THE CANADIAN SCIENCE FAIR JOURNAL

ARTICLE

From the Ground Up: The Effects of Air Pollution on Soil Health

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Kuper Academy Science Fair Bronze Medalist, Kuper Academy Science Fair Silver Medalist, Youth Science Canada Online STEM Fair Regional Award Science Canada Online STEM Fair Regional Award

Inspired by the ongoing climate crisis, this project investigates the effects of air pollution on soil. This project was done in order to inspire people to be mindful of the impacts of man-made air pollution in regard to the environment. Soil samples were collected from five locations with varying levels of air pollution (airport, factory, suburb, farmland, and store-bought soil) and certain soil characteristics (pH, salinity, water holding capacity, and nutrient content) were tested. It was discovered that soil that was subjected to greater amounts of air pollution had unhealthier characteristics than soil that had been subjected to smaller amounts of air pollution. This finding demonstrates that air pollution appears to have a negative impact on soil health. It is hoped that this experiment illustrates the importance of protecting one of the planet's most valuable resources: soil.

INTRODUCTION

There are various soil characteristics that make important contributions to the makeup and growth of vegetation. For example, when plants are grown in soil with a high concentration of lead, the plants also demonstrate significant quantities of lead (Soil Science Society of America, 2020). Factors of soil health examined in this study include pH, water holding capacity, nutrient content, and salinity.

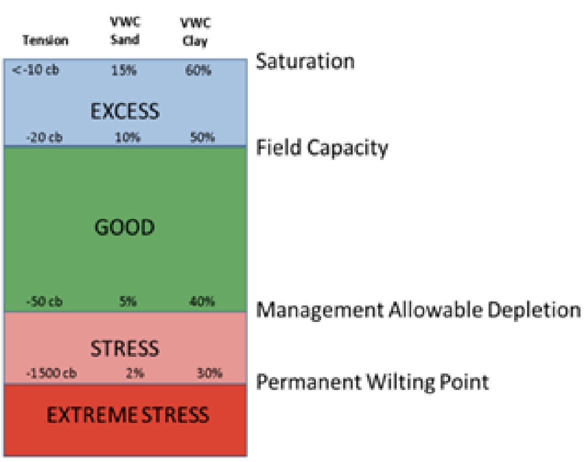

Figure 1
Levels of Water Holding Capacity
This figure from Pitts (2016) demonstrates the acceptable volumetric water content (VWC), also known as water holding capacity, parameters for clay and sand soil types as well as the parameters that would be considered too low or too high for healthy soil.

SOIL CHARACTERISTICS

pH: The optimal pH range for soil is 6.2-6.8. If soil is too acidic, it lacks the ability to retain certain important nutrients like magnesium, calcium, and potassium (Oklahoma Gardening, 2016). If soil is too alkaline, minerals such as iron and zinc will solidify and negatively impact the health of plants (Oklahoma Gardening, 2016).

Water Holding Capacity. Water holding capacity (WHC) is the amount of water soil can hold against the force of gravity; the ideal range is 40 %-50 % (Pitts, 2016). A low WHC will result in plants not having access to enough water. A high WHC will result in plant roots sitting in water and the plants subsequently wilting. Refer to Figure 1 for an illustration of water holding capacity.

Nutrient/NPK Content. NPK content refers to the amount of nitrogen, phosphorus, and potassium that soil contains. A lack of any one of the three aforementioned macronutrients causes adverse effects for plant growth and immunity (Ball, 2007).

Salinity. Soil salinity is the amount of salt contained in soil. High soil salinity can adversely affect plants because it causes the water within plants to rush towards the soil and hydrate the soil (due to the principles of osmosis) leaving plants and crops dehydrated (Simons & Bennett, 2019). Refer to Table 1 for salinity levels of different types of soil.

AIR POLLUTANTS AND SOIL

Various air pollutants can be examined in order to determine the causes of poor soil health. Particulate matter, for example, is found in the air and can consist of of dust, smoke, and dirt particles. Particulate matter is highly detrimental to the nutrient content of soil (Lafond, 2018).

Ground-level Ozone. Ground-level ozone is harmful to the growth and productivity of greenery. It is a mixture of nitrogen oxides and volatile organic compounds, mainly produced by the burning and production of fossil fuels (e.g. burning gasoline, oil,

Table 1
Analysis of Different Soil Salinity Contents Note. This table from Simons and Bennett (2019) demonstrates the acceptable and unacceptable ranges for salinity in different soil types using the 1:5 volume method. Ranges are measured by electrical conductivity (EC) using milliSiemens per metre (mS/m).

