Geochemically Determining Urban Garden Suitability: Surveying Oakland Soils

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ABSTRACT

Food insecure communities in highly urbanized areas lack access to fresh, affordable produce. Urban gardens for sustenance provide a solution to food insecurity. However, anthropogenic disturbance may generate hazardous levels of contaminants in soils. These contaminants could be unhealthy for urban gardeners and consumers. To determine the suitability for urban gardens in Oakland, I analyzed soil samples from 50 sites for geochemical characteristics. The criteria for determination of the most suitable space for an urban garden combines spatially categorized data from open spaces, public parks, unused lots, and vacant areas with site specific geochemical parameters of soil solution pH, total lead, total organic carbon, and total organic nitrogen concentrations. I hypothesized that highly industrialized areas would have higher lead levels than less industrialized areas. Using soil solution pH values, total organic carbon and nitrogen as partial fertility indices and lead levels as a toxicity indicator, I determined that with the exception of a few exceptionally toxic areas, Oakland soils have great potential for urban gardens. Land managers, policymakers, and potential urban gardeners should both be aware of lead levels as well as other potential industrial contaminants before establishing an urban garden.

KEYWORDS

Urban Agriculture, soil, Pb, Oakland, pH

INTRODUCTION

Non-commercial gardens grown in urban soils give local communities access to a safe space, a fresh supply of produce, and a venue for increasing community cohesion (Hanna & Oh, 2000). Urban soils provide an attractive solution to families and community members that wish to eat healthy, locally grown foods. However, not all available soil plots should be immediately used for urban gardens. Soils contaminated with heavy metals or industrial wastes are unsafe environments for food growth (Purves, 1966; Teichman et al., 1993; Beavington, 1975).

Urban land use practices often generate soil contamination (Mielke, 1999). Soils are contaminated by a host of anthropogenic products including industrial emissions, airborne contaminants from fuel combustion, and paint chips (Kelly, 1996). Heavy metals are a major source of soil contamination (McClintock, 2010). Many urban environments have high lead (Pb) concentrations in urban soils due to a variety of industrial practices pre-1970. Toxic heavy metals contaminants such as Pb can severely impair the intelligence, development, and behavior of children. Extensive studies have emphasized Pb as a major source of soil contamination in urban environments (Mielke, 1999; Tiechman, 1993; Chaney, 1989; Moir, 1989).

Adverse health effects of Pb are well documented. Young children are at risk for ingesting Pb contaminated soil. Proper nutrition can help to protect children from Pb poisoning, as calcium and iron deficiencies increase Pb absorption in the body. While urban gardens might provide some of those essential nutrients, Pb ingested from fruits or vegetables grown in Pb-contaminated soils still pose a threat of toxicity. For example, mean values of Pb in vegetable samples grown in Australian urban soils indicate moderate (13 ppm) to high (23 ppm) levels of Pb contamination (Kelly, 1996; Moir, 1989; Beavington, 1973).

Long-term exposure to ambient Pb in the environment is hazardous. Pb poisoning can contribute to a variety of illnesses. While plants do not readily take up Pb, eating produce grown in Pb contaminated soils does increase the risk of ingesting Pb dust as well as inhaling Pb contaminated dust. Soil Pb levels above 400 ppm are considered hazardous for young children's play areas, and for all other areas 1200 ppm and above is considered potentially damaging (EPA Hazard Standards, 2001).

What could be done to produce food safely and efficiently in an urban environment? The first step is to identify sites that pose the least risk to consumers and that have optimal soil fertility. The central objective of this project is to determine the best area for urban gardens in Oakland. Specifically, my objectives in determining the best areas for urban gardens in Oakland are to: 1) diagnose the toxicity of the soil; 2) determine the fertility of the soil; and 3) offer land management solutions for urban garden creation based on the previous two objectives. I hypothesized that soils in highly industrialized areas will be the least suitable for urban garden creation.

METHODS

During the spring and summer of 2010, I sampled soil sites with Nathan McClintock, a PhD candidate in Geography researching urban agriculture in Oakland. To determine the most suitable locations for urban gardens in Oakland, we wanted to identify sites with both minimum heavy metal contamination, and optimal nutrient availability. These three parameters, soil Pb concentration, carbon to nitrogen ratio, and pH, provide quantitative parameters to characterize fertility and toxicity. Each site considered has different qualities that may or may not promote the use of the land for urban agriculture. First, I analyzed fifty spatially diverse soil samples for total carbon, total nitrogen, total Pb, and pH values. I then categorized sites with increasingly narrow criteria for fertility to select sites representative of the best fit for an urban garden.

