



Extended essay cover

Candidates must complete this page and then give this cover and their final version of the extended essay to their supervisor.

Candidate session number

Candidate name

School name

Examination session (May or November)

May

Year

2015

Diploma Programme subject in which this extended essay is registered:

Chemistry

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay:

Optimizing the Amount of CaCO_3 Needed to Reverse the Effects of Acid Rain on the Acidity of Soil.

Candidate's declaration

This declaration must be signed by the candidate; otherwise a mark of zero will be issued.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

This is the final version of my extended essay.

Candidate's signature:

Date: 12/15/14

Supervisor's report and declaration

The supervisor must complete this report, sign the declaration and then give the final version of the extended essay, with this cover attached, to the Diploma Programme coordinator.

Name of supervisor (CAPITAL letters) _____

Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

Student chose and undertook this highly relevant research for her extended essay with minimal guidance by mentor. Student's work appears to demonstrate understanding of the underlying soil chemistry relevant to her research.

This declaration must be signed by the supervisor; otherwise a mark of zero will be issued.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

As per the section entitled "Responsibilities of the Supervisor" in the EE guide, the recommended number of hours spent with candidates is between 3 and 5 hours. Schools will be contacted when the number of hours is left blank, or where 0 hours are stated and there lacks an explanation. Schools will also be contacted in the event that number of hours spent is significantly excessive compared to the recommendation.

I spent hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: _____

Date: 2-10-2015

Assessment form (for examiner use only)

Candidate session number					
--------------------------	--	--	--	--	--

Achievement level

Criteria	Examiner 1	maximum	Examiner 2	maximum	Examiner 3
A research question	1	2		2	
B introduction	2	2		2	
C investigation	2	4		4	
D knowledge and understanding	2	4		4	
E reasoned argument	2	4		4	
F analysis and evaluation	2	4		4	
G use of subject language	2	4		4	
H conclusion	1	2		2	
I formal presentation	2	4		4	
J abstract	2	2		2	
K holistic judgment	2	4		4	
Total out of 36	20				

Name of examiner 1: _____ Examiner number: _____
(CAPITAL letters)

Name of examiner 2: _____ Examiner number: _____
(CAPITAL letters)

Name of examiner 3: _____ Examiner number: _____
(CAPITAL letters)

IB Assessment Centre use only: B: _____

IB Assessment Centre use only: A: _____

Optimizing the Amount of CaCO_3 Needed to Reverse the Effects of Acid Rain on the Acidity of
Soil.

Extended Essay

Subject: Chemistry

Word Count: 2,900

Abstract

Agriculture is important to the world both economically and environmentally, however with growing population and pollution, fertile soil is hard to come by. The acidity of soil is an important factor in determining its ability to produce good plant growth whether naturally or through agriculture.

This is why I decided to study how to alter this pH to reverse the effects of pollution in the form of wet deposition. Through research I developed the question:

“What is the effect of varying the amount of CaCO_3 needed to reverse the effects of acid rain on the acidity of soil?”

The amount of CaCO_3 needed to neutralize the pH of the soil sample was found. 100 grams of soil was measured and mixed with acidified water in a 1:1 ratio. With the appropriate addition of varying amounts of CaCO_3 , measurements of pH, conductivity and temperature were taken automatically by probes. The results of these measurements were presented on a graph where results can be seen visually. The most stable mixture over the most amount of time was considered the appropriate CaCO_3 to soil mixture for the reversal and maintaining of pH.

In the end, lowering the amount of CaCO_3 to measurements below recommendation is not effective and definitely affects the ability for the soil to neutralize stably as every measurement below the mathematically determined 0.05g of CaCO_3 did not reach stability within the span of the experiment, while 0.05g did. The liming process seemingly reverses the effects of acid rain on the acidity of soil and brings stability to the micro processes.

