

# Development of a Soil Analysis Toolkit for Landscape Professionals and Home Gardeners

Lilian Chou, Kyle Gregory Kneeland, Alessandro Lorenzo Lallas, Kimberly See-Yan Mak, Victoria Suzanne Mcrae, Nicholas Chester Tom, Shiyi Zheng

## Abstract

The goal of this project is to examine soil health indicators, test various methods for evaluating those indicators, and create a toolkit using data collected to provide a cost effective way for people to test their soil. Soil quality relies on a combination of many chemical and physical characteristics that ensure plants grow healthy. Through a literature review, a plethora of soil quality parameters was sorted through to find the most relevant for home gardeners. Once our list of parameters of interest was narrowed, we then wanted to look at how to easily and accurately test for parameters, so that gardeners could evaluate the quality of their own soil. Much research has been done about the best standards for different soil quality tests, and this project aimed to determine which tests were the most helpful and feasible. This was accomplished with the aid of two clients, the Huntington Botanical Gardens in Pasadena, CA (the Huntington) and the Natural History Museum (NHM) in Los Angeles, CA. Samples were gathered from various locations at both to test soil quality via widely accepted lab standards and internal, informal tests. By comparing different testing methods to industry-standard laboratory results, methods that could accurately measure soil quality were pinpointed and so are indicated as useful to home gardeners. The information on important soil quality parameters and corresponding test methods were incorporated into a handbook that could be used by gardeners, or anyone of interest.

## Introduction

Soil health is a culmination of chemical, physical, and biological properties of soil. Among others, these properties include nutrient content, pH, soil texture, soil organic matter, bulk density, and infiltration. For the purposes of this project, these properties are focused on as important soil quality indicators and thus indirect measurements to assess soil health. They indicate what conditions are most appropriate for agricultural and horticultural productivity, plant and animal habitat, and ecosystem functionality.

One of the most prevalent issues affecting soil health is soil compaction, the reduction of pore sizes and particle distribution. It often negatively affects ecosystem functioning (particularly plant health) by restricting root growth, reducing water infiltration, and by limiting the storage of organic matter. Some related properties such as pH, electrical conductivity, and nutrient content can be measured through soil sampling and analyzed in the lab. Microbial indicators, such as respiration, can be used to assess soil health by evaluating microbial activity in the soil via microbial assays. Thriving microbial activity indicates functional soil where nutrients can be processed and cycled. If plants and microorganisms are thriving in the soil, then it is likely that the soil is healthy and thus not compacted.

The project's aim is to create a toolkit that will allow home gardeners to use methods that provide comparable results to laboratory soil quality testing methods. Data is comprised of results from at home tests and results from Wallace Laboratory, a prominent soil testing lab. At-home tests will be analyzed relative to professional tests to see which can most accurately

determine soil quality. Soil compaction appears to be one of the biggest issues in terms of soil quality, so it is hypothesized that the soil quality indicators will show that compacted soil is less productive than non compacted soil. The toolkit will ideally be able to explain the various soil quality indicators and show the best method that can be used to test for each parameter and also recommendations for improving soil quality in a way that the general public can understand. Because getting results from professional laboratories is very expensive, it is not practical for a layperson to be capable of getting professional help. Our toolkit outlines methods that home gardeners can purchase at an affordable price relative to expensive lab testing, with results that are easily understood so they can alter the soil as efficiently but effectively as possible.

## **Methods**

Testing sites were determined based on our clients' recommendations and wishes. A variety of areas was necessary to compare results based on the types of site: problem areas with diminished plant growth, nonproblem areas, and compacted areas. Different at-home methods were chosen for each soil quality testing indicator. Each of the methods chosen were used at all sites. Data from Wallace labs was then compared to results from the at-home testing methods. Finally, each parameter was statistically analyzed to determine both how accurate and how feasible at home tests are compared to professional laboratory tests.

### **a. Site Descriptions and Sampling Locations**

To determine which sites to collect soil samples from, we walked through the gardens with each client or client contact. Sites were selected based on client's previous knowledge and desire to learn more about soils from that particular area. All sample sites had mulch on top and were landscaped with a combination of native and non-native plants.

For the Huntington, 8 samples were collected (Fig 1). Of these samples, six were taken to compare soil quality in areas where plants were successful to compare to areas where plant growth was visibly stunted or missing. These were designated as non-problem and problem areas, based on information from the client. The remaining two samples were taken from areas of compacted soil, in order to determine the difference in quality and whether the remediation techniques used by the client to decompact soil were successful. There were four non-compacted non-problem samples (NCNP, NE, CNP, SC), two samples from non-compacted problem areas (NCP, CP), and two samples from compacted areas (CA, S).

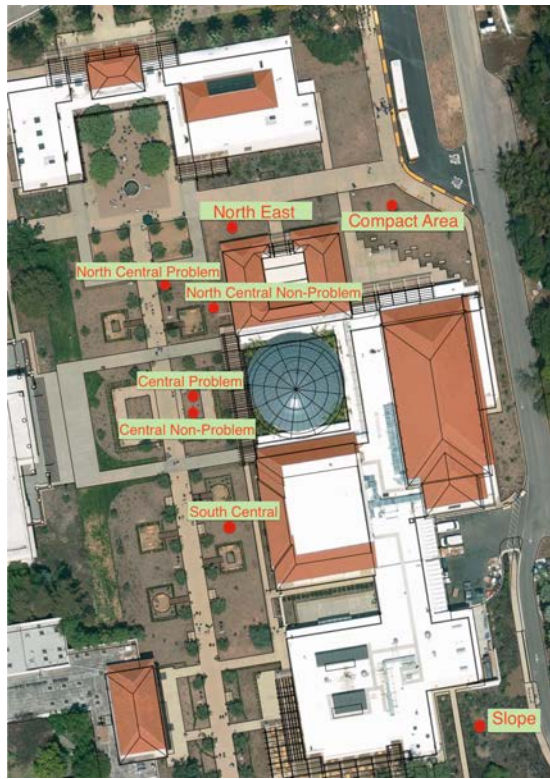


Figure 1. Map of Huntington Gardens with red circles indicating 8 sites from which soil samples were collected.

From NHM, 3 soil samples were collected, based on ease of access, previous site knowledge by the gardener, and desire to know more about site characteristics (Fig 2). One of the samples from NHM was compacted due to construction practices of the past (BP), whereas the other two were non-compacted problem areas (NS and UW). Northside (NS) was exposed to sunlight and had little plant cover, whereas UW was underneath trees in a man-made riparian environment, so soil was much more moist.



Figure 2. Map of Natural History Museum, with red circles indicating locations where soil samples were collected.

