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**Possible Relocation Sites for the Center for Environmental Studies's Forest Garden:**

**Gardening Suitability of Eastern Dodd Lawn with Special Concerns for Lead**

An Independent Study

ENVI 102, Professors Art, Dethier, & Thoman

by

Charles Soucy '09, Maya Lama '09, & Gillian Tedeschi '09

Experiment Performed: April 17 – May 17, 2006

Report Submitted: May 18, 2006

**Abstract**

Consumption of plants grown in lead contaminated soil has various health hazards for people. Especially children, infants and fetuses are highly vulnerable. High lead blood levels affect the neurological development in children causing behavioral and learning disorders while in adults it might cause high blood pressure. Therefore, before planning on using any plot of land as a garden, it is necessary to check the concentration of lead in soil, extent of contamination, and location of high-risk areas within the plot so that one can mitigate the health hazards related to it. The analysis of the soil samples of the Dodd garden showed maximum contamination of lead right below the house, with Pb level of 1,546 ppm. Its major source has been found to be the house paint that contained a very high lead concentration of 180,000 ppm. Other areas within the plot had Pb concentrations well within the level proposed to be safe by the EPA (400ppm) and MA DEP (300ppm) except for the coal field sites with Pb concentration level as high as 659 ppm. Therefore, these areas must be avoided for safe gardening practice.

## Introduction

Currently located on the half-acre hillside between Stetson Hall and Kellogg House's Center for Environmental Studies, the Williams College forest garden will have to be relocated once the Stetson-Sawyer Library construction project is underway, as the plans, if completed, will overtake the current garden's land. One possible site for relocation lies on the eastern side of Dodd House. Erected in 1880 and expanded upon in later years, Dodd has been a residence, a boarding house and a college hotel—the Williams Inn—in the past; today, it is a dormitory complete with dining facilities.

The purpose of our experiment was to assess the quality of the soil behind Dodd House—and its suitability for gardening. We analyzed each of twenty-seven soil samples, measuring moisture content, organic content, pH, total lead concentration and exchangeable cation (calcium, sodium and potassium) concentrations. While moisture content, organic content, pH and exchangeable cation concentrations certainly affect the plants' health and growth capacity, our main concern was the amount of total lead present in the soils to the east of Dodd. Past studies have shown that plants grown in lead-contaminated soil do contain lead concentrations greater than those considered to be “normal” baseline levels. Roots and tubers typically have the highest lead concentrations; fruits and seeds usually have the lowest lead concentrations. It seems that lead is readily taken up by plant roots and retained—not transported higher up within the plant (Washington State University). Moreover, the forest garden is a gathering place, both for Williams College students and for members of the Williamstown community at large. In particular, children playing in and around a lead-contaminated garden area may suffer serious adverse health effects, namely “impaired physical and mental development,



decreased heme biosynthesis, elevated hearing threshold and decreased serum levels of vitamin D” (Center for Disease Control). As compared to adults, children have smaller bodies; in proportion to body size, they take in more air, food and water. They are also more likely to ingest lead particles by putting their hands and/or contaminated objects into their mouths. Finally, they are more likely to be nutritionally deficient in calcium, phosphorus, iron and zinc: nutritional deficiencies tend to increase lead absorption and retention within the body (Center for Disease Control). Adults involved in gardening in lead-contaminated areas also risk ingesting lead particles via inhalation (Carroll).

We hypothesized that lead contamination would be likely in the soils that we tested for a number of reasons. First, it seemed likely that the paint on the exterior of Dodd House would contain lead: approximately two-thirds of American homes built before 1940 were painted with heavily-leaded paint, as lead was traditionally used as a pigment and a drying agent in “alkyd” oil-based paint (Consumer Product Safety Commission). Second, Mission Park Drive—a small side street—runs along the southern and southeastern sides of the Dodd lawn; in the United States, leaded gasoline was not made illegal until 1995 (Detwyler). (Tetraethyl lead was added to gasoline to reduce engine “knock” from the 1920s onward (Detwyler).) Third, upon conducting a visual survey of the site area, we found a “digsite” where construction workers had unearthed a number of old pipes. Thus we expected total lead concentration levels to be highest in spots closest to Dodd House, closest to the road, and closest to the “digsite.”

## **Methods**

### Observation

On April 21, we went to the proposed site behind Dodd house to do a quick visual survey, to measure the total area of land. Upon comparing the area of the Dodd (2803.25 meter squares) with the current forest garden (922 meter square), we found that there is certainly more than enough room for the forest garden behind Dodd. We also found a “digsite”. The construction workers laying water lines between the Dodd Annex (a collection of campus buildings, including Dodd House) and Southworth Street had unearthed several metal pipes, three of which we brought back to the lab for later analysis. Right behind the “digsite,” between the end of the Dodd lawn and the beginning of residential property on Southworth Street is a wooded area with soils rich in organic matter (high in carbon content). In past years, Southworth Street residents would dump charcoal dust and ash onto the ground in this area. There is vegetation growing, but, according to a Southworth resident, the Williams College horticulturist has had little success in his attempts to create a true garden in the “coalfield.”

### Collection and Storage

We collected 27 soil samples from the surface of the soil layer, using a cylindrical core and placed them into a clearly labeled polyethylene bags. Our criteria was to collect the soil samples such that they would cover all the important areas within the garden- those closer to the house, closer to the road, in the digsite and coalfield and others in between - so that we could see the trend in lead concentration. We recorded the distance from the house to the sampling locations for those that were closer to the house, the distance from the sidewalk to the sampling locations for those closer to the road and finally the distance from the property line for those in the coalfield. We then stored the

soil samples in a cold room set at 4° C (room 255, Bronfman Science Center) in order to avoid any changes in the chemical characteristics of the soil.

#### Calculation of moisture and carbon content

For the calculation of moisture, the soil samples were sieved in a 2mm sieve. 2.5 grams of the sieved soil was weighed out using electronic top-loading balance and then put into crucibles. They were then put in a 100° C oven for 24 hours to get rid of all the moisture. Percentage moisture was determined using Equation 1 (Appendix 1). For the calculation of carbon, the weights of the crucibles and the dry soil were recorded. The crucibles were then placed in a muffle furnace at 600° C for 6 hours to be ashed. This decomposes all the carbon from the soil and the weight difference gives the amount of carbon stored in the soil (Appendix 1, Equation 2).

#### pH value

25 grams of non-seived wet soil was added with 50mL of purified water into a 100mL beaker. The mixture was stirred and allowed to settle for 10 minutes. The pH meter was calibrated using known buffer solutions of pH 4 and pH 7. After standardization, the pH of the soil slurry was measured by letting the electrode sit in the slurry for at least 5 minutes. The standardization process was repeated after every third sample.

#### Measurement of Lead (Pb), Calcium(Ca), Sodium (Na) and Potassium (K)



The cations and lead on soil colloids were measured by digesting the ashed soil samples in boiling 5mL 50% nitric acid ( $\text{HNO}_3$ ) for 30 minutes. The mixtures were then filtered through 0.45 micron membrane filters in polyethylene filter flasks. The filtrates were then diluted to a volume of 100mL and stored in polyethylene bottles. For analysis, the air-acetylene flame apparatus of the AAS (Atomic Absorption Spectrometer) was used. For other cations, the solutions were prepared for the AAS by adding 1mL of the matrix modifier –Lanthium Chloride ( $\text{LaCl}_3$ ) for Ca and Cesium Chloride ( $\text{CsCl}$ ) for Na and K - to 4mL of the diluted solutions. After the running the analysis, those with values of cations greater than the highest standard were diluted further and again analyzed.

## **Results**

### Carbon Content

The carbon content (measured as the percentage of mass lost upon ignition—Loss-On-Ignition, or L-O-I) was greatest for the soil samples taken at the “coal field”—the area between the Dodd lawn and the residential properties on Southworth Street. All other samples had L-O-I percentages of less than 10% (Table 1).

### pH

All samples had pH values between 4.0 and 8.0, with only three values exceeding 7.0 (neutral). Thus almost all soil samples were determined to be acidic. There appeared to be no noticeable trends in pH with changes in location at the site (Table 2).

### Exchangeable Potassium Cation Concentration



Exchangeable potassium concentrations seemed to be higher in soil samples taken farther away from Dodd House, although this correlation was not terribly strong (Table 3). (In general, samples with lower numbers were taken closer to Dodd House; samples with higher numbers were taken at locations further away from the house.) There appeared to be a positive—albeit somewhat weak—correlation between organic content and exchangeable potassium concentration. A scatterplot of the two variables—carbon content as the independent variable, exchangeable potassium concentration as the dependent variable—yielded a scattering of points that suggested the presence of a linear relationship. However, the line fitted to the graph had a correlation coefficient of only 0.4315 (Figure 1).

#### Exchangeable Calcium Cation Concentration

Exchangeable calcium cation concentration was highest in the samples taken the farthest from Dodd House. However, exchangeable calcium concentrations were also relatively high in the samples taken closest to Dodd House (Table 4). There was also a positive correlation between carbon content and exchangeable calcium concentration; when a linear equation was fitted to the scatterplot with carbon content plotted on the x-axis and calcium concentration plotted on the y-axis, a high correlation coefficient—0.8244—was produced. This indicates a strong positive correlation between the two variables (Figure 2).

#### Sodium

Sodium levels from all sampling sites seemed to be similar with some noise (Figure 3). There is not much correlation between Na and carbon content of the soil (Figure 4) There is very little correlation between Na and pH of the soil (Figure 5).

### Lead

Most samples show lead concentrations below the EPA and MA DEP Advisory Levels of 400 ppm and 300 ppm, respectively (Figure 6). Exceptions to this are samples 4, 5, 25, and 26, which show concentrations above the EPA level, and samples 22 and 24, which show levels above the MA DEP level (Figure 6). The lead concentrations of the pipes and paint collected from Dodd property ranged from non-detectable in the ceramic pipe, to entirely lead based in the house paint (Table 5).

### Lead and Proximity to Dodd House

The relationship between lead and distance from the Dodd House showed an initially weak correlation with outliers identified in samples 4, 5, and 15 (Figure 7). The relationship was graphically displayed again without the outliers but the correlation coefficient was still too low for lead levels and distance from the house to be considered correlated (Figure 8).