Word Count: 259

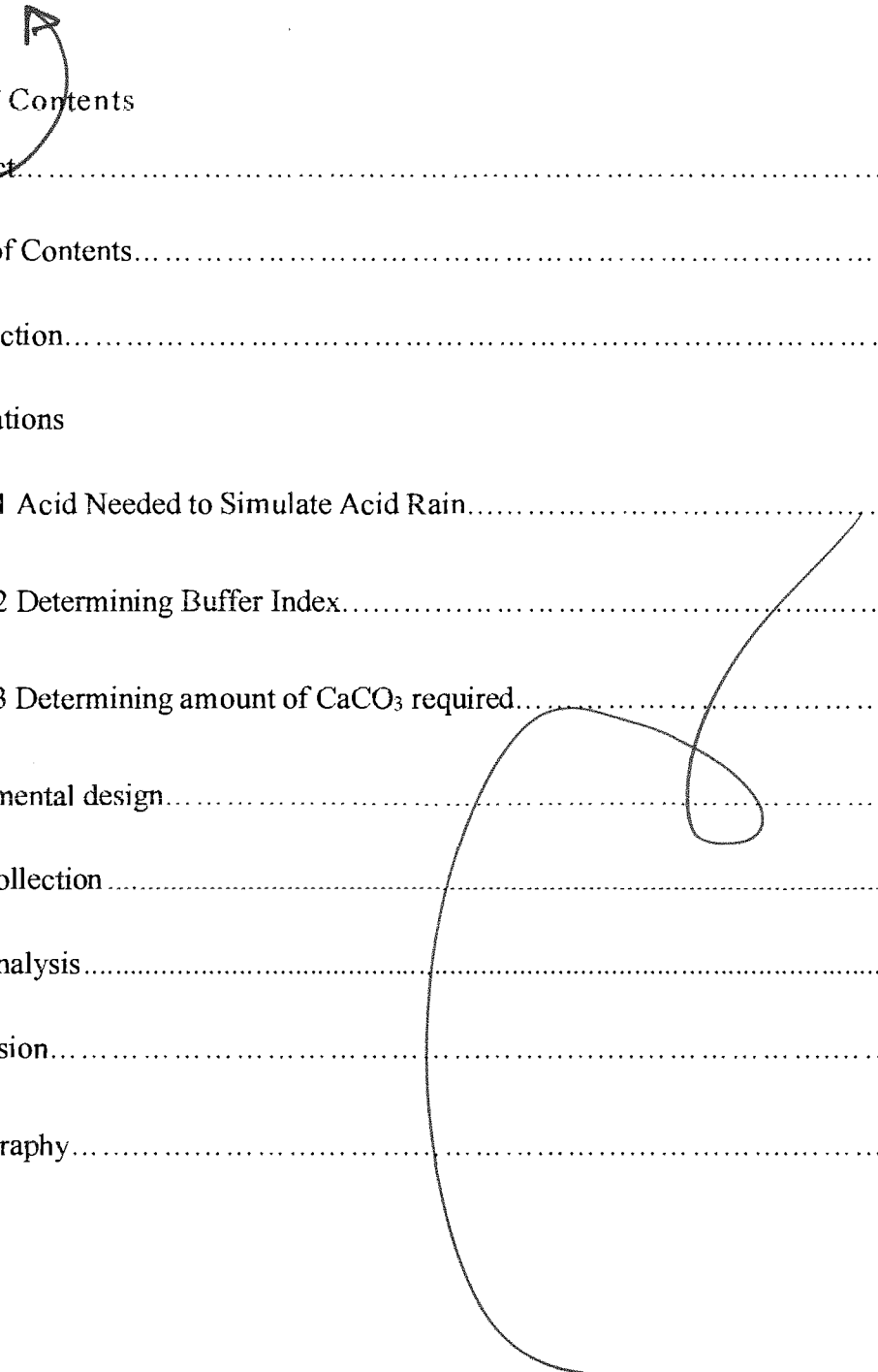


Table of Contents

1. Abstract..... 2

2. Table of Contents..... 3

3. Introduction..... 4-6

4. Calculations

 4.1 Acid Needed to Simulate Acid Rain.....7-8

 4.2 Determining Buffer Index.....9-10

 4.3 Determining amount of CaCO₃ required.....10-11

5. Experimental design.....11

6. Data Collection.....12-15

7. Data Analysis.....16-17

8. Conclusion.....18-19

9. Bibliography.....20

3. Introduction

Agriculture is important to the continuity of the rapidly growing population on earth. This vital yet often overlooked industry provides crops that nourish and maintain society, therefore rendering it crucial to understand the chemistry of soil and how this affects the plants grown therein. A major issue concerning crop health is the acidity of soil which upholds both environmental and economic concerns, because of this I decided to investigate the improvement of soil acidity and how this can be done the most effective way, leading to my research question:

not clear
“What is the effect of optimizing the amount of CaCO_3 needed to reverse the effects of acid rain on the acidity of soil?”

Today, a larger demand leads to focus on efficiency and less of such on the actual health of the crops. Many soils are considered acidic and become this way due to multiple reasons including chemical fertilizers, mass and rapid harvesting and the growing problem of acid rain. To understand how soils are considered “acidic” and why this is detrimental to plant health it is required to understand acidity and pH. Soil acidity comes primarily from H^+ and Al^{3+} ions in solution which tend to sorb into an exchange filter in the soil. The soil naturally contains base cations such as calcium and magnesium which tend to counteract this acidity, however, these cations tend to leach out of the soil, especially in areas of high rainfall.