Study system and site selection

The city of Oakland, located in Northern California, United States, has a Mediterranean climate with an annual average temperature of 57º F and annual average precipitation of 22 inches. Potential garden sites in Oakland range from the hills to the flatlands, from San Leandro to Berkeley. Fifty sites were selected from an urban space bordered by the hills and flatlands from east to west and from Berkeley to San Leandro from north to south as potential garden locations across Oakland.

Site characterization

To establish sites for analysis, I categorized the samples based on spatial distribution, land cover, and land use. The first distinguishing feature for characterizing sites is spatial distribution. These sites were categorized as West, Central, East, Hills, and North categories.

There are at least seven sites in each of the neighborhood categories: North, East, Central, West, and Hills. Over half of these are residential, second in abundance is open space, then industrial areas, and finally commercial. (Figure 1)

Soil sampling

Soils vary in nutrient and toxin concentration so an aggregate of samples (or "composite sample") was needed for greater accuracy. I sampled topsoil from six spatially distributed points at each of the fifty sites, using a steel auger to take a core of soil from 20cm to 25cm deep. I collected samples from the topsoil area where plant roots are most likely to interact with soil. I flagged each site with a surveyor flag and collected a georeferenced waypoint using a Trimble Nomad G GPS unit at individual core locations to facilitate for spatial analysis later. Soil cores were collected in a paper bag and dried at 40º C overnight. To account for potential variations of concentrated substances due to soil heterogeneity, soil cores were ground using a mill into flour-like consistency for processing (Brady & Weil, 2002).

Soil analysis

To determine the chemical characteristics of the soil samples, I compared the results of three different lab analyses. I used EPA guidelines when taking the pH of a soil sample (EPA pH, 2010). I measured the pH of aqueous soil solutions with a glass electrode, conducted combustion analysis to determine total carbon and nitrogen concentration, and reviewed total Pb concentration from the University of California, Davis analytical lab (Analytical Laboratory, 2011).

RESULTS

Overview

Overall, I found the samples ranged from pH 5 to 8, from 1 to 10% total organic carbon, 0.1 to 0.9% total nitrogen, and C:N ratios from 10 to 20. Most samples were within EPA standards for Pb concentration of less than 400ppm. The total organic carbon levels, nitrogen levels, and carbon to nitrogen ratios found in many residential areas are characteristic of soils fertile enough to yield crops.

Pb levels

All samples sent to the UC Davis labs for analysis were tested in duplicate for quality control and outliers removed so as not to confound results.

Total organic carbon and nitrogen

North Oakland soils had the highest mean nitrogen concentration, while Central Oakland soils had the highest mean carbon concentration out of the five zone categories. West Oakland soils had the widest spread of carbon and nitrogen levels with the highest and lowest individual site levels of carbon and nitrogen.

pH values in Oakland's soils

The pH values were between 5.9 and 7.6 for Oakland soils. There was not much deviation from expected soil pH values.

C:N ratios

All C:N ratios were between 12:1 and 21:1. The majority of the C:N ratios were between 10:1 and 17:1. Carbon and nitrogen concentrations are reported in percent by weight.

Table 1. Numerical summaries of chemical parameters.

	Mean	SD	Minimum	Median	Maximum
Pb (ppm)	181.26	361.53	13	58.5	2262
C (%)	4.59	2.17	1.42	4.61	10.54
N (%)	0.34	0.15	0.06	0.37	0.71
C:N	13.56	2.3	10.3	13.2	20.99
pH	6.68	0.40	5.94	6.70	7.61