### Lead and Organic Content

The data showed a positive correlation between organic content and total lead concentration in the soils sampled (Figure 9). When samples 4 and 5 (taken right next to Dodd House) were eliminated from the data set as visible outliers, the strength of the

correlation increased (Figure 10). (Samples 4 and 5 had the highest total lead concentrations—1397 and 1547, respectively—but not the highest L-O-I percentages. Their L-O-I percentages were 6.1% and 8.99%, respectively.)

### Lead and pH

Total lead concentration seemed to increase with increasing pH for the soils sampled. A plot of pH versus total lead concentration for the entire data set showed a very weak positive correlation (Figure 11). Upon eliminating samples 4 and 5 from the data set once more, this time because their total lead concentrations were so high with respect to the other data points, the positive correlation was strengthened, but it still remained very weak (Figure 12).

### Lead and Potassium

There appeared to be a weak positive correlation between exchangeable potassium concentration and total lead concentration (Figure 13): total lead concentration increased exponentially with increasing exchangeable potassium concentration. Eliminating samples 4 and 5 as outliers yielded a slightly stronger correlation (Figure 14).

### Lead and Calcium

No visible correlation was present between exchangeable calcium concentration and total lead concentration when the entire data set was considered (Figure 15). However, upon eliminating three outlying points—samples 4 and 5 due to their extremely

high lead concentrations and sample 1 due to its extremely high calcium concentration—a fairly strong positive correlation was visible between the two variables (Figure 16). After eliminating the three apparent outliers, it seemed that total lead concentration increased linearly with exchangeable calcium concentration.

## **Discussion**

### Carbon Content

The greatest L-O-I percentages occurred in soils taken from the “coal field” area. Organic matter is essential to plant growth in soils. It improves the soil’s ability to store and transmit air and water; stores and supplies nutrients for plants; and increases soil cation- and anion-exchange capacities (United States Department of Agriculture). Plants generally thrive in soils with higher carbon contents.

### pH

Most plants prefer a soil pH between 5.5 and 7.5, with the majority doing best in the middle of this range (University of Massachusetts Amherst). Only eleven of twenty-seven soil samples had pH values within this range (Table 2), with the majority of soils being too acidic (pH lower than 5.5). However, due to the large uncertainty inherent in measuring soil pH using a pH meter, we cannot be sure that our results are entirely reliable.

### Exchangeable Potassium Cation Concentration



Potassium is required by plants in much greater amounts than are other soil-supplied nutrients, with the exception of nitrogen. As such, successful gardening requires an adequate supply of usable—exchangeable—potassium within the plants' root zones (Murdock & Wells): exchangeable potassium replenishes the potassium used during plant growth (Carpenter, Trefethen & Magnuson). Optimal levels of potassium in soil are between 120 and 200 parts per million for most plants. Concentrations below 150 parts per million are considered low; those between 250 and 800 parts per million are considered high; those above 800 parts per million are considered excessive (Tree Fruit Research & Extension Center, Washington State University) and unhealthy for plants. Almost all soil samples yielded excessive exchangeable potassium concentrations (well over 800 parts per million). Of the three concentrations remaining all exceeded the upper bound of the optimal range and were therefore high (Table 3).

Exchangeable potassium concentration seemed to increase with carbon content in the soils sampled. Plants obtain potassium from the soil, and, when plant residues are returned to the soil, the potassium they contain is readily released and adsorbed into the negatively-charged humus (highly decomposed organic matter) particles and into the exchange sites within the soil (Murdock & Wells). As a result, soils with higher levels of organic matter can be expected to have higher exchangeable potassium concentrations.

#### Exchangeable Calcium Cation Concentration

Calcium, available to plants in the exchangeable cation  $\text{Ca}^{2+}$ , is considered a macronutrient with regard to plant growth, as it comprises about 0.2 to 1.0% of a plant's total biomass. Calcium aids in building the structure and permeability of cell

membranes, enhances the uptake of exchangeable potassium and nitrate in plant roots and helps with cell division and elongation (which result in plant growth) (University of Missouri). While optimum calcium values are considered to be between 600 and 4000 parts per million for most soils (Tree Fruit and Soil Research Institute, Washington State University), high concentrations of calcium in soil are not considered to be detrimental to plant development because the plants themselves can limit their uptake (University of Missouri).

Thirteen—roughly half—of twenty-seven soil samples had calcium concentrations exceeding 1000 parts per million (Table 4). Concentrations less than 1000 parts per million are considered to be low (Tree Fruit Research & Extension Institute, Washington State University). Sixteen samples had concentrations exceeding 600 parts per million—the lower boundary of the optimum range (Table 4). Thus the calcium concentrations in eleven soil samples were extremely low—probably low enough to inhibit plant growth. All of the samples from the “coal field” had very high calcium concentrations, and six of the first eight samples—those taken closest to Dodd House—had calcium concentrations well over 1000 parts per million (Table 4).

Coal ash frequently contains calcium; in fact, calcium is one of the most abundant minerals found in low rank coals, and it occurs in significant amounts in most bituminous coals (Shah, Huffman, Huggins, Shah, Heble, Peterson, Wendt & Sarofim). As a result, it seems likely that the high calcium concentrations in samples taken from the coal field can be attributed, at least in part, to past dumpings of coal ash.

There was a strong positive correlation between carbon content and calcium cation concentration. Typically, soils with greater organic contents have greater nutrient-

holding capacities (Soil and Plant Laboratory). Negatively charged humus particles bind readily to positive nutrient cations (Murdock & Wells), thereby increasing the nutrient-holding capacity of a soil. The samples taken at the “coal field” had both very high carbon contents and very high calcium concentrations.

### Sodium

Although Na is not a plant nutrient and is therefore not important for plant growth, it is still considered important because it affects the physical conditions of the soil. The movement of water and air through soil is dependent on good soil porosity which in turn is dependent on the individual soil components, clay minerals and organic matter, remaining clumped together in aggregates. Sodium destroys this 'soil structure' by causing the individual soil particles to repel each other. Therefore, soils high in exchangeable sodium may cause adverse physical and chemical conditions to develop in the soil. These conditions may prevent the growth of plants. Reclamation of these soils involves the replacement of the exchangeable sodium by calcium and the removal by leaching. Calcium sulfate ( $\text{CaSO}_4$ ), better known as gypsum, is the most frequently used Ca source for the restoration of high sodium soils. Gypsum can be applied to the soil directly.

The presence of Na in the soil can be attributed to the use of road salt that is washed to the land by melting snow and rain. It is confirmed by the high presence of Na in the soil samples that were closer to the sidewalks than in any other places. However, excessive sodium levels can be naturally occurring as well.



With increased acidity, higher Na content in soil solution can be estimated because decrease in pH result in a release of positively charged ions (cations) from the cation exchange surfaces of organic matter and clay minerals. The soil in Dodd garden has a wide range of pH from quite acidic (4.01) to quite basic (7.79). For gardening it is necessary to maintain the pH level to an optimum of about 6-7. This can be done by adding crushed lime to areas that have very low pH and adding, sulfur, iron sulfate or aluminum sulfate to areas with very high pH, although these tend to be expensive with only short term effects. Urea, urea phosphate, ammonium nitrate, ammonium phosphates, ammonium sulfate and monopotassium phosphate also lower soil pH.

### Lead

Most of the samples taken from Dodd Property soils contain safe levels of lead ( $Pb^+$ ) according to both the Environmental Protection Agency (EPA) Advisory Level of 400 ppm and the Massachusetts Department of Environmental Protections (MA DEP) of 300 ppm for residential areas. This means that the sites that have a lead content below these marks are safe for all residential uses, including gardening. Although these sites have lead contents above baseline for undisturbed soils, 20 ppm, they are not high enough to raise health concerns. The sites that draw special interest are those samples taken from soil directly adjacent to Dodd House (samples 4 and 5) and those samples taken within the “coal field” (samples 22-27). Samples 4 and 5 were taken within a meter of Dodd House and are considered, in this report, to be representative of any lead ( $Pb^+$ ) contamination whose direct source could be traced to the house itself. Various paints from Dodd House were scraped off down to the wood, so as to capture as many years as



possible, and tested for lead. As the lead content of the house paint, specifically, is astoundingly high not only can the paint be considered lead based, but Dodd House can also be attributed as the direct source of the lead contamination in samples 4 and 5.

Samples 22 through 27 are located in an area known fondly in this study as the “coal field” due to its historical uses. As it is situated along the property line that borders the Dodd property and Southworth residencies, its uses have been dubious in nature. We know, by first hand account from a local resident, that the area was used by past Southworth residents as a place to dump their coal refuse, when coal was used as a heating source. The dumping of coal refuse can be indicated as the direct source of lead ( $\text{Pb}^+$ ) contamination in the “coal field) samples. As the area was used as a dumping space, there is question as to what else is in the area’s soil and what its possible sources are. More research is needed to determine the health risks of any activity in or on these soils.

#### Lead and Proximity to Dodd House

While lead content does indeed decrease as the distance from Dodd House increases, the correlation between the two factors is weak. This would be due to the fact that organic content in the soil binds to the lead ions ( $\text{Pb}^+$ ) immobilizing them for many years. Thus, it is unlikely that any sort of flow or dispersion would be seen when considering lead. Any lead content in soil is a result of nearly direct application or contamination, or it is the result of notable soil movement, most likely erosion or gardening.

### Lead and Organic Content

In the soils sampled, greater organic content seemed to result in greater lead content, although the correlation between the two variables was weak. Organic matter does bind lead particles in soil, making them virtually immobile unless the soil is overturned or disturbed in some other way. For this reason, lead concentrations tend to be highest in the upper soil horizons (Cooperative Extension, Washington State University): we took all of our soil samples from the O and/or A horizons.

However, adding organic matter to soil usually reduces plant uptake of soil lead—up to a point. This is probably because the added organic material dilutes the pre-existing concentrations of lead in the soil (Cooperative Extension, Washington State University).