Salinity class	$EC_{1:5}$ range for sands (mS/m)	$EC_{1:5}$ range for loams (mS/m)	$EC_{1:5}$ range for clays (mS/m)	EC_e range (mS/m)
Non-saline	0–14	0–18	0–25	0–200
Slightly saline	15–28	19–36	26–50	200–400
Moderately saline	29–57	37–72	51–100	400–800
Highly saline	58–114	73–145	101–200	800–1600
Severely saline	115–228	146–290	201–400	1600–3200
Extremely saline	>228	>290	>400	>3200

and coal, producing oil and gas, wood combustion, etc.) (Government of Canada, 2016).

Sulfur Oxides. Sulfur oxides are the result of industrial activities related to refining basic resources such as coal and crude oil. Sulfur oxides contribute to acid rain and interfere with the composition of soil (Pan, 2011).

Lead. Lead is primarily released by exhaust from vehicles; therefore, areas with greater traffic and commercial activity will likely possess higher levels of lead. The result of lead pollution is vegetation absorbing small amounts of lead through the soil (Soil Science Society of America, 2020).

The purpose of this experiment is to determine the effects of air pollution on soil by measuring nutrient content, water holding capacity, salinity, and pH. Furthermore, the existing information about air pollution in relation to soil health is discussed.

HYPOTHESIS

It was predicted that soil that is subjected to low air pollution will demonstrate safe salinity levels, high NPK content, satisfactory water holding capacity, and a healthy pH. On the contrary, soil extracted from areas exposed to high levels of air pollution will possess harmful salinity levels, low NPK content, inefficient water holding capacity, and an unhealthy pH.

METHODS

Due to the risk that acid rain could cause inconsistencies in the results of the pH tests (Nunez, 2019), rain patterns were monitored, and several samples were collected and tested. They were found to be in the normal pH range for rainwater and this concern was therefore eliminated as a possible source of error.

Soil Collection.

Areas with high industrial or transportation-related activity were classified as areas with high air pollution.

Three soil samples were collected from each of the chosen locations and were collected spaced apart in order to ensure precision and accuracy in the measurement of the characteristics. The samples were dug out (at a depth of about 5 in) with clean shovels and stored in air-tight containers until testing. One bag of store-bought soil (Selection Garden Soil) was used for testing. After extraction, the soil type was determined by pressing and touching each sample; all the soil samples were classified as some form of loam. In this experiment, the independent variable is the soil sample location, whereas the dependent variables are: pH, water holding capacity, nutrient content, and salinity.

The first l ocation w as a f armland l ocated i n O ka, Quebec (45°29’41.8”N, 74°07’56.1”W). Samples were collected 25 m apart on October 6th, 2019. The temperature was 7 °C and it had rained six days prior to extraction. The second location was Jacques-de-Lesseps Park, located directly next to the runway of Pierre Elliott Trudeau International Airport (45°27’42.0”N, 73°43’53.6”W). Samples were collected 15 m apart on October 6th, 2019. The temperature was 11 °C. The third location was a synthetic crude manufacturer (factory) named Suncor Energy located in Sherbrooke (45°38’23.5”N, 73°30’56.9”W). Samples were collected 25 m apart on October 10th. The temperature was 15 °C and it had rained three days prior to extraction. The fourth location was a suburban area (Pierrefonds) and the exact coordinates are 45°27’36.8”N, 73°52’59.2”W. Samples were collected 8 m apart on October 10th. The temperature was 14 °C.

Soil Testing.

Thirteen samples total (three samples per the four locations and one store-bought sample) were tested, and the average results from each location were analyzed.

pH. Using weighing paper and an electric scale, 20 g of soil and 100 mL of distilled water were measured. The soil and distilled water were combined in an air-tight container and shaken vigorously for one minute. The solution sat until a clear, yet slightly cloudy liquid had accumulated at the top and the soil rested at the bottom (see Figure 2). Afterwards, pH paper was dipped into the clear liquid (avoiding the soil at the bottom of the container). The color of the pH paper was recorded and analyzed.

