Evaluation of Northwestern Seattle Parking Strip Soil for Urban Horticulture Land Use and Urban Food Production

Kathryn Allison Murphy

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Committee:
Sarah Reichard
Sally L. Brown
Soo-Hyung Kim

Program Authorized to Offer Degree:
School of Forest and Environmental Science

University of Washington
Graduate School

This is to certify that I have examined this copy of a master's thesis by

Kathryn Allison Murphy

and have found that is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Committee Members:

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Sarah Reichard

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Sally L. Brown

____

Soo-Hyung Kim

Date: ________________________________

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DEDICATION

To my grandaunt, Rita M. Daubenspeck.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Number Page

LIST OF TABLES

"Eat well-grown food from healthy soil."

- Michael Pollan, FOOD RULES

INTRODUCTION

Plants are a key component of the environment in both natural and human influenced ecosystems. Known as green infrastructure, plant communities are an integral part of ecosystem functions in urban and suburban areas (Volder, 2010). By stabilizing soil, purifying air, absorbing excess water, mitigating the urban heat island effect and providing habitat for urban wildlife and pollinators, plants help sustain ecological processes within the built urban environment (Mendes, 2008). Plant communities also provide many social and economic benefits to urban residents by adding a natural aesthetic, bringing urban dwellers relaxation and an improved quality of life (Volder, 2012; Vrščaj, 2008).

Three primary plant communities exist in the urban environment: gardens that are intentionally planted to serve an aesthetic or functional need, patches of weedy volunteer plants that colonize small and large areas, and plant communities that are remnants of native vegetation that has existed since before an area was urbanized (Volder, 2010). Plants grow in a variety of urban settings from rooftop gardens and urban plazas, greenbelts and parks to small container plantings and residential properties. With over 6,200 acres of public open space, all three types of plant communities exist in the Seattle metropolitan area. This makes Seattle a city rich with urban forests, beautiful parks and a thriving community garden network (Seattle Parks and Recreation, 2012). As city populations swell and increasing pressures are placed on urban ecosystems, preserving green infrastructure, open space and healthy soil to support health plant growth is becoming a priority of many municipalities and policy makers (Mendes, 2008).

Urban Horticulture in Seattle

The practice of cultivating and managing urban gardens that are intentionally planted is known as urban horticulture. Horticulture is defined as the science and art of cultivating fruits, vegetables, flowers and ornamental plants (Miriam-Webster Dictionary, 1981) on both public and private property. Urban agriculture, an urban horticulture practice, focuses on growing food and medicinal plants for human consumption. As urban residents are becoming more conscious about the sources of their food, demanding more fresh and locally grown produce, and becoming increasingly involved in community gardens in many metropolitan areas, urban agriculture has boomed in recent years (Bellows et al., 2008).

Until only recently most urban residents were not intimately involved with the production of their own food. Historically people in both rural and urban settings grew their own food in close proximity to where they lived. Since World War II, many developed countries have seen a drastic shift away from local urban food production to a passive acceptance of long distance food transport from rural areas via refrigerated trucks travelling on highways. Practices such as industrialized farming and large-scale food production also drastically influenced our food system and changed the relationship urban residents have to food production (Mendes, 2008). Over the last 60 years, many city planners adapted to the idea that food production was a rural issue and did not think it was the ‘turf’ of city planners to engage in food policy or production issues (Mendes, 2008). As cities grow, becoming home to over 50% of the world's population (Vrščaj, 2008) gardening and horticulture is being considered as a way not only to produce food and ensure a sustainable food system (Mendes, 2008) but to enhance the ecological functioning of urban areas (Cheng et al., 2011) and provide healthier lifestyles and stronger communities for urban residents (EPA, 2011).

Homeowners have become more involved with the design, creation and maintenance of private residential gardens surrounding their home. While horticulture and raising ornamental plants has always been popular in Seattle, urban agriculture is becoming increasingly popular on private residential property. Private urban agriculture practices include household kitchen gardens, edible ornamental plantings integrated into an ornamental garden design and the creation of entirely edible landscapes. However, city lots are often small (Cheng et al., 2011) and adequate garden space with appropriate amounts of sunlight for vegetable growing can be difficult to find (Loram, 2008).

The P-Patch community garden network, established in Seattle in 1973, provides many Seattle residents with low-cost garden space. In conjunction with the non-profit P-Patch Trust, this program provides 4,400 Seattle gardeners with part-year and year-round garden plots. P-Patches serve gardeners who live in all types of residences from apartments to single-family homes and are intended to serve all members of the community. Seventy-eight community gardens grow food on 13.5 acres of land, and gardeners steward another 31 acres of land for the public. Gardeners must employ only organic, non-synthetic gardening methods, control potentially invasive plants, care for their soil by improving it with compost and well rotted manure and volunteer 8 hours a month to help maintain the garden outside their small assigned garden plot (Department of Neighborhoods, 2012). In 2008, a waiting list of 1,719 people requesting space in a community garden arose from a shortage of available P-Patch space. With a rise in urban agriculture practices and, in Seattle, a demand that is greater than supply, city officials looked for alternative vegetable gardening areas to augment the popular P-Patch community gardens (SLI Tab 76, November 12, 2008). To fill this growing need, one urban landscape feature identified as a place to grow small vegetable gardens, is the parking or planting strip, right in front of many residential homes.

The Parking Strip

The parking strip is street side right-of-way land. Located between the sidewalk and the street, parking strips are usually two to eight feet wide and run parallel to the road (Fig.1). In Seattle, this right-of-way land is owned by the city but is the maintenance responsibility of the property owner immediately adjacent to the planting strip.

Figure 1: Seattle Parking Strip in the Crown Hill Neighborhood.

Five different City of Seattle departments have jurisdiction over the parking strip right-of-way. The Seattle Department of Transportation (SDOT) has authority over any work done in the right-of-way. Trees planted this area are the responsibility of the Seattle city arborist. Seattle City Light has authority for overhead and underground utility and electrical lines that run through or over the parking strip. Seattle Public Utilities has governance over any work done on drainage and water infrastructure, and the Department of Neighborhoods (DON) is responsible for historic site preservation and community projects, and has initiated the street tree program where trees are donated for planting in the parking strip (Seattle Right-of-Way Improvement Manual).

Concerns about horticultural practices occurring on the parking strip were brought before the Seattle City Council in 1948 and again in 1951. A Committee on Parking Strip Care and Beautification was formed in 1948 to identify the main issues with this right-of-way land. The topics of concern at the time were "the unrestricted planting of trees, shrubs and other plants with no consideration of their ultimate size or appearance nor their relation to the safety of its citizenry." The solution to this problem, according to this committee, was to define what could be planted in the parking strip and remove any plantings that were the cause of "emergency situations." To control unrestricted plantings, it was suggested that: "parking strips less than three feet wide should be seeded with lawn or surfaced with asphalt concrete, parking strips 3-6 feet wide should be seeded in lawn except at bus stops where paving is desirable, and parking strips over 6 feet in width shall be seeded to lawn and planted with approved street trees except in commercial districts." The committee also suggested that plants which violated these planting guidelines be removed immediately to reduce hazards which "provide sanctuary to the criminally minded, obscure clear vision at street intersections, obscure children or adults who may dart out into traffic, and [plants that] interfere with sewer lines or the transportation system." (Summary of Findings. Committee on Parking Strip Care and Beautification, 1948)

In 1951, the Seattle Department of Engineering published a Public Information Brochure, 'Keep Seattle Clean: Regulations for Use of Street Area, Parking Strips, Sidewalks and Roadways, In the City of Seattle.' This brochure defined certain vegetation growth patterns as public nuisances: trees or shrubs that overhang the sidewalk and impair the full use of the sidewalk, grass and weeds that have died are considered a fire hazard, and no trees, shrubs or flowers over two feet in height may be planted in any parking strip within 30 feet of the intersection (Seattle Department of Engineering, 1951).

The results of these parking strip guidelines created parking strips that were paved or planted in lawn, both of which result in little ecological function. Pavement reduces water infiltration and increases runoff, and lawn has very little ecological diversity unless infested with volunteer plants such as weeds. Manicured lawns also require large nutrient inputs often supplied by chemical synthetic fertilizer. Now that many municipalities understand the importance of a healthy green infrastructure and the importance of diverse plant communities, more complex plant communities are being allowed to grow in the parking strip.

Food Production in the Parking Strip

On November 12, 2008 the Seattle City Council voted in favor of a Statement of Legislative Intent that encourages food production on the parking strip. The historical precedents set in 1948 and 1951: concerns about public safety, interruption of sight lines, limited vehicle clearance, and impaired pedestrian mobility were referenced as reasons to discourage such practices in the past. But as the need for more community-accessible gardening space grew, the Seattle City Council amended some of the parking strip policies. As of June 1, 2009, the City of Seattle has changed the permitting process necessary for transforming and cultivating a parking strip by lifting the permitting fee and allowing urban agriculture practices in accordance with the well defined parking strip guidelines. As of April 2009, the DOT was assigned the task of clarifying relevant rules and regulations about gardening on the parking strip on the department's web site in order to educate gardeners about gardening street-side. One suggestion by SDOT was for residents to test their soil before gardening and growing food plants (Seattle Department of Transportation, 2009). Unfortunately, most gardeners do not know how to test key soil components, where to go to have their soil tested, or how to interpret soil test results.

Purpose and Need of Research

Some Seattle residents have expressed both enthusiasm and concern about growing fruits, vegetables, and plants intended for human consumption in the parking strip. Due to the proximity to the street, concerns arise about potential pollution and contamination from automobile emissions. There also seems to be a lack of information available to the general gardening public about the key components of a soil test and how those components relate to healthy plant growth. It is also assumed that urban soil is very disturbed, polluted, low in fertility (Volder, 2010; EPA, 2011; Cheng et al., 2011) and not able to support healthy plant growth. A study specifically designed to investigate Seattle parking strip soil and evaluate the appropriateness of this land for urban agriculture had not been done. This necessary investigation of the health of parking strip soil will yield a great deal of information about Seattle's urban residential roadside planting areas to support plant growth, and the feasibility of urban horticulture land use adding additional vegetable and ornamental gardens adding to Seattle's green infrastructure.

Objectives

There are two primary objectives of this research. The first is to test a soil evaluation method developed by Vrščaj et al., (2008). The soil evaluation method is a way to grade soil by testing certain chemical and physical soil properties as a way of matching existing soil to an appropriate gardening practice or land use. The second objective is to measure the concentrations of lead, an automobile related heavy metal found in parking strip soils to determine if cars and their emissions have had an effect on urban street-side soil and if there is legacy pollution from leaded gasoline emissions. These two objectives will provide homeowners with more information about the 'ingredients' of parking strip soil and identify if it is an appropriate place for urban agriculture and food production. It is also important to stress that this study focuses on soil to plant interactions and apply that information to real life horticulture practices. Hydrologic and atmospheric effects are not included in this work.

Research questions

1. Is the planting strip an appropriate place for urban horticulture and urban food production? Do the soil properties match what is required for vegetable production?

2. Do traffic patterns and automobile emissions affect the suitability of parking strip soil? Is there a significant difference in lead concentrations as an indicator of legacy automobile emissions between high traffic, medium traffic, and low traffic areas?

- 2.1 Are there any significant differences between parking strip soil and backyard soil in regards to lead contamination?
  - 2.1.1 If so are they linked to traffic class?
- 2.2 Do lead concentrations change as distance form the street increases?

LITERATURE REVIEW

Many scientific papers on the subjects of urban horticulture, arboriculture and city planning call for the need for scientists to study urban soil. Although there is a growing base of scientific literature about urban soils there seems to be a collective opinion that more needs to be known about soil functions and soil characteristics in the urban environment (Jim, 1998).

Soil as a Functional Medium

Soil is a complex medium that supports terrestrial plant species and is home to countless soil organisms. The main ingredients of soil are mineral particles, organic matter, water and pore (air) space (Li and Chunchang, 2007). Soil is a major component of any ecosystem acting as a filter for water, a site for nutrient cycling, and often a sink for particles contributed by atmospheric deposition and chemical breakdown (Li and Chunchang, 2007).

The National Soil Resource Institute has recognized the great environmental importance of soil, and ranked soil functions in order of their importance to support a human population. The main functions of soil according to the NSRI are:
(i) environmental interaction, (ii) food and fiber production, (iii) provision of a platform for human activities, (iv) support for ecological habitats and bio-diversity, (v) provision of raw materials, and (vi) protection of cultural and natural heritage (NSRI, 2001).
Because soil requires a long time to develop under natural weathering conditions, soil is considered a non-renewable resource during the human lifetime (Vrščaj, 2008).
Preserving functional soil is becoming an ecological priority around the globe.

Soil functions are ecosystem services we expect the soil to provide (Vrščaj, 2008). Functions such as filtering water, sequestering carbon, supporting healthy plant communities, cycling nutrients and buffering contaminants are some provisions. Certain soil functions are of greater or lesser importance when different land uses are considered for a given area. Soil quality is based on how well the soil performs required soil functions. Soil quality can be categorized as “good” or “bad” according to how well the soil supports or inhibits biological productivity, health and functioning of organisms, and the ability to mitigate environmental contaminants and pathogens. Because of the myriad possible combinations of land uses and soil types, overall soil quality and fitness for use cannot be determined by a single measurement or parameter. Instead, issues of soil quality must be determined from a variety of measurable soil characteristics and synthesized in a simple, understandable manner (Vrščaj, 2008). With the increase in the importance of soil management to preserve soil resources, methods of soil quality evaluation for non-scientists have been developed. Applying useful management tools and evaluation methods to urban soils will add great understanding about soil health and appropriate land uses in our urban centers.

Urban Soil

It is commonly thought that urban soils differ from rural soils due to anthropogenic influences (Volder, 2010; Vrščaj, 2008). Activities such as mixing (Fig.2), compacting, tilling, burning, and adding mineral and chemical materials have created a heterogeneous mosaic of soil types that is highly disturbed and unpredictable (Volder, 2010; Vrščaj, 2008).

Figure 2: Soil disturbed during construction of an irrigation pipe for the Intramural Fields at the University of Washington. Soil was mechanically excavated one day and stockpiled during the pipe construction (photo on left). The soil was then replaced two days later (photo on right). The area was then hydro-seeded making the large amount of soil excavation and replacement almost invisible.