It is also important to note that lead concentrations were very high in the “coal field” area, where organic matter contents were also high. But, the high lead concentrations in this area should probably not be attributed to organic content alone. In the past, Southworth Street residents dumped coal fly ash onto the ground in the “coal field,” and coal fly ash traditionally contained lead (primarily as lead oxides).

### Lead and pH

A very weak positive correlation existed between soil pH and lead for the soils that we sampled. Increased pH tends to decrease plant uptake of lead, though (Cooperative Extension, Washington State University). To compare lead uptake of plants grown in soils taken from different locations at the Dodd sampling site—to see how much pH affected lead uptake—would require further experimentation. We did not grow plants in any of the soils that we sampled.

### Lead and Exchangeable Cations

Positive correlations also appeared to exist between potassium and lead concentrations and between calcium and lead concentrations. (However, the strength of such correlations—and, in the case of calcium versus lead, the very existence of a positive correlation—depended largely on the removal of samples 4 and 5 from the data set. The lead concentrations measured for those two samples were incredibly high as compared with the other twenty-five values, so they appeared to be visible outliers.) It seems plausible that increased amounts of organic matter correlate with greater holding capacity for potassium, calcium and lead: all three metals have exchangeable cation forms which bind readily to negatively-charged humus particles in soil.

### **Conclusion**

From the soil analysis of the Dodd garden, we found that the Dodd house was the major source of lead contamination in the soil immediately below the house. The house paints with very high concentration of lead supports our conclusion. High lead concentration was also found in the coal field which can be attributed to the fly ash and coal that was discarded in the earlier days by the residents of the nearby houses. But, on the whole, the Dodd garden is conducive to a safe gardening practice. However, gardening should be avoided in areas closest to the house and in the coal field. These areas should be utilized for other purposes like composting. Another alternative is to grow only fruit crops in those areas instead of root vegetables and herbs because roots contain more lead in their edible parts and therefore can contribute more to the total body



burden of lead. However, we recommend that further studies be conducted on the coal field area in order to gain a better understanding of its soil characteristics because we simply do not know what other things might have been dumped into the area.

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## **Appendices**

### Appendix 1

Equation 1. Formula for calculating moisture content.

$$\% \text{ H}_2\text{O} = ((\text{wet-dry}) / (\text{wet- crucible})) \times 100\%$$

Where wet= mass of the wet soil and crucible

dry= mass of dry soil and crucible

cru= mass of empty crucible

Equation 2. Formula for calculating carbon content

Carbon content ( %) = ((dry-ash)/(dry- crucible)) X 100%

Where dry=mass of dry soil and crucible

ash= mass of ashed soil and crucible

## Appendix 2

See attached map.

## **Tables and Figures**

*Table 1:* Carbon Content of Soils on the Eastern Side of Dodd House (Carbon Content Measured as Loss-On-Ignition Percentage)

Sample Number	% L-O-I
1	1.29
2	9.60
3	4.76
4	6.10
5	8.99
6	5.73
7	6.29
8	6.86
9	7.78
10	8.02
11	5.95
12	5.95
13	5.92
14	6.56
15	5.88
16	5.79
17	6.01

18	7.38
19	8.70
20	8.91
21	7.84
22	20.00
23	12.87
24	13.28
25	14.88
26	20.61
27	12.10

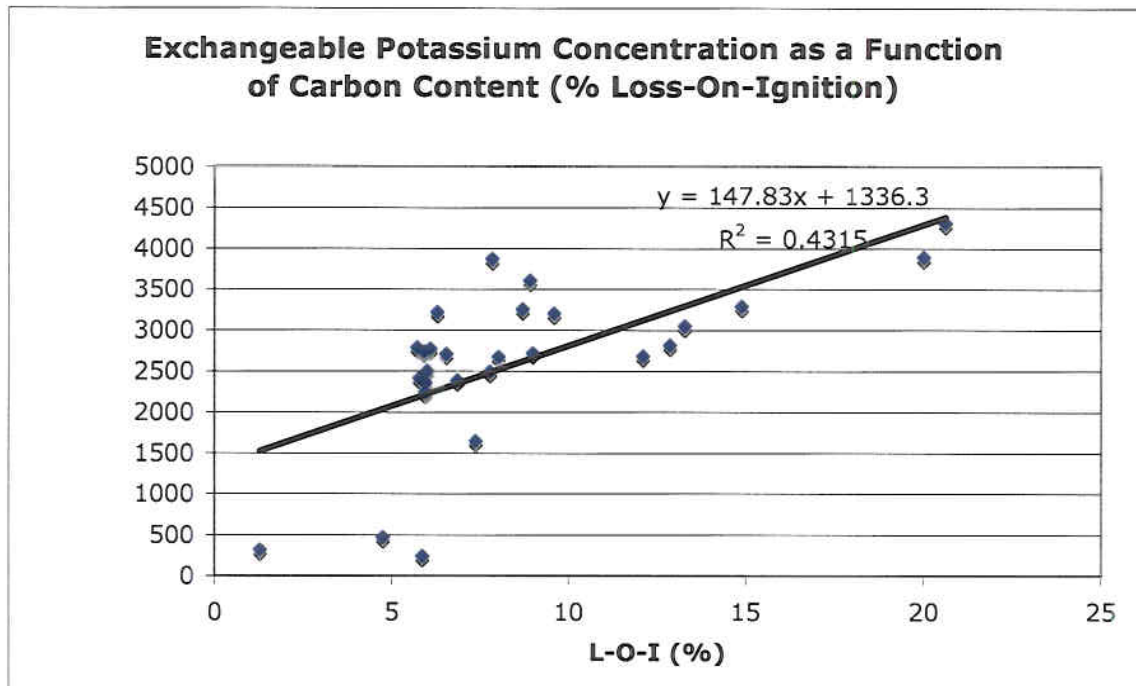
*Table 2: pH Values of Soil Samples Taken from the Eastern Side of Dodd House*

<b>Sample Number</b>	<b>pH</b>
1	Not available
2	6.54
3	7.54
4	6.19
5	6.53
6	6.22
7	6.79
8	4.49
9	4.78
10	6.04
11	Not available
12	5.46
13	5.24
14	4.11
15	4.66
16	4.99
17	5.21
18	5.07
19	4.01
20	4.34
21	Not available
22	6.37
23	7.79
24	6.5
25	6.27
26	7.35
27	5.37

*Table 3:* Exchangeable Potassium Cation Concentrations in Soil Samples Taken from Land on the Eastern Side of Dodd House

<b>Sample Number</b>	<b>Potassium Concentration (parts per million)</b>
1	315.3
2	3203
3	471.6
4	2779
5	2722
6	2791
7	3219
8	2387
9	2493
10	2673
11	2236
12	2358
13	2740
14	2711
15	240.5
16	2412
17	2501
18	1643
19	3255
20	3605
21	3872
22	3894
23	2819
24	3054
25	3292
26	4305
27	2687



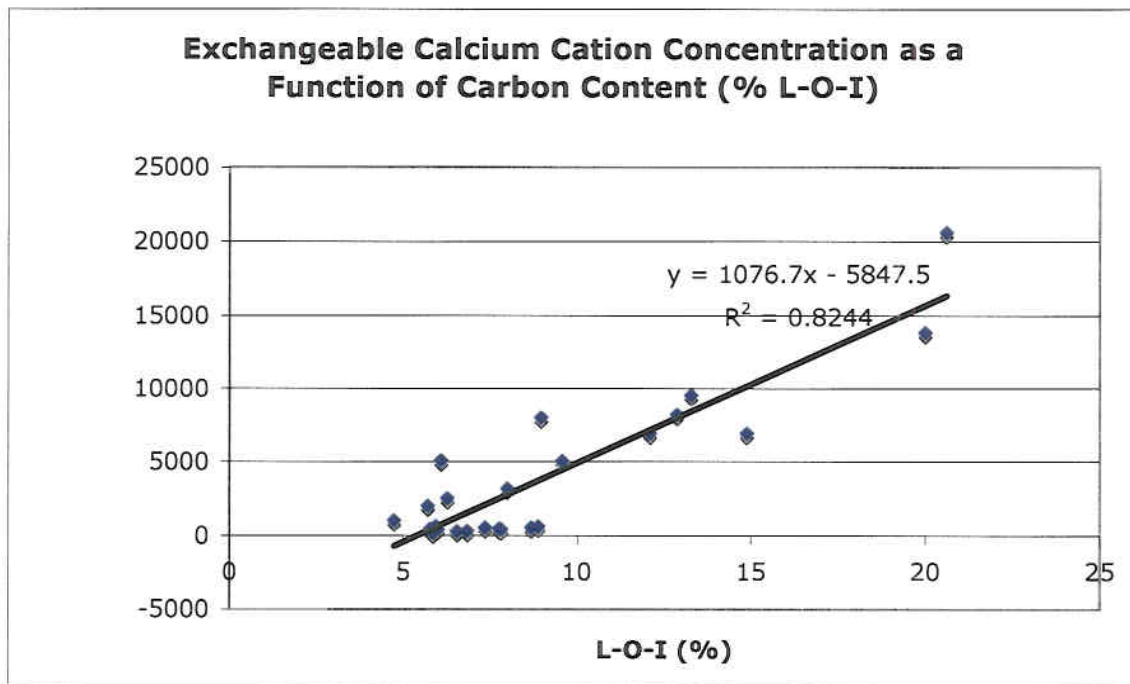


*Figure 1:* Exchangeable Potassium Cation Concentration as a Function of Carbon Content (L-O-I Percentage) in Soil Samples Taken from the Land to the East of Dodd House

*Table 4:* Exchangeable Calcium Cation Concentrations in Soil Samples Taken from Land to the East of Dodd House

<b>Sample Number</b>	<b>Exchangeable Calcium Concentration (parts per million)</b>
1	$1.604 \times 10^5$
2	5064
3	982.5
4	5099
5	8000
6	1999
7	2511
8	311.5
9	447.2
10	3186
11	608.0
12	514.4
13	491.8
14	262.1
15	181.6

16	397.4
17	410.4
18	529.2
19	544.4
20	603.5
21	428.4
22	$1.381 \times 10^4$
23	8208
24	9532
25	6920
26	$2.062 \times 10^4$
27	6909