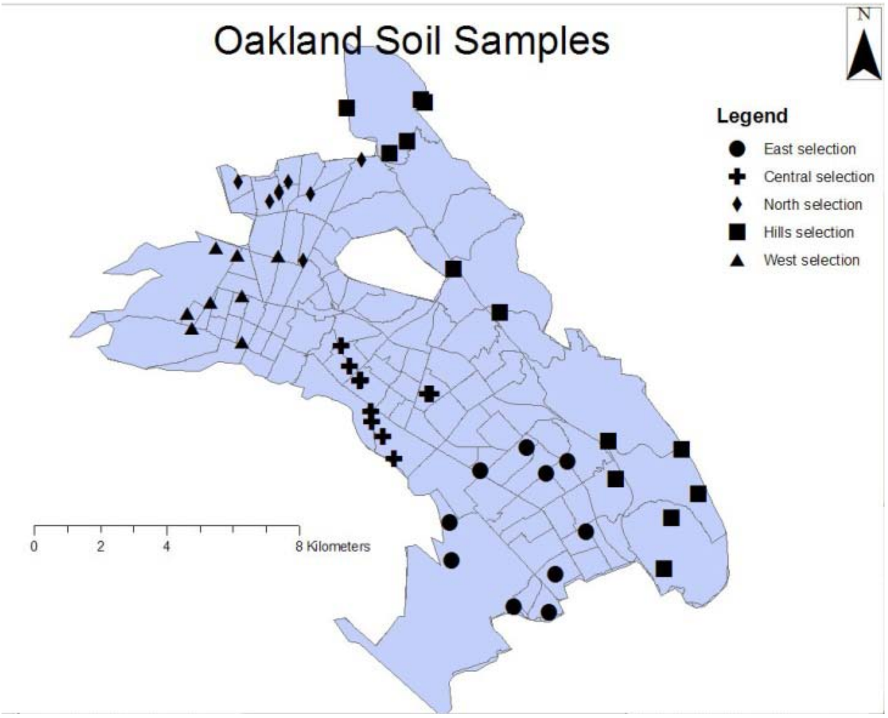

Figure 1. Spatial categories of selected soils in Oakland, CA.

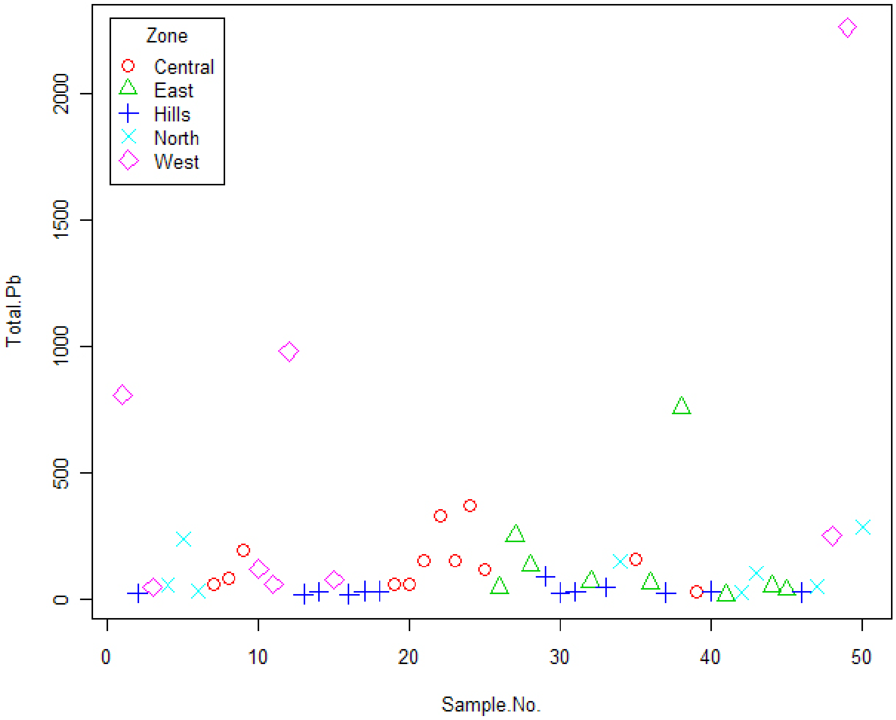

Figure 2. Total Pb levels from selected soils in Oakland.