### **b. Sample Collection Method**

Two methods for collecting samples were used at each site location. Before the samples were collected the topsoil and mulch had to be removed. In compacted areas, a pickaxe was used to loosen sediment so that soil could be collected (Figure 3). Using a trowel we dug approximately 6 inches into the soil and filled about three quarters of gallon sized ziplock bags with soil sample (Figure 4). Our other method was core sampling which required us to push a soil core sampler down into the ground 6 inches deep, or as far as possible. In order to successfully push the tool into the ground the handle was twisted until it reached the 6 inch mark. When removing it, it was important to prevent the sample from falling out. Then the soil sample from the core was emptied into a ziplock bag. To get all of the sample off of the core, it could be hit or the remaining soil could be scraped off. All samples were kept in a refrigerator 4 degrees celsius until sampled or tested.



Figure 3. Compacted soil sometimes required breaking up the top layer with a pickaxe in order to loosen sediment and allow soil sample to be collected. This image shows the Butterfly Pavilion, which was the compacted location at the Natural History Museum.



Figure 4. Using a trowel to dig 6 inches into the soil to collect sample.

**c. Developing a Soil Analysis Toolkit: Comparison of professional techniques and at-home test methods**

The literature review has covered what are the most important parameters in regards to soil health. Soil health is dependent on multiple factors and to determine which factors are the most relevant in examining soil quality we sent out an interview to professionals in the field including professors in related fields. From those results, these six soil quality indicators were chosen to test for: nutrients, pH, soil texture, soil organic matter, and bulk density. For each of these parameters, laboratory methods and at-home methods were chosen based on their procedures and feasibility. Wallace lab was used to receive accurate data from a professional laboratory. Results from at home methods, which are cheaper are more accessible to a wide range of people, were compared to the results from Wallace lab to examine which at home methods were most accurate. How these at home tests can be used will be included in the toolkit.

I. **Nutrients (N, P, K):**

To test nutrient levels, Wallace Labs used the methods described in Methods of Soil Analysis Part 3 for extractable nitrogen, phosphorus, and potassium (Method of Soil Analysis Ch. 37, 32, 19).

For the at-home test to compare to Wallace Lab methods, we chose to use a testing kit because it is affordable and can be easily ordered online. The test kit includes tests for N, P, and K. Following the instructions in the testing kit, we mixed some soil samples with water in a ratio of 1:3. Next, we waited the solution to settle for 48 hours. This amount of time ensures that a majority of the soil particles including the clay particles settled to the bottom, but that the nutrients would still be suspended. Then, a dropper was used to take the upper level clear solution from the mixture and fill up the test chamber and reference chamber of the comparator. Then, a capsule containing the appropriately colored testing powder for the nutrient of interest was opened and added to the testing chamber. After shaking the comparator vigorously for 30 seconds, it was allowed 10 minutes for color change to occur. Then the color change in the testing chamber was compared to the color chart on the reference chamber (Luster Leaf Rapitest Soil Tester Kit).

II. **pH:**

Professional soil testing lab can conduct pH tests that are more accurate than homecrafted methods, but for results not requiring high accuracy, the at-home method is sufficient. The testing kit can be ordered online, together with the nutrients testing kit. The process is similar: mix the soil sample with water, add the solution to test chamber with dropper, add testing powder to the solution in chamber, and then compare the color with the reference color list after shaking. Compared to a professional lab, the at-home test is fast and cheap, but the pH testing kit has a very limited result range, from 4.5 to 7.8, which sometimes may not cover the exact pH value of the sample.

III. **Soil Texture:**

For the analysis of soil texture by a professional method, a test was conducted to determine particle size distribution using a hydrometer, following standard test method D 422-63 (ASTM 1985). We conducted this test within a research laboratory at UCLA that had the

necessary standard equipment and materials, thus the setting could be considered professional. The process is complex and requires equipment not easily accessed by a nonprofessional audience. However, results are more accurate than a mason jar test.

To analyze soil texture through home method, a mason jar test was implemented. This method is low cost and can be easily conducted at home. The mason jar test consists of mixing a soil sample with water and detergent in a glass jar (Whiting et al., 2016). After mixing, measurements of particle layers determine the soil texture. Key aspects include avoidance of moving the jar after settling, marking (e.g. with a fine permanent marker) the depth of sand and then silt after a specific interval of time, and leaving it on a flat surface. Results depend on sand and silt layer depths immediately after settling rather than the final layers. After a long period of time, these final layers are fully settled and particles are no longer separated by sand, silt, and clay.

#### IV. **Soil Organic Matter:**

Wallace labs determined soil organic matter based on percent organic carbon amount using the combustion method described in *Methods of Soil Analysis, Part 3, Ch. 34*. This method involves heating a subsample of soil to a very high temperature to burn off the organic matter. The difference in weight between the original subsample and the heated subsample was the loss of organic matter. Using this weight, the percent organic matter is calculated by dividing the organic matter weight by the total weight of the original subsample (ASTM D 2974-14, 2014). Because this is the only standard method for measuring soil organic matter, we did not conduct our own tests for soil organic matter on the soil samples.

#### V. **Bulk density:**

Instead of looking directly at bulk density, Wallace Labs analyzed the soil for total porosity, using Method 2.3 from *Methods of Soil Analysis, Part 1*. Porosity is a measure of the total amount of pore space within the soil. It is related to bulk density, as a soil with low porosity will have a high bulk density. To test the bulk density of the soil samples, we used the NRCS Soil Quality Test Kit Guide methods for bulk density (1999). Before testing, soil samples within plastic bags were thoroughly mixed by kneading with fingers. Then, small subsamples of a known volume were extracted from each sample bags and placed within pre-weighed ceramic cups to account for the added weight. The weights of the subsamples within ceramic cups were then taken and recorded. Ceramic cups were placed in a drying oven at a very high temperature, enough to remove water but not to burn off organic matter or alter mineral structure. The weight of subsamples was taken periodically. When there the weight of subsamples stopped decreasing, the final weights of the subsamples were taken and recorded as the oven dry weight. From this data, bulk density was calculated using the following equation:  $\text{bulk density (g/cm}^3\text{)} = \frac{\text{oven dry weight of soil subsample}}{\text{volume of soil subsample}}$  (Soil Quality Test Kit Guide, 1999).

Comment [1]: Actual temperature needed: ask Brandon?