*Figure 2:* Exchangeable Calcium Cation Concentration as a Function of Carbon Content (Measured as the Percentage Loss-On-Ignition) for Soil Samples Taken from Land to the East of Dodd House

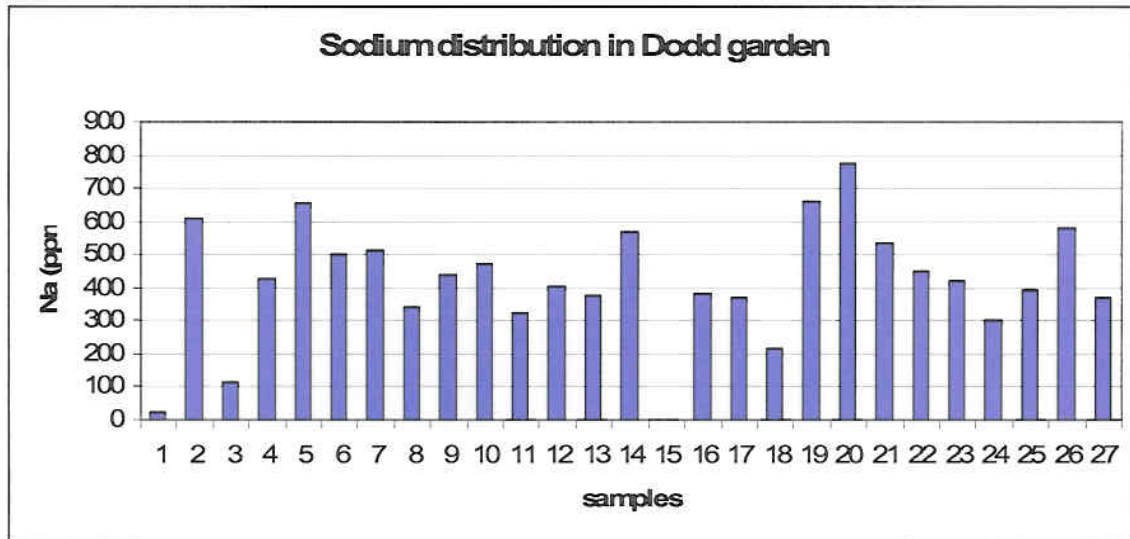


Figure 3. Sodium distribution in Dodd garden

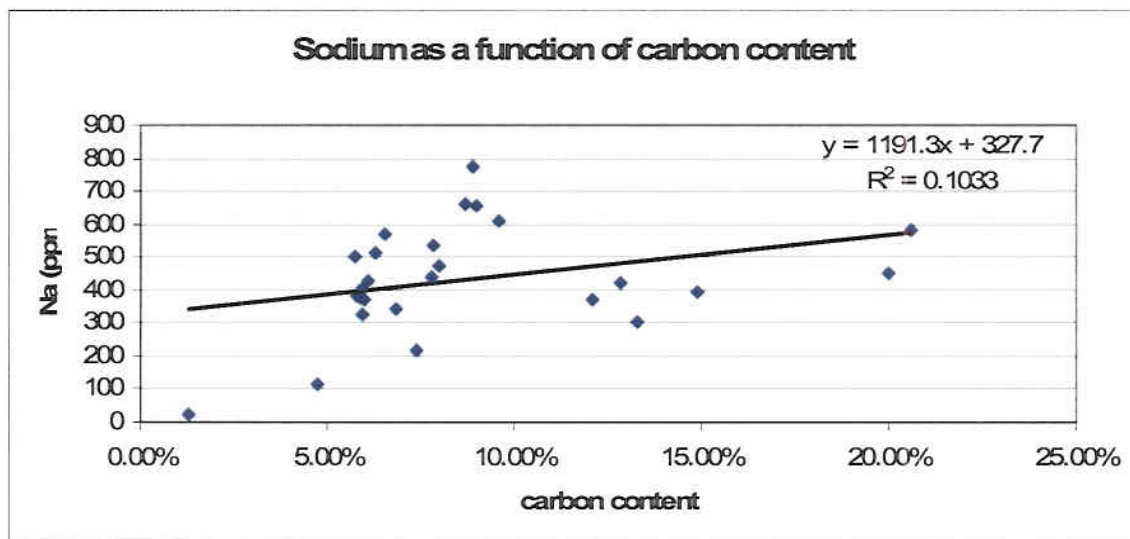


Figure 4. Sodium as a function of carbon content

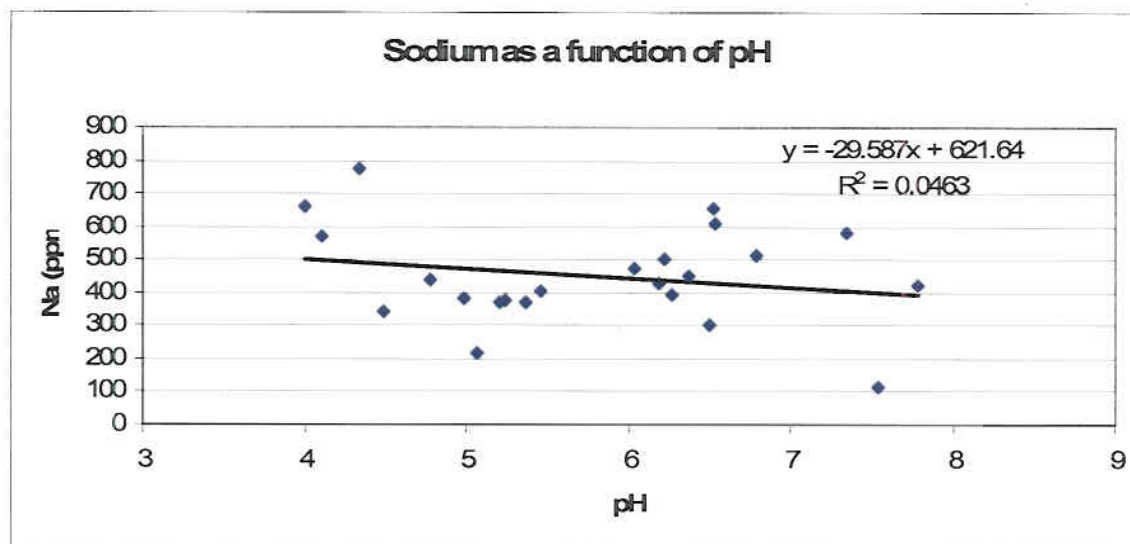


Figure 5. Sodium as a function of pH

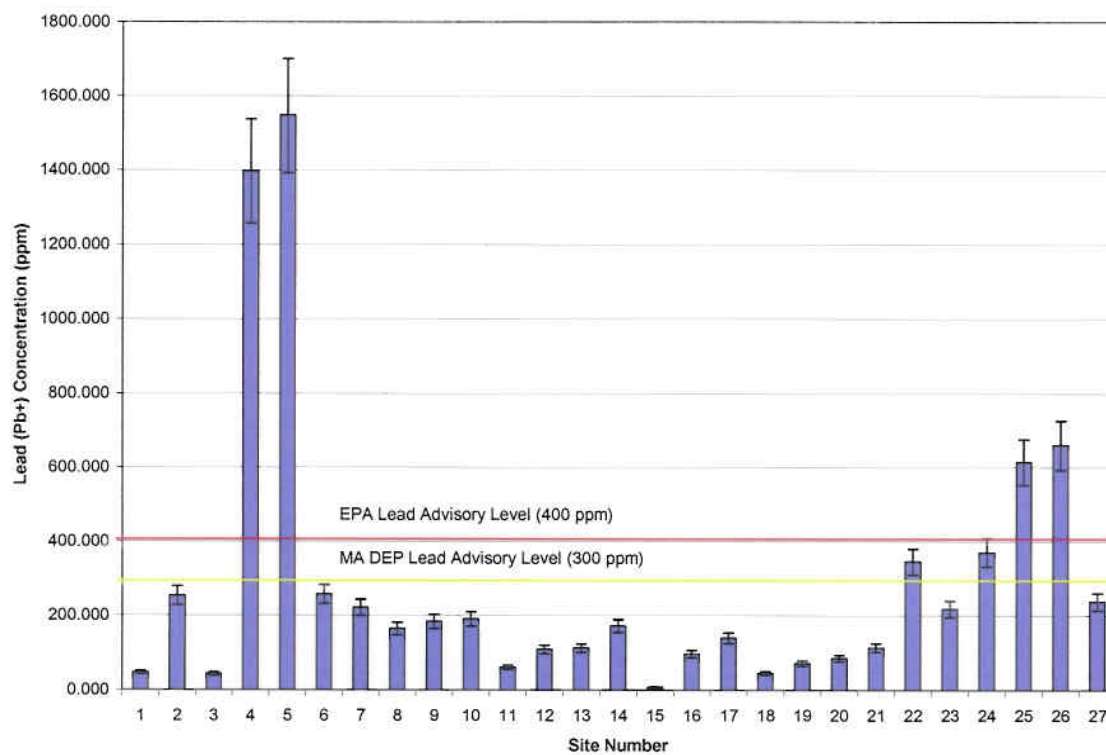


Figure 6. Lead (Pb<sup>+</sup>) Concentrations (ppm) of Sample Sites with EPA and MA DEP Advisory Levels.

Table 5. Lead (Pb<sup>+</sup>) Concentrations (ppm) of Pipes and Paint found on Dodd Property.