Urban soils are also thought to be nutrient deficient and highly polluted (EPA, 2011). For both aesthetic and practical reasons, gardeners in urban areas tend to ‘clean up’ yards, gardens, walkways, city streets and accumulated litter blocking storm drains, removing organic material that would otherwise be broken down and returned to the soil as leaf litter (Volder, 2010). Due to the close proximity of soil to humans, soil pollution and contamination is of great concern in the urban area (Vrščaj, 2008). Legacies of industrial practices, leaded gasoline and pesticide use are often found in urban soil because it acts as a sink for these pollutants (Volder, 2010; Li and Chunchang, 2007; Vrščaj, 2008; Cheng, 2011). The primary sources of lead pollution: lead paint, leaded gasoline, and industry are historic yet persist in soil for hundreds of years. With the banning of leaded paint, the removal of lead from gasoline and the closing of industrial operations over the last 30 years, the deposition of lead from these sources has greatly decreased (Ryan et al., 2004). With lead sources greatly diminished, it is possible to begin to restore urban soils and minimize the risk of legacy lead to the urban population.

Urban development and the built environment have affected urban soils in significant yet less direct ways. Because of large amounts of pavement and concrete, soils tend to be more alkaline, and soils temperatures warmer because of the ‘urban heat island’ effect. Compacted soil that develops around building sites from the weight of heavy machinery and human foot traffic also presents challenges to expanding plant root systems. Paving or sealing roads by adding impervious surfaces has also lead to reduced water and oxygen flow within the soil profile creating extreme soil conditions that adversely effect plant growth (Volder, 2010).

Roadside Soil

Roadside environments exposed to traffic, wind, mowing and storm water runoff are challenging conditions for the growth of healthy plant communities (Volder, 2010). Increased air pollution and elevated heavy metal concentrations have been studied and documented. According to one study in the United Kingdom, many high hazard indexes (increased metals levels) for soils are found around junctions of major roads (Hough et al., 2004).

A study done in Chicago, found that automobile emitted lead was greatest within 100m of busy roads. This study also found that lead levels were higher near roads with higher speed limits and around areas where cars were known to accelerate (Shinn et al., 2000).

An urban soil study done in Hong Kong aimed to provide appropriate planting areas for trees. The study targeted roadside soils and measured many soil physical properties that affect root development. The study found increased soil particle size (rocks) that inhibited root growth, highly compacted soils, increased pH to very alkaline levels, low organic matter, and low Cation Exchange Capacity which inhibits nutrient holding capacity within the rooting zone (Jim, 1998).

Given the total land area covered by and adjacent to roads in urban areas, roadsides cannot be ignored as places with inherent gardening potential. Established, healthy plant communities can have a great effect on mitigating some common ecological challenges found in cities. Studying the existing roadside soil to better understand appropriate land uses and what plants the soil will support, is the first step in growing successful urban roadside gardens. Urban gardeners should start with a soil test to evaluate the specific area they are intending to cultivate.

Components of a Soil Test

The methods of testing soil are often confusing to the average urban gardener. It is most important to test soil properties that will affect the health and well being of the plants grown in the soil at the site.

<u>pH</u>

One of the most important measurements taken in a soil test is pH. A measure of the soils' acidity (or alkalinity), pH determines what nutrients will be available to plants and which ones will be locked up in the soil unavailable to plants. Measured on a scale of 1-14, with 7 being the neutral point, acidic substances (including soils) have a pH of 1-6.9 while alkaline substances have a pH of 7.1 to 14. In the Pacific Northwest, soils are often slightly acidic with pH in the 5.5 - 6.5 range (Marx et al., 1999). In general terms, most vegetable species prefer a soil pH of 6.5-7.0, just slightly acidic. In this ideal range, nutrients such as phosphorus, potassium, calcium and magnesium are more readily available to plants (Brady and Weil, 2000). The pH of a soil can also determine the availability of toxic heavy metals (Spargo et al., 2012). For example, aluminum is more mobile and available in soils with a pH of less than 4.0 and is highly toxic to plants (Brady and Weil, 2000).

Soil texture

Soil texture is a basic soil property and is very important to understanding how a soil will behave. Soil texture is determined by the percentages of three different soil particles: sand, silt and clay. Sand grains, fine and coarse, are 2.0 to 0.05mm in size, the largest of soil particles. Sand is useful in soils because it helps them drain. Silt particles are between 0.05 and 0.002mm. The smaller size of the particle allows the particles to compact more tightly allowing soil to hold on to more water than sandy soils. Clay is the smallest of the soil particles at less than 0.002mm. The smallest particles have the largest surface area per volume allowing clay to attract water and nutrients and holding them in the rooting zone of plants. But if soil has too much clay, soil does not drain and plant roots can suffer from lack of oxygen. It is most important for soil to have all three particles sizes- soil particles to provide water, oxygen and nutrients to plant roots. Different combinations of soil particles are called soil texture classes. The most desirable soil texture for vegetable growing is loam. Other variations of loam such as sandy loam and silty loam are also good for vegetable growing (Vrščaj et al., 2008).

Organic matter content

Organic matter, decomposed plant and animal material, has many effects on soil properties and plant growth. One of the most important effects of soil organic matter is as a food source for soil microbes and soil organisms increasing the overall biological activity of soil. When mixed into soil, organic matter can help to change and diversify soil structure by acting like glue and creating soil aggregates. By volume, organic matter is much lighter than mineral soil allowing for 'fluffier' soil with better water holding capacity when organic matter is mixed into mineral soil. Like clay, organic matter usually has a small particle size and can help to retain more water and nutrients in the rooting zone, making those nutrients more available to plants. Organic matter also helps to moderate soil temperature, reduces water loss, and increases soil fertility. As a source of slow release nutrients, additions of organic matter add important macro and micronutrients back to the soil. It also binds to toxic heavy metals such as lead making lead less available to plants (Brady and Weil, 2000).

Carbon to Nitrogen (C/N) ratio

The carbon to nitrogen ratio in soils is the proportion of carbon to nitrogen found in the organic matter. Organic matter that has a lot of woody material is very high in carbon and is very slow to break down and slow to add nutrients to the soil. Organic matter too high in nitrogen leads to an explosion of soil microbes that feeds on the nitrogen depleting the supply before the plants have a chance to access the nutrient pool.

Excess nitrogen can also leach from the soil into groundwater causing environmental pollution (Brady and Weil, 2000).

Available nutrients

Nutrients are essential for healthy plant growth and physiological function. The three most important nutrients are nitrogen (N), phosphorus (P) and potassium (K) often referred to as N-P-K. Adequate amounts of macronutrients vary according to specific plant species, but there are some general guidelines as to what is appropriate for most commonly grown vegetable species. These three macronutrients are necessary ingredients of soil or plant growth will be limited (Marx et al., 1999).

Nitrogen (N) is an essential plant nutrient responsible for many functions in plants especially leaf growth and photosynthesis (Spargo et al., 2012). Two forms available to plants are nitrate (NO_3^-) and ammonia (NH_4^+). These forms of nitrogen fluctuate constantly in soils and do not remain stable even in one growing season (Marx et al., 1999). Nitrates are easily leached from soil when soils are overwatered or exist in areas of very high rainfall (Marx et al, 1999). It is often necessary to add nitrogen inputs to the soil at the beginning of the growing season to ensure an adequate nutrient supply of plant available nitrogen. Organic matter is a slow release form of nitrogen that can supply adequate amounts of soil N to satisfy most vegetable crops (Spargo et al., 2012).

Phosphorus (P) is important because it drives a plant’s metabolic process. This nutrient allows plants to use energy captured by photosynthesis. Utilization of this energy helps a plant to assemble the vegetative building blocks it has gathered from the soil and created during photosynthesis to grow leaves, build healthy roots and elongate strong stems. Adequate amounts of phosphorus also help a plant develop a good flower and fruit set, important for an abundant vegetable yield. Phosphorus is most available to plants in sufficient quantities when the pH of a soil is between 5.5 and 7.0. If soil is more acidic (lower than 5.5) phosphorus will be bound to soil minerals such as iron and availability to plants will decrease. If soil pH is alkaline (above 7.0) phosphorus is bound to calcium and availability will decrease (Spargo et al., 2012). It is important to ensure both an adequate supply of Phosphorus and maintain an appropriate pH so it is available to plants.

Potassium (K) helps plants use nitrogen during photosynthetic processes. Adequate amounts of potassium can ensure healthier plants that can better fight off pests and disease (Spargo et al., 2012). Potassium is easily leached from soils and often-adequate amounts are not supplied with additions of organic matter. Potassium is returned to soil when plants die, and decompose. Potassium is not returned to the garden when plants are harvested and leaf litter cleaned up (Lambers et al., 2008). Like phosphorus, potassium is most available to plants when the soil pH between 6.5 and 7.5 (Lambers et al., 2008). Good sources of potassium are wood ash and seaweed, which are rich in important micronutrients as well (Brady and Weil, 2000).

Two positively charged essential nutrients called cations important to plant growth are calcium (Ca^{+}) and magnesium (Mg^{+}). Calcium is an important nutrient to the stability and functionality of plant cell walls and membranes within plant structures. Also very important to the formation of plant storage organs such as roots and fruits, calcium provides necessary building blocks for edible plant parts. Magnesium works along with phosphorus to aid a plant's metabolic processes and production of chlorophyll for photosynthesis (Spargo et al., 2012). Both magnesium and calcium are most available to plants when soil pH is in the range of 5.5 to 9.0.

Cation Exchange Capacity (CEC)

CEC is a soil's ability to hold on to positively charged essential plant nutrients (ie, K^+, Ca^+, Mg^+) and supply them to plant roots when necessary. This reserve and release process is very important to ensure healthy plant growth. Smaller particle sizes often hold onto nutrients and organic matter because of the increased surface area of the particles and have a higher CEC than soils with larger particle sizes. Sandy soils do not adhere to nutrients as well and have a lower CEC. Knowing a soil's ability to hold and supply essential plant nutrients to plant roots is very important when growing nutrient-hungry vegetable crops (Spargo et al., 2012; Marx et al., 1999).

Bulk Density

Bulk density is a measure of the weight of soil per a given volume. The more mineral matter in a sample the higher the bulk density, the more air or pore space in a sample the lower the bulk density. Bulk density is an important measure of soil compaction. When soil is too compact, plant roots have a difficult time expanding into surrounding soil and accessing available water and nutrients. Water flow and airflow is also reduced in compact soils with high bulk density (Brady and Weil, 2000).

Heavy Metal Contamination and Pollution

It is important to know the heavy metal content in soil to be aware of any contamination or pollution issues. Heavy metals such as lead are present in soils in background levels (10-45ppm) but in urban environments elevated levels are possible from many direct and indirect sources. Testing soils for metals before gardening is important information to have and can inform gardening choices (Spargo et al., 2012).

Heavy metals are metal elements which have a specific mass higher than 5g per cm^3 and have the ability to form sulfides (Duffs, 2002). They form naturally in soils by geological processes such as erosion and deposition (Li and Chunchang, 2007). In naturally formed soils, heavy metals will be found in ‘background levels’ that vary from region to region and also by soil type (EPA, 2011). Unlike other chemicals that may build up in soils due to natural or anthropogenic influences, heavy metals do not break down and can accumulate in soils, sometimes to potentially hazardous levels (van Gestel, 2008). In reference to plants, heavy metals or “trace metals” such as zinc, copper, manganese, nickel, and cobalt are necessary for growth and physiological function in small or trace amounts. Lead, cadmium, arsenic and mercury however, have no known biological function in plants and can interrupt their physiological function and growth causing harm to structures and processes within the plant (Lambers et al., 2008.)

Substances that have accumulated to levels that pose health risks to living organisms are considered contaminants. At elevated levels they are called pollutants (EPA, 2011). Contaminants can build up in soils, sediments, bodies of water, and the air. Some heavy metals are known soil contaminants in the urban environment and as mentioned previously, are often found in urban soils. Although many metals are found in urban areas, the metal of most concern commonly found in urban soils is lead (Pb). Historically used in leaded gasoline as an anti-knock agent and in exterior and interior paint, lead deposition has created a legacy of soil lead contamination though automobile exhaust and flaking paint from aged structures (Brown, 2009).

Public Health Concerns

The presence of heavy metals such as lead, arsenic and cadmium in urban environments concerns many urban residents and municipal policy makers involved in gardening and garden policy. Plant uptake of metals from soil is one way that heavy metals enter the food chain (Sipter et al., 2007). Metals can accumulate in the edible portion plants. If eaten, the plant can possibly be toxic to animals and humans. But metals are also toxic to plants interrupting physiological functions and which challenges healthy growth (Cheng et al., 2011). Understanding different routes of exposure, biological strategies organisms have developed to protect them against heavy metal toxicity, and the mobility of metals in soils and plants is crucial to understanding the risks and fates of toxic heavy metals that may be present in soils.

One important concept supported in the literature, is that certain demographics of the population are more at risk than others (Hough et al., 2004.) The age of individuals as well as the health of their immune system has a great deal to do with how a person would react to heavy metal exposure. Small children, the elderly, pregnant women, and individuals with compromised immune systems are at greatest risk (Vrščaj, 2008 and Hough et al, 2004.) Care should be taken to reduce exposure to highly impacted populations. Heavy metals present in soil, water and air affect the human population through different exposure routes: ingestion and inhalation. Because of the varying effect of metals on different population groups compounded by different exposure routes, risks to the population may be over or underestimated when one single measurement is used to calculate risk and determine safe levels (Sipter et al, 2007).

A common concern of the urban horticulturist is whether vegetables grown in contaminated soil are of any significant health risk when consumed by people. Sipter et al., found that vegetables grown on contaminated soil at a study site in Hungary do not increase the health risk for this population. Levels of heavy metals in the produce were lower than expected (Sipter et al, 2007). Cheng et al., 2011 conducted a study in New York, New York and found that eating vegetables grown on contaminated soils are of much less concern than ingestion of actual soil and/or soil particles.

Although small, there is the potential for vegetables to take up measurable amounts of some metals when grown in contaminated sites. Cadmium has been measured in homegrown garden vegetables and is a metal of concern (Chaney, 1984) when plants are consumed. Carefully choosing the types of vegetables grown on potentially contaminated ground can further reduce the potential heath risk. A few studies have demonstrated that leafy green vegetable species like lettuce, sorrel and cabbage have the highest concentrations of metals in the edible portion of the plant when compared to root vegetables and fruiting vegetables (Sipter et al, 2007, Cheng et al, 2011, Hough et al., 2004). Root vegetables whose edible potion is protected by a thick skin that can be peeled off, such as carrot, potato, and beet and fruiting crops such as tomato, squash and beans are much better choices for growing in potentially contaminated areas (Sipter et al., 2007; EPA, 2011). Thoroughly washing all vegetables and peeling any root vegetables grown in potentially contaminated soil will reduce risk even more by removing any soil particles that may be ingested (EPA, 2011).