Nutrient/NPK Content. Using the weighing paper and the electric scale, 20 g of soil and 100 mL of distilled water were measured. The soil and distilled water were combined in an air-tight container and shaken vigorously for one minute. The solution sat until a clear, yet slightly cloudy liquid had accumulated at the top and the soil rested at the bottom. Then, a filtering system was prepared by placing a funnel in an Erlenmeyer flask and placing folded filter paper in the funnel. Using a dropper, the clear liquid was moved from the container to the flask (avoiding the soil at the bottom). The liquid was left to drip until around 100 mL had accumulated in the flask. Using a Rapitest testing kit, each compartment of each color comparator (nitrogen, potassium, and phosphorus) was filled with the filtered liquid. Afterwards, the contents of each capsule were gently dropped into its corresponding color comparator (purple for nitrogen, blue for phosphorus, and orange for potassium). The comparators were shaken, and the color was left to develop for exactly ten minutes (see Figure 3). Finally, the color of each liquid in comparison to the color chart was recorded.

Salinity. Using the weighing paper and the electric scale, 20 g of soil and 100 mL of distilled water were measured. The soil and distilled water were combined in an air-tight container and shaken vigorously for 30 s every 5 min over an hour. The electrical conductivity (EC) meter was placed in the solution and the reading was left to stabilize for 10 s (Vineyard Activity Guides, 2010). The results were recorded in mS/m.

Water Holding Capacity. A filtering system was prepared by placing a funnel in an Erlenmeyer flask and placing folded filter paper in the funnel. Then, 25 g of soil and 100 mL of distilled water were measured. The water and soil were added to the flask and the system left to drain for exactly 15 min (see Figure 4). The funnel containing the soil and filter paper was removed from the flask and the amount of liquid that had accumulated in the flask was measured in millilitres (Mobile Science Laborato-

Figure 2
Separation of the Soil from the Desired Solution. The separation process lasted between a few hours and a few days depending on the texture of the soil (clay soils required more time than sandy soils).

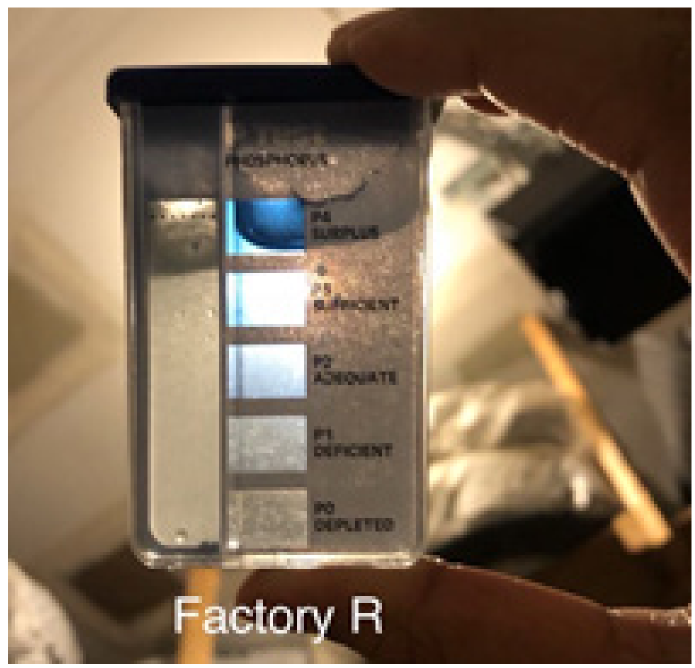

Figure 3
Example of Nutrient Content Testing. This figure demonstrates the colour chart present on every nutrient colour comparator used (whether it be nitrogen, phosphorus, or potassium). Each chart demonstrates the colour of the solution and the corresponding analysis of the soils nutrient content (depleted, deficient, adequate, sufficient, or surplus).

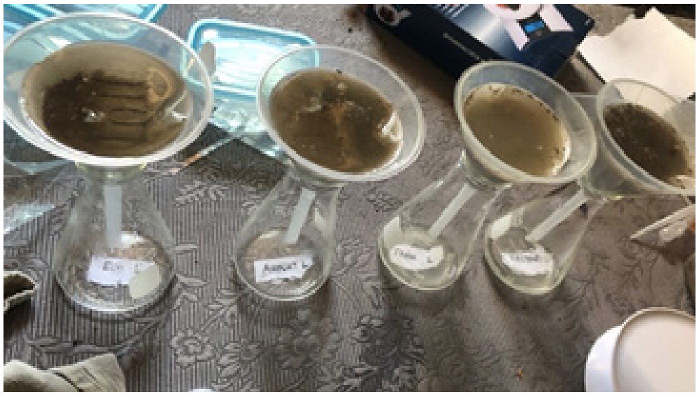

Figure 4
Improvised Filtration System. The removal of the funnels at the end of the 15 min occurred simultaneously in order to prevent excess liquid in the flasks and faulty results.

ry, 2018).
The results were classified as "below range" if they were below the healthy range for the given characteristic, "above range" if they were above the healthy range for the given characteristic, and "within range" if they were within the healthy range for the given characteristic. Due to the thicker texture of the samples, their results were analyzed using the clay soil parameters for WHC. Soil samples were considered within the healthy range for salinity if they could be classified as moderately saline or lower, in the loams category.

