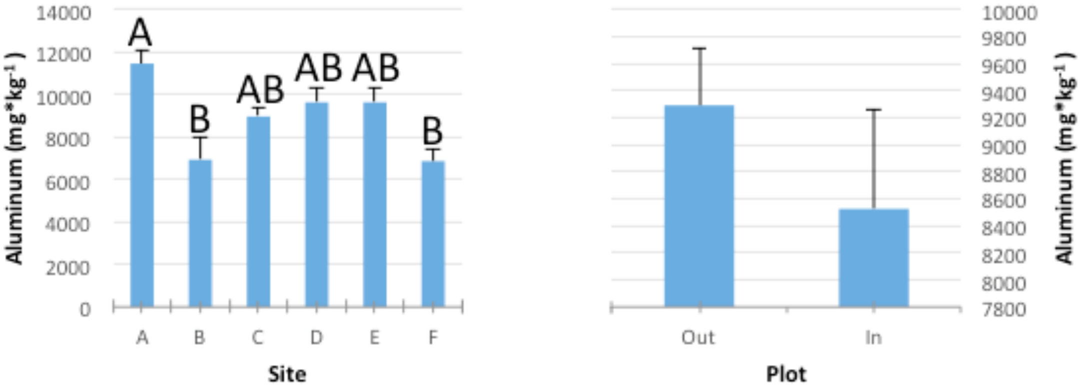


Figure 5. Aluminum concentrations in urban agriculture soils. Four cores were taken from each site (a), while 12 core samples make up each of the in and out of growing plot data sets (b). Fig. 5a represents levels of aluminum across sites. Fig 5b represents concentrations of aluminum in versus out of growing plot samples. Differences in concentrations between plot locations and sites were analyzed using ANOVA; asterisks indicate mean values are significantly different ($p<0.05$). Posthoc pairwise comparisons between sites were analyzed using Tukey's HSD; values with different letters are significantly different ($p<0.05$).

Arsenic

Arsenic is a heavy metal, well known for its toxic effect on both plants and humans. When the comparison between sites was run, site B had levels of arsenic about two times higher than any other site (Fig. 6b). Beyond this, when the sub samples were examined individually out of plot was much higher than each of the in plot for arsenic. Also, one in-plot sample was taken from older beds of about five years since construction, while the other in-plot soil was new within the year. The older plot was shown to have levels in between that of the new soil and the original land. More samples would be needed to achieve significance, but the trend itself is noteworthy and suggests arsenic addition with time. Arsenic was also found at significantly higher levels out of the plot than inside (Fig. 6e).