Comment [2]: Farmer thinks that disturbing soil may lower bulk density than in actual site? He thinks we should take an undisturbed sample. (This could explain lower than expected values for Table 9)

#### VI. **Infiltration:**

Wallace labs provided a relative infiltration rate, using Method 34b of *Agricultural Handbook Number 60*. It could only be relative because actual infiltration rate data must be obtained in the field. For our portion of research, we conducted two different types of infiltration tests at Huntington Gardens and the Natural History Museum. The first infiltration test was

simplified version of a ring infiltrometer test, using a large soup can as the ring. The second type of test used was called a percolation test. At Huntington, infiltration tests were carried out on locations *compact area*, *north central non-problem*, and *slope*, which was compacted as well. These locations were chosen in order to compare infiltration rates in compacted versus non-compacted areas. At Natural History Museum, infiltration tests were done at two locations, *north side* and *urban wilderness*, which are both areas in the garden where plants struggle to grow. We used both types of tests at each of these locations in order to compare the accuracy of the testing methods, and to provide data on those location's soil quality. Tests were conducted side by side, with around 1 ft of undisturbed soil between them.

For the ring test, we adapted methods used in the Soil Quality Test Kit Guide, 1999. First, we removed the top and bottom lids of a large metal soup can with dimensions of 6" diameter and 9" height. We used a soup can in order to demonstrate the ability to use home products in these tests. At each test location, vegetation and mulch was removed from the top layer of the soil. Using a short piece of 4x4 wood placed on top of the can and a rubber mallet, the soup can was uniformly hammered into the cleared soil area to a depth of 3 inches. In order to minimize horizontal water movement within the soil, the can needs be level. A ruler was fastened to a metal stake which was inserted vertically into the center of the can so that the 0 inch mark lay at the soil surface. This was used to measure water height at a fixed reference point. The can was filled to the top with water and the timer started immediately. The height of water within the can was measured and recorded at the start of the timer and every 30 minutes thereafter for the next three hours.

Methods for the percolation tests were adapted from the Environmental Protection Agency (EPA) Falling Head Percolation Test Procedure (EPA 2002). On the day prior to conducting the percolation test, a hole with dimensions 12 in deep and 6 in diameter was excavated, carefully filled to the top with water, and covered with a large bucket to prevent evaporation. The water was allowed to infiltrate overnight, as presoaking in advance can limit lateral infiltration from the hole during actual testing (Cahill et. al, ORESU-G-11-008). On the day of testing, a ruler was taped to a camping stake which was then inserted into the center of the pit so that the 0 inch mark pointed up and the 12 inch mark was at the soil surface. It remained fixed at this spot for the length of the test, so to provide precise readings. The hole was filled to the 0 inch mark and the timer was immediately started. The height of water within the hole was measured and recorded every 30 minutes for the next three hours.

Using the recorded measurements of water height from both the ring and percolation test, infiltration rate was calculated for each testing location using the following formula:  $(B-A)/C$  where B is last recorded water level, A is the initial water level, and C is the number of hours the water infiltrated for.

#### **d. Analysis of Compacted versus Non-Compacted Soils**

To determine the quality and characteristics of soils in compacted areas to non-compacted areas, samples were collected at both client sites in areas of compacted and non-compacted soil using similar methods as discussed above. Sample location for compacted soils were determined based on previous knowledge held by clients, data from previous construction projects, and failure or difficulty of plant growth. The same test as discussed in Section II.b were



applied to these samples to determine their quality. Compacted samples and non-compacted samples were then qualitatively analyzed.

## **e. Statistical Analyses**

### *I. Nutrients (N, P, K)*

For the statistical tests, the nutrient values were averaged between “North Central Problem” site and “North Central Non-problem” site values because the samples were taken in close proximity to each other (approx. 10 feet); nutrient values from Central Problem were omitted due to contamination with mulch. Nitrogen values from the lab were compared to nitrogen values from the at-home method, using statistical t-test at a significance level of 0.05. The same manner of conducting the t-test was done on potassium values and phosphorus values. The Rapitest phosphoric acid and potassium oxide ranges were converted to parts per million (ppm) potassium and ppm phosphorus values.

### *II. pH*

For the statistical tests, the pH values were averaged between problem and non-problem values; nutrient values from Central Problem were omitted due to contamination with mulch. pH values from the lab were compared to nitrogen values from the at-home method, using a statistical t-test at a significance level of 0.05.

### *III. Particle Size Distribution*

The % clay was qualitatively compared between the mason jar and hydrometer tests.

### *IV. Soil Organic Matter (SOM)*

SOM from the Huntington Garden samples will be qualitatively compared to the overall average SOM level.

### *V. Bulk Density*

Bulk densities between compacted and noncompacted soil samples were qualitatively compared to each other.

### *VI. Infiltration*

Infiltration rates from percolation test and ring method were compared to each other using the statistical t-test at a significance level of 0.05.

## **Results**

### **A. At-Home Test Method Verification**

Below are the results from Wallace Laboratory’s analysis and our at-home test methods for all soil samples. They are organized into tables so that results from both sources can be compared.  
 \*See Appendix Section A for sample location labels

A. Summary Statistics for at-home tests

	Professional Average	Std Error	Home Average	Std Error	Significant
pH	7.78	0.038	7.16	0.090	***
N (ppm)	11.61	1.93	11.67	1.32	No
P (ppm)	16.89	1.42	6.97	2.85	**
K (ppm)	185.88	26.41	336.61	97.31	No
Infiltration (R   P) in/hr	-3.27	0.74	-1.91	0.62	No
Bulk Density (g/cm <sup>3</sup> )	N/A	N/A	0.84	0.033	N/A
SOM (%)	3.72	.0095	N/A	N/A	N/A