Source	Pb Content ppm
porch	
paint	18.450
trim paint	111.268
house	
paint	180000.000
small pipe	3947.879
rusted	
pipe	43.775
ceramic	
pipe	-22.271

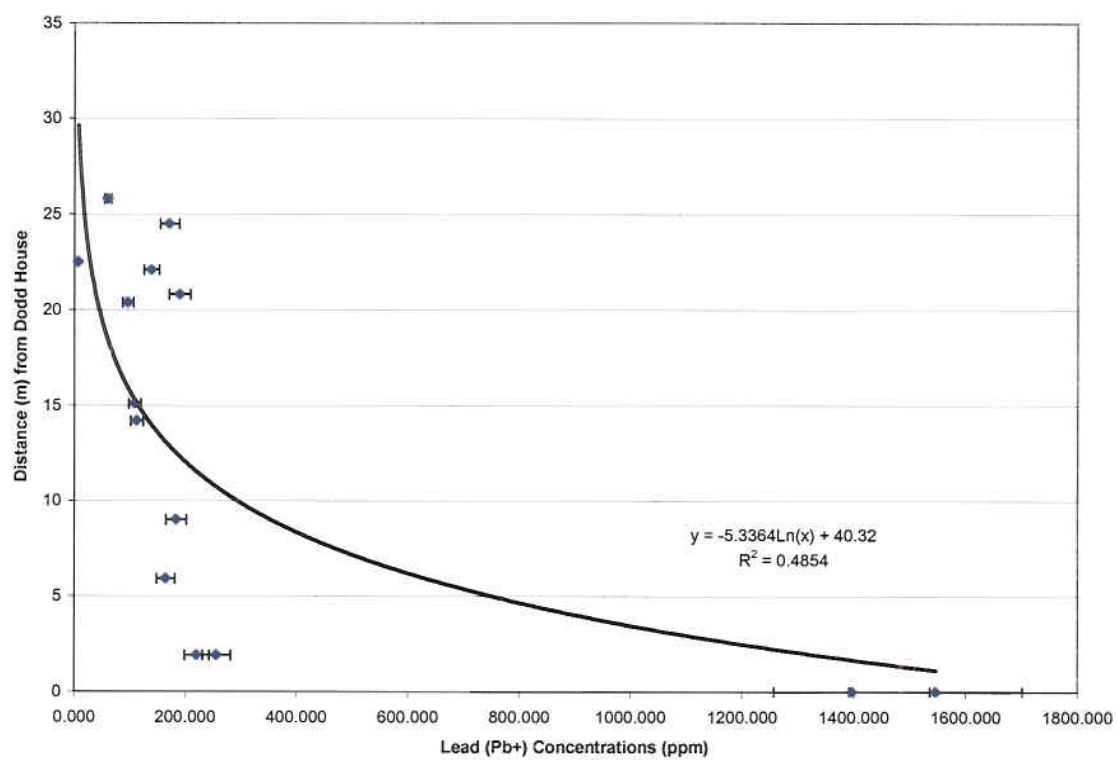


Figure 7. Lead ( $Pb^+$ ) Concentrations (ppm) as compared to distance (m) from Dodd House with Samples 4, 5, and 15 included using line of best fit.

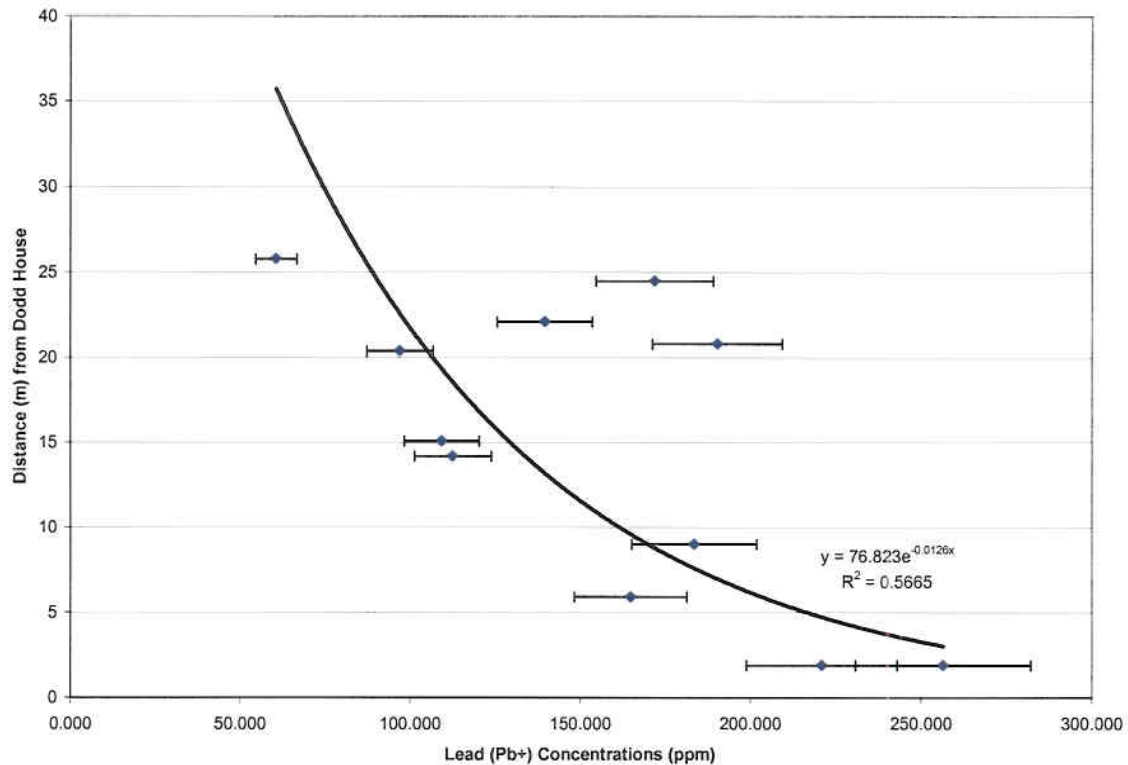
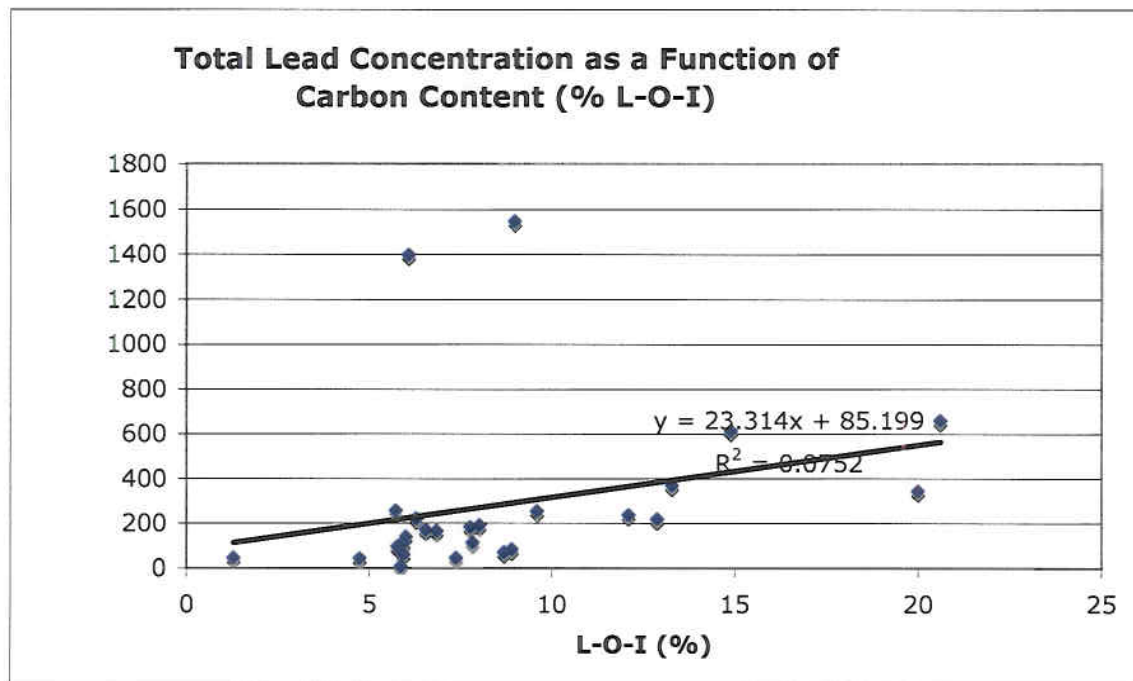
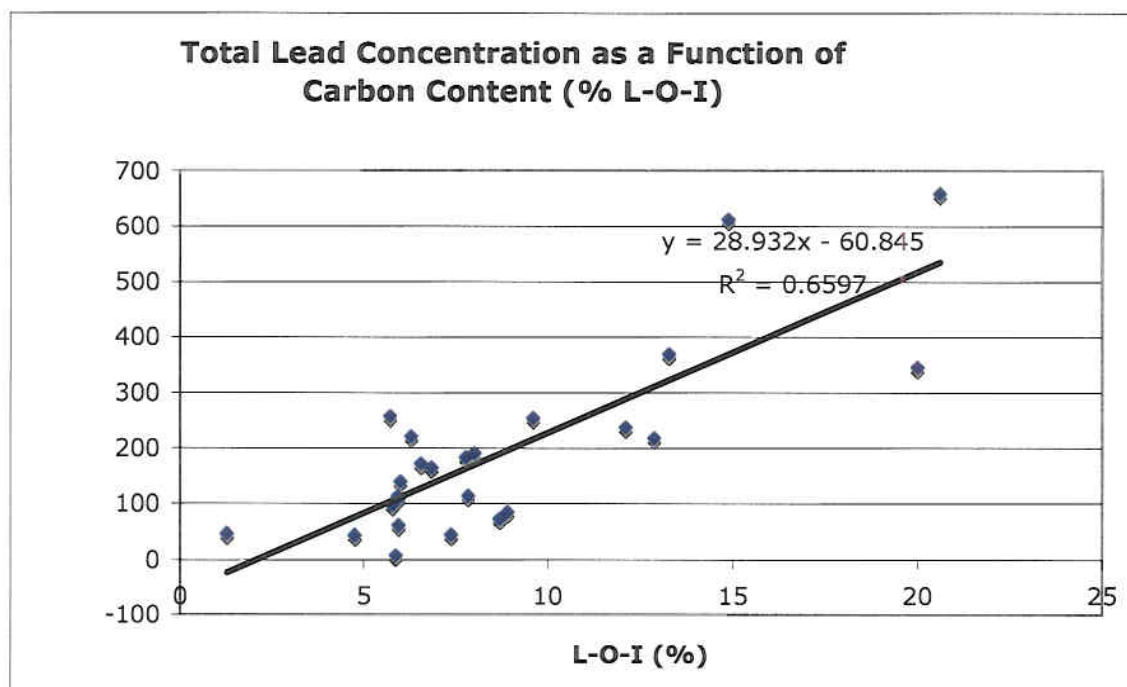


Figure 8. Lead ( $Pb^+$ ) Concentrations (ppm) as compared to distance (m) from Dodd House without Samples 4, 5, and 15 using line of best fit.