RESULTS

In Table 2, the average results of each test are listed by location. The factory soil had an average WHC of 14 %, a salinity of 113 mS/m, a pH of 7.25, and a nitrogen, phosphorus, and potassium contents measured at 0 according to the Rapitest Soil Testing Kit. The farmland soil had an average WHC of 45 %, a salinity of 47 mS/m, a pH of 6.33, and a nitrogen, phosphorus, and potassium contents measured at. The airport soil had an average WHC of 76 %, a salinity of 154 mS/m, a pH of 7.25, nitrogen and phosphorous content measured at 1, and a potassium content measured at 0. The suburban soil had an average WHC of 49 %, a salinity of 81 mS/m, a pH of 7, a nitrogen content measured at 1, a phosphorus content measured at 3, and a potassium content measured at 2. The store-bought soil had an average WHC of 69 %, a salinity of 172 mS/m, a pH of 6.25, and a nitrogen, phosphorus, and potassium content measured at 2 according to the Rapitest Soil Testing Kit. Table 3 demonstrates how the results from this experiment compare to healthy ranges for the characteristics measured.

DISCUSSION

Factory

The factory soil had an average water holding capacity of 14 %, which is not in the optimal range for WHC (40 % to 50 %). This soil type loses 86 % of the water that it receives. This lack of water would result in the dehydration and eventual death of plants. Additionally, this soil had an average EC of 113 mS/m, which means it is highly saline. This will lead to the dehydration of plants grown in this soil. Moreover, the soil from this area had an average pH of 7.25, which is not in the healthy range of 6.2-6.8. This excess in alkalinity may cause minerals present in the soil (such as iron and zinc) to turn into solids and impact the health of plants. As for the nutrient content tests, the factory soil's average nitrogen content, phosphorus content, and potassium content were all depleted. This lack of nutrients means that plant growth and immunity will be stunted or unsatisfactory. Ground-level ozone was presumably present at the factory (which is Suncor, Quebec's second highest greenhouse gas emitter (Gerbet, 2019)). Additionally, sulfur oxides are likely present at the factory, as it produces synthetic crude oil.

Farmland

The farmland soil had an average water holding capacity of 45 %, which is within the optimal range for WHC. This means that this soil type loses 55 % of the water that it receives, and the result will be a healthy amount of hydration for plants. Additionally, this soil had an EC of 47 mS/m, which means it is moderately saline and will not cause significant to plant life. Moreover, the soil from this area had an average pH of 6.33, which is in the healthy range. This indicates a healthy environment for most of the plant life. As for the nutrient content tests, the farmland soil's average nitrogen content, phosphorus content, and potassium content were all sufficient. This abundance of nutrients means that plants will have a good growth rate and possess an excellent immunity against foreign elements and disease.

Airport

The airport soil had an average water holding capacity of 76 %, which is not in the optimal range for WHC. This means that this soil type loses 24 % of the water that it receives. This excess of water would result in the plant roots sitting in water for long periods of time and the eventual death of the plants. Additionally, this soil had an EC of 154 mS/m, which means it is severely saline. So, according to the laws of osmosis, the plants would not receive enough water and would therefore be dehydrated. Moreover, the soil from this area had an average pH of 7.25 which is not in the healthy range. The alkalinity may cause minerals present in the soil (such as iron and zinc) to turn into solids and impact the health of plants. As for the nutrient content tests, the airport soil's average nitrogen and phosphorus content were less than satisfactory, whereas its average potassium content was depleted. This lack of nutrients means that plant growth and immunity will be stunted and unsatisfactory. Ground-level ozone was presumably present at the airport (since great amounts of fossil fuels are burnt at this location).

Suburb

The suburban soil had an average water holding capacity of 49 %, which is within the optimal range for WHC. This means that this soil type loses 51 % of the water that it receives, and the result

Table 2
Results of Soil Testing by Soil Sample Location. This table demonstrates the average results of each soil location in each area of testing. The average results were determined by calculating the average of the three samples from each location (excluding store-bought soil for which only one sample was used).
[a]The values of the nutrient tests are based on the color comparator charts provided by the Rapitest Soil Testing Kit.