\*p value<0.05, \*\*p value<0.01, \*\*\*p value<0.001

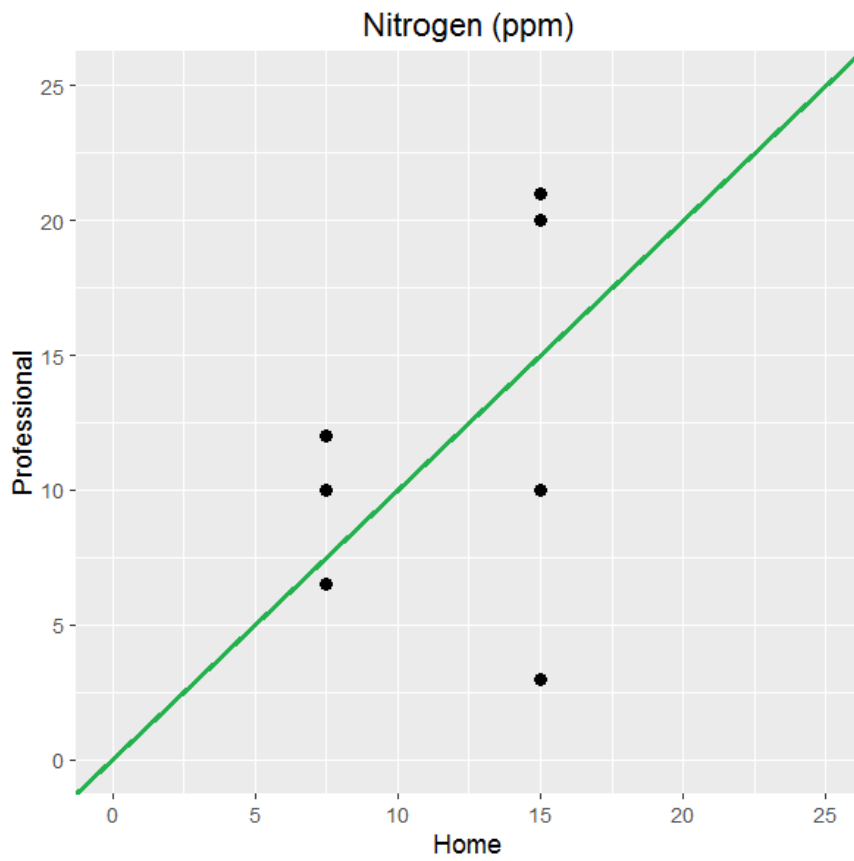
I. *Nutrients (N, P, K)*

For complete data for nutrient tests, see Appendix Section B.I

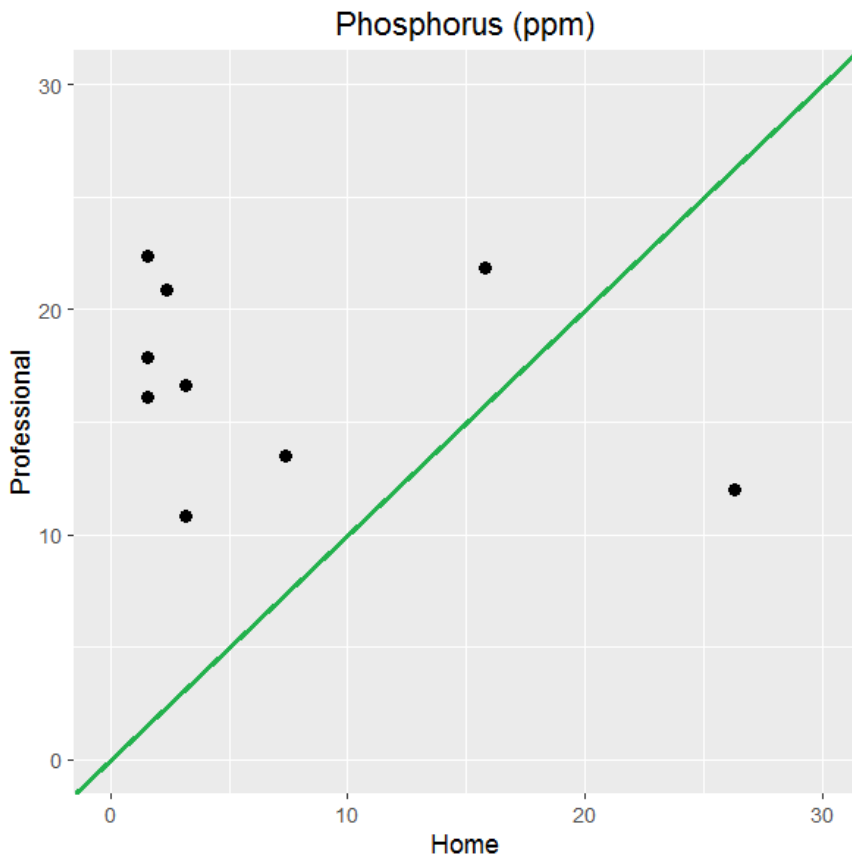
None of the nutrient level classifications from Wallace labs overlap with the nutrient level classifications from the “rapitest” kit. The p-values of the t-test for nitrogen, phosphorus, and potassium respectively: 0.9813, 0.006711, and 0.1544. Graphs 1, 2, and 3 are linear models that show the correlation between the home and professional nutrient tests. Each data point is a sample location. The Home test methods would be a perfect substitute for the Professional methods if their values are the same. That would result in a line with a slope of 1 that starts from the origin. The linear models between the home tests and professional tests resulted in the following R squared values for nitrogen, phosphorus, and potassium respectively: -0.07477, -0.0622, and 0.3571.



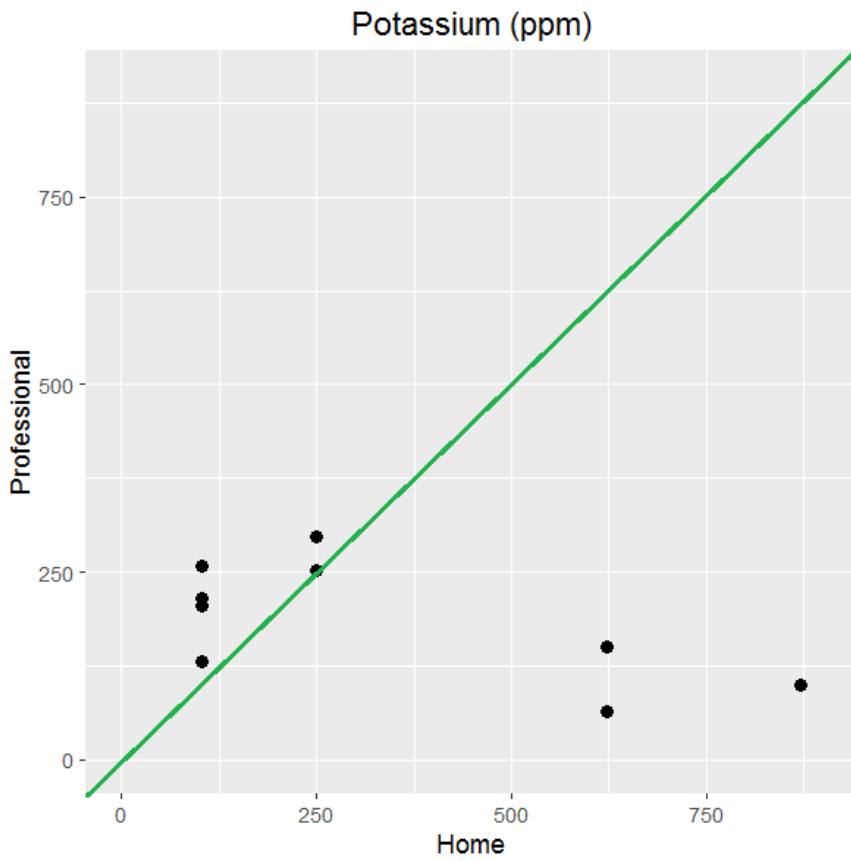
Graph 1: Correlation between Home and Professional nitrogen test results. The green line indicates where the data points would lie for a perfect correlation.