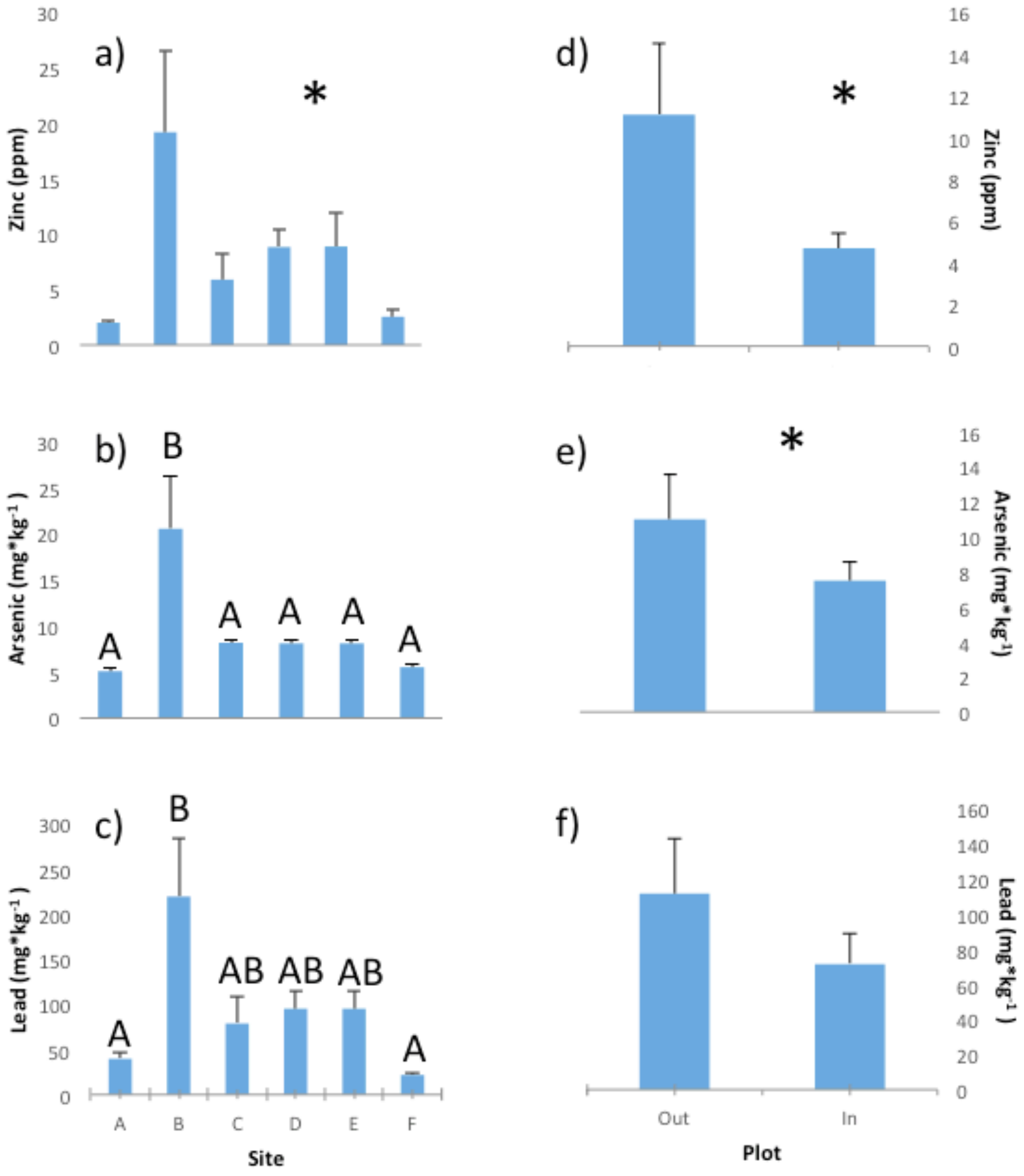


Figure 6. Heavy metal concentrations in urban agriculture soils. Four cores were taken from each site (panels a-c), while 12 core samples make up each of the in and out of growing plot data sets (panels e-f). Figs. 6a-c represent concentrations of zinc, arsenic and lead across sites. Figs. 6d-f represent concentrations of zinc, arsenic and lead in versus out of growing plot samples. Differences in concentrations between plot locations and sites were analyzed using ANOVA; asterisks indicate mean values are

significantly different ($p<0.05$). Posthoc pairwise comparisons between sites were analyzed using Tukey's HSD; values with different letters are significantly different ($p<0.05$).

Lead

Lead shows a pattern very similar to that seen in arsenic and other heavy metals. Site B was again much higher than any of the other sites at Site B (Fig. 6c). Sites A and F were also shown to be significantly lower than the other sites. Despite the lack of significance for in versus out of plot concentrations, with additional sampling the trend for higher lead out of plot might become important.

Discussion

The data collected lends itself to some very interesting and relevant trends as it pertains to urban gardening. As hypothesized, in-plot values for organic matter were consistently higher than out-of-plot samples (Fig. 2d). This is important as the organic matter can help the soil hold onto key nutrients and water. It also provides a food source for the microbes present in the soil, allowing for the organic matter to be broken down, releasing key nutrients into the soil. This breakdown of organic matter is illustrated in the respiration levels, as well as protein levels in the soil (Fig. 2e & f). Each of these indicates that that the in plot soils are healthier and thus better equipped to support crop growth than the original soil. Suggesting that the farming practices are having a positive impact in this regard.