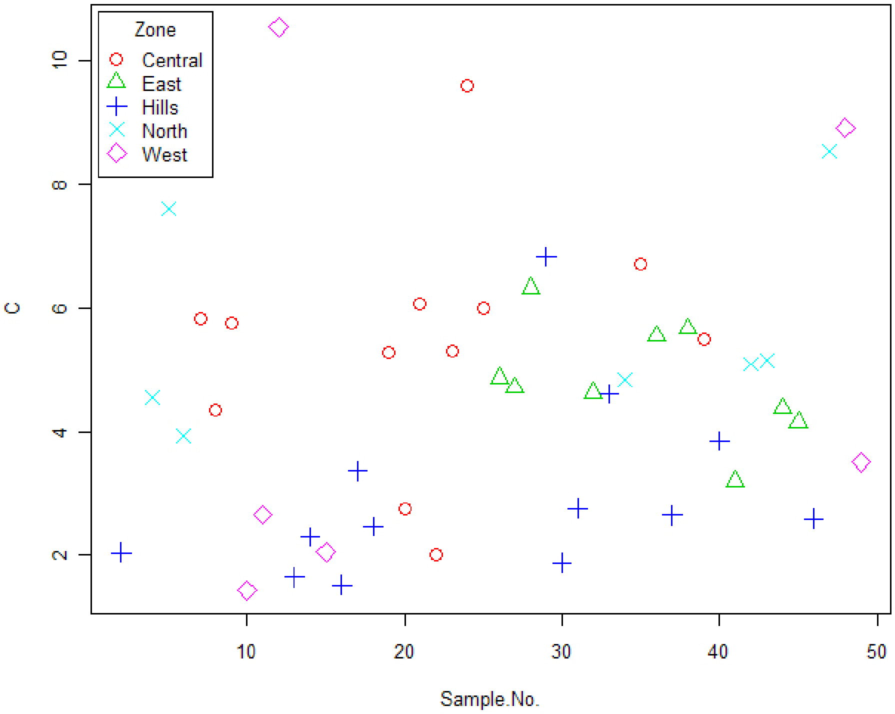

Figure 3. Total organic carbon by percent weight.

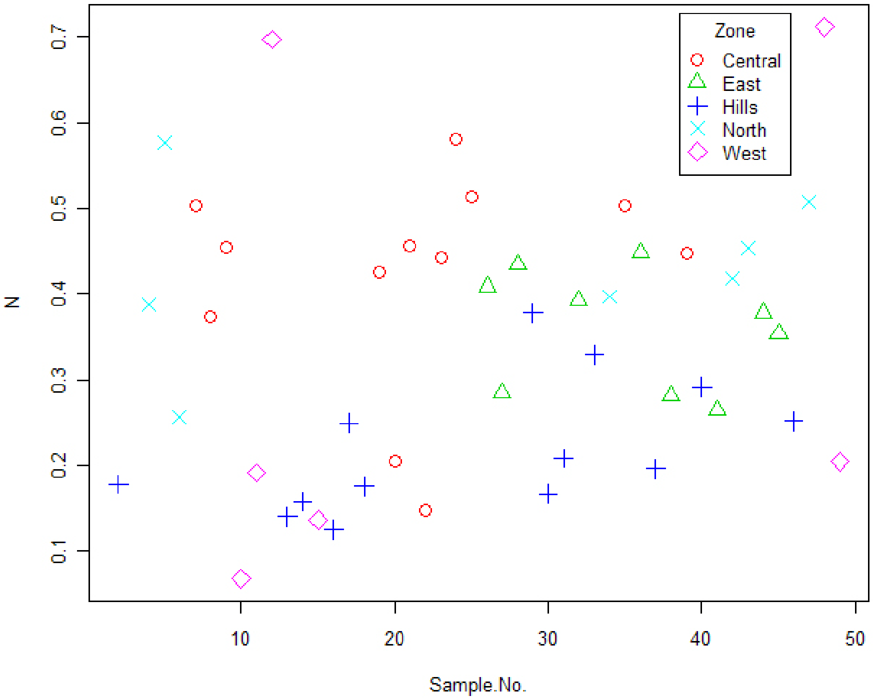

Figure 4. Total organic nitrogen by percent weight.