*Figure 9:* Total Lead Concentration as a Function of Carbon Content (Measured as the Percentage Loss-On-Ignition) for Soil Samples Taken from Land to the East of Dodd House



*Figure 10:* Total Lead Concentration as a Function of Carbon Content (Measured as the Percentage Loss-On-Ignition) for Soil Samples Taken from Land to the East of Dodd House, Samples 4 and 5 Eliminated as Outliers

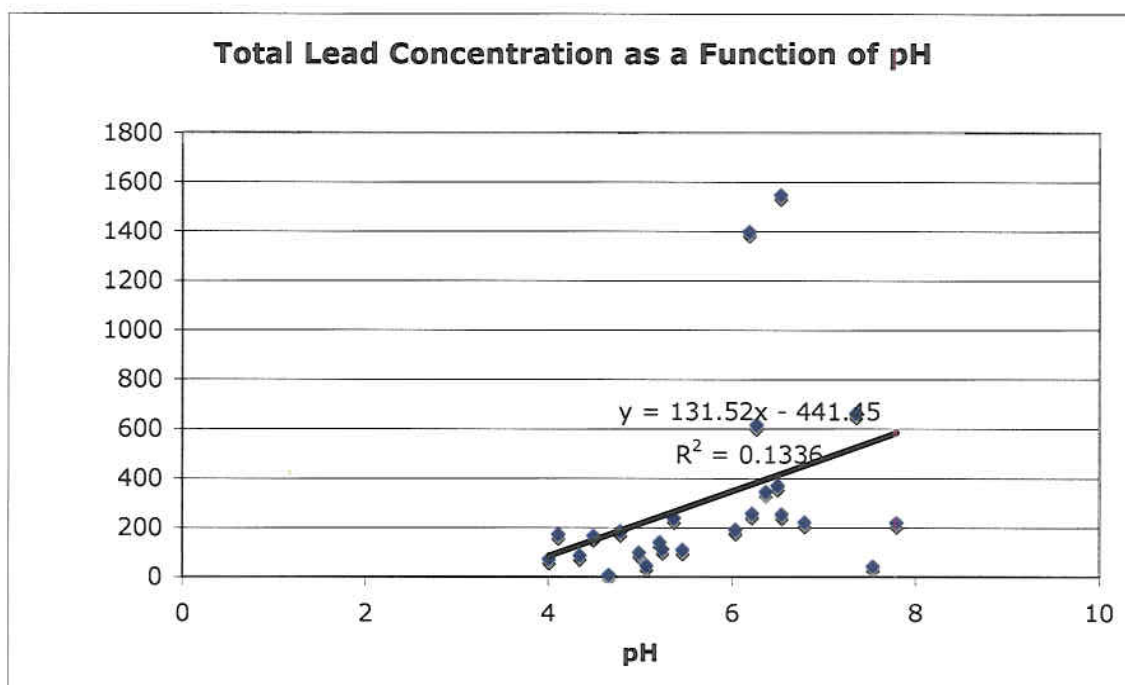


Figure 11: Total Lead Concentration as a Function of pH for Soil Samples Taken from Land to the East of Dodd House

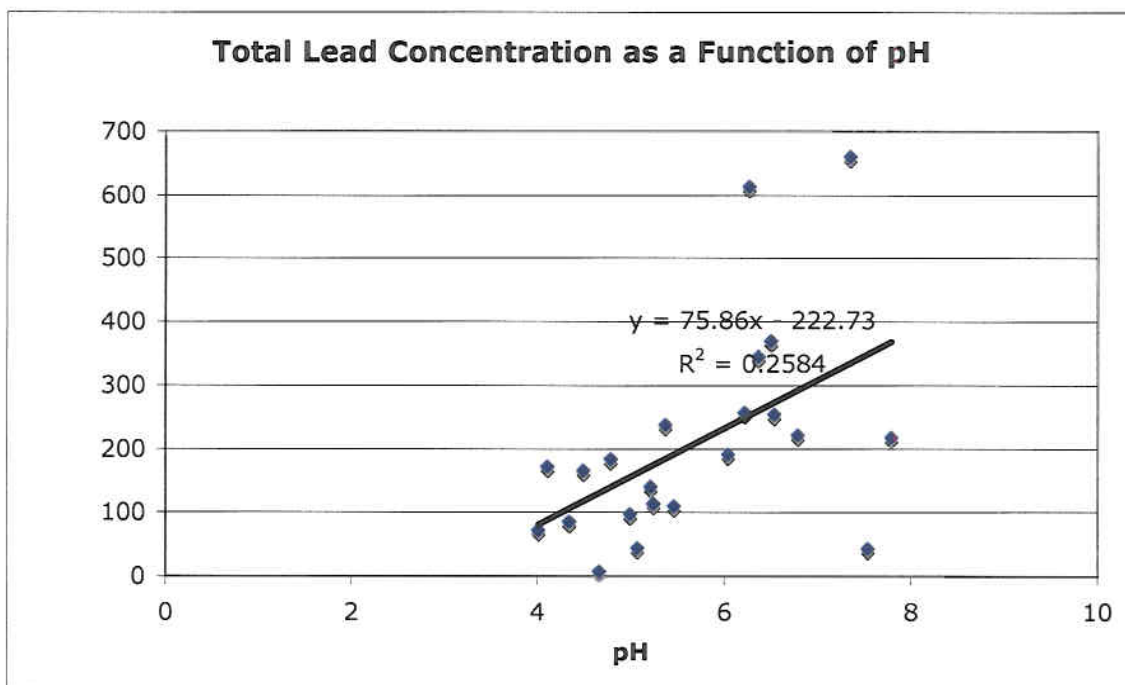
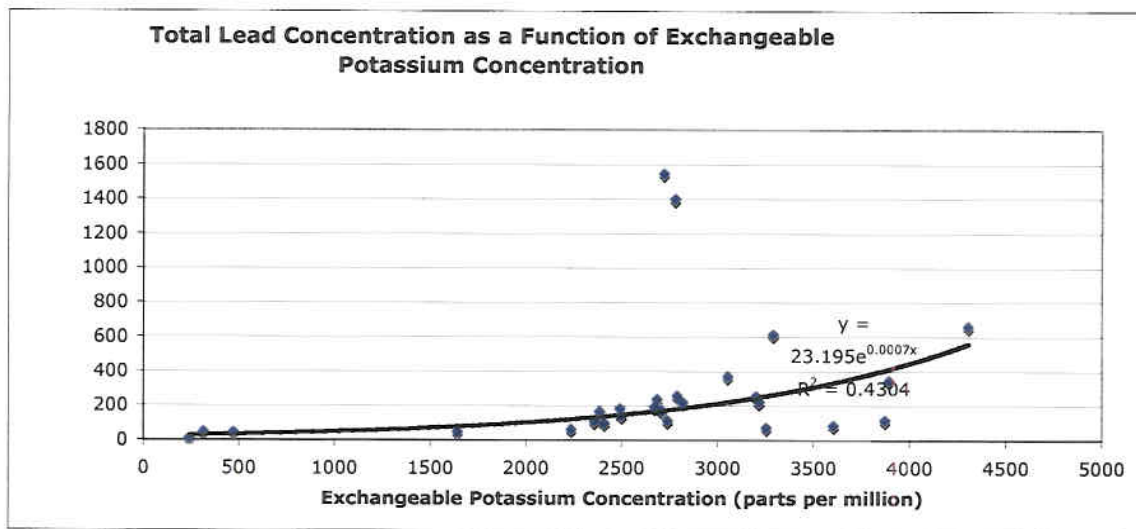
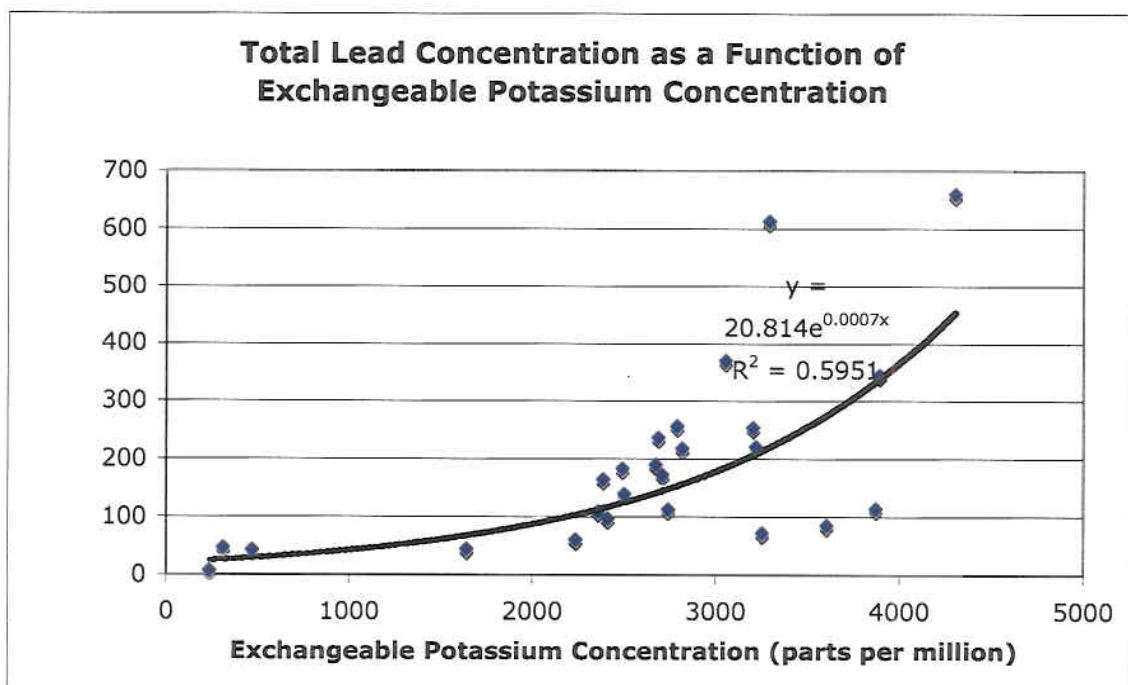