Bioavailability

Soil is a dynamic medium with constantly fluctuating levels of nutrients, organisms, pollutants and interaction effects within the soil profile. Using static measurements, such as total concentration amounts in parts per million to determine risk, is becoming outdated (Cheng et al., 2011). The current method of assessing risk is to apply the concept of bioavailability: the amounts of a contaminant that can be taken up by an organism and in turn cause risk to that organism. Bioavailability has been defined by many (Brown, 2009; van Gestel, 2008; EPA, 2011; Cheng et al., 2011) and is now a more accepted method of calculating risk of contaminants.

Bioavailability considers the process by which a toxin travels from the place or origin, like the soil, to the place the toxin might actually cause harm, such as in a human body (Fig.3). The first step is that a toxin is released from where it is bound and becomes available to an organism such as a plant root, an earthworm or a person. Then an organism consumes the toxin by ingesting or absorbing the potentially harmful substance. When the organism ingests the toxin or the plant roots absorb water that contains the toxin, the toxin crosses a physical boundary like skin, or root channel and is considered absorbed by that organism. The toxin now resides within the organism instead of outside in the greater environment. The toxin then travels to where the toxic substance might be metabolized by the organism and it may or may not cause damage to those structures such as a stomach or liver in the case of animals or within the cells in the case of plants. The amount of toxin ingested by an organism also has an effect and will be a factor in whether or not the substance causes harm to the organism.

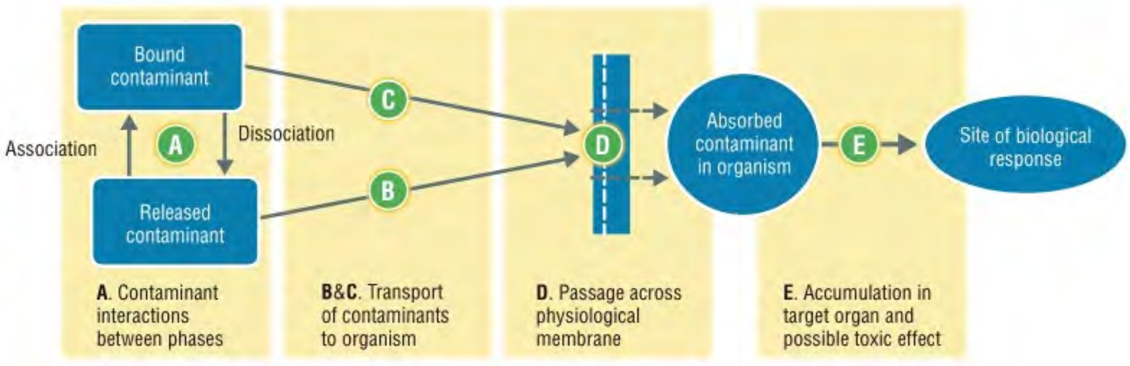

Figure 3: National Research Council diagram of bioavailability (Brown, 2009)

A few measurable soil parameters can help define the bioavailability of a contaminant or pollutant and if the contaminants will stay bound in the soil or have a greater chance of being released. The amounts of organic matter present in the soil, the percentage of clay particles, and the pH all have an effect on bioavailability (van Gestel, 2008). A study in the Netherlands found that low bioavailability of contaminants was due to high pH (very alkaline soil), high levels of organic matter and the high clay content of the soil (van Gestel, 2008). Addition of organic matter and manipulation of soil texture is one way to reduce the bioavailability of contaminants and reduce potential risk to the urban gardening community (EPA, 2011).

Studies have also indicated that it can be very difficult to predict the concentrations of nutrients and metals from one site to another and that site specific risk analysis must be done to truly determine risk to a population (van Gestel, 2008).

Current Suggestions for Safe Gardening

With the rise of urban horticulture and the interest in food gardening, suggestions for safe gardening have been made by federal, state and local agencies. The first step is to determine the health and suitability of soil by testing soil from the potential gardening location for contaminants such as lead, pH, texture, organic matter and essential nutrients. With this information, problems can be corrected and risk can be mitigated before gardens are constructed and food crops planted (EPA, 2011; City of Seattle, 2009). A second suggestion is to build raised beds and fill these beds with clean soil (EPA, 2011). But given the concerns about site lines and traffic hazards, raised beds may cause undesirable conditions when placed on the parking strip.

This study aims to undertake site-specific soil analysis to determine the appropriateness of growing food plants on the parking strip. By measuring soil parameters that effect bioavailability and using this information to present a holistic picture of the on-site soil, gardening best practices can be determined for individual sites. With a clear picture of the Seattle's urban soil, residents can use this information to make educated decisions about gardening food in the parking strip.

METHODS

Defining the Study Area

The area of Seattle included in this study was carefully defined to minimize the influences of spatial variation. Seven contiguous neighborhoods in northwestern Seattle with primarily residential development were included: Ballard, Crown Hill, Phinney Ridge, Greenwood, Greenlake, Fremont and Wallingford (Fig.4). The boundaries of the study area were defined to include all Seattle transit classes (Fig.5). Interstate I-5 defines the east boundary. The Lake Washington Ship Canal and Shilshole Bay, bodies of water, define the south boundary and west boundary. The north boundary, NW 85th Street, was naturally defined because parking strips with curbs do not exist north of NW 85th St except in very small pockets.

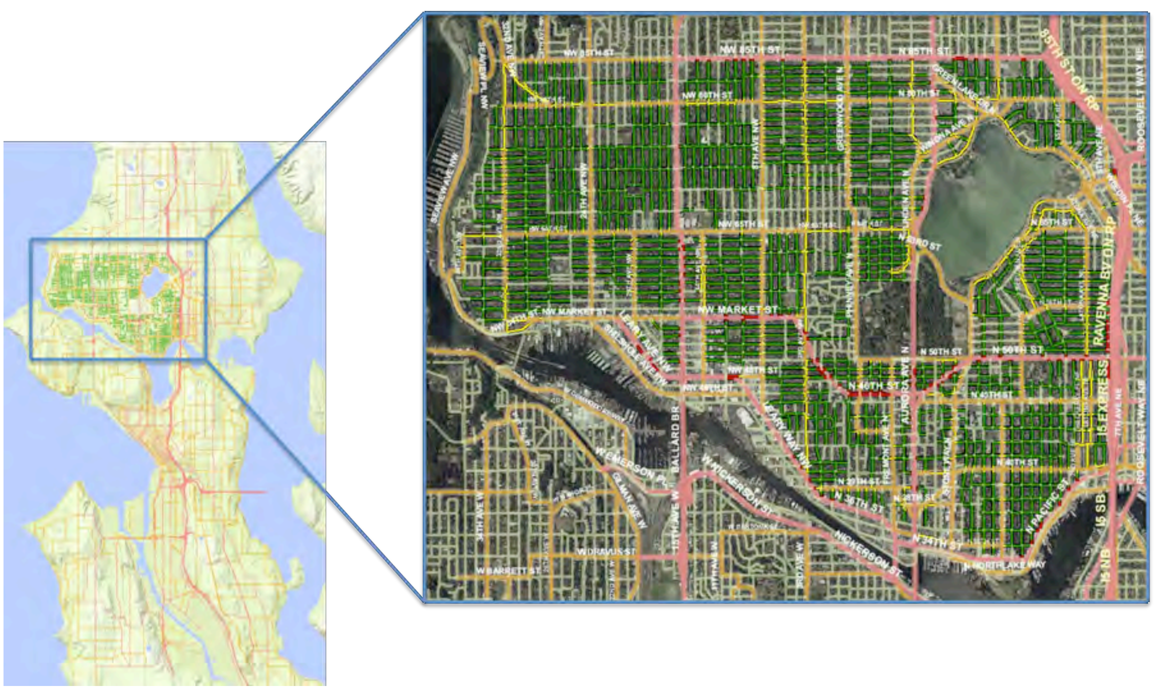

Figure 4: Area of Seattle included in study. The study area includes the neighborhoods of Ballard, Crown Hill, Phinney Ridge, Greenwood, Greenlake, Fremont and Wallingford.

Figure 5: Map of Seattle transit streets and major traffic flow.

The Sampling Population

A database of possible sampling locations was created for this study. Using digital aerial images from the Washington State Geospatial Data Archive (WAGDA) a base map of the sampling area was created and uploaded to Arch GIS, v.10.0. Street centerlines, city boundaries and traffic classes were also added as additional layers in GIS. Beginning in the northwest sector of the sampling area, each side of every street was measured and evaluated. For inclusion in the study, the following criteria were met: the parking strip must be over 5 feet wide, without continuous tree canopy cover and adjacent to residential property (Fig.6).

Figure 6: GIS survey work. Street segments highlighted in green are low traffic street segments included in the sampling population.

The digital aerial survey yielded 4,072 street segments in the total sampling population (Table 1). Once the Seattle traffic class data layer was applied in GIS, the total sampling population was stratified according to the traffic class of each street. Low traffic sites are located on residential streets with no centerlines marking the roadway. The speed limit is usually 25 mph. Medium traffic sites are located on arterials. These roads have a yellow dotted line marking the center of the roadway and are intended to move traffic through a neighborhood with a minimum amount of stoplights and stop signs. Arterials have a speed limit average of 30 mph. High traffic sites are roads with a double yellow line, or a turn lane marking the center of the roadway. There are often multiple lanes headed in each direction. There are usually many stoplights causing a 'stop-and-go' traffic pattern at peak rush hours. These roads often connect neighborhoods and run through commercial parts of town. Historic parking strip recommendations applied in commercial districts has limited the amount of available study sites. Many areas in commercial districts have been paved and do not have strips to sample. This greatly reduced the number of available high traffic study sites and explains the order of magnitude difference between the amount of low traffic sites in the population and high traffic sites in the population. Streets acting, as on-ramps leading to Highway 99, were included in the high traffic class. These streets have a higher amount of traffic than the average residential street and are important sampling points. The total sampling population consists of 2,672 low traffic sites, 1,174 medium traffic sites, and 222 high traffic sites.

Table 1:Metrics of parking strips within the sampling area

Total street segments included in the sampling population	4,072
Average width of each parking strip	2.4 m (6 ft)
Average length of each segment	77.3 m (84.6 yards)
Total length of all included parking strips	314.9 km (195.7 miles)
Total Area of parking strips within the study boundary	57.3 ha (141.6 acres)

Study Site Selection

Site selection began by using a random number generator to choose random street segments from the sampling population database. Each street segment included in the database has a corresponding unique site number, and cross street location. A list of randomly selected locations was created for use in the field to ground truth the aerial survey and choose study sites.

Once in the field, at a randomly generated location within the study area, sites were selected by finding the closest, most appropriate parking strip to the randomly chosen intersection (Fig.7). The address for the appropriate study site was recorded and the resident mailed a letter explaining the study (Fig.8). Only one house per street was selected to eliminate the risk of choosing multiple sites on a block creating pseudo-replication. Also included in the mailing: a permission form, self-addressed stamped envelope and a flyer visually defining the study area, purpose and need of the study.

Figure 7: Site Selection Field work. Parking strip in the photo on the left optimal for inclusion in the study. Parking strip in the photo to the right not optimal. Ornamental woody plants and a tree have established, potentially changing the soil structure. It also appeared as if compost and/or organic matter has been added.

When the homeowner or tenant returned the permission letter for inclusion in the study, the residence was given a site number and added as an official study site. Six rounds of site selection yielded 256 randomly selected addresses that received letters to participate in the study. A total of 39 study sites: 13 low traffic, 13 medium traffic, and 13 high traffic sites were accepted on a first-come, first-serve basis (Fig.9). The number of study sites was limited to 39 due to time and funding constraints.

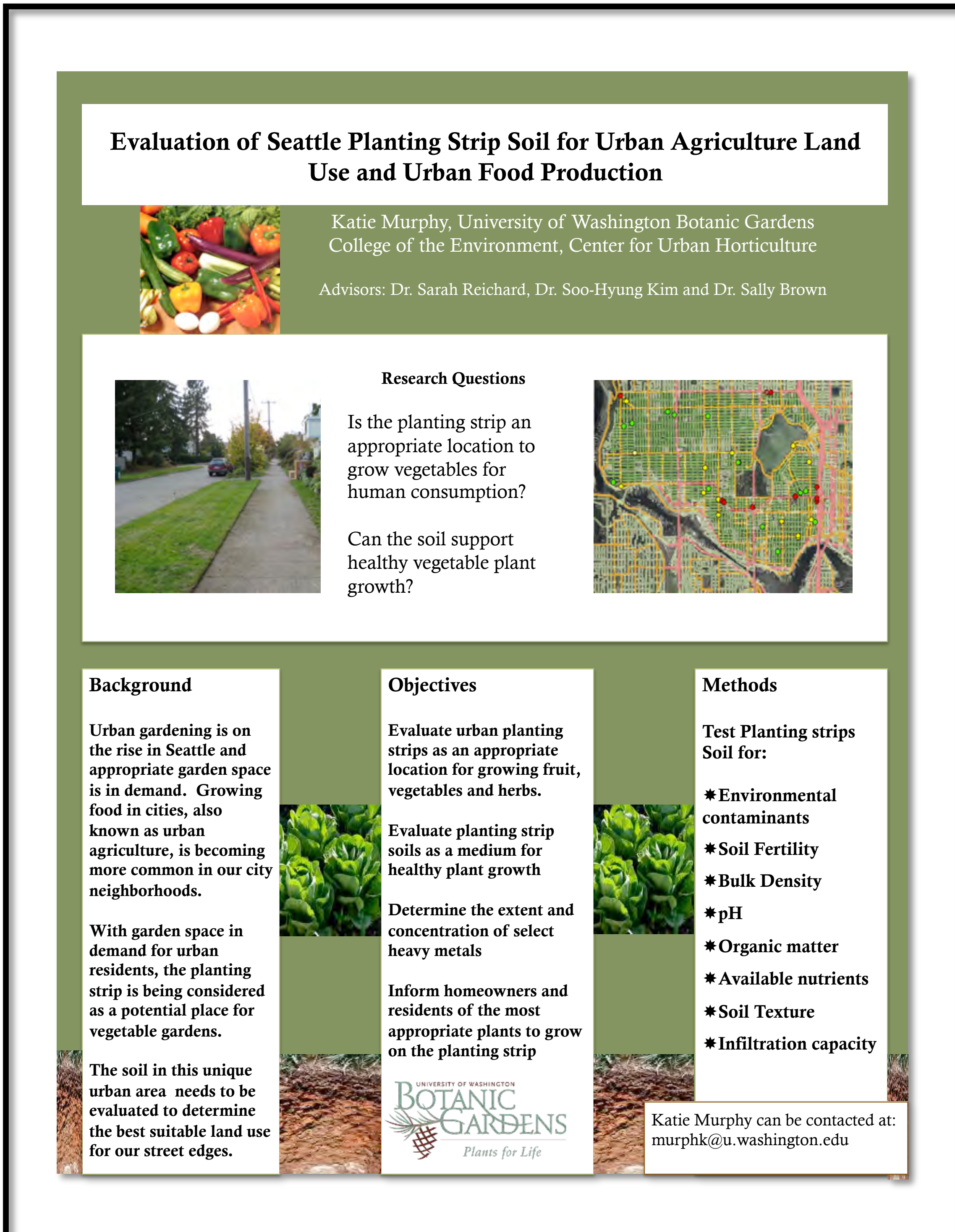

Figure 8: Flyer sent out to randomly selected addresses explaining the study.