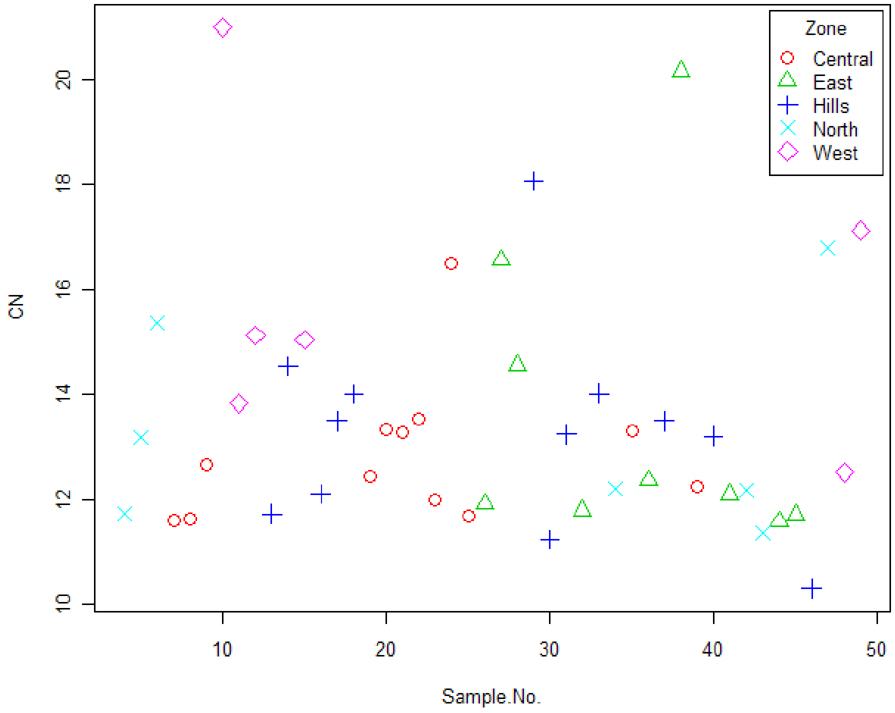

Figure 5. C:N ratio.

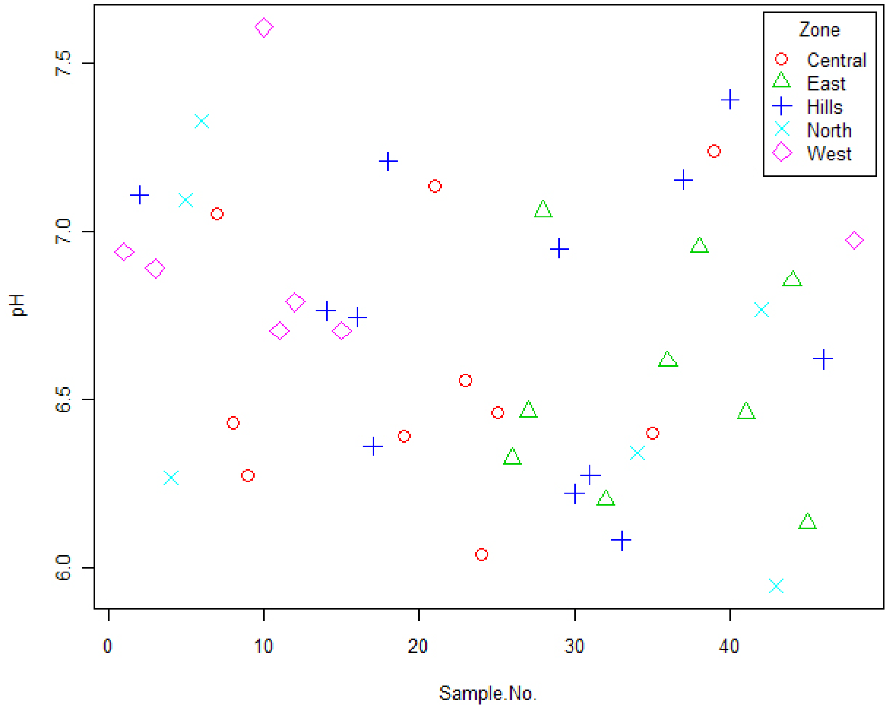

Figure 6. pH values of sampled sites.