Figure 12: Total Lead Concentration as a Function of pH for Soil Samples Taken from Land to the East of Dodd House, Samples 4 and 5 Eliminated as Outliers





*Figure 13:* Total Lead Concentration as a Function of Exchangeable Potassium Cation Concentration for Soil Samples Taken from Land to the East of Dodd House



*Figure 14:* Total Lead Concentration as a Function of Exchangeable Potassium Cation Concentration for Soil Samples Taken from Land to the East of Dodd House, Samples 4 and 5 Eliminated as Outliers

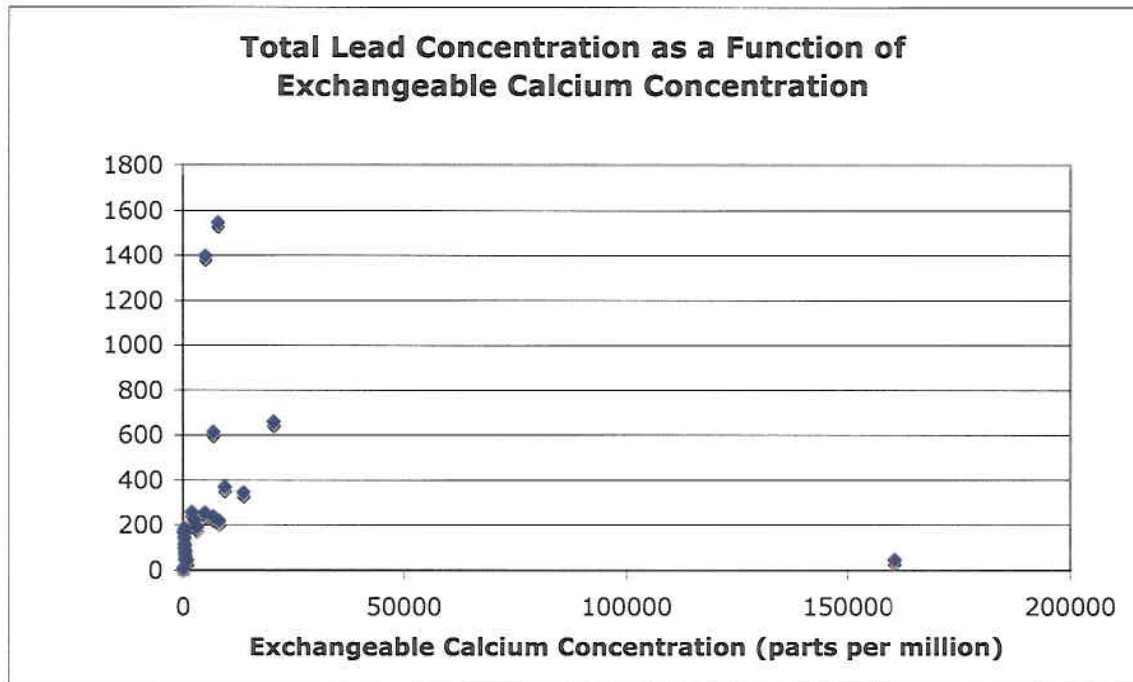


Figure 15: Total Lead Concentration as a Function of Exchangeable Calcium Cation Concentration for Soil Samples Taken from Land to the East of Dodd House

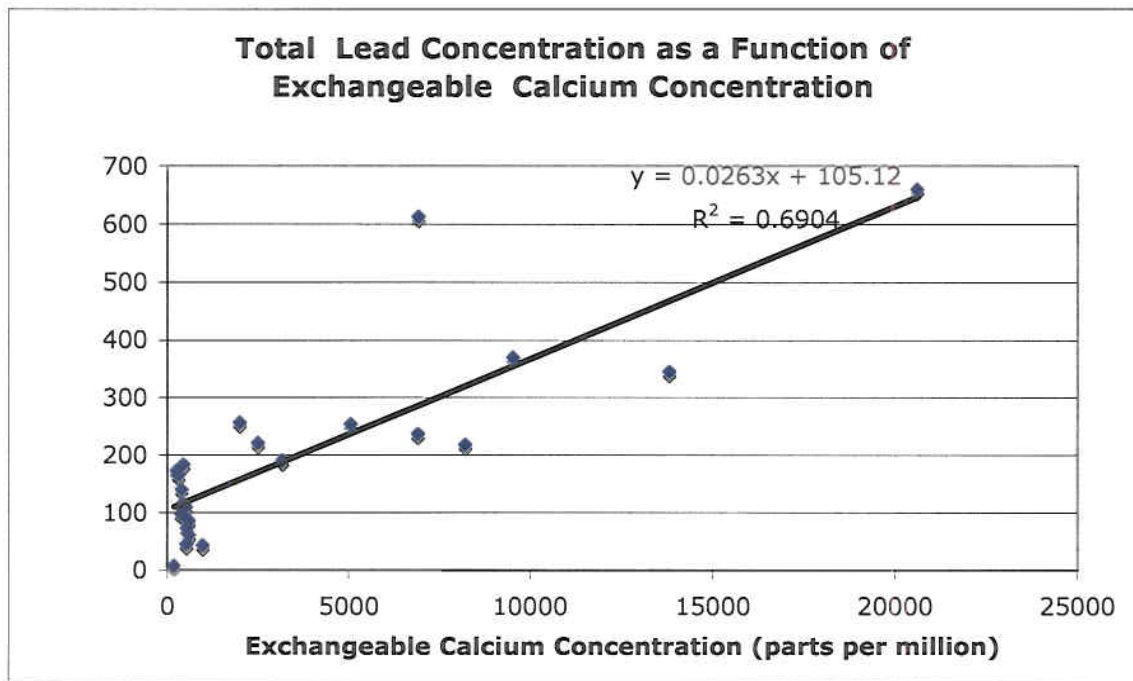
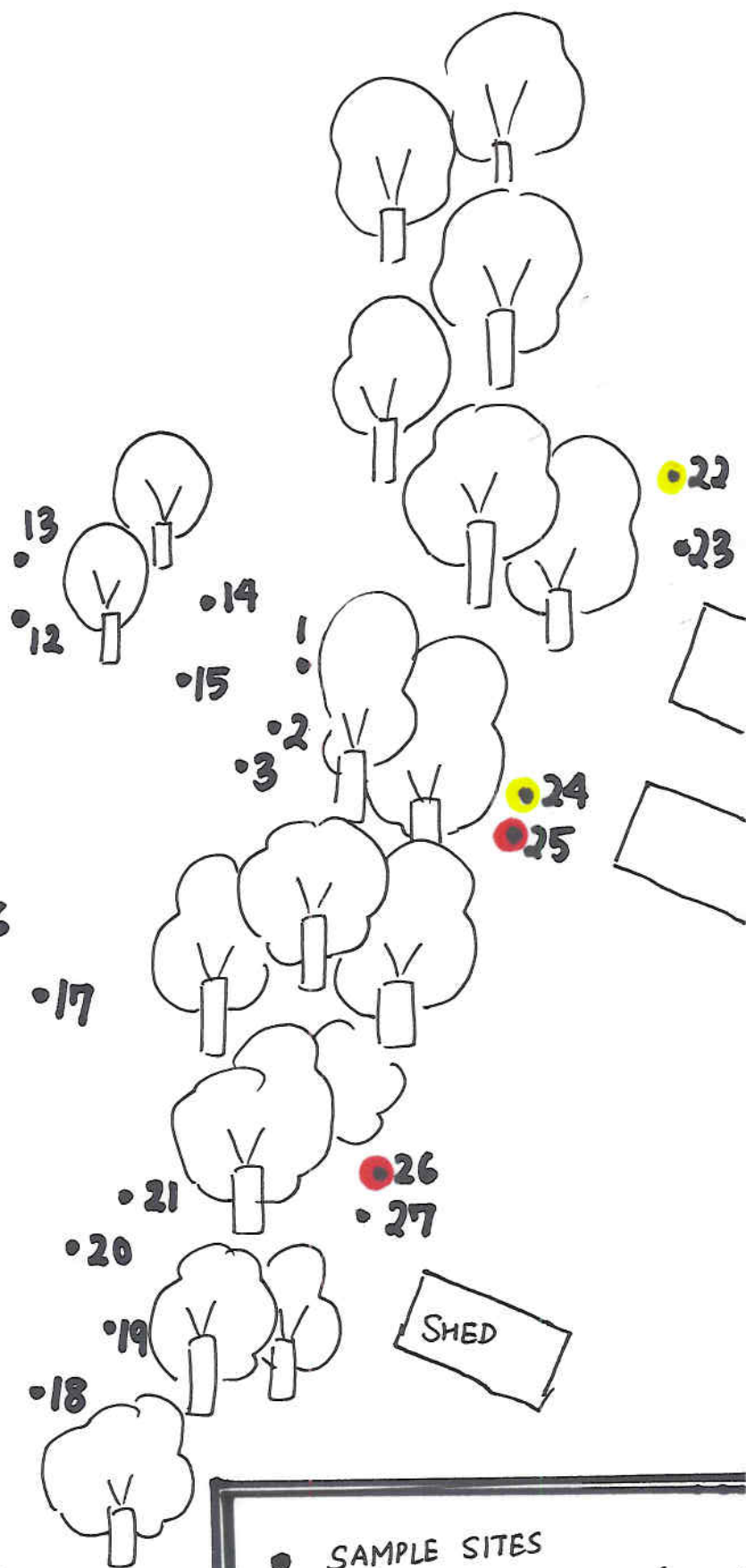
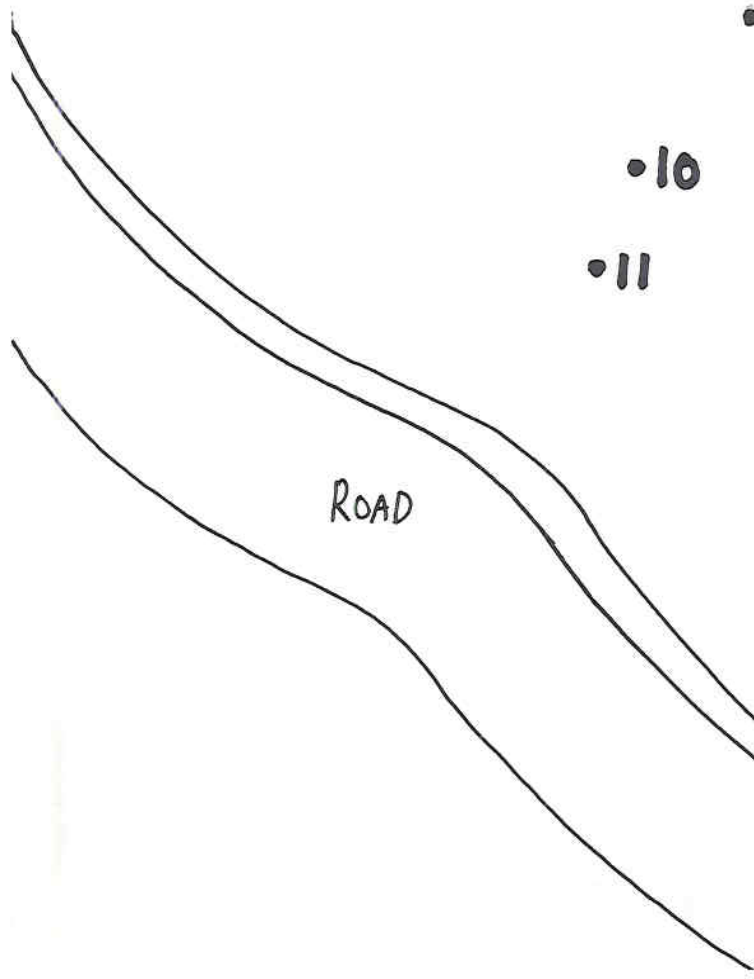
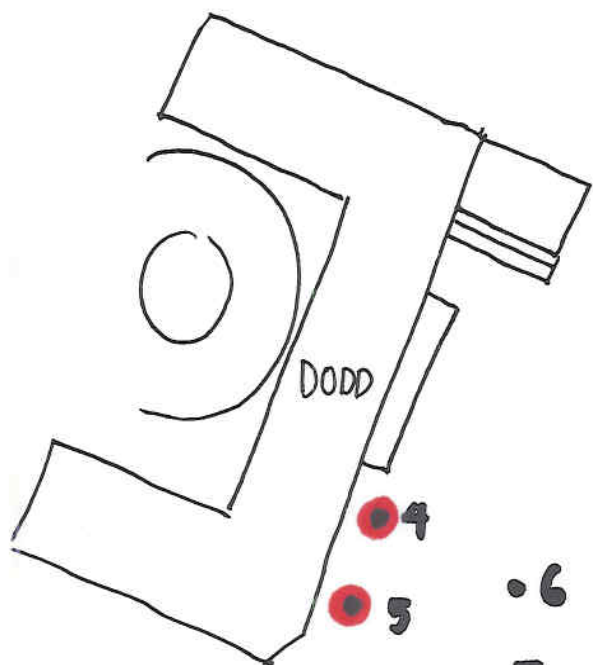