Figure 9: Map of study sites. Green pins mark low traffic sites, yellow pins mark medium sites and red pins mark high traffic sites.

Sampling Protocol

Each parking strip was measured and photographed, briefly assessed for plant composition (ie. grass, weeds, small volunteer seedlings) and surveyed for any fungus species present. Observations were also made about mowing and horticulture practices, the existence of cars parked adjacent to the parking strip and the presence/absence of obvious pet waste. Sites #1-21 were sampled in June and July of 2010, and Sites #22-39 were sampled in September and October of 2010. Within these two distinct sampling groups, individual sites were sampled randomly.

Composite samples were taken from the parking strip and the backyard of each property (Archbold and Goldacker, 2011). By dividing the parking strip in sections parallel to the street, three sampling areas were created. Sample A was the closest to the street, sample B came from the middle of the parking strip and sample C was located closest to the sidewalk (Fig.10). Using a stainless steel soil core, five individual soil cores were taken from each sampling area. All five cores were then combined in one labeled, gallon-sized, clear plastic Zip-lock bag, to represent the soil from that sampling area. Each individual core sampled the top 15cm of soil.

Figure 10: Parking strip sampling design (left photo) and backyard sampling plot. Individual soil cores were sampled from locations marked by orange flags.

Backyard samples collected according to the same sampling protocol as parking strip samples. Two composite samples labeled sample 1 and sample 2 were taken from areas of the backyard where the residents would be most likely to plant a garden. Care was taken to avoid sampling too close to the foundation of a house, shed or garage to avoid areas that may be effected by old lead paint. If a property did not have a proper backyard, samples were taken from a large side yard as far from the house as possible. Bulk density samples were also collected from each sampling area using the Ring or Core method (Brady and Weil, 2008). All samples for each study site, 5 soil core samples and 5 bulk density samples were then stored in a labeled, flat cardboard box and returned to the lab for analysis (see below). Analysis was performed on 195 composite soil samples and 195 bulk density samples.

Laboratory Analysis

Soil samples were analyzed at two locations on the University of Washington, Seattle Campus: the Conservation Lab in Merrill Hall at the University of Washington Botanic Gardens, Center for Urban Horticulture and the University of Washington Analytical Service Center in Blodel Hall, part of the School of Environmental and Forest Sciences. All composite samples were air dried for 72 hours and then sieved with a 2mm brass sieve. Coarse organic and mineral materials larger than 2mm were set aside and placed in separate Zip-lock plastic bags. Sub-samples of the sieved soil required for different lab tests were weighed using a Sartorius BP 310S scale and a mortar and pestle if the sub-sample required grinding. Prepared sub-samples were then stored in labeled, 2x3 inch manila coin envelopes and transported to the UW Analytical Service Center.

I performed all soil texture, pH and bulk density analysis at the Center for Urban Horticulture Conservation Lab. Using a 2:1 ratio of de-ionized water to soil, pH measurements were taken with a glass electrode and an ORION pH meter, model 420A. Bulk density samples were weighed before samples were dried and after water loss. The equation of total volume of the ring/ mass of the dry mineral soil was calculated. Soil texture was evaluated by using the ribbon, or feel method (Brady and Weil, 2008).

Dongsen Xue, lab manager of the UW Analytical Service Center, analyzed samples for NO_3, NH_4, PO_4, and total metals using Inductively Coupled Argon Plasma Spectrometry (ICAP), and available nutrients and CEC by HCl extraction. All testing procedures followed EPA guidelines. Mr. Xue also assisted with testing samples for total Carbon and Nitrogen with a Perkin Elmer 2400 Series II CHNS/O Analyzer. Ground sub-samples prepared at the Conservation Lab were used for CHN analysis. Thirty-milligram samples were placed in a small aluminum tubes and weighed using a scale with a detection limit of 0.00001g. Weights were entered into the CHN analyzer and samples were digested. Percentages were then printed out, and transcribed to a spreadsheet. I calculated the C/N ratio by using the total percentage of carbon and total percentage of nitrogen obtained from CHN analysis and diving carbon by nitrogen to equate the ratio. Using the total percentage of carbon and multiplying those numbers by 1.74 calculated the percentage of soil Organic Matter.

Data Storage and Management

Data was stored and managed using Microsoft Excel, 2008. Information transcribed from field collection sheets and information gathered from lab analysis was organized by study site and by traffic class.

Data analysis

There are many published methods to evaluate soil quality. The general ideology is based on: defining the soil properties used in the analysis, determining the indicator weight of how important the factor is to the overall picture of soil health, and matching this report to a certain soil function such as preventing erosion or growing food. Brady and Weil, 2000, among others, have developed a variety of ways to examine soil quality. For this study, a method that could examine a variety of soils for a variety of purposes and match soil to an appropriate land use was selected. The aim of this method is one of conservation and preserving soil resources. The idea is to preserve existing ‘good’ soils and use them for activities such as growing vegetables which require such soil, and identify poor soils to be assigned to land uses that require a lower soil quality, such as an area slated to become a building site (Vrščaj et al., 2008).

Soil Health Analysis Using the Vrščaj Method

Soil health was analyzed using the methods and equations developed by Vrščaj, et al. (2008). Measurable soil quality indicators (SQI) important to urban agriculture were selected first. A range of values 1-5, for each soil quality indicator were defined and complied in a reference table (Table 2 and Table 3). In urban agriculture, high values of 4 or 5 are required for all soil quality indicators to meet many physiologic and environmental requirements for healthy vegetable plant growth. Field data complied from laboratory analysis was compared to the reference chart and quality class (QC) values were assigned for each SQI for all parking strip study sites.

The second step of this process is to calculate the soil quality for urban agriculture to see if what has been measured from the parking strip soil matches what is required.

$$QD = (QC_{identified} - QC_{required})$$

This equation yields a soil quality difference (QD) revealing to what extent the individual soil quality indicators meet the required criteria for urban agriculture land use. The value and magnitude of the QD values indicate how the soil quality indicators differ from what is required.

Table 2: Reference Table for Soil Quality Indicators and Quality Class Values

Soil Quality Indicator	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Soil Texture (3)	Clay, Sand	Loamy sand, sandy clay	Sandy loam, loam silt, silty clay	Silt loam, silty clay loam, sandy clay loam	Loam, clay loam, silt loam
C/N Ratio (2)	4 or 18	6 or 17	8 or 15	10 or 14	12
CEC (2)	0-5	6-10	11-15	16-20	21-25
Bulk density (2) in g/cm^3 **(3)**	>1.7	1.61 to 1.7	1.51 to 1.61	1.41 to 1.5	Less than 50% mineral matter = < 1.4
Soil pH (3)	Very strong acidity (pH <4.5) or very strong alkakinity (pH > 9.5)	Strong acidity (pH 4.5 to 5.0) or strong alkalinity (pH 8.5 to 9.5)	Moderate acidity (pH 5.0 to 5.5) or moderate alkalinity (pH 6.0 to 7.0)	Slight acidity (pH 5.5 to 6.0) or neutral (pH 7-7.5)	pH 6.0 to 7.0 slightly acid to neutral
Soil Organic Matter (3)	Very low/ mineral soil (OM < 1%)	Low (OM 1-2%)	Low to Medium (OM 2-4%)	Medium (OM 4-6%)	High (OM > 6%)
Nutrients* (2)	Low		Medium		High

* See table 3

Table 3: Oregon State University Soil Testing Guide nutrient recommendations for soils west of the Cascades

	Low	Medium	High
Phosphorus (P)	< 20	20-40	40-100
Potassium (K)	<150	150-250	250-800
Calcium	<1000	1000-2000	>2000
Magnesium	< 60	60-80	>180

Values identified after the equation are then compared to the following classification as defined by Vrščaj et al, 2008.

- $-1 > QD \geq -4$: the soil quality is lower than required
- $-1 \approx QD$: the quality is slightly below that required, soil remediation measures should be carried out to improve the evaluated soil property
- When QD is << 1 (eg., it is close to -4) the quality is well below that required. A different land use other than urban agriculture should be considered
- $QD \approx 1$: the evaluated quality of the soil indicators matches that required for urban agriculture
- $1 < QD \leq 4$: the evaluated indicator quality exceeds that required; the quality is better than needed

The information gained from this evaluation will uncover which soil quality indicators align with urban agriculture land use and which indicators may present challenges to this land use designation. This method can isolate problematic conditions that could be corrected through proper horticultural practices.

Once individual soil quality indicators are evaluated, an overall index of soil quality (ISQ) for every study site can be calculated.

$$\mathrm{ISQ} = \sum_{i=1}^{n} \frac{[\mathrm{QD}_i * (\mathrm{IW}_i/2)]}{6n}$$

ISQ= Index of Soil Quality
QD_i = the deviation of soil quality expressed in classes for each individual soil quality indicator
IW_i= the SQI weight for each individual i
2 is a factor to normalize the IW_i values
6 is a factor used to distribute the output ISQ values in a range from -1 to 1
n= amount of SQI considered in the equation (Vrščaj, 2008)

N=39

The ISQ is a single-value index of soil quality acting as a 'report card' for current soil conditions. Through this one value, numerical representation can be evaluated for urban agriculture land use on Seattle parking strip soils. Calibrated to values between -1 and 1, the ISQ can be interpreted as follows:

ISQ < 0 : The soil quality is low or unsatisfactory

- When ISQ is a little below zero, the soil marginally deviates from what is required.
- When the ISQ value is ≈ -0.5, the soil quality is considered unsatisfactory. Soil remediation is recommended.
- When the ISQ value is below -0.5 or approaching -1, the soil is not suitable for the selected land use and remediation measures are needed. If

remediation is not feasible a less demanding soil quality land use should be considered for the area

ISQ > 0 : The soil quality exceeds the requirements for the evaluated land use

- ISQ = 0: the SQ marginally exceeds the required quality
- ISQ = 0.5: land use with higher soil quality requirements should be considered
- ISQ = 1: the soil is “too good”. The evaluated/ planned land use would be considered wasteful for this particular soil type (See page 58)

After calculating the ISQ for each individual parking strip, all ISQ values were combined to find mean values to represent the entire parking strip sampling population.

Statistical Analysis

Data for metals concentrations and general traffic effect on the parking strip were analyzed using Sigma Plot v.12.0. Non-parametric statistics were used. Data did not normalize and meet the required assumptions for parametric ANOVA analysis. ANOVAs by Ranks were used to find statistical significance and patterns in the data for: low, medium and high traffic class comparisons and sample A, sample B and sample C comparisons. Rank sum tests were used to determine the differences between parking strip samples and backyard samples. Data were not transformed but kept in mg kg^{-1} units to reflect numbers received in an average soil test. All graphs were created using Sigma Plot v.12.0.

RESULTS

A summary of all parking strip samples (Table 4) reveal soil that is moderately acidic with an average pH of 5.36 and a sandy or silty loam texture. The measured CEC (11.29) is common for silt and sandy loam soils. For mineral surface soil, it has a relatively high percentage of organic matter (7%) and a carbon to nitrogen ratio that is common of a highly cultivated soil (14). It is not heavily compacted and is less than 50% mineral matter by volume (1.05g/cm^3). Nitrogen available as both NO_3^- (22ppm) and NH_4^+ (14.5) is available in adequate levels. Other nutrients are low in quantities optimal for vegetable plant growth: Mg (120), Ca (1192), and K (80). Phosphate levels are low (63.5) (Brady and Weil, 2000).

Parking Strip Soil Health

Evaluation of individual soil measurements, or soil quality indicators (SQI) at all parking strip sites, derived from equation 1:

$$QD= (QC_{\text{identified}} - QC_{\text{required}})$$

yields soil that has many individual soil measurements below what is required for urban horticulture and urban food production (Table 5). Almost all SQI reveal slight deficiencies to support healthy vegetable plant growth: nutrients (-0.1795), soil organic matter (-0.2564), soil texture (-0.4359), C/N ratio (-0.3864), CEC (-1.1538), and soil pH (-0.6579). The value for CEC (-1.1538) being greater than -1 indicates that this one soil factor needs to be addressed or another land use should be considered. Bulk density was the only SQI that was adequate for urban food production land use (Fig.11).