In areas such as the subtropics precipitation is a common event and produces higher acidity in the soils due to the presence of more hydrogen ions. This acidity, or hydrogen ion activity, is measured in terms called pH and put on a scale of 1 to 14 (the higher on the scale the more basic the solution is considered and only partly dissociates therefore). pH can be defined as $\text{pH} = -\log(\text{H}^+)$ or minus the logarithm of the hydrogen ion activity in solution (Tisdale,

Nelson, and Beaton). pH is measured automatically in laboratories with electronic pH meters. This is vital to the agricultural industry in the production of healthy crops. In areas where the soil pH is below 5.5 (considered fairly acidic), such as the subtropics, many plants suffer as the raised acidity deplete necessary nutrients and compromise plant structure (Likens). With highly acidic soils, the elements such as aluminum and manganese, for example, are more active and more easily extractable by plants. When too much of these are absorbed by plant roots, the plant suffers as a whole as these elements increase cell rigidity and interfere with cell division. Ultimately, this harms the part of the plant that uptakes, transports and uses vital nutrients and water that aid plant growth, rendering health unachievable. All in all the natural soil acidity found in a lot of areas of the world cannot yield healthy or abundant crops and with the Earth's growing population agricultural industries need all the land they can get, therefore finding out how to change the acidity of soil is important.

Fortunately, this can be done through a method called liming and has been utilized to ameliorate over-harvested and barren lands since the early years of commercial agriculture. The substance used in liming is a form of calcite, a basic, calcium containing compound such as calcium carbonate (CaCO_3), the purest form of liming material as it has the largest concentration of calcium. Calcium found in these correcting substances replace the hydrogen ions that react with the oxygen in the compound and raise the pH (or lower hydrogen ion activity), rendering a soil with the optimal pH range of 5.5-7.0 (Tisdale, Nelson, and Beaton).

Altering the pH in order to produce a high quality product in mass amounts helps the economic issue, however my experiment is to assess not only theoretical improved production but if liming soil can reverse the volatile effects of acid rain on the environment. Because of this it is important to understand acid rain and how it affects soil productivity.

The compounds released by volcanos and other natural sources provide for a small amount of toxins in the atmosphere that react with evaporated water molecules to produce acid rain, the real source of this is human-based. With higher emissions of sulfur dioxide and nitrogen oxides from burning coal or fossil fuels, acid rain is an often occurring phenomena. Water usually has a pH, considered neutral, of 7.0, pure rain water is naturally more acidic with a pH of 5.5 or higher because of the carbon dioxide naturally found in the air. Acid rain, however, can be found with a pH as low as 4.3 and the introduction of this into the water sources of crops can seriously lower the pH of soils. The process and reactions found in acid rain is depicted in this illustration (Likens):

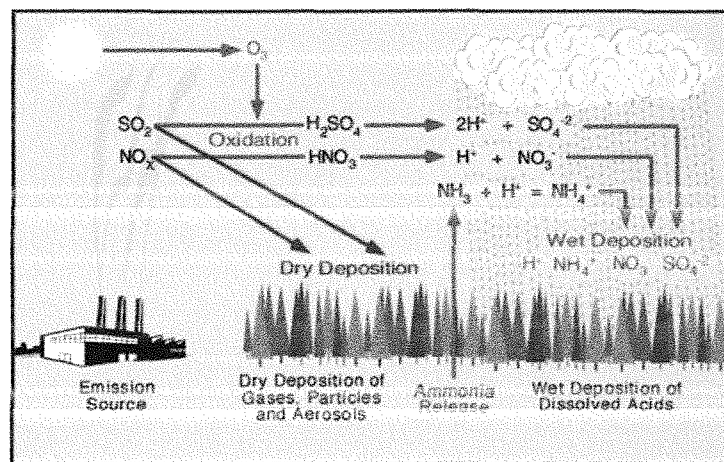


Figure 1.1: Production of acid rain also known as “wet deposition.”

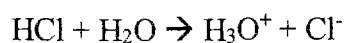
Consequentially, I designed my experiment around this fact and decided to simulate acid rain and then assess the effect of calcium carbonate’s addition.

The experiment’s data does not stop here, however, as there are plenty more factors contributing to the soil’s health, conductivity will also be measured. This is the measure of the amount of salts in the soil. In areas such as the subtropics that receive a lot of rain, the conductivity is higher as salt moves with the water. Higher conductivity leads to lower microorganism activity and will destroy the soil’s processes and, ultimately, the health of the crops (NRCS 1).