Trends in nutrient levels were also as expected, with the in plot samples being higher than the out of plot. Yet, we encountered levels of some nutrients, potassium and phosphorous in particular, that were much higher than expected. Again, we must acknowledge that in-plot soil was always higher than out-of-plot for each of the key nutrients tested for, suggesting more viability inside the plot. Toxicity levels have not been established for elements like phosphorous and potassium, so we cannot conclude that these levels may be harming the plants, but could potentially lead to runoff and loss into surrounding ecosystems. What we do know is that these levels greatly exceed the recommended levels and thus, provide the plant with an excess of these essential nutrients. This data then raises the question of how much fertilizer is actually sufficient for these imported soils. Since potassium and phosphorous are among the most common elements in fertilizer, we can conclude that no more fertilizer needs to be added at most of the sites to ensure plant growth, as long as nitrogen, not measured, is also significantly high. If the nutrients have been applied as complex compost material, then the application rates could also likely be decreased.

Calcium is one key nutrient that did not follow the trend that was expected. This analyte was intriguing because it was actually found in higher concentrations outside of plot, in the native soil. This suggests that Indianapolis has high levels of calcium in its soils. Another important aspect of nutrient concentration is their ratios. Higher ratios of potassium, phosphorous, and magnesium to calcium can reduce plant uptake of calcium (Agronomic Library). Therefore the innate high calcium levels may also provide stabilizing effect for potassium and phosphorous uptake, compared to areas that are high in other cations but low in calcium.

Heavy metals also provided some interesting trends. It seems that in-plot soils ended up being lower than the native, out-of-plot, soils which agreed with our hypotheses. This trend is most likely a result of the import of newer, uncontaminated soil, in addition to the mulch barrier. There is one site in particular, site B, which has high concentrations of these heavy metals. Although specific toxicity levels for both plants and humans have not been explicitly determined, the levels seen at site B lend themselves to concern. The data from this site also suggests higher levels of these heavy metals in plots that have been there for a long period of time, though we would need more samples to determine this definitively. This would suggest that the mulch is not completely isolating the new soil from the original soil and that these heavy metals have the ability to migrate either vertically via plant uptake or horizontally via aerial or aqueous transport. This undoubtedly raises questions on the long-term efficacy of the mulch barrier method. However, since no other sites had long and short-term plots, we have nothing to compare to. This comparison between contamination level and time would lend itself to interesting future research.

Site B is also constructed significantly closer to an industrial site than the others, suggesting location is also a more susceptible to the aerial or aqueous transport of contaminants. These elevated concentrations of heavy metals could potentially negatively affect crop yield. However, more importantly, if concentrations are high enough they may cause negative health consequences in the farmer. More research needs to be conducted on the plant uptake of these heavy metals, but if they are being taken up, this may lead to health issues in the populations that are consuming the produce as well.

In closing, urban gardening poses many complications for farmers to deal with. Two of the issues illustrated here are low nutrient availability and high levels of heavy metals. The method of isolating imported soil from the native soil or modifying existing soils with large amounts of compost seems to provide a barrier in the short term, but long term isolation of heavy metals depends on multiple temporal and site factors. Fertilizer is also a popular practice among urban and rural farmers alike, however, the very high levels of available nutrients like potassium and phosphorus in-plot indicate that fertilizer application rates are much higher than needed to reach recommended levels.

The trends presented here are interesting and further research could hold many more answers to a field that is largely under-studied. More samples may be useful to this current study in order to provide statistical significance to the data. Beyond this, there are many other routes to be taken too. We must strive to develop comprehensive and easily testable toxicity levels of these heavy metals and nutrients alike, as they will become much more relevant through the increase in the popularity of urban gardening. These levels need to be determined for the plants and humans alike as they are both brought into contact with the contaminants via farming. Furthermore, expansion of urban farms will make it increasingly important to study if and how plants take up these heavy metals and accumulate them in their tissues, as this may have adverse effects on the consumers.

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