Table 4: Minimum, Mean and Maximum values for parking strip samples

	Minimum	Mean	Maximum
Nutrients			
Mg	88.16	120.3858	326.3664
Ca	119	1192	2338
K	TR	80.6094	263.2883
PO4	15.6600	63.7725	102.4
NO3	0.2600	22.2043	133.0000
NH4	3.21	14.5299	73.0000
Soil Organic Matter	3.742	7.78503	16.5793
Soil Texture	---	sandy loam, silty loam	---
C/N Ratio	9.9178	14.5959	17.2300
CEC	6.2	11.2959	17.79
Bulk Density	0.6454	1.045739	1.52
Soil pH	4.112	5.3585	6.353

Table 5: Results of Equation 1 determining average overall soil health by individual soil quality indicator (SQI)

Soil Quality Indicator	Quality Class Required	Quality Class Identified	Quality Class Difference
Nutrients	4	1.718	-2.282
Soil Organic Matter	5	4.7435	-0.2564
Soil Texture	4	3.5897	-0.4359
C/N Ratio	4	3.6154	-0.3846
CEC	4	2.8462	-1.1538
Bulk Density	4	4.7436	0.7368
Soil pH	4	3.307	-0.6579

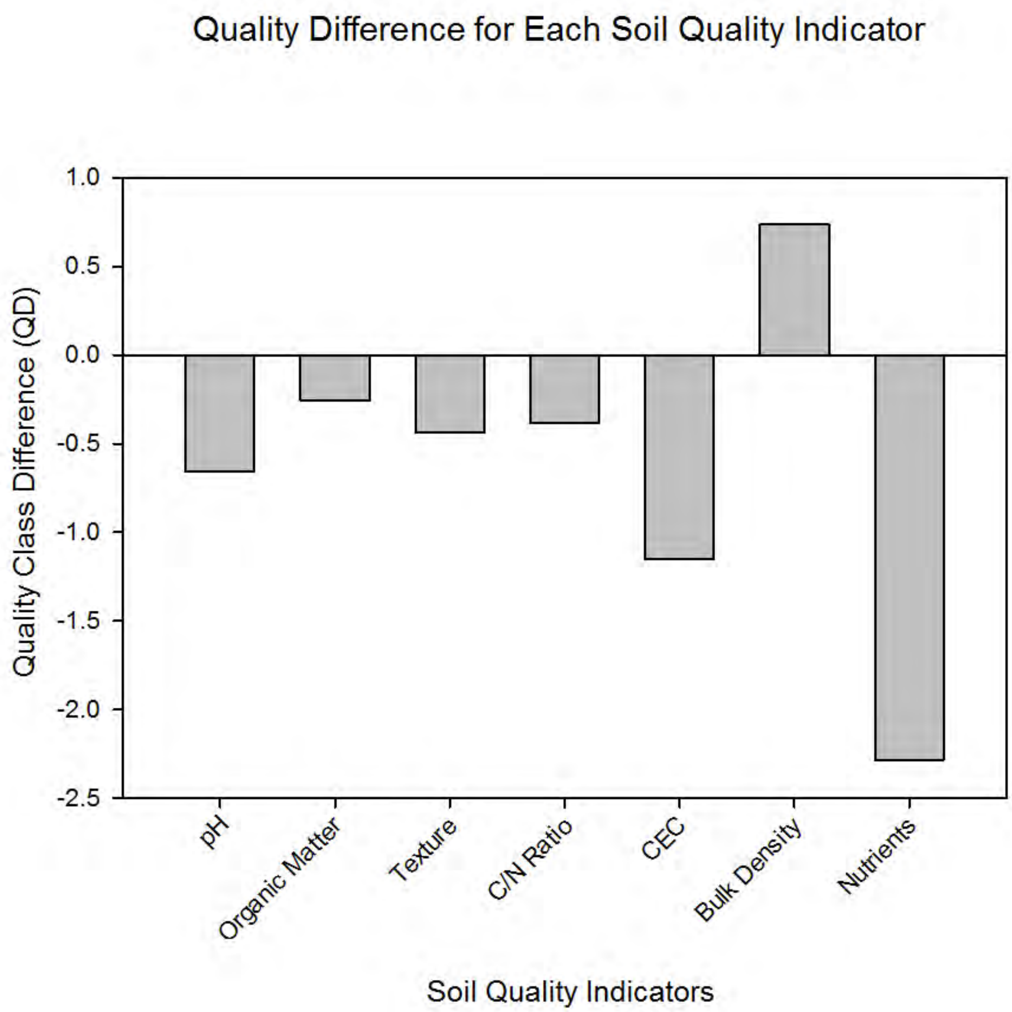

Figure 11: Graph representing each SQI as defined for urban agriculture land use. Values equal to 0 indicate the SQI matches the indicated land use, values less than 0 indicate deficiencies for that SQI, values greater than 0 indicate adequate or excessive levels of an SQI as defined for a specific land use.

The average index of soil quality (ISQ) for all parking strips derived from equation 2:

$$ISQ = \sum_{i=1}^{n} \frac{[QD_i * (IW_i/2)]}{6n}$$

indicates that overall, parking strip soil marginally deviates from what is ideal for urban agriculture. The ISQ average for all sites is -0.1236, slightly below what is required but not such a low index to require soil remediation or an alternative land use (Table 6). The four soil quality indicators with the greatest negative impact on the overall ISQ are CEC (-0.0275), soil pH (-0.0256) available nutrients (-0.0543), and soil texture (-0.0156). Soil organic matter (-0.0092), C/N ratio (-0.0092) also contributes to the negative ISQ. The SQI with the greatest positive impact on overall ISQ is bulk density (0.0177) (Figure 12).

Table 6: Results of Equation 2 determining Index of Soil Quality average for all parking strips sampled

Soil Quality Indicator	**Indicator Weight**	**Quality Class Difference**	**Index of Soil Quality**
Nutrients	2	-2.2821	-0.0543
Soil Organic Matter	3	-0.2564	-0.0092
Soil Texture	3	-0.4359	-0.0156
C/N Ratio	2	-0.3846	-0.0092
CEC	2	-1.1538	-0.0275
Bulk Density	2	0.7368	0.0177
Soil pH	3	-0.6579	-0.0256
ISQ for Parking Strip Soil			**-0.1236**

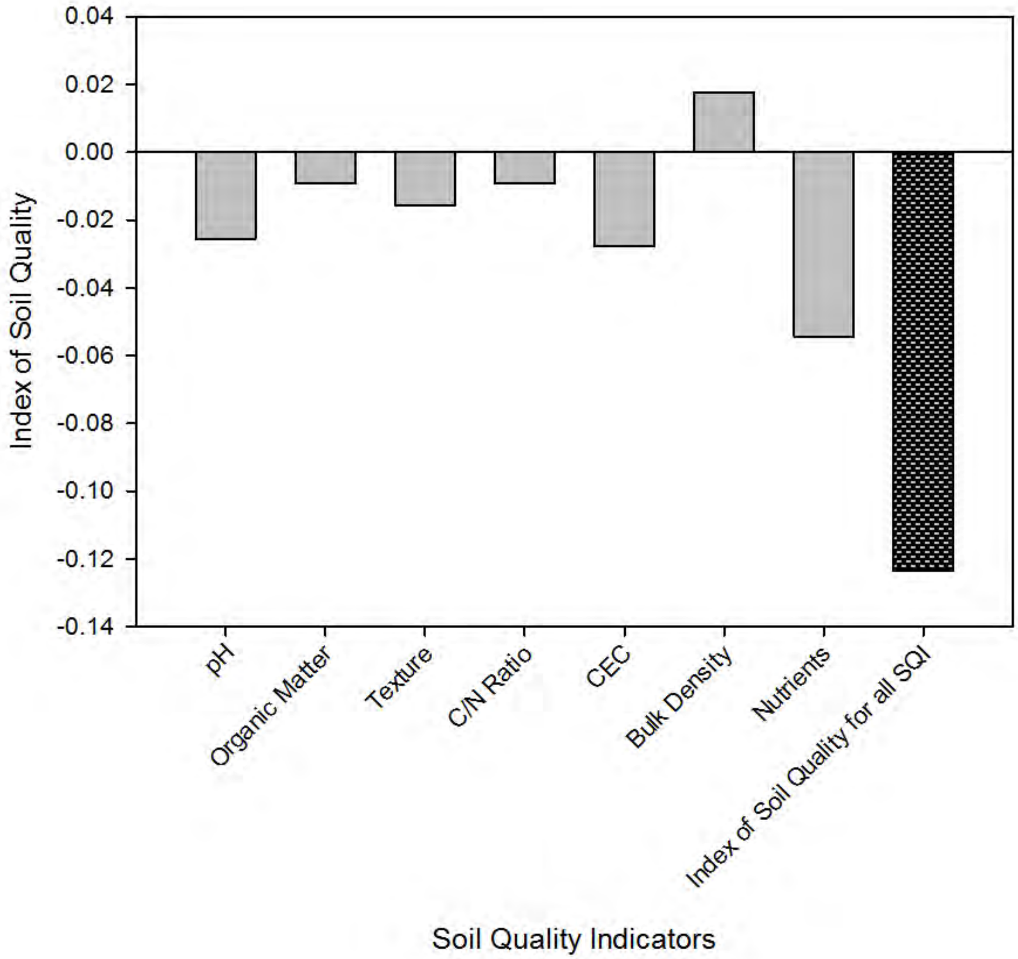

Figure 12: Graph representing Index of Soil Quality as a summation of all SQI.

Patterns of Lead Concentrations in Soil

Parking strip soil samples revel a range of soil lead concentrations that have a non-normal distribution. Samples from parking strip section A, taken closest to the street, have a minimum lead concentration of 51.85ppm, a maximum concentration of 1616.0ppm, and a median concentration of 205.8ppm. Samples from parking strip section B, taken in the middle of the parking strip, have a minimum lead concentration of 44.18ppm, a maximum concentration of 538.2ppm, and a median concentration of 159.7ppm. Samples from parking strip section C, next to the sidewalk have a minimum lead concentration of 44.62ppm, a maximum concentration of 508.5ppm, and a median concentration of 144.3ppm. To obtain a single number to represent parking strip lead concentrations by study site, a mean value was calculated by combining sample A, sample B, and sample C lead concentrations. Parking strip concentrations have a minimum lead concentration of 49.01ppm, a maximum concentration of 863.33ppm, and a median concentration of 180.0ppm. Backyard samples have a minimum lead concentration of 47.87ppm, a maximum concentration of 580.1ppm and a median value of 166.4ppm.

Comparison of Traffic Classes

A one-way ANOVA by ranks determined a statistically significant result ($P=<0.001$) between low, medium and high traffic classes (Table 7). A Tukey test reveals that there is a significant difference ($P<0.05$) in lead concentrations between groups low and medium, low and high, but not between medium and high (Fig.13).

Table 7: ANOVA Summary statistics for comparison low, medium and high traffic classes

Group	N	25%	Median	75%
Low	13	84.833	111.430	142.215
Medium	13	246.515	264.000	313.165
High	13	128.435	203.600	290.950

H = 17.11 with 2 degrees of freedom (P=<0.001)

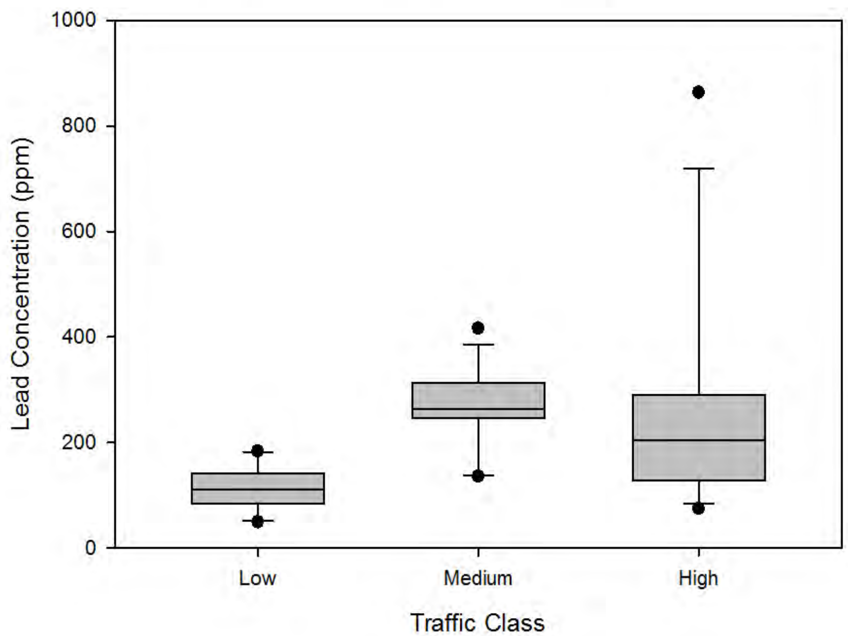

Figure 13: Comparison of lead concentrations in soil by traffic class.

Parking Strip vs. Backyard Lead Levels

A rank sum test comparing average lead levels from parking strips and from backyards revealed a non-significant result (P=0.379) (Table 8). There seem to be no significant differences between the mean level of parking strip samples (Median=180.700) and backyard samples (Median=166.350) (Fig.14).

Table 8: Rank sum test summary statistics for parking strip vs. backyard samples.

Group	**N**	**Median**	**25%**	**75%**
Parking Strip	39	180.000	113.430	264.000
Backyard	39	166.350	126.530	206.900

T = 1629.000, (P = 0.379)

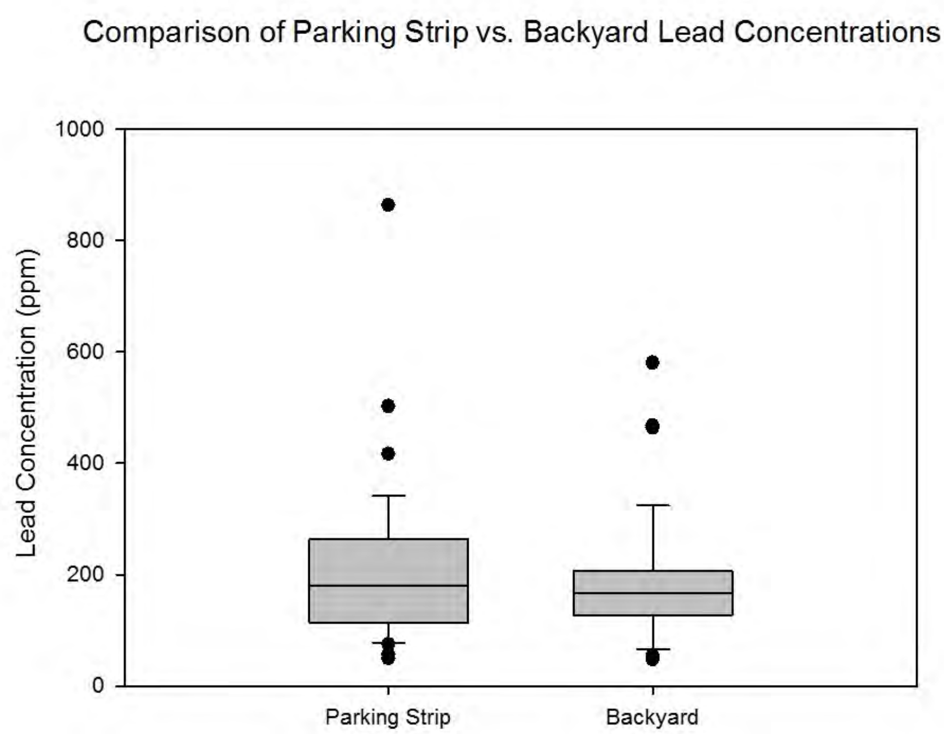

Figure 14: Comparison of parking strip soil to backyard soil for lead concentrations.

Parking Strip vs. Backyard Lead Levels by Traffic Class

Individual t-tests indicate some differences between parking strip soils and backyard soils by traffic class (Table 9). Low traffic sites did not have a significant difference (P=0.496) between the parking strip and the backyard, medium traffic sites did have a significant difference (P=0.046) and high traffic sites did not (P=0.878) (Fig.15).