Graph 2: Correlation between Home and Professional phosphorus test results. The green line indicates where the data points would lie for a perfect correlation.



Graph 3: Correlation between Home and Professional potassium test results. The green line indicates where the data points would lie for a perfect correlation.



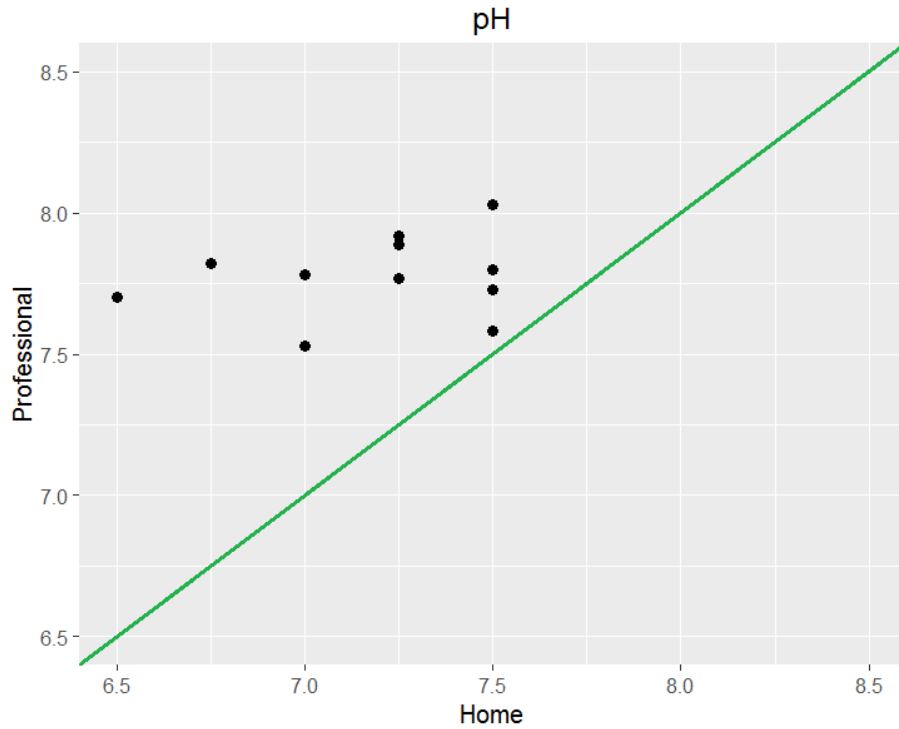
II. *pH*

For complete data from pH tests, see Appendix Section B.II

The result was  $p\text{-value} = 3.077 \times 10^{-5}$ , therefore the mean pH values from the lab method are statistically different from the mean pH values from the at-home method. Graph 4 is a linear model that shows the correlation between the Home and Professional pH test results. Each data point is a sample location. The Home test methods would be a perfect substitute for the

Professional methods if their values are the same. That would result in a line with a slope of 1 that starts from the origin. The linear model between Home and Professional pH test values resulted in an R squared value of -0.05874.

Graph 4: Correlation between Home and Professional pH test results. The green line indicates where the data points would lie for a perfect correlation.



### III. *Particle Size Distribution*

For complete data from particle size distribution tests, see Appendix Section B.III.

The particle size distribution in the mason jar was similar to those from the hydrometer with regards to each texture being at the same relative proportion, when 0 values were excluded. For example, they all reflect that clay was the smallest proportion, silt was the medium proportion, and the largest proportion was sand. 5 out of 11 mason jar results matched with the hydrometer results. The t-test between the percent clay between home and professional methods resulted in a p-value=0.008929.

### IV. *Soil Organic Matter (SOM)*

At-home SOM test methods were not conducted. For complete data from professional SOM tests, see Appendix Section B.IV

### V. *Bulk Density*

Professional bulk density tests were not conducted. For complete data from at home bulk density tests, see Appendix Section B.V

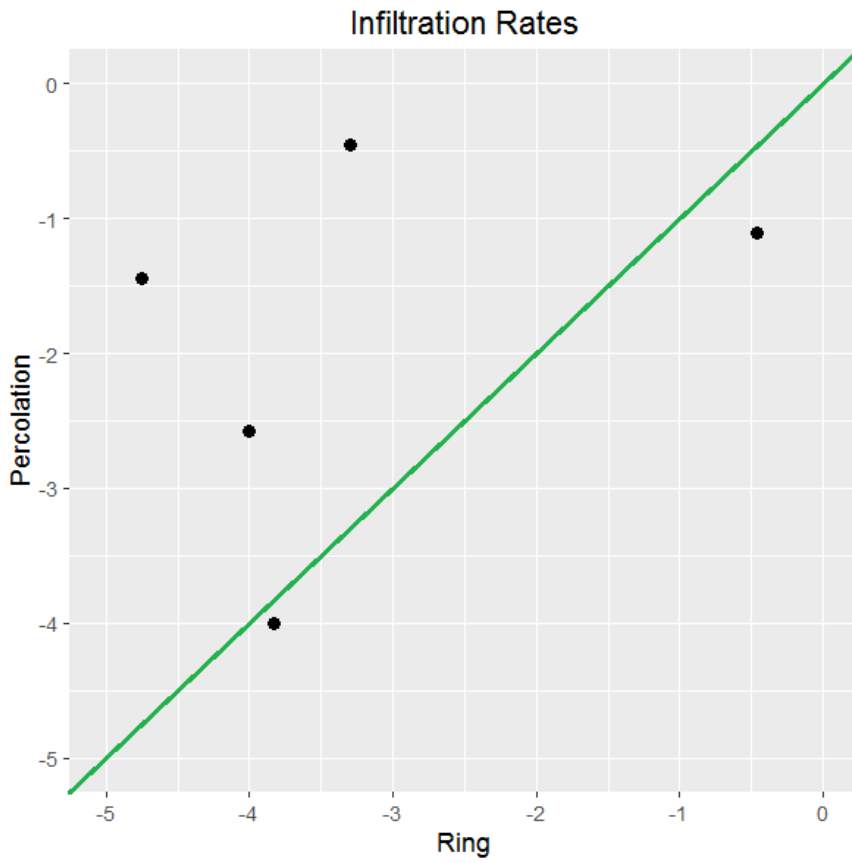
### VI. *Infiltration*

For complete data from infiltration tests, see Appendix Section B.VI

The result was p-value = 0.199, therefore the mean infiltration rates using the percolation test were not statistically different from the mean infiltration rates from the ring method. For the ring method, "Slope" and "Compact Area" had below-average infiltration rates, while only "Compact Area" had below-average infiltration rates for percolation test. Graph 5 is a linear model that shows the correlation between the Home and Professional pH test results. Each data point is a sample location. The Home test methods would be a perfect substitute for the Professional methods if their values are the same. That would result in a line with a slope of 1 that starts from the origin. An R squared value of -0.1746 resulted from the linear model.