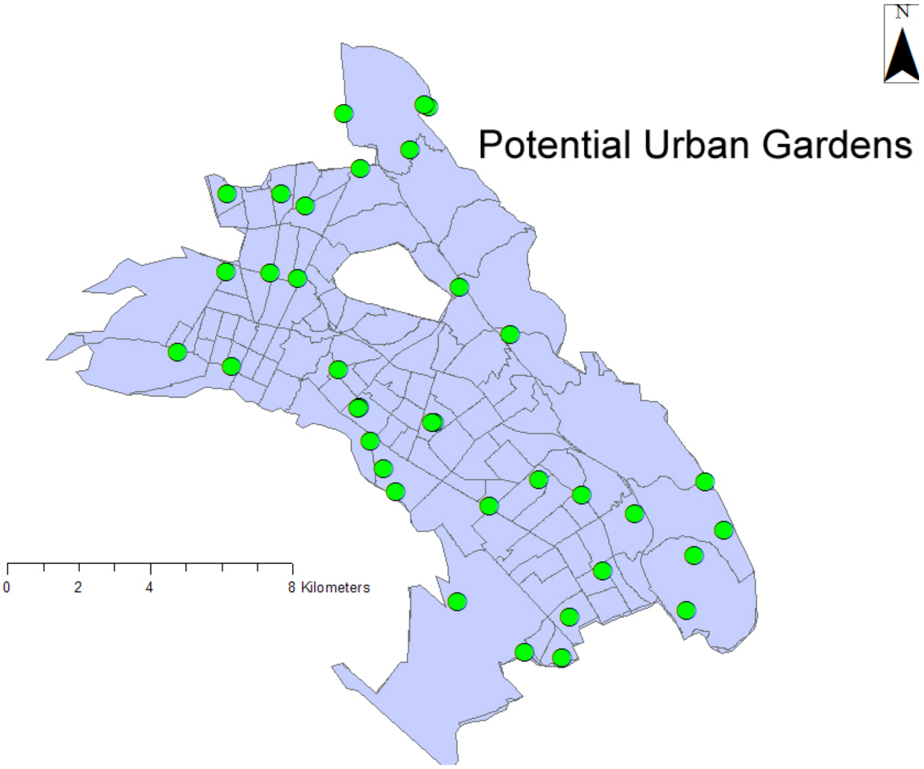

Figure 7. Urban garden selection based on fertility and toxicity criteria.

DISCUSSION

Soil analysis by category

The Central Oakland zone displayed the most fertile soils, while the Hills displayed the least toxicity. An interesting finding in Central Oakland on East 11th Avenue and 23rd St. revealed one of the highest nitrogen levels of a soil site that was not already an established garden. This particular site had untended vegetative growth that may have cycled over time to accumulate nitrogen. The soil surveys performed were analyzed with consideration to previous studies showing relationships between pH values, organic carbon, and trace metals (Wu, 2006; Sauve, 1998). Overall the soil in Oakland is very suitable for garden or urban garden use.

Soil fertility and toxicity

For the purposes of this study, I have only considered soils fertile if the pH values and CN ratios are optimal for plant nutrient uptake as citied in literature. A fertile soil is then generally defined by a pH value between 5.5 and 7.0 with a CN ratio between 8 and 15 (Brady & Weil, 2002). A toxic soil is defined by Pb levels exceeding 400ppm (EPA Hazard Standards, 2001). My analysis of the sampled sites revealed fertility and toxicity levels within acceptable limits, with a few outliers.

There are a few outliers that change the spread of the data, especially when considering total Pb concentrations (Figure 2). One sample in West Oakland had total Pb concentrations of over 2000 ppm. Although this sample is a statistical outlier, it is included as a representative of a highly toxic soil. The outstanding Pb concentration could unintentionally represent West Oakland as zone with higher Pb levels on average.

Most cultivated grain and vegetable crops grow well on soils between a pH range of 5.5 to 7.0 (Sposito, 2008). All of the Oakland soils samples fell within this range (Figure 6). Plants such as potatoes, coffee, and blueberries have adapted to lower pH and may not grow as well in these soils due to the higher pH values (Brady & Weil, 2002). The most suitable pH value for gardens, commercial vegetables, and grasses is between 6.0 and 6.5 (Donahue, 1983).

Soil pH determines the availability of essential nutrients and compounds for healthy plant growth (Xian, 1989). Lower values of pH are associated with higher levels of Pb uptake in plants. Soil pH is an important factor for managing soils without herbicides for optimum weed control (Johnson, 1985). Partially moderated by soil pH, carbon and nitrogen are critical in healthy plant growth (McGill, 1981).

Studies have shown a link between carbon and nitrogen cycling in soils (McGill, 1981; Rixon, 1966). CN ratios give some insight to the amount of nitrogen, an essential plant nutrient, available to plants in soils. Microbial activity partially moderates plant nitrogen uptake (Donahue, 1983). The CN ratio of cultivated soils commonly range from 8 to 15. All soils analyzed had CN ratios between 10 and 20 with the majority between 11 and 16 (Figure 5, Table 1). The presence of a suitable carbon to nitrogen ratio for planned crops in a soil would indicate suitability for urban garden conversion (Rixon, 1966).

Potential urban gardens

All sites considered, the geochemical analysis revealed thirty-six out of fifty sites as optimal for urban garden creation. The criteria for these thirty-six select sites include Pb levels below 400ppm, pH values between 5.5 and 7.5, and CN ratios between 8 and 15 (Figure 7).

Limitations

Soil fertility is defined by Donahue (1983) as the optimal nutrient availability of phosphorus, potassium, sulfur, calcium, iron, magnesium, boron, copper, manganese, zinc, molybdenum, nitrogen, and chlorine in the soil. Soil taxonomic data would be helpful in determining the fertility of a soil because known mineral and carbon concentrations for documented soil types could be compared with concentrations needed for essential nutrient uptake by plants.