Low traffic lead concentrations were distributed in a normal bell shaped curve, passing the normality test required for many statistical tests. Medium and high comparisons did not pass normality tests due to some outliers in the data set. Outliers included in the data set seem to affect the normality of the data, but outliers were included to represent all values from the data set.

Table 9: T-Test summary statistics for parking strip vs. backyard lead concentrations

Low Traffic	**N**	**Mean**	**Std. Deviation**		**P Value**
Parking Strip	13	115.848	41.468		P=0.496
Backyard	13	116.005	43.720		
Medium Traffic	**N**	**Median**	**25%**	**75%**	
Parking Strip	13	264.000	246.515	313.165	P=0.046
Backyard	13	178.900	162.250	237.850	
High Traffic	**N**	**Median**	**25%**	**75%**	
Parking Strip	13	203.600	128.435	290.950	P=0.878
Backyard	13	199.500	138.500	301.450	

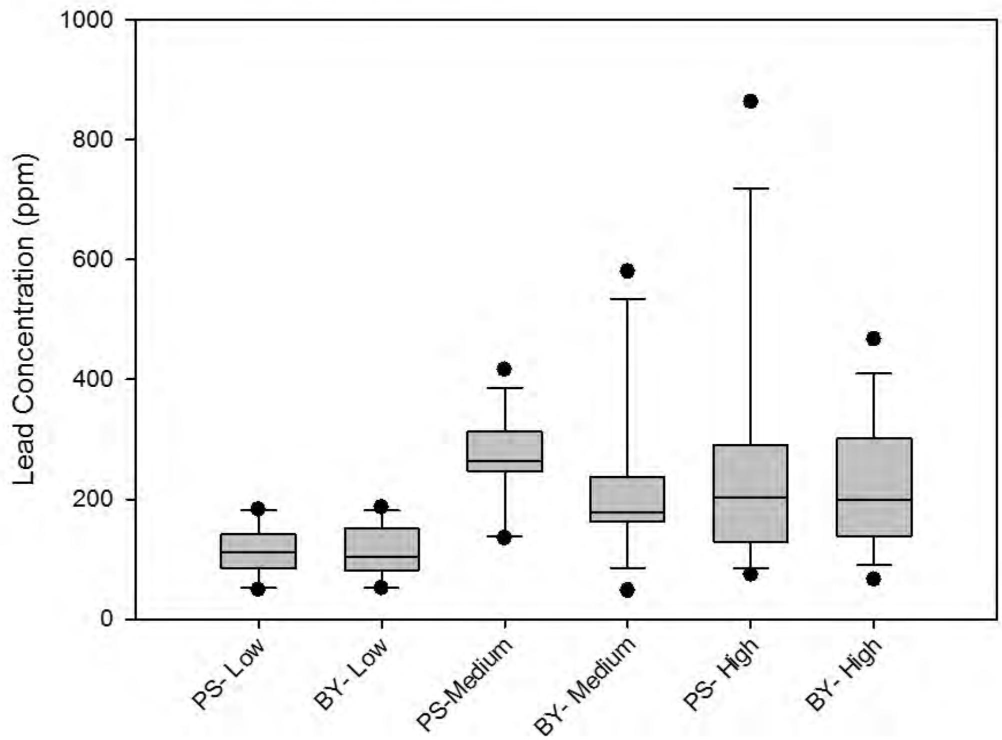

Figure 15: Comparison of Parking Strip Soil to Backyard Soil by Traffic Class. PS = Parking Strip samples and BY = backyard samples.

Lead Concentration as a Function of the Distance from the Street

The parking strip was divided into three distinct sampling areas parallel to the street. When compared to each other a gradient from the street developed (Table 10). Although not significant by alpha=0.05, there is a trend in the data suggesting lead levels drop as distance from the street increases (Fig.16). A one-way AVOVA by ranks uncovered a trend in the data (P=0.118).

Table 10: ANOVA Summary Statistics for comparison of Sample A , Sample B and Sample C lead concentrations.

Group	N	Median	25%	75%
A	39	205.800	112.300	389.900
B	39	159.700	103.500	225.400
C	39	144.300	115.200	233.700

H = 4272 with 2 degrees of freedom (P=0.118)

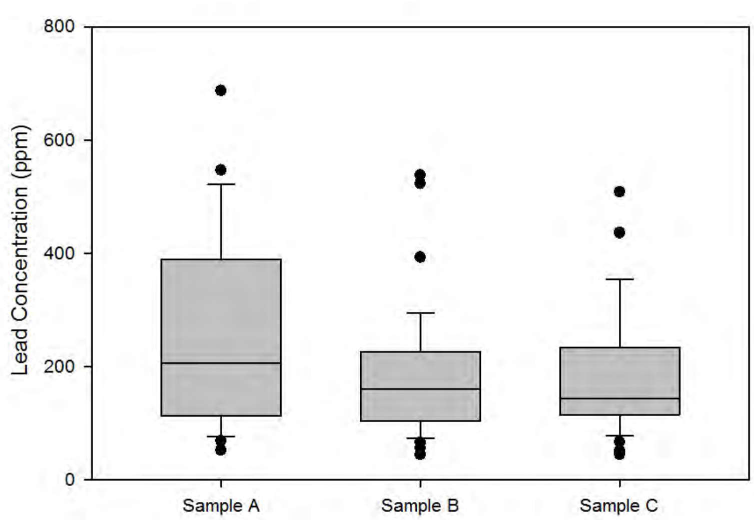

Figure 16: Comparison of parking strip sampling areas A, B, and C. A is closest to the street, B is in the middle of the strip and C is closest to the sidewalk.

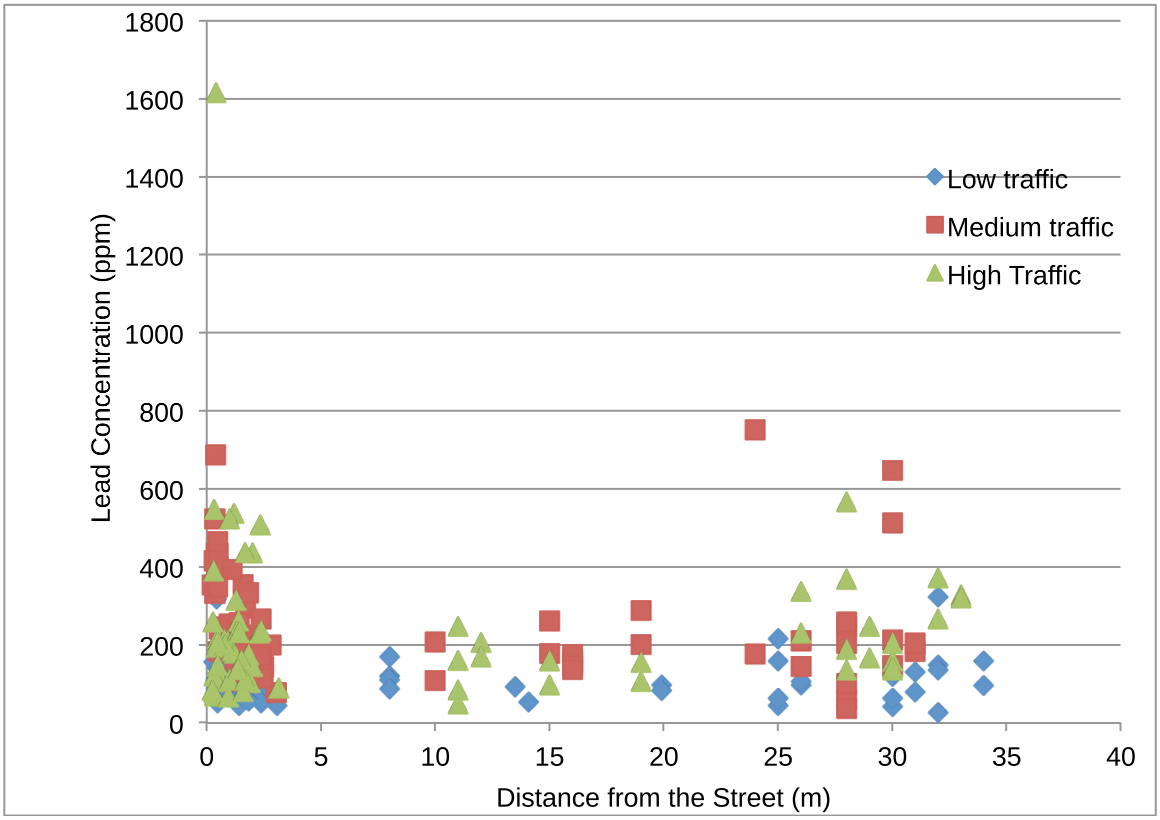

Figure 17: Scatter plot displaying individual data points for parking strip samples and backyard samples. All values <4m are parking strip values. Lot size of properties included in the study were variable so many different distances were plotted.

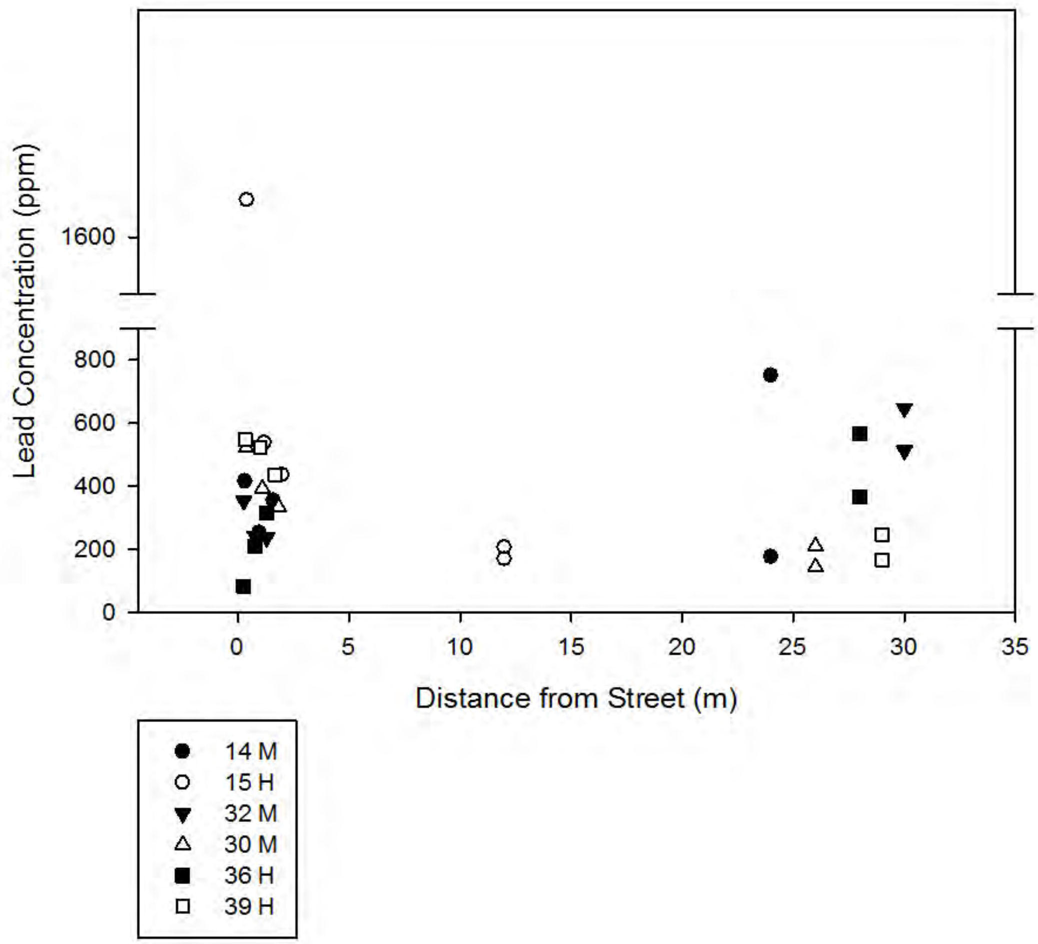

Figure 18: Scatter plot of samples taken from study sites with average parking strip or backyard lead levels measured over the EPA limit of 400ppm. Data uncovers 'hot spots' rather than high or low ambient levels for a samples of a study site.

DISCUSSION

Suitability of Parking Strips for Urban Horticulture Food Production

Evaluated parking strips reveal an area that has workable soil but shows deficiencies in a few key soil quality indicators to support healthy vegetable plant growth.

The soil quality evaluation method applied in this study adds an Indicator Weight (IW) to each soil quality indicator on a scale of 1 to 3. This indicator weight applies a greater or lesser value to each measurable parameter in the final equation that determines the Index of Soil Quality. Soil quality indicators with a weight of 3 are: Soil texture, pH, and soil organic matter. These three SQI have great influences on vegetable plant growth. They affect many soil functional qualities such as retaining water, allowing air and oxygen flow to plant roots, and releasing and retaining nutrients in the rooting zone. Soil texture and pH are fairly stable basic soil qualities that require inputs to change or modify. Soil quality indicators with a weight of 2 are: C/N Ratio, CEC, bulk density and nutrients. While still important soil qualities, they are of less overall influence to the Index of Soil Quality because these factors are easier to change or modify with additions of compost, informed gardening practices and careful soil treatment.

The two most common soil textures identified in this study are sandy loam and silty loam. The small percentages of clay in the samples suggest a lack of the soil's ability to hold water and retain nutrients. Only additions of mineral material such as sand or clay will change soil texture. This would require a great amount of tilling and digging to incorporate new mineral matter at rates that would change the overall soil texture. High levels of mechanical inputs often damage to existing soil structure, destroy root channels that help oxygen flow to roots and may even cause soil compaction once soil settles after watering. Compost and organic matter can be added to help change overall soil structure but it does not change soil's innate mineral composition or soil texture.

Soils in the Pacific Northwest are commonly acidic with pH in the range of 5.5-6.5. The pH of parking strip soils is consistent with soils of the region and has been affected by the same environmental influences of high rainfall and moderate temperatures. While not an extreme pH, acidic soils do influence what nutrients are available to plants. Many vegetable plant species require a pH of 6.5 to 7.5 to access adequate amounts of phosphorus and potassium. If these nutrients are tied up because of acid soil, plant growth will be negatively affected (Lambers et al., 2008). Liming soil and raising the pH to a range better suited for vegetable growth would be recommended. Raising the pH is also one way to immobilize heavy metals such as lead (Brown, 2009).