	WHC (%)	Salinity (mS/m)	pH	N[a]	P[a]	K[a]
Factory	14	113	7.25	0	0	0
Farmland	45	47	6.33	3	3	3
Airport	76	154	7.25	1	1	0
Suburb	49	81	7	1	3	2
Store bought	69	172	6.25	2	2	2

Table 3
Analysis of Soil Test Results (Below, Within or Above Healthy Range). This table refers to the healthy ranges discussed in the background research (Ball, 2007; Oklahoma Gardening, 2016; Pitts, 2016; Simons & Bennett, 2019).

	WHC	Salinity	pH	N	P	K
Factory	Below range	Above range	Above range	Below range	Below range	Below range
Farmland	Within range	Within range	Within range	Within range	Within range	Within range
Airport	Above range	Above range	Above range	Below range	Below range	Below range
Suburb	Within range	Above range	Above range	Below range	Within range	Within range
Store bought	Above range	Above range	Within range	Within range	Within range	Within range

will be a healthy amount of hydration for plants. Additionally, this soil had an EC of 81 mS/m, which means it is highly saline, and the plants would not receive enough water. The soil from this area had an average pH of 7, which is not in the healthy range and may cause minerals to solidify and impact the health of plants. The average nitrogen content was deficient, its average phosphorus content was sufficient, and its average potassium content was average. This satisfactory amount of nutrients means that plants will have a good growth rate and possess immunity to foreign elements and disease.

Store bought

The store-bought soil had an average water holding capacity of 69 %, which is not within the optimal range for WHC. This means that this soil type loses 31 % of the water that it receives. This ex-cess of water would result in the plant roots sitting in water for long periods of time and the eventual death of plants. Additional-ly, this soil had an EC of 172 mS/m, which is severely saline. The soil had an average pH of 6.25, which is in the healthy range. As for the nutrient content tests, the store-bought soil's average ni-trogen content, phosphorus content, and potassium content were all average.

These results demonstrate that, generally, locations possessing higher levels of air pollution display worse soil health characteristics than locations possessing lower levels of air pollution. These results could be caused by the presence/lack of the following air pollutants, which were discussed in the introduction: particulate matter, ground-level ozone, sulfur oxides, and lead (Degreasers, 2018). The areas that possessed these contaminants displayed insufficient soil health compared to the areas that had not been exposed to much of these contaminants. Thus, the damage endured by soil in certain areas could be related to the usage of fossil fuels, which led to the abundance of the aforementioned pollutants (The Climate Reality Project, n.d.). Therefore, the results of this experiment have demonstrated how this burning of fossil fuels and the resulting air pollution are detrimental to soil health.

CONCLUSIONS

The hypothesis is partially accepted; the farmland soil demonstrated safe salinity levels while the airport, factory, suburban, and store-bought soils did not. Furthermore, the farmland, suburban, and store-bought soils displayed high NPK contents while the airport and factory soils were insufficient in this area. Moreover, the farmland and suburban soils possessed satisfactory water holding capacities while the factory, airport, and store-bought soils did not. Finally, the farmland and store-bought soils were within the healthy range for pH while the factory, airport, and suburban soils were not.

Generally, the soil samples from the areas with less air pollution demonstrated healthier soil characteristics than the soil samples from the areas with higher air pollution. This indicates that air pollution seems to have an overall negative impact on soil characteristics.

FUTURE STEPS

Given a second chance to conduct this experiment, with more time and access to more resources, more soil samples could be collected to increase accuracy of the results. Additionally, more extensive research on the extraction locations (the effects of humidity and fuel contamination, determining air pollutant levels in each location, etc.) could aid in clarifying the connections be-tween air pollution and soil health.

ACKNOWLEDGEMENTS

I must acknowledge Nihari Senaratne, my hard-working partner who contributed hundreds of hours of effort to this important and laborious experiment; without her, this task would have been impossible. Additionally, I would like to thank Mr. Harris, our dedicated mentor who provided us with essential and greatly appreciated guidance.

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A motivated high honours student and aspiring engineer who believes in the power of youth in STEM: Mehnu is a 16-year-old student from Kuper Academy High School in Montreal, Quebec. In her free time, she enjoys coding, playing piano or reading a good book. She hopes to further her passion for programming and to study the process of early disease detection using machine learning. Additionally, Mehnu advocates for all STEM initiatives geared towards young women (such as Women In Engineering) and believes in the importance of decreasing the gender-related disparities within the field.