Copper, zinc, and molybdenum are required by plants, but also appear in the environment in increased concentrations due to mining operations, fossil fuel production, or other anthropogenic mobilization factors. These perturbed biogeochemical cycles can be problematic in that these nutrients become toxicants when concentrated above levels normally generated by crustal weathering processes (Sposito, 2008). The concentrations of these minerals should be monitored when considering urban garden creation.

Within the parameters of this study, there are no absolute indicators of fertility and toxicity; rather, the ranges and combination of assessed variables indicate that the tested soils are likely to produce viable plants with the least hazard of Pb dust contamination. A broader sample of fertility indicators based on analyses of aforementioned soil chemical and physical properties would provide a more accurate diagnosis of fertility. Nutrient availability can be partially determined by pH, but a soil in an optimal pH range may lack critical nutrients to provide for optimal plant growth (Brady & Weil, 2002).

Future research

Future research directions could include further exploration of urban chemical soil characteristics, as well as a suitability assessment for communities likely to be involved with an urban garden. A more intensive geochemical analysis could include a survey of total and extractable soil concentrations of essential macronutrients in order to further aid in assessing fertility.

An analysis of access issues for urban gardens would also be valuable. Land use practices and zoning policies for farming open spaces should be analyzed to assess practicality of urban garden creation. Funding from city governments as well as national grants could be taken into account to transition from potential to actual. Future studies in different urban environments, especially cities with limited open space and high urbanization, are necessary to generalize the suitability of urban gardens on a national scale.

This study is exploratory in nature. Practical experiments involving yield maximization, long term sustainability practices, and distribution methods are all potential next steps for urban agricultural research. Future soil analyses for urban areas similar to Oakland would be beneficial. Further precautionary research into other chemical indicators of toxicity such as mercury, zinc, nickel, arsenic, copper, molybdenum, silver, cadmium, and chromium would benefit at risk communities.

Broader implications

The broader implications of urban garden use on a global scale are immense. Multiple urban gardens in a food insecure region potentially provide a resource to build nutrition programs, forge stronger interactions between community members, and promote the proliferation of sustainable land management practices. Ecologically, urban gardens would reduce the distance food is traveled from production to consumption, which would provide an ecological benefit over time that could play a role in climate change mitigation. Federal subsidies for ecologically sound urban gardens have the potential to solve problems inherent in contemporary monoculture farming processes, such as excess nitrate leaching from the overuse of synthetic fertilizers and minimizing the risk of synthetic fertilizer contamination in food.

When designing experiments such as this, care needs to be taken not to interpret results from one plot as applicable to a greater zone. The findings of this study reveal general trends in fertility and toxicity but should not be used to characterize an entire region of soils due to the heterogeneous nature of soil on both micro and macro scales. The spatial dispersion of sample sites gives only an approximation for the soils in the City of Oakland as a whole. The inclusion of more study sites would not necessarily yield more significant results due to the extreme heterogeneity of urban soils. Therefore, if specific sites are being considered for urban gardens, these should be assessed on an individual basis.

The city of Oakland has a tremendous potential for urban garden space. Residential zones could be utilized by their owners immediately for local food production, while underutilized publicly owned land could provide healthy food access points to disenfranchised communities. Open space areas are mostly undisturbed land plots situated in the city. Cultivating open space areas with minimal perturbation could also be a viable option for urban garden creation. Commercial and industrial areas with untested exposed soils may be the least likely areas to transform into urban gardens due to the uncertainty of contamination and the expense of potential remediation. This is interesting because commercial soils and industrial soils had some of the most elevated nitrogen levels, which would likely eliminate the need for constant fertilizer amendments. Although the amount of soil amendments needed to transform an unused soil plot into a hub for sustainable food production varies from plot to plot, minimal amendments would be needed for the majority of soils in Oakland. Future land management practices may be optimized by using this analysis as a guide.

Previously unknown numerical data about Oakland soils are now known values that could help decide land-use decisions. The methods and findings of this study can be replicated in other cities or urban environments to produce similar results yielding a general range of fertility and toxicity for urban soils in regards to urban garden production. Depending on the city, anthropogenic impact and soil perturbation may be minimal. Special investigations into industrialized areas and densely populated urban spaces should be a priority because these areas are often home to disenfranchised communities that would benefit from urban gardens the most. The information contained within this study can also be applied to rural soils, where knowledge of trace toxins is equally beneficial.

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REFERENCES

390 — Analytical Laboratory. *Welcome to the UC Davis Analytical Lab — Analytical Laboratory*. Retrieved March 28, 2011, from http://anlab.ucdavis.edu/analyses/soil/390

Beavington, F. (1975). Heavy Metal Contamination of Vegetables And Soil In Domestic Gardens Around a Smelting Compex. *Environmnental Pollution*, *9*, 211-217.