Graph 5: Correlation between Home and Professional infiltration test results. The green line indicates where the data points would lie for a perfect correlation.



## **B. Analysis of Compacted versus Non-compacted Soils**

### **I. *Nutrients (N, P, K)***

The slope and compacted site had the lowest potassium and phosphorus values compared to the rest of the sites except for Urban Wilderness, which had the lowest level of phosphorus. Butterfly Pavilion had the second-highest level of nitrogen, but slope had the second-lowest level of nitrogen.

### **II. *pH***

The pH of the compacted sites is in the middle range of values.

### **III. *Particle Size Distribution***

The values from the compacted sites are in the middle range of values relative to the non-compacted sites.

### **IV. *Soil Organic Matter (SOM)***

Slope had the lowest levels of SOM while Compact Area had the third-lowest SOM. Both of those sites had below-average SOM values (Appendix A). Central Problem had the highest level of SOM due to contamination with mulch. The sites at Natural History Museum did not have SOM tested.

### **V. *Bulk Density***

Bulk density of the slope site is the highest, but the value for Butterfly Pavilion and Compact Area are in the mid-range of values relative to the non-compacted sites. Qualitatively, the "slope site" had the highest bulk density value, while the second compacted site had a bulk density value that fell within the range of values from the uncompacted sites'. Four of the non-compacted sites had above-average bulk density levels (Appendix A).

### **VI. *Infiltration***

The compacted sites (Slope and Compact Area) did not have the slowest infiltration rates.

## Challenges

### *I. On-site*

Throughout the course of our project we overcame many challenges. The first difficulty we encountered was during our data collection process at the client sites. We performed a ring infiltrometer test which involved hammering a large can into the ground to a depth of three inches. Due to the the soil being highly compacted at the one of the test locations, the can bent as we hammered it down. This created a very shallow water column that caused the water to drain out before adequate data points could be collected. This occurred at the *Urban Wilderness* location at the Natural History Museum. Due to this mishap we were only able to recover good data points from the infiltrometer test at the *North Side* location. Meanwhile, at The Huntington, we compiled adequate data from all of our designated locations.

### *II. In-lab*

We also surmounted a few obstacles while analyzing the laboratory data. Wallace Labs provided the results from their analyses of the soil samples in a straightforward, easy to read manner. However, some of the at-home tests we conducted in the lab were somewhat ambiguous and open to interpretation. This presented difficulties for us both in establishing the correct methodology for conducting experiments and also in analyzing the results. The pH and nutrient tests worked by producing a colored solution that had to be compared to a chart, the solution never exactly matched the color-coded legend, rendering it very difficult to pinpoint accurate results especially since the intervals were large. Due to this ambiguity, some of the data we recorded was based on the judgement of the person conducting the experiment. There were a few instances when multiple people looked at the solution and thought it matched to different values on the chart. This led to some confusion and possible misinterpretation in the results.

There was further confusion due to unclear labels on the soil samples. The various names we used to refer to the sites were reflected in our sample labels. We had to ensure not to swap any soil samples when trying to understand which site they were from. The Huntington *Slope* area was given two different labels: slope and compact area 2. This created a lot of confusion when recording data and figuring out which soil sample corresponded to each location. This problem persisted a bit longer but we eventually unified our terminology. The labeling inconsistencies led us to developing a universal naming system (which we should have created before conducting soil analysis). Though this caused some additional stress, we straightened out the data and amended the labeling disparities.

## Discussion

### *I. Nutrient (N, P, K)*

Potassium values from the lab test were not statistically different from values from the at home test. Nitrogen and phosphorus values were statistically different between the lab and at-home tests. The lack of overlapping nutrient classification levels reflects the statistical differences between the nutrient values..

Based on these findings, in our toolkit we suggested use of the test methods for soil nitrogen content as outlined by the NRCS Soil Quality Test Kit because they have independently verified this test and it may provide more accurate results while having relatively similar ease of use (NRCS Soil Quality Test Kit Section 7). We also have found that there are no “at-home” methods to determine P and K amounts in soil, as every test kit is likely to provide inaccuracies due to P and K being difficult to extract using water (Elrashidi, Soil Survey Laboratory). Therefore, in our toolkit we have recommended an alternative way of assessing P and K levels in soils through the examination of plants growing in the area. Plants deficient in phosphorus are often stunted in growth and shown unusual dark-green or reddish-purple coloration (Plant and Soil Sciences eLibrary, USDA). Plants that are deficient in potassium will have leaves towards bottom of plant initially turn light green or yellow in appearance. This abnormal coloration will soon move throughout entire plant (Rehm and Schmitt 2002).

## II. *pH*

According to the p-value, the pH values acquired from the at-home method were statistically different from Wallace Lab’s pH values, suggesting that the at-home rapitest test kit does not produce reliable results to professional lab methods. However, both Wallace and rapitest test kit pH values for six samples were still within 0.6 of each other. The urban wilderness and northside samples from NHM and compacted site, central, and south central samples from Huntington had pH values from Wallace and rapitest that were more than 0.6 units away from each other. All of these samples though were still within the “moderate” level as designated by Wallace which shows that the rapitest can give a rough idea of pH within a similar range to professional methods. Future studies could compare whether another at-home method, pH litmus paper, produces results similar to lab methods.

## III. *Particle Size Distribution*

The large variations in particle size distribution is most likely due to incorrect readings of the mason jar. Only 5 out of 11 mason jar results matched the hydrometer results. There was confusion when reading the results because after 10 minutes of settling elapsed, the soil level that was taken after 2 minutes of settling had lowered under the recorded level.

## IV. *Soil Organic Matter (SOM)*

“Compacted site 1” had a SOM within the range of the non-compacted sites’ bulk densities. The “slope site” had the lowest SOM. “Compacted site 1” may have had a SOM similar to the uncompacted sites due to similar maintenance conditions, whereas the “slope site” may have been maintained differently.

## V. *Bulk Density*

“Butterfly Pavilion” and “Compacted Area” had a bulk density within the range of the non-compacted sites’ bulk densities. The “slope site” had the highest bulk density.