Soil organic matter is adequate in parking strip soil. Most of the vegetation surveyed on parking strips was grass and weed species. As grass dies annually, many of the roots die as well. As these roots break down they add organic matter to the soil and contribute to the organic matter available to plant roots (Cook and Ervin, 2010). Organic matter does decompose, especially once soil is tilled and cultivated. Organic matter is adequate in soils currently planted in grass and weedy species but should be added to soils cultivated for any other land use type, including vegetable gardens.

The identified carbon to nitrogen ratio is common of most grasslands and cultivated soils (Brady and Weil, 2000). This suggests an appropriate ratio of woody organic matter (carbon) to green leaf litter (nitrogen) in the soil. Any additions made to the soil should have a C/N ratio of 12:1 to maintain this balance (Brady and Weil, 2000) and not encourage any microorganism blooms that occur when composts too high in nitrogen are applied to soils.

The Cation Exchange Capacity (CEC) of parking strip soils of 11.29 $cmol_c$/kg is fairly common for sandy loam and silty loam soils. CEC can also be effected by pH: the lower the pH, the lower the CEC. Increases in soil pH will increase the CEC of soil, depending on the source of CEC. Mineral soils have about half the CEC coming from permanent charges and the other half coming from pH dependent charges. Organic soils have about 25% of the CEC from permanent charges and 75% of the CEC from pH dependent charges. Additions of organic matter will also increase the CEC. Organic matter such as finished compost and leaf litter often has a CEC of 50. By adding organic matter to the planting area, CEC will be improved and in a range adequate for vegetable gardens (Bray and Weil, 2000).

Bulk density was low and adequate for vegetable gardens. One common belief is that bulk density is high in urban areas along roads, sidewalks and areas impacted by pedestrian traffic creating compacted soil. This may be true for old parking lots and some areas with high amounts of pedestrian traffic, but the parking strips sampled for this study seem rather unaffected by compaction. In some cases, bulk density samples taken from Sampling Area A, closest to the street, showed signs of compaction most likely caused by people entering and exiting parked cars. But a more detailed study would have to be designed to investigate this pattern. As lawns develop thatch when grasses die seasonally, the roots contribute to soils with lower bulk density and a fluffier overall structure. Most strips sampled were covered in vegetation. The two strips that had patches of exposed dirt demonstrated the highest bulk densities and most compacted soils.

Nutrients were generally low in parking strips. Amounts of nitrates (NO_3^-) and ammonia (NH_4^+) suggested that parking strips are fertilized (Marx et al.,1999). Field surveys and observations support this. Phosphorus and potassium are low. Without further additions, vegetable plant growth would suffer and yields would be low (Marx et al, 1999). Calcium and magnesium are in moderate amounts suggesting that these nutrients would only have to be added sparingly. But without adequate amounts of macronutrients the moderate amounts of calcium and magnesium would have negligible positive effect on plant growth and development.

The average Index of Soil Quality for parking strip soils is -0.1236. This slightly negative score suggests that the soil deviates slightly from what is required for urban agriculture land use and food production (Vrščaj et al., 2008) but not enough to completely disregard food production as a viable horticulture practice. Vegetable species do require prime soil conditions with the highest quality classes of all potential land uses. Quality classes required for vegetable gardens are all in the 4-5 range, the values at the high end of the scale. It is almost impossible to find a soil that is ‘too good’ for urban agriculture land use.

Certain soil quality indicators can be influenced to bring the SQI closer to zero indicating a good match between soil and land use. Additions of compost, decomposed plant material, or bio-solids, composted municipal soils waste, would add vital nutrients, increase the CEC and improve the water holding capacity of sandy soils. Additions of lime would adjust the pH and improve the CEC to be in the range necessary for most vegetable plant species.

Comparison of Lead Concentrations for Low, Medium and High Traffic Classes

Comparison of samples from low traffic residential streets (N=13), medium traffic single lane arterials (N=13), and high traffic multi-lane arterials (N=13) revealed some statistically significant results between traffic classes. Parking strips on low traffic residential streets had significantly lower levels of lead than parking strips located on medium traffic or high traffic classified streets. Low traffic sites had a median lead level of 111.430 ppm. Medium traffic sites had the highest median levels of lead at 264.000 ppm. High traffic sites had a median level of 203.600 ppm. Medium traffic sites and high traffic sites were not statistically different from each other. One major difference between low traffic and medium and high traffic classes other than the amount of cars driving down the street is speed limit. Studies have shown that lead levels are higher along roads with greater speed limits where cars accelerate (Shinn et al, 2000; Chaney, 1984). Residential streets have a speed limit of 25 mph. Arterials and multi-lane arterials have a speed limit of 30-35 mph. The higher level of lead found in medium traffic class roads may be attributed to the sustained speed limit along arterial streets. Because they were designed to move traffic around the city, single lane arterials often have fewer stop signs and stop lights allowing traffic to travel at sustained higher speeds.

This data set included all data points and outliers. The highest measured level of lead was located on what is historically known as the Ballard-Greenlake Highway, now known as NW Market Street. This very busy thoroughfare is a well-travelled road that connects N 46th Street in Freemont to NW Market Street in Ballard. A site included in the high traffic class is on this road. The house was built in 1906 and was moved to make room for the highway. It is situated near the top of the hill on a curve on the west side of the street. Cars accelerate to make it up the hill and round the curve. The speed limit on this stretch is 35mph. Levels of lead were measured at 863.330 ppm, the highest in the dataset and twice the recommended level of lead deemed safe for gardening by the US EPA (see page 62). These numbers are consistent with high speed limits and acceleration attributing to higher levels of lead. Due to the historic nature of this property, the age of the house, and the fact that it was moved to make room for the road, old lead paint could also have contributed to the high levels of lead on the soil.

It is important to note that lead found in soil samples is likely due to legacy pollution. Leaded gasoline was outlawed in 1972 and from then on not a component of automobile emissions. It is also unlikely that traffic patterns on Seattle city streets today are exactly the same as they were from 1930-1970, the decades when cars were fueled by leaded gas. It is also still possible that old lead paint can flake from buildings and structures contaminating soil, but all new paint on the market today does not contain lead.

Comparison of Parking Strip vs. Backyard Lead Concentrations

It has been assumed that parking strip soils are more contaminated than backyard soils. Comparison of all parking strip samples (N=39) and backyard samples (N=39) revealed that parking strip lead concentrations are not statistically different from backyard lead concentrations (P=0.379). Median lead levels for all parking strips are 180.000 ppm and median concentrations for backyard levels are 166.3500 ppm. Sources for lead contamination come not just from legacy automobile emissions, but also from lead paint that has flaked into soil (EPA, 2011). Although care was taken to sample away from houses, garages and other outbuildings, it is possible that there has been some legacy contamination from structures. It is important to sample soil anywhere a vegetable garden is to be constructed.

When considering all samples from parking strips and backyards (N=78), lead levels generally do tend to drop as distance form the street increases on the street side of a property. But lead levels can be much higher around houses, in side yards and in backyards then they are on the street (Fig.17). Outliers in the scatter plot, reveal blocks in the study area that have back alleys accessible by cars driving to garages, carports or parking places. This access to backyards from the alley may have contributed to some of the higher backyard lead levels, especially for older properties.

Often the site history of a property is unknown. Outbuildings such as sheds that once stood in a backyard may have been removed. Pesticides that contained lead and other metals may have been applied to garden areas to treat pest problems. Unknown site history and the persistence of lead in the soil is another reason to test the soil anywhere a vegetable garden is proposed. As urban residential properties change hands information about how the property was used in the past is often lost.

It is common to find hot spots of contamination in a given area. For a variety of reasons, lead contamination can be higher in one part of a property than another. For study sites that have lead concentrations over the EPA limit of 400ppm (Fig.18) high levels of lead are found on the parking strip or in the backyard, but not all over the property. Two backyard samples often revel one sample that is over the EPA limit and another sample taken from the same backyard that is under the limit. It is uncommon to find a property that has elevated levels of lead all over the site. Properties that demonstrate high ambient levels for samples taken in a variety of places may have been affected by atmospheric deposition from industrial activity such as a smelter or coal plant.

The area included in this study is adjacent to Gasworks Park, an industrial operation that once turned coal into gasoline (Seattle Parks and Recreation, 2012). Now closed and no longer acting as an industrial site, but functioning as a city park on the shores of Lake Union, Gasworks is no longer contributing to lead pollution to the area. Like leaded gasoline that has been banned, emissions from Gasworks could be a source of legacy pollution in northwest Seattle. Medium and high traffic classes did show a statistically significant elevated level of lead in soil sampled. Although randomly chosen, many study sites included in this study are located in the southeast sector of the sampling area (see fig.9). The proximity to Gasworks Park may be one reason for the elevated levels of lead in these samples. A more specific investigation would have to be designed to investigate this possibility.

Comparison of Sampling Areas Within the Parking Strip

Sampling of the parking strip was designed to detect any differences in lead concentrations between areas of the parking strip: sample A next to the street (N=39), sample B in the middle of the strip (N=39), or sample C next to the sidewalk (N=39). The aim was to detect any differences between median levels of lead as the distance from the street increased. Although not statistically significant there is a strong pattern in lead concentrations. Sample A showed the highest median levels of lead (205.800 ppm), sample B showed the second highest levels of lead (159.700 ppm), and sample C showed the lowest amounts of lead (144.300 ppm). Lead is a heavy element (Gove, 1981). This suggests that it will not travel very far from the pollution point source. It is wise when planting a street side garden into existing soil to avoid planting at least three feet from the street-side curb to avoid the highest levels of legacy soil lead and also allow passengers to open doors and have a clear path to the sidewalk.

Confusion Around 'Safe' Lead Levels

When consulting information from various federal, state and local agencies it is difficult to understand what levels of soil lead are considered 'safe' for gardening. The US EPA considers soil lead less than 400ppm safe for gardening as long as certain precautions are taken (EPA, 2011). The State of Washington considers lead levels above of 250 ppm as unfit and restricts agriculture and other land uses above this threshold (WAC-code). A major soil testing lab, The University of Massachusetts at Amherst considers soil lead to be low at 150ppm, and suggests that gardeners take precaution if lead levels are higher than 300ppm (Spargo et al., 2012). The lead levels uncovered in this study are in the range of all of those guidelines. If the Washington State guideline of 250ppm were applied to the concept of 'safe for gardening' parking strips with soil lead levels above 250ppm would be excluded from urban agriculture land use. If the EPA guidelines were used, the EPA would consider those parking strips excluded by the State of Washington to be deemed safe for gardening if the limits were between 250 and 400ppm (Fig.19). It has also been discussed earlier that safety is difficult to measure from a single soil parameter such as total concentration. Consensus about 'safety levels' and the application of bioavailability concepts would be useful to the average gardener trying to decide to grow a vegetable garden in an urban area.

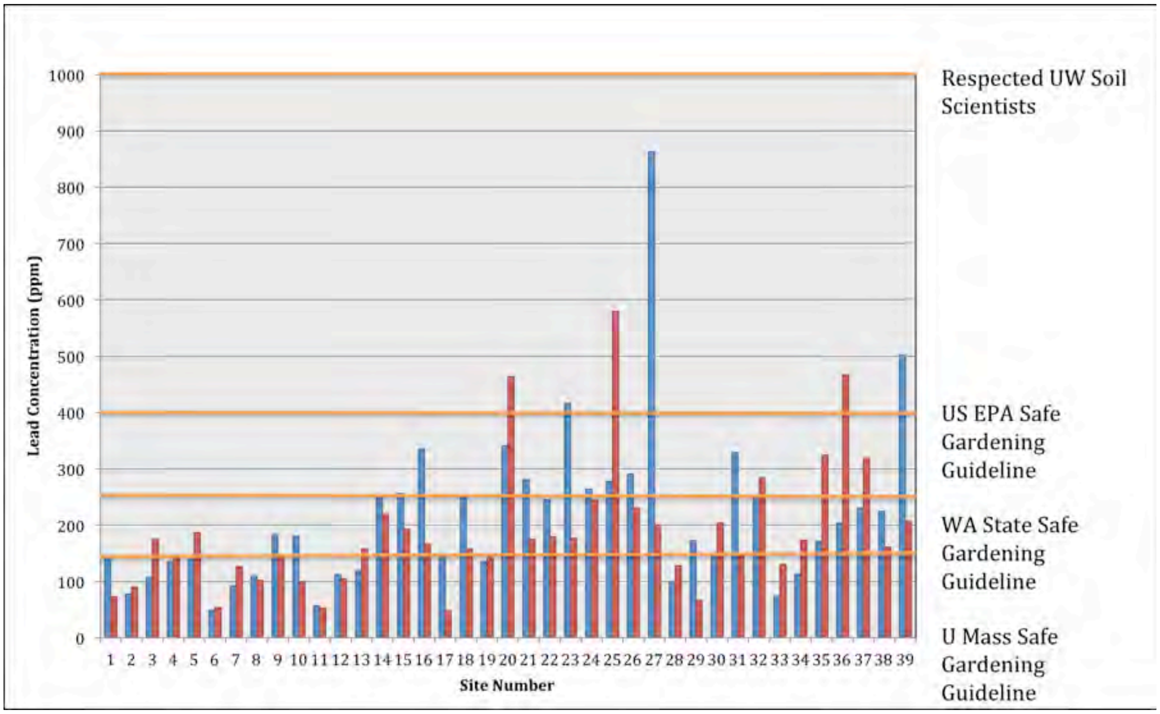

Figure 19. Display of all lead concentrations in paired (parking strip and backyard) groups. Many sites have levels over the WA State recommended levels of lead. A few sites have levels over the EPA recommended levels.

Suggestions for Safe Gardening

If urban residents are concerned about levels of lead in soil, there are some alternatives to planting in potentially contaminated street side or backyard soils. Building raised beds and filling them with clean soil is one way to reduce the risk of potential contamination. Covering existing soil with landscape fabric before construction is one way to reduce exposing potentially contaminated lead to the new clean soil in the raised bed (EPA, 2011). Planting fruiting crops such as tomatoes, squash or berries is another way to reduce lead exposure. Although it has been documented that vegetable consumption is a very low risk of lead exposure to the gardening population, fruiting plants sequester lower levels of lead in the edible portion of the plant than leafy greens (Finster, 2004). It is also wise to wash all vegetables and peel root vegetables before eating or cooking. The highest potential risk of lead in garden soil is from eating soil or inhaling soil dust. Make sure that children do not eat dirt, as direct ingestion is potentially more harmful than eating vegetables grown in that very same soil (Cheng et al., 2011).