Brady, N. C., & Weil, R. R. (2002). *The nature and properties of soils: Nyle C. Brady, Ray R. Weil.* (13. ed.). Upper Saddle River, N.J.: Prentice Hall.

Chaney, R. L., & Mielke, H. (1989). Speciation, mobility, and bioavailability of soil lead. *Environmental Geochemistry and Health*, *11*, 105-129.

Donahue, R. L., Miller, R. W., & Shickluna, J. C. (1983). Soil Chemical and Colloidal Properties. *Soils: an introduction to soils and plant growth* (5th ed., p. 108). Englewood cliffs, N.J.: Prentice-Hall.

Hanna, A., & Oh, P. (2000). Rethinking urban poverty: a look at community gardens. *Bulletin of Science, Technology & Society*, *20*(3), 207-216. Hazard Standards | Lead in Paint, Dust, and Soil | US EPA. (2001). *US Environmental Protection Agency*. Retrieved March 28, 2011, from http://www.epa.gov/lead/pubs/leadhaz.htm

Johnson, J., & Burns, R. (1985). Effect of soil pH, fertility, and herbicides on weed control and quality of bermudagrass (cynodon dactylon) turf. *Weed Science, 33*, 366-370. *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties (Agronomy)* (2 Sub ed.). (1983). Madison: Amer Society Of Agronomy.

Kelly, J., & Thornton, I. (1996). Urban geochemistry: a study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and nonindustrial areas of Britain. *Applied Geochemistry*, *11*, 363-370.

McClintock, N. (2010). Looking for lead in all the wrong places: an assessment of heavy metals at potential urban farming sites in Oakland, California. *Annual Meetings of the Association of American Geographers*, *1*, 2-3.

McGill, W., & Cole, C. (1981). Comparative aspects of cycling of organic c, n, s, and p through soil organic matter. *Geoderma* , *26*, 267-286.

Mielke, H., Gonzales, C., Smith, M., & Mielke, P. (1999). The urban environment and children's health: soils as an integrator of lead, zinc, and cadmium in New Orleans, Louisiana, U.S.A. *Environmental Research Section A*, *81*, 117-129.

OAKLAND, CALIFORNIA - Climate Summary . *Western Regional Climate Center*. Retrieved Jan 11, 2011, from http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca6332

Purves, D. (1966) Contamination of urban garden soils with copper and boron. *Nature*, 210, 1077-1078

Rapid Bioassessment Protocols For Use in Streams and Rivers: Periphyton, Benthic, Macroinvertebrates, and Fish. Appendix A: | Bioassessment | US EPA. (n.d.). *EPA Office of Water Home | Water | US EPA*. Retrieved December 8, 2010, from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/app_a.cfm

Rabinowitz, M. B. (1993). Modifying soil lead bioavailability by phosphate addition. *Bulletin of Environmental Contamination and Toxicology*, *51*, 438-444.Sposito, G. (2008). The Chemical Composition of Soils. *The chemistry of soils* (2. ed., pp. 5-13). Oxford : Oxford University Press.

Rixon, A. (1966). Soil fertility changes in a red-brown earth under irrigated pastrures. *Australian Journal of Agricultural Research*, *17*, 303-316.

Sauve, S., McBride,, M., & Hendershot, W. (1998). Soil Solution Speciation of Lead(II): Effects of Organic Matter and pH. *Soil science Society of America journal*, *62*, 618-621.

Sposito, G. (2008). *The chemistry of soils* (2nd ed.). Oxford: Oxford University Press. Teichman, J. et al (1993) A survey of lead contamination in soil along interstate 880, alameda county, California *American Industrial Hygiene Association Journal*, 54: 9, 557 — 559

US Environmental Protection Agency. Electrometric Procedure for Measuring pH in Soils. *Soil and Waste pH*. Retrieved December 8, 2010, from www.epa.gov/osw/hazard/testmethods/sw846/pdfs/9045d.pdf

Wu, J., Norvell, W., & Welch, R. (2006). Kriging on highly skewed data for DTPA-extractable soil Zn with auxiliary information for pH and organic carbon. *Geoderma* , *134*, 187-199.

Xian, X., & Shokohifard, G. (1989). Effect of pH on chemical forms and plant availability of cadmium, zinc, and lead in polluted soils. *Water, Air, and Soil Pollution*, *45*, 265-273.