## VI. *Infiltration*

The percolation test and ring test produce statistically similar infiltration rates. This suggests that both methods will provide similar infiltration rates when conducted by at-home gardeners using the methods outlined above. However, there are difficulties and issues associated with both testing methods. For the ring method, using a soup can or other home product as the

metal cylinder may not be large or sturdy enough to be driven to a sufficient depth in the soil to prevent lateral infiltration. For the percolation test, running the test on soil that was not presoaked (saturated with water), may affect the infiltration rate. In addition, both single ring infiltrometer tests and percolation tests are often known to overestimate infiltration rate (WSDOE 2005). Further research should be done to compare the at-home single ring infiltrometer test and percolation test to professional field tests to see if the at-home methods provide reliable results. For the goals of this project however, our data shows that at-home gardeners could choose either method to find an estimate for infiltration rates of their soil. Based on our experiences, we recommend the percolation test because it was easier to set-up and run.

## Conclusion

We cannot recommend the “Rapitest” soil test kit for nutrient tests. The mason jar method can possibly be an appropriate substitute for the professional tests if the tester adheres strictly to the recording the soil levels at the specified times, and doesn’t get confused by the different soil layer appearances. The ring and percolation test results do not correlate well with each other, but the t-test shows that the means of the infiltration rates between one test do not differ significantly between the other. We recommend the percolation test because the ring is difficult to hammer into the soil properly. The mean pH results for professional and at-home tests significantly differed, but we still recommend the pH test kit because it provides an adequate general picture of soil pH.

Compacted soil did not necessarily have the poorest soil quality. However, not very many samples were taken so more research needs to be done on the difference in soil quality parameters between compacted and non-compacted soil.

Our toolkit provides at-home gardeners a sufficient counterpart to professional soil tests, but at a much lower cost.

## Literature Cited

ABDTPA. Methods of Soil Analysis, Part 3 Chemical Methods. (1996). *Soil Science Society of America, Inc.* Ch. 19, pgs 570-571.

ABDTPA. Methods of Soil Analysis, Part 3 Chemical Methods. (1996). *Soil Science Society of America, Inc.* Ch. 32, pgs 897-898.

ASTM D 2974-14. (2014). Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Organic Soils. *ASTM International*, West Conshohocken, PA.

ASTM D 422-63. (1985). Standard Test Method for Particle-Size Analysis of Soils. *ASTM International*, West Conshohocken, PA.

Cahill, M., Godwin, D., Sowles, M. Infiltration Testing. *Low Impact Development Fact Sheet*. Oregon Sea Grant. ORESU-G-11-008. Oregon State University Extension, Corvallis, OR.

Combustion. Methods of Soil Analysis, Part 3 Chemical Methods. (1996). *Soil Science Society of America, Inc.* Ch. 37. pg. 1088

Diagnosis and Improvement of Saline and Alkali Soils. (1969). Agricultural Handbook No. 60. *U.S. Department of Agriculture*. Method 34b.

Elrashidi, M. "Selection of an Appropriate Phosphorus Test for soils." *Soil Survey Laboratory*. Natural Resources Conservation Service.

Environmental Protection Agency (EPA). (2002). Falling Head Percolation Test Procedure. *In Onsite Wastewater Treatment and Disposal Systems Design Manual*, EPA/625/1-80-012.

Kibblewhite, M., Ritz, K., Swift, M., 2008. Soil health in agricultural systems. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363, 685–701.  
doi:10.1098/rstb.2007.2178

Methods of Soil Analysis, Part 1. (2002). Physical and Mineralogical Methods, *Soil Science Society of America, Inc.*, Method 2.3, pgs 241 - 293

Methods of Soil Analysis, Part 3. (1996). Chemical Methods. *Soil Science Society of America Inc.*, ch. 34, pgs 965-977 & 1001-2.

Plant and Soil Sciences eLibrary. "Soils- Part 6. Phosphorus and Potassium in the Soil." *United States Department of Agriculture*.

Rehm, G. and Schmitt, M. 2002. Potassium for Crop Production. *Nutrient Management*. University of Minnesota Extension.

Soil Quality Test Kit Guide. (1999). Natural Resource Conservation Services. U.S. Department of Agriculture.

"Soil Nitrate Test." 1999. Soil Quality Test Kit Guide. Section 7. Natural Resource Conservation Services. *U.S. Department of Agriculture*.

Washington State Department of Ecology (WSDOE) Water Quality Program. (2005). Hydrologic Analysis and Flow Control Design/BMPs. *In Stormwater Management Manual for Western Washington*, Vol. III. Pub. No. 05-10-31. Washington Department of Ecology, Olympia, WA.

Whiting, D., Card, A., Wilson, C., and Reeder, J. "Estimating Soil Texture: Sand, Silt or Clayey?" *Colorado State University Extension*. Colorado Master Gardener Program, 13 Jan. 2016. Web.

# Appendix

## A. Labels for Sample Locations

CA	Compact Area
NE	North East
NCP	North Central Problem
NCNP	North Central Non-Problem
CP	Central Problem
CNP	Central Non-Problem
SC	South Central
S	Slope
NS	North Side
UW	Urban Wilderness
BP	Butterfly Pavilion

P/H: Professional or Home

N/A: Data not available as it was not provided

## B. Complete Results

The following data is a compilation of all the data collected from Wallace Labs and from our own laboratory tests.

### *I. Nutrients*

Table 1. Ranges of N, P, and K in parts per million that correspond to the relative levels given by rapitest test kit color chart.

PARTS PER MILLION EQUIVALENCY CHART
-------------------------------------



Level	0-depleted	1-deficient	2-adequate	3-sufficient	4-surplus
N (ppm)	5	10	20	50	100
Measures NO <sub>3</sub> , nitrate					
P (ppm)	5	10	20	50	100
Measures P <sub>2</sub> O <sub>5</sub> , phosphoric acid					
K (ppm)	50	200	400	600	900
Measures K <sub>2</sub> O, Potassium Oxide					

Table 2. Converted table 1 values of P<sub>2</sub>O<sub>5</sub> to ppm P and K<sub>2</sub>O to ppm K

Level	0-depleted	1-deficient	2-adequate	3-sufficient	4-surplus
P (ppm)	1.05	2.1	4.2	10.5	21
K(ppm)	41.5	166	332	498	747

Table 3. Levels of nutrients that we established to correspond to ranges of extractable nutrient amounts in parts per million, according to results provided by Wallace Labs.

extractable - ppm (mg/kg) soil dry weight basis	Interpretation of data			
	low	medium	high	Very high
<b>Phosphorus</b>	0 - 7	8-15	over 15	Over 50
<b>Potassium</b>	0-60	60 -120	121-180	Over 300
<b>Nitrogen</b>	Problematic over 150			

Table 4 . Phosphorus, Potassium, and Nitrogen levels for each sample, showing results from both professional and Rapitest test kit. N, P, and K indicate the nutrient of interest. Home refers to the Rapitest test kit and Lab refers to professional methods.