Future Research

Future research could focus on other metals found in the urban environment: cadmium, arsenic, zinc and copper for their presence/absence in parking strip soils. Measurements of the metals would add valuable information for risk assessment purposes. A study of the effects of potential atmospheric deposition from Gasworks Park would also be informative for those now growing vegetables in the surrounding neighborhoods.

It would also be interesting to plant some parking strips with various kinds of plants and create vegetable gardens, ornamental gardens and pollinator pathways to study how well plants function in existing parking strip soil. Experiments on the best soil amendments would be interesting and helpful to many gardeners.

This study was a first step to understanding the soil in areas along our right-of-way streets. Urban soil science is an ever-expanding field that presents many questions to ask and paths to explore.

CONCLUSION

The aim of this study was to evaluate Seattle parking strip soil for urban agriculture land use and urban food production. A soil quality evaluation method reveals parking strips in northwestern Seattle contain soil of moderate quality that needs some improvement to be fit for healthy vegetable production. Soil texture, cation exchange capacity, pH, and nutrients were found to be low and in need of slight remediation to support vegetable plant growth. These soil quality indicators can be improved with additions of compost or bio-solids. Adjusting the pH of the soil should not be overlooked. Proper pH will help nutrients present in the soil be available to plants and reduce the availability of heavy metals such as lead.

Lead, a ubiquitous metal in urban environments was measured in all samples. Levels of lead were measured from parking strip and backyard soils. No statistical difference between parking strip lead concentrations and backyard lead concentrations were found. There is however a statistical difference between low traffic and medium and high traffic sites. Medium and high traffic sites had higher levels of lead than low traffic sites. This is possibly linked to higher speed limits and increased traffic on these roads. It is very possible that the traffic observed today is very different from traffic patterns of the era when leaded gasoline was still in use and other factors could be influencing concentrations of lead found in soil. A comparison of different sampling areas representing the proximity of a parking strip sampling area to the street was also calculated. Sample A, located closest to the street had the highest levels of lead. Although not statistically significant a strong pattern developed suggesting that lead levels decrease as distance form the street increases.

It is important for urban residents to test soil before they construct a vegetable garden. If unfit soil conditions or high levels of lead are found in the parking strip, raised beds are a good alternative to planting right in the soil. Careful attention to the Seattle Right-of-Way Manual www.seattle.gov/transportation/rowmanual/) and consideration of sight lines is recommended. Attention to not blocking sight lines is very important as limited line of sight while pulling a car out of a driveway could be much more dangerous than levels of soil lead. Careful design of street side gardens can be a wonderful addition to Seattle streets and increase the walk-ability of a neighborhood. Well-planned street side gardens should also be well maintained as to enhance a property instead of creating a garden that becomes messy and unkempt.

A surprising discovery of this project was the total amount of land covered by the parking strip. This long, skinny landscape feature is often overlooked or ignored. But in just the NW corner of Seattle, 141 acres of parking strips with moderately healthy arable soil lines our city streets. Many street trees grow in the parking strip creating the backbone of green infrastructure in residential areas. Urban street tree forests could be augmented with other types of plants creating a multi-level canopy of woody and non-woody plant species that would intercept rainfall and maybe decrease storm runoff. A comparison of different types of parking strip gardens: street trees with groundcovers, vegetable gardens, ornamental gardens, and bio-swales could be studied to find the design that would greatly enhance ecosystem functions along city streets. These skinny parking strip gardens may become the mortar that holds ecosystem functions together throughout an entire neighborhood. Parking strips with healthy soil should be planted with appropriate species to enhance existing plant communities in Seattle.

The results of this study should be considered the first step to a systematic investigation of roadside soil in Seattle. Urban soil is highly heterogeneous and it is very difficult to extend these results to other neighborhoods in other quadrants of Seattle. Lead has left a legacy, but not one as severe as in other cities around the country. Compared to lead levels found in Chicago (Shinn et al., 2000) and New York City (Cheng et al., 2011), lead levels measured in this study were half the concentrations found in other, older metropolitan areas. Further studies should be conducted in other neighborhoods of Seattle to complete the picture of parking strip soils in all of Seattle. Information gathered in this study reveals generally healthy soil that is low in contaminants. Healthy soil is a precious resource that is hard to find in many urban areas, and we have acres of it in Seattle. Treating our parking strips with care, planting appropriate gardens and using our soil resources wisely may be one key to Seattle's ecosystem functions and ensure a healthy thriving green infrastructure for generations.

RECOMMENDATIONS

- Test your soil. It is very important to test soil exactly where a vegetable garden will be planted. Urban soil is highly variable.

- If soil tests reveal high levels of lead consider building raised beds and fill those beds with clean soil. Also, use landscape fabric or plant a groundcover on any exposed soil around the raised bed to decrease the potential hazards of dust inhalation, or tracking soil dust inside.

- Plant gardens and build raised beds at least three feet from the street and curb. Potential levels of legacy lead are highest within three feet of the curb. Planting some distance from the curb will also allow access to cars parked on the street adjacent to the parking strip.

- Pay attention to Seattle Right-of-Way guidelines and regulations. Use these guidelines to create gardens that do not block site lines at intersections, block the view of the street from a driveway, or create any other safety hazards.

- If planting directly in the parking strip without constructing a raised bed, add compost or bio-solids to enhance soil nutrients, improve soil water holding capacity, improve soil structure and sequester any low levels of lead that may be present in the soil.

- Adjust soil pH if soils are too acidic. This will make nutrients more available to plants and also make toxic heavy metals less available.

- Plant a cover crop to add nitrogen to the soil instead of using granular fertilizers. Cover crops will enhance available nitrogen without the risk of fertilizer runoff into the street and into nearby waterways. If granular fertilizers are added, apply only the amount needed to supply the necessary nutrients. More is not necessarily better and could lead to runoff and pollution.

- If a vegetable garden isn't desirable, plant an ornamental garden to attract pollinators, provide wildlife habitat for insects, birds and other urban creatures. Ornamental plants of varying heights can slow intercept rainfall and slow runoff from impervious surfaces.

- Call before you dig! Keep in mind that an entire infrastructure of sewer lines, buried power lines and cable connections can exist under the parking strip. Please take care when constructing any garden in the right-of-way.

RESOURCES

Seattle Right-of-Way Improvements Manual
www.seattle.gov/transportation/rowmanual/

SDOT Client Assistant Memo-2305
http://www.seattle.gov/transportation/cams/cam2305.pdfof

Growing Gardens in Urban Soils: EPA Fact Sheet 542/F-10/2011
www.epa.gov/region4/foia/.../**urban_gardening_**fina_fact_sheet.pdf

USDA and NSRC- Urban Soils Primer
soils.usda.gov/use/**urban**/**primer**.html

Gardening on Lead and Arsenic Contaminated Soils
www.ecy.wa.gov/programs/tcp/area.../AppK**_gardening_**guide.pdf

Growing Healthy Soils Guide- City of Seattle
*www.**seattle**.gov/util/groups/.../growinghe_200311261701557.pdf*

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APPENDIX

Lead Concentrations

Site ID Number	A	B	C	Parking Strip	Backyard
1L	167.9	134.5	132	144.8	72.65
2L	91.82	74.2	66.71	77.576	90.455
3L	140.2	93.45	86.82	106.82	174.645
4L	165.5	110.7	128.6	134.93	141.45
5L	157.1	111.1	150.7	139.63	186.85
6L	51.85	44.18	51	49.01	53.855
7L	86.44	83.23	106.6	92.09	126.53
22L	108.8	88.33	133.7	110.276	101.985
23L	317.3	92.62	138.9	182.94	145.1
24L	241.1	167.7	133.3	180.7	99.555
25L	68.82	56.13	44.62	56.523	51.96
26L	142	89.09	130.2	111.43	104.775
27L	112.3	117.6	128	119.3	158.25
8M	435.6	159.7	149.3	248.2	219.65
9M	332.7	216.2	218.9	255.93	193.5
10M	687.1	178.7	139.9	335.23	166.35
11M	244.9	104.4	77.36	142.22	47.87
12M	400.6	200.2	144.2	248.33	158.15
13M	183.6	107.1	115.2	135.3	142.1
14M	415.7	252.8	354.6	341.033	463.75
28M	435.3	225.4	181.5	280.73	175
29M	240.6	294.6	199.3	244.83	178.9
30M	521.8	393.1	333.8	416.233	177.2
31M	464.8	155.5	171.7	264	244.8
32M	353.6	242.2	236.9	277.56	580.1
33M	349.2	256.8	267.3	291.1	230.9
15H	1616	538.2	436.3	863.33	199.5
16H	106.1	103.5	89.07	99.56	127.99
17H	193.6	180	144.3	172.63	66.24
18H	68.72	186.6	175	143.44	203.65
19H	217.2	262.2	508.5	329.3	146.8
20H	389.9	209.8	159	252.6	283.6
21H	76.74	65.83	80.63	74.4	130.2
34H	120.1	109.9	110.3	113.43	173.15
35H	146.7	136.3	230.5	171.16	323.95
36H	83.3	211.6	314.3	203.6	467.2
37H	258.8	199	233.7	230.5	319.3
38H	205.8	231.6	235.7	224.366	160.8
39H	546.9	523.2	436.6	502.233	206.9

Soil Quality Indicators

Site ID Number	pH	Organic Matter %	Soil Texture	C/N Ratio	CEC $cmol_c/kg$	Bulk Density g/cm^3
1L	5.47	7.01	Sandy loam	15.6	10.36	0.76
2L	5.34	5.89	Sandy loam	14.8	10.21	0.92
3L	5.39	6.12	Sandy loam	13.79	12.43	0.84
4L	4.95	5.61	Silty loam	12.87	11.64	1.04
5L	4.75	6.42	loam	14.39	9.36	0.82
6L	5.52	5.63	Silty loam	14.59	14.93	0.97
7L	5.42	6.76	Loamy sand	14.17	7.64	1.03
22L	5.49	7.16	Sandy loam	14.21	14.57	1.16
23L	4.84	6.48	Sandy loam	9.92	8.93	1.1
24L	4.94	11.67	Sandy loam	14.49	9.43	0.64
25L	5.24	4.82	Sandy loam	13.84	13.29	1.09
26L	5.31	7.82	Sandy loam	13.98	10.71	1.06
27L	5.51	6.63	Loamy sand	14.57	12.36	1.16
8M	4.11	11.67	Sandy loam	15.89	6.2	0.88
9M	6.35	8.33	Silty loam	14.14	16.07	0.99
10M	5.12	7.86	Sandy clay loam	15.14	11.57	0.72
11M	5.72	3.74	Sandy loam	13.02	6.64	1.37
12M	5.68	6.22	loam	14.5	12.57	0.81
13M	5.4	6.21	Sandy loam	15.53	8.79	0.92
14M	5.16	6.75	Sandy loam	13.46	8.5	1.63
28M	5.29	6.8	Sandy loam	15.47	7.79	1.19
29M	5.11	7.33	Silty loam	15.03	9.29	1.22
30M	5.29	14.09	Silty loam	16.7	6.79	0.83
31M	5.48	7.4	Silty clay loam	14.61	7.12	0.95
32M	5.26	9.68	Silty loam	14.88	11.25	1.52
33M	5.26	9.7	Silty loam	13.83	14.93	0.98
15H	5.16	16.57	Silty loam	14.84	6.43	0.91
16H	6.16	6.35	Sandy loam	15.59	13.5	1.09
17H	5.73	6.883	Silty loam	15.36	10.07	1.13
18H	5.55	9.09	Sandy loam	14.64	17.5	1.09
19H	5.58	7.62	Silty loam	13.31	11.21	0.87
20H	5.87	8.92	Silty loam	14.81	13.21	1.27
21H	5.79	8.16	Silty loam	16.16	17.79	1.13
34H	5.06	8.95	Silty loam	15.35	15.64	0.96
35H	5.28	6.76	loam	13.97	13.36	1.19
36H	5.35	5.67	Silty loam	14.92	9.57	0.87
37H	5.42	6.37	Silty loam	14.53	11.37	0.95
38H	5.53	6.64	Silty loam	14.67	15.29	1.21
39H	5.08	11.53	loam	17.23	13.29	1.15

Available Nutrients

Site ID Number	NO3 µg/g	NH4 µg/g	P µg/g	K µg/g	Ca µg/g	Mg µg/g
1L	11.7	13.3	ND	TR	878	52.81
2L	0.26	13.63	ND	35.12	988	80.21
3L	14.63	20.43	TR	87.29	1302	90.54
4L	19.7	23.2	TR	50.33	1169	116.06
5L	44.46	8.1	TR	60.17	1038	72.21
6L	1.8	16.8	TR	113.68	1634	215.2
7L	3.87	13.23	TR	37.57	807	111.8
22L	4.5	3.45	TR	124.4	1666	164.32
23L	73.86	6.37	ND	46.98	820	79.9
24L	11.03	11.3	ND	TR	569	66.16
25L	7.5	3.51	7.28	113.44	1675	165.06
26L	2.16	4.61	ND	50.5	927	91.21
27L	2.37	5.85	ND	37.51	664	63.46
8M	8.33	19.87	ND	TR	119	8.16
9M	23	16	TR	129.32	2338	175.78
10M	28.33	21.33	TR	TR	1180	128.01
11M	2.33	11.07	ND	42.65	776	129.39
12M	6.56	12.03	ND	58.06	1057	89.08
13M	10.93	29.57	ND	53.35	801	60.43
14M	5	7.93	ND	53.53	953	87.96
28M	56.76	3.21	ND	55.75	875	128.64
29M	133	3.486	ND	41.4959	908	63.77
30M	6.76	9.3	ND	41.21	770	54.94
31M	7.93	5.97	7.71	54.54	1088	99.89
32M	1.13	36.13	ND	121.47	1819	246.07
33M	125.36	5.8	TR	155.02	2056	272.58
15H	10.33	18.83	ND	TR	249	18.49
16H	2.46	14.67	ND	63.36	1580	113.7
17H	3.63	17.75	ND	82.55	1020	127.78
18H	1.4	17.46	TR	180.91	1554	156.37
19H	10.03	17.33	ND	52.06	1217	100.14
20H	34.63	23.56	ND	129	1610	112.55
21H	15.17	17.47	ND	158.72	2094	143.83
34H	6.67	6.47	TR	153.11	1815	326.36
35H	67.42	73.56	TR	263.288	1602	176.82
36H	2.6	6.17	ND	60.81	1209	115.16
37H	18.78	9.32	ND	104.25	1229	127.77
38H	77.26	3.51	ND	220.03	1648	186.56
39H	17.66	10.23	ND	142.99	848	76.84