4. Calculations

4.1 Calculating Acid Needed for Simulation of Acid Rain

The first step in this investigation was to recreate acid rain and in order to do this, the pH of acid rain was to be found. From published research the pH of acid rain was found to range from 4.0-4.8, making it highly acidic (Likens). Knowing the goal pH was step one, step two was to measure the pH of the sample of water collected for the experiment. In order to do this accurately a calibrated glass electrode pH meter was utilized. The pH meter is a probe with a small glass electrode containing a neutral solution, it measures the pH by comparing the voltages of hydrogen ions of the solution it is testing to the neutral solution within through a process called ion exchange. Metal ions on the surface of the glass electrode swap with hydrogen ions moving in the tested solution, the higher the frequency this occurs, the higher the hydrogen ion activity and the solution, therefore, has a lower or more acidic pH (Woodford). Using this the water sample was found to have a pH of 6.23. Due to available materials, the acid used in this acid-base reaction was hydrochloric acid (HCl), not found in acid rain but capable to reduce the pH of the water in order to mimic acid rain's effect. The reaction between these two solutions can be seen below:



According to the Bronsted-Lowry theory an acid is defined as a substance that gives a proton while a base is a substance that accepts the proton as this reaction shows, HCl as the acid and water as the base (Tisdale, Nelson, Beaton).

In order to determine how much hydrochloric acid was necessary to mix with water to reach the target pH of 4.0 the following equation was used:

$$M_1V_1 + M_2V_2 = M_3(V_1 + V_2)$$

“M” standing for Molarity and “V” for volume respectively. Rearranged to find V_1 or the volume of acid needed the equation looks like so:

$$V_1 = (M_3V_2 - M_2V_2) / (M_1 - M_3)$$

The Molarity of the acid HCl is provided on the manufacturer's container as 0.1M, the Molarity of the rain water of 6.23 pH was found to be 0.0000002M leading to this final calculation:


$$V_1 = \frac{0.0001(1000) - 0.0000002(1000)}{0.1 - 0.0001} = \frac{0.0998}{0.0999} = 0.999g$$

Resulting in 1g HCl needed for every 1000g of H₂O. The scale of this experiment is 100g of soil to 100mL of water (1:1 ratio) as often used in lab based tests to create a soil suspension.

Because of this I reduced the ratio of HCl:H₂O for a final measurement of 0.1g HCl to 100mL water. Another measurement of the water's pH after the addition of acid rain with a <1mL dropper was conducted to ensure correct pH was reached. This reading resulted in a pH of 3.75, only .25 away from the target pH of 4.0.

4.2 Determining Buffer Index

Every soil sample is different as soil has uncountable components, therefore, it is required to determine the soil sample's buffer index or its ability to resist change. The buffer capacity can be defined by the concentration of acid or base needed to change the soil's pH and is influenced by many aspects of the soil including amount of organic matter, the type of soil and from this its natural reservoir. Beginning with organic matter, this is the amount of stable, fully composed organic material in the soil. This is very beneficial to soils as it absorbs water and nutrients such as nitrogen in the soil for plants to use at their disposal. To determine exactly how much organic matter is in a soil sample, laboratories take the sample and weigh it then will heat it for up to 4 hours at high temperatures, making the sample ash only to weigh it again. The comparison of the initial weight to the final weight tells what percentage of the soil was organic matter as it burns away in the process (this method was not used in my experiment as I do not have access to such high heats) (Urbansky, Schock). Unfortunately, with commercial farming the amount of organic matter is dwindling as it is lowered with tillage and improper fertilization rendering soils more vulnerable to the effects of acid rain. Along with this are the types of soil, there are three main types including sandy, loamy and clay soils and others that contain properties of two of these mixed (loamy sand for example). It is fairly easy to assess what type of soil the sample is by looking at it physically, the courser soils such as sand have a lower buffer capacity than finer soils such as clay. The soil used in my experiment was treated as a sandy soil as it was very course and loosely composed. Furthermore, the buffer index will tell how much CaCO_3 is needed as the less persuadable the soil is, the more lime is needed. The process to find this was to add 1% of the sample's weight (200g so 1% would be 2g) of CaCO_3 and test the pH



from here. Results of this was a buffer index or pH of 7.1. This was then compared to the graph shown below (Ball Table 1):

Buffer index	Lime required	
	pH 6.8	pH 6.4
> 7.1	none	none
7.1	0.5	none
7.0	0.7	none
6.9	1.0	none
6.8	1.2	0.7
6.7	1.4	1.2
6.6	1.9	1.7
6.5	2.5	2.2
6.4	3.1	2.7
6.3	3.7	3.2
6.2	4.2	3.7

*Effective calcium carbonate equivalent.

Figure 1.2: This shows that with a buffer index of 7.1 it requires 0.5 tons of lime in order to reach a pH of 6.8 for that soil sample.

4.3 Calculation for CaCO₃ Required

The measurements typically found are for an “acre furrow slice” of soil which is the top 6 inches of an acre of soil. This translates to approximately 1000 tons of soil, however, for sake of plausibility I had to reduce this to the scale I planned working with being 100 grams of soil. In this process the following calculations took place (Scott):

0.5 tons of CaCO₃:1000 tons of soil = 1000 pounds of CaCO₃:2000000 pounds of soil

This translates to a total of 453,592g of CaCO₃ for every 907,184,740g of soil meaning that 0.05% of the soils weight should be added of CaCO₃. 0.05% of 100g is 0.05g and this is the

final amount of CaCO_3 needed for this experiment to reach a pH of at least 6.8. In order to minimize the amount of CaCO_3 needed, I included 0.02%, 0.03% and 0.04% CaCO_3 to the trials as well.



5. Overall Experimental Design

This experiment was adapted by what is typically done in soil test laboratories, this information was found from a Clemson University document (Sikora and Kissel).

Begin by taking a 6 inch deep sample of soil in various locations of the area to be tested, leave this in an open container occasionally stirring until completely dry. This will be mixed in a 1:1 ratio with acidified deionized water to simulate acid rain, this was exclusive to my experiment as it focuses on reversing the pH changing effects of acid rain on soil. The experiment consisted of three separate trials, all three spanning 7 days including the monitoring of temperature, pH and conductivity. The procedure followed this process:

1. Measure 100g of soil using a digital scale (accurate to ± 0.01 g) and place into a glass container, repeat this 5 times.
2. Once the soil is set up, mix 100mL of deionized water with 0.1mL HCl for each sample and pour on top.
3. Mix this suspension vigorously and let sit for about 15 minutes.
4. Place a glass probe pH meter, conductivity meter and thermometer into freshly stirred mixture and allow 20 seconds to pass and pH readings are stable, record these numbers.

6. Data Collection *w/ 1A titles?*

Initial Measurements (the measurements of CaCO_3 have error numbers of $\pm 0.01\text{g}$ throughout, Temperature measured in Celsius and Conductivity in siemens per meter):

Trial 1

	Control	0.02g CaCO_3	0.03g CaCO_3	0.04g CaCO_3	0.05g CaCO_3
pH	5.17	4.98	5.4	4.96	5.42
Conduct.	236.2	152.1	148	176	220.4
Temp($^{\circ}\text{C}$)	27	26.9	26.5	26.4	26.4

Trial 2

	Control	0.02g CaCO_3	0.03g CaCO_3	0.04g CaCO_3	0.05g CaCO_3
pH	5.2	4.97	5.33	4.85	4.95
Conduct.	236.1	40.7	238.7	32.4	56.3
Temp($^{\circ}\text{C}$)	26.7	26.7	26.5	26.4	26.4

Trial 3

	Control	0.02g CaCO_3	0.03g CaCO_3	0.04g CaCO_3	0.05g CaCO_3
pH	5.22	5.15	5.17	5.12	5.07
Conduct.	233.1	68.3	53	91.9	38.7
Temp($^{\circ}\text{C}$)	26.7	26.6	26.6	26.5	26.5

Daily data collected for 7 days:

Trial 1

	Control	0.02g CaCO_3	0.03g CaCO_3	0.04g CaCO_3	0.05g CaCO_3	
pH	5.20	5.52	5.90	5.74	6.19	
Conduct.	236.3	229.3	65.8	136.2	119.5	Day 1
Temp.	26.90	26.8	26.7	26.4	26.5	
pH	5.23	5.63	5.92	5.94	6.34	
Conduct.	233.1	139.3	149.7	193.3	131.1	Day 2
Temp.	27.4	27.6	27.4	27.2	27.4	
pH	5.33	5.59	6.16	6.17	6.52	
Conduct.	235.3	227.2	220.5	210.9	229.1	Day 3
Temp.	27.5	27.7	27.6	27.2	27.5	
pH	5.40	5.82	6.10	6.20	6.50	
Conduct.	230.1	244.5	243.5	248.9	239.3	Day 4
Temp.	27.0	27.3	27.1	26.9	27.1	
pH	5.45	5.89	6.19	6.21	6.55	
Conduct.	232.0	230.9	229.8	237.1	242.3	Day 5
Temp.	26.9	26.9	26.9	26.7	26.7	
pH	5.5	5.99	6.18	6.20	6.55	
Conduct.	233.2	240.2	231.2	235.4	240.2	Day 6
Temp.	26.9	27.0	26.9	27.1	27.0	
pH	5.65	5.85	6.19	6.21	6.55	
Conduct.	234.1	236.2	228.3	238.2	241.1	Day 7
Temp.	26.9	26.9	27.0	27.1	27.0	

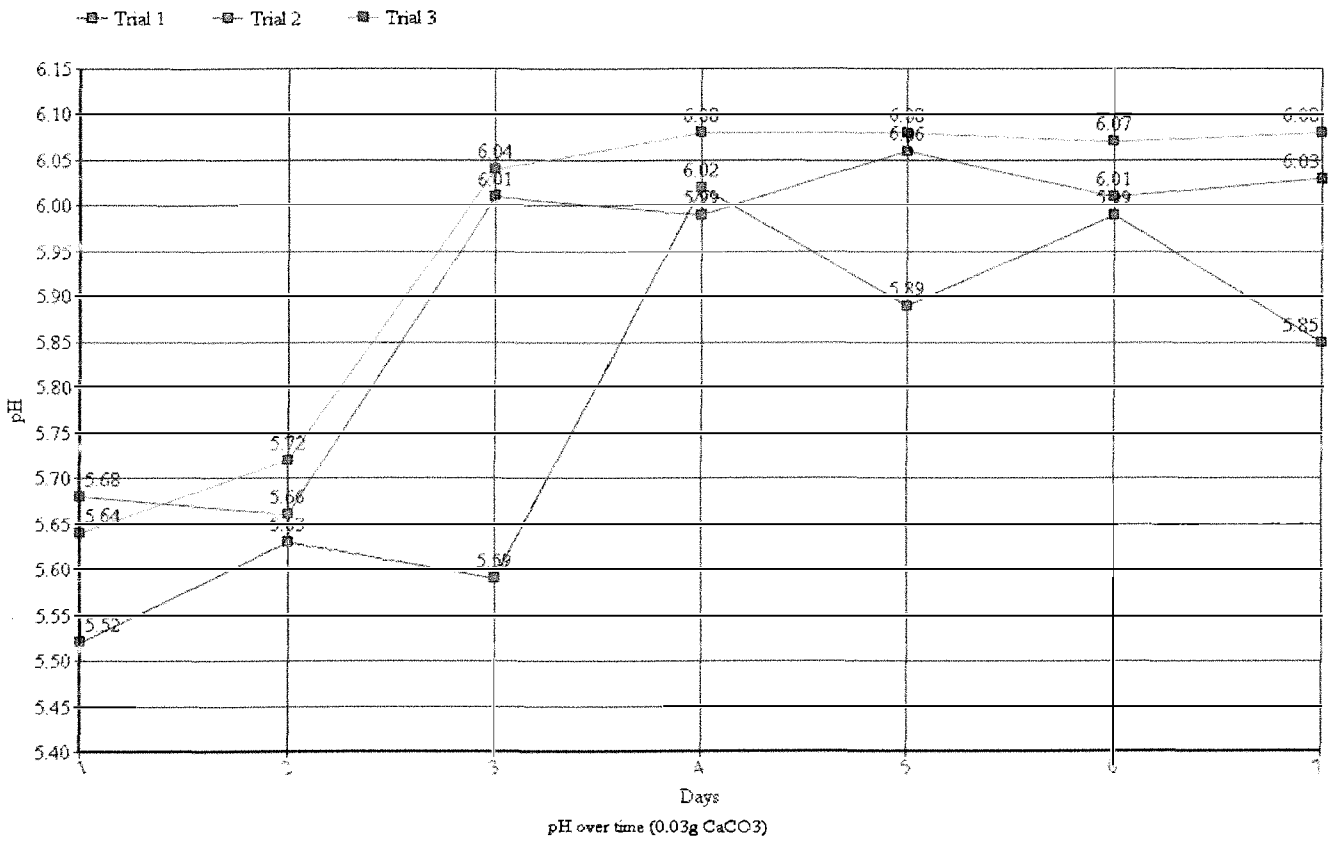
Trial 2

	Control	0.02g CaCO ₃	0.03g CaCO ₃	0.04g CaCO ₃	0.05g CaCO ₃	
pH	5.32	5.68	5.74	6.21	6.14	
Conduct.	201.2	127.2	130.2	184.5	225.4	Day 1
Temp.	26.9	26.9	26.9	26.7	26.9	
pH	5.40	5.66	5.99	6.31	6.18	
Conduct.	198.3	199.3	165.2	227.5	207.3	Day 2
Temp.	27.5	27.6	27.4	27.4	27.4	
pH	5.45	6.01	6.16	6.46	6.36	
Conduct.	190.4	242.3	208.6	223.2	234.1	Day 3
Temp.	27.3	27.4	27.3	27.3	27.4	
pH	5.50	5.99	6.11	6.47	6.4	
Conduct.	186.2	246.6	240.4	245.5	234.6	Day 4
Temp.	27.0	27.1	27.0	26.9	26.9	
pH	5.53	6.06	6.15	6.46	6.41	
Conduct.	192.5	227.7	242.5	240.0	234.2	Day 5
Temp.	26.8	26.9	26.8	26.8	26.9	
pH	5.58	6.01	6.14	6.46	6.41	
Conduct.	176.4	240.3	243.2	236.1	234.2	Day 6
Temp.	26.9	26.8	26.9	26.9	26.8	
pH	5.61	6.03	6.12	6.46	6.41	
Conduct.	160.8	242.4	238.4	241.4	234.3	Day 7
Temp.	26.5	26.9	27.0	26.9	26.9	

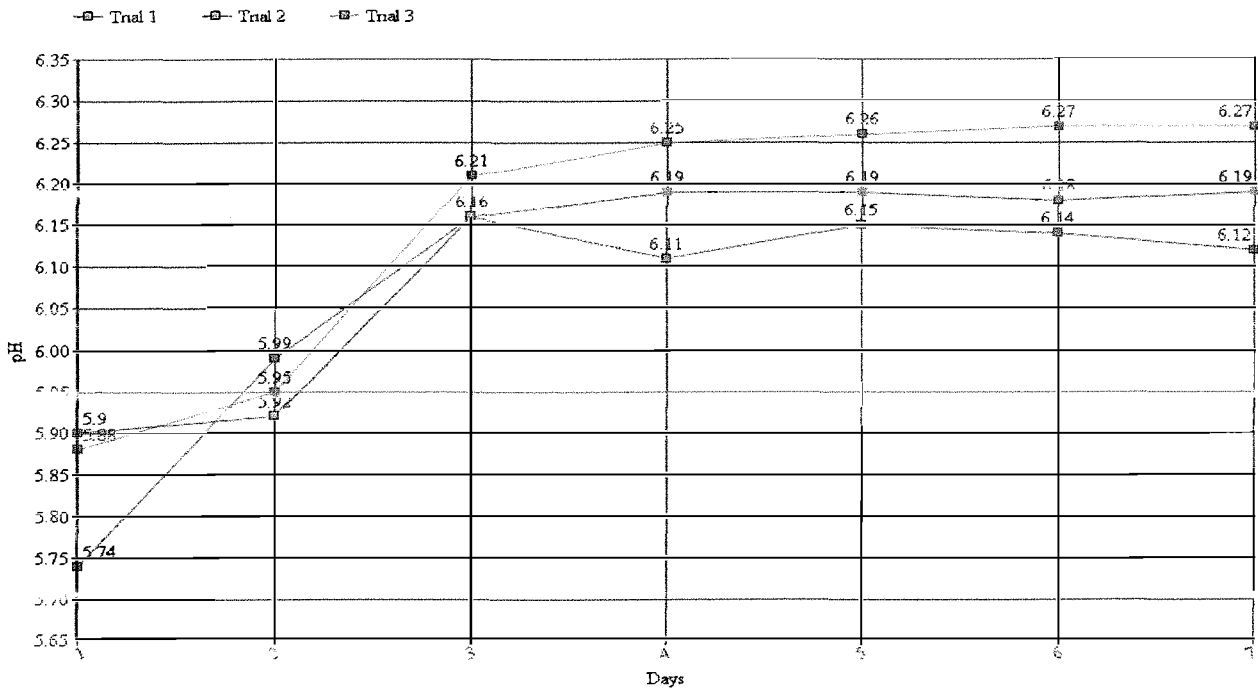
Trial 3

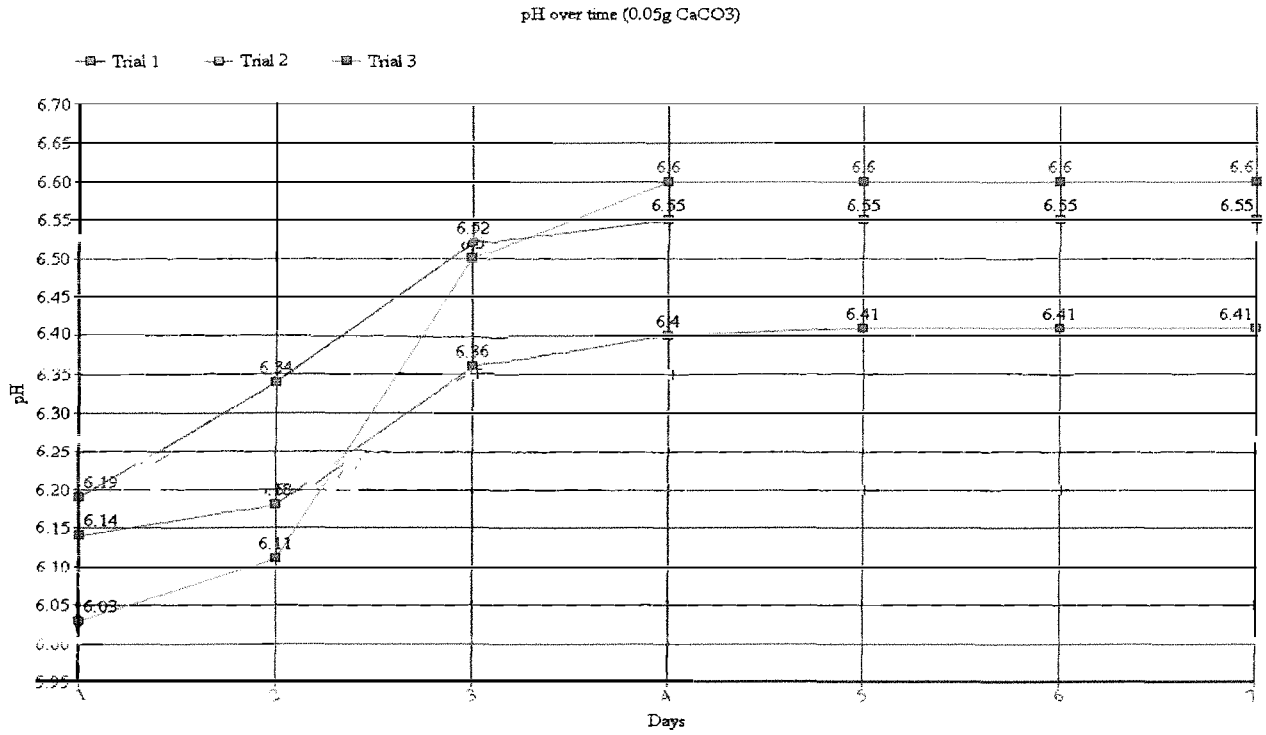
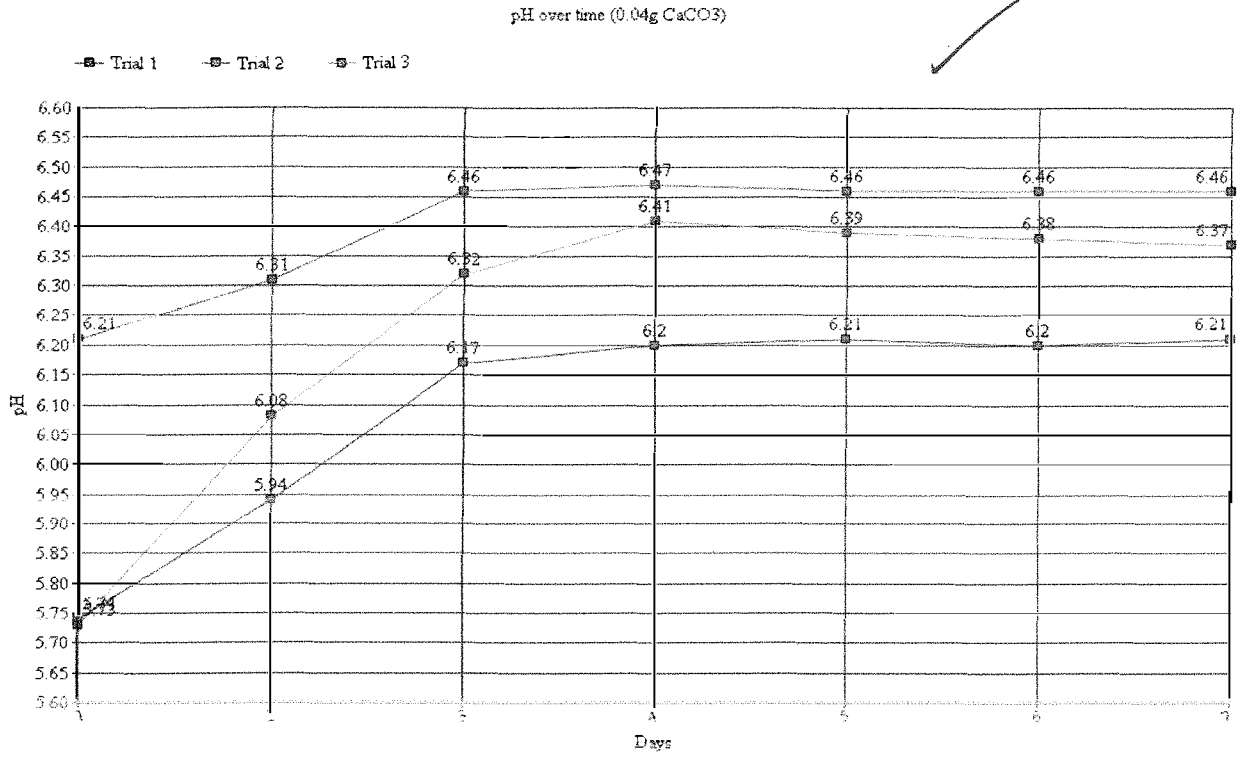
	Control	0.02g CaCO ₃	0.03g