Sites	N_Home	N_Lab	P_Home	P_Lab	K_Lab	K_Home
CA	10	10	21	11.97	99.68	747
NE	10	10	10.5	1.05	252.65	166
NCP	0	11	1.05	17.3	212.48	41.5
NCNP	0	2	2.1	24.45	303.28	41.5
CP	80	60	4.2	76.71	672.38	498
CNP	0	10	10.5	16.14	150.25	498
SC	0	12	10.5	1.05	297.69	166
S	10	3	4.2	13.48	63.17	498
NS	10	20	2.1	16.63	130.62	332
UW	0	12	2.1	10.83	205.88	332
BP	10	21	10.5	21.86	215.07	331

## II. pH

Table 5. pH values from Rapitest soil test kit are designated under the Home column. pH values from Wallace Labs are found in the Professional column.

Soil Samples	Home Method	Professional Methods
CA	7	7.78
NE	7.5	7.8
NCP	7.5	7.73
NCNP	7	7.53
CP	7.5	7.58
CNP	7.25	7.92
SC	6.75	7.82

S	7.25	7.77
NS	7.25	7.89
UW	6.5	8.03
BP	7.5	7.7

III. Particle Size Distribution

Table 6. Table indicates proportions of soil layers

Sites	Home			Professional		
	%clay	sand%	%silt	%clay	%sand	%silt
CA	3.571429	0	96.42857	7.75	79.3	12.95
NE	3.333333	0	96.66667	7.75	79.3	12.95
NCP	3.225806	58.06452	38.70968	7.75	77.3	14.95
NCNP	3.571429	0	96.42857	5.75	87.3	6.95
CP	6.896552	68.96552	24.13793	7.75	81.3	10.95
CNP	3.125	46.875	50	7.75	77.3	14.95
SC	6.896552	62.06897	31.03448	7.75	77.3	14.95
S	10.71429	53.57143	35.71429	9.4	79.3	11.3
NS	6.451613	64.51613	29.03226	11.4	77.65	10.95
UW	10	0	90	13.4	75.65	10.95
BP	6.25	75	18.75	13.4	71.3	15.3

Table 7. Texture Triangle values

	<b>Professional</b>	<b>Home</b>
CA	Sandy Loam	Silt
NE	Sandy Loam	Silt
NCP	Sandy Loam	Sandy Loam
NCNP	Loamy Sand	Silt
CP	Sandy Loam	Sandy Loam
CNP	Sandy Loam	Silt Loam
SC	Sandy Loam	Sandy Loam
S	Sandy Loam	Loam
NS	Sandy Loam	Sandy Loam
UW	Sandy Loam	Silt Loam
BP	Sandy Loam	Sandy Loam

*IV. Soil Organic Matter (SOM)*

Table 8. Levels of soil organic matter for each soil sample.

SOM Tests by Wallace Labs	% SOM
CA	2.41%
NE	2.34%
NCP	2.67%
NCNP	4.98%
CP	9.65%
CNP	2.65%
SC	4.08%
S	0.98%

NS	N/A
UW	N/A
BP	N/A

\*No SOM data was taken for Natural History Museum samples (NS, UW, BP)

*V. Bulk Density*

Table 9. Values indicate bulk density in units of g/cm<sup>3</sup>

Bulk Density	
CA	0.76496
NE	0.94778
NCP	0.7577
NCNP	0.64593
CP	0.76343
CNP	0.84601
SC	0.92817
S	1.0155
NS	0.75496
UW	0.89815
BP	0.76078

*VI. Infiltration Rate*

Table 10. Infiltration rates from the ring method and the percolation method

Site	Ring	Percolation
CA	-4.75	-0.45
NCNP	-4.75	-1.44

S	-3.83	-4.00
NS	-0.46	-1.11
UW	-3.30	-0.45

### C. Raw Data

Table 11. Compiled data received from Wallace Labs and results of home method tests.

Comment [3]: Make numbers one line each?

DATA			SITE										
Parameter	P/H	Test	CA	NE	NCP	NCNP	CP	CNP	SC	S	NS	UW	BP
Nutrients (ppm)	P	N	10	10	11	2	60	10	12	3	20	12	21
	P	P	11.97	17.85	17.3	24.45	76.71	16.14	22.36	13.48	16.63	10.83	21.86
	P	K	99.68	252.65	212.48	303.28	672.38	150.25	297.69	63.17	130.62	205.88	215.07
	H	N	10	10	0	0	80	0	0	10	10	0	10
	H	P	21	1.05	1.05	2.1	4.2	1.05	1.05	4.2	2.1	2.1	10.5
	H	K	747	166	41.5	41.5	498	498	1.66	49.8	332	332	332
pH	P	pH	7.78	7.8	7.73	7.53	7.58	7.92	7.82	7.77	7.89	8.03	7.7
	H	pH	7	7.5	7.5	7	7.5	7.25	6.75	7.25	7.25	6.5	7.5
P	%clay		7.75	7.75	7.75	5.75	7.75	7.75	7.75	7.75	9.4	11.4	13.4
	%sand		79.3	79.3	77.3	87.3	81.3	77.3	77.3	79.3	77.65	75.65	71.3

Particle Size Distribution	P	%silt	12.95	12.95	14.95	6.95	10.95	14.95	14.95	11.3	10.95	10.95	15.3
	H	%clay	3.57	3.33	3.23	3.57	6.9	3.13	6.9	10.71	6.45	10	6.25
	H	%sand	0	0	58.06	0	68.97	46.88	62.07	53.57	64.52	0	75
	H	%silt	96.43	96.67	38.71	96.43	24.14	50	31.03	35.71	29.03	90	18.75
Soil Organic Matter (%)	P	Carbon	2.41	2.34	2.67	4.98	9.65	2.65	4.08	.98	N/A	N/A	N/A
Bulk Density (g/cm <sup>3</sup> )	P	Bulk Density	.76	.95	.76	.65	.76	.85	.93	1.02	.75	.9	.76
Infiltration (inches/hr)	H	Ring	-4.75	N/A	N/A	-2.57	N/A	N/A	N/A	-3.83	-46	-3.3	N/A
	H	Perculation	-1.44	N/A	N/A	-4	N/A	N/A	N/A	-4	-1.11	-45	N/A