Figure 16: Total Lead Concentration as a Function of Exchangeable Calcium Cation Concentration for Soil Samples Taken from Land to the East of Dodd House, Samples 1, 4 and 5 Eliminated as Outliers



- SAMPLE SITES
- Pb EXCEEDS EPA LEVEL (400ppm)
- Pb EXCEEDS MASSDEP LEVEL (300ppm)

Site Number	Crucible Num	Empty Crucib	Crucible + we	Wet soil	Weig crucible + dry	dry soil weight
	1 w1	10.82	13.16	2.34	13.15	2.33
	2 w2	11.04	13.39	2.35	12.81	1.77
	3 w3	11.92	13.94	2.02	13.6	1.68
	4 w4	18.12	20.15	2.03	19.76	1.64
	5 w5	16.95	19.34	2.39	18.84	1.89
	6 w6	18.16	20.55	2.39	20.08	1.92
	7 w7	11.76	13.8	2.04	13.35	1.59
	8 w8	16.57	19.03	2.46	18.61	2.04
	9 w9	18.41	20.59	2.18	20.21	1.8
	10 w10	17.53	19.74	2.21	19.15	1.62
	11 w11	17.24	19.64	2.4	19.09	1.85
	12 w12	18.18	20.5	2.32	20.03	1.85
	13 w13	18.06	20.02	1.96	19.58	1.52
	14 w14	20.87	23.26	2.39	22.7	1.83
	15 w15	17.82	20.21	2.39	19.69	1.87
	16 w16	21.03	23.43	2.4	22.93	1.9
	17 w17	18.45	20.76	2.31	20.28	1.83
	18 w18	18.03	20.11	2.08	19.52	1.49
	19 w19	18.39	20.73	2.34	20	1.61
	20 w20	17.59	19.01	1.42	18.6	1.01
	21 w21	17.89	19.92	2.03	19.42	1.53
	22 w22	18.77	21.24	2.47	20.32	1.55
	23 w23	17.01	19.27	2.26	18.72	1.71
	24 w24	17.83	19.95	2.12	19.11	1.28
	25 w25	17.58	20.08	2.5	19.26	1.68
	26 w26	11.48	13.49	2.01	12.79	1.31
	27 w27	11.84	14	2.16	13.41	1.57
porch paint		17.28				
trim paint		18.2				
house paint		18.31				
small pipe		17.66				
rusted pipe		17.53				
ceramic pipe		18.16				



crucible + ash weight	Moisture	Conl	Carbon	Conte	pH	Pb content	Pb ppm
13.12	2.3	0.43%	1.29%			1.067	46.391
12.64	1.6	24.68%	9.60%	6.54		4.054	253.375
13.52	1.6	16.83%	4.76%	7.54		0.687	42.938
19.66	1.54	19.21%	6.10%	6.19		21.510	1396.753
18.67	1.72	20.92%	8.99%	6.53		26.600	1546.512
19.97	1.81	19.67%	5.73%	6.22		4.642	256.464
13.25	1.49	22.06%	6.29%	6.79		3.292	220.940
18.47	1.9	17.07%	6.86%	4.49		3.132	164.842
20.07	1.66	17.43%	7.78%	4.78		3.046	183.494
19.02	1.49	26.70%	8.02%	6.04		2.835	190.268
18.98	1.74	22.92%	5.95%			1.056	60.690
19.92	1.74	20.26%	5.95%	5.46		1.902	109.310
19.49	1.43	22.45%	5.92%	5.24		1.610	112.587
22.58	1.71	23.43%	6.56%	4.11		2.938	171.813
19.58	1.76	21.76%	5.88%	4.66		0.130	7.386
22.82	1.79	20.83%	5.79%	4.99		1.737	97.039
20.17	1.72	20.78%	6.01%	5.21		2.401	139.593
19.41	1.38	28.37%	7.38%	5.07		0.616	44.638
19.86	1.47	31.20%	8.70%	4.01		1.056	71.837
18.51	0.92	28.87%	8.91%	4.34		0.783	85.109
19.3	1.41	24.63%	7.84%			1.603	113.688
20.01	1.24	37.25%	20.00%	6.37		4.275	344.758
18.5	1.49	24.34%	12.87%	7.79		3.244	217.718
18.94	1.11	39.62%	13.28%	6.5		4.099	369.279
19.01	1.43	32.80%	14.88%	6.27		8.768	613.147
12.52	1.04	34.83%	20.61%	7.35		6.858	659.423
13.22	1.38	27.31%	12.10%	5.37		3.272	237.101
19.28	2					0.369	18.450
20.25	2.05					2.281	111.268
20.37	2.06					3708.000	180000.000
19.31	1.65					65.140	3947.879
19.57	2.04					0.893	43.775
20.23	2.07					-0.461	-22.271

Na (mg/L)	Na (ppm)	K Content	Potassium, ppm	Ca Content	Ca, ppm
0.567	24.335	7.252	315.304	3691	160478.261
10.82	611.299	51.25	3203.125	81.03	5064.375
1.888	112.381	7.546	471.625	15.72	982.500
6.99	426.220	42.79	2778.571	78.52	5098.701
12.43	657.672	46.81	2721.512	137.6	8000.000
9.66	503.125	50.52	2791.160	36.19	1999.448
8.13	511.321	47.96	3218.792	37.42	2511.409
7.03	344.608	45.36	2387.368	5.919	311.526
7.85	436.111	41.39	2493.373	7.423	447.169
7.69	474.691	39.83	2673.154	47.47	3185.906
5.96	322.162	38.91	2236.207	10.58	608.046
7.43	401.622	41.03	2358.046	8.951	514.425
5.7	375.000	39.19	2740.559	7.033	491.818
10.46	571.585	46.36	2711.111	4.482	262.105
0.742		4.232	240.455	3.196	181.591
7.27	382.632	43.17	2411.732	7.114	397.430
6.79	371.038	43.01	2500.581	7.059	410.407
3.253	218.322	22.68	1643.478	7.303	529.203
10.68	663.354	47.85	3255.102	8.002	544.354
7.85	777.228	33.17	3605.435	5.552	603.478
8.19	535.294	54.6	3872.340	6.04	428.369
6.99	450.968	48.28	3893.548	171.3	13814.516
7.21	421.637	42.01	2819.463	122.3	8208.054
3.89	303.906	33.9	3054.054	105.8	9531.532
6.59	392.262	47.07	3291.608	98.96	6920.280
7.61	580.916	44.77	4304.808	214.4	20615.385
5.79	368.790	37.08	2686.957	95.34	6908.696

Distance (m) from	2nd Distance (m)	From
0 dig site		
0 dig site		
0 dig site		

---

0 house		
0 house		
1.9 house		
1.9 house		
5.9 house		
9 house		
20.8 house	19.1	road
25.8 house	19.4	road
15.1 house		
14.2 house		
24.5 house		
22.5 house		
20.4 house		
22.1 house		
6.1 road		
7.3 road		
14.7 road		
16.3 road		

---

6 property line
6.5 property line
5.3 property line
5 property line
3.3 property line
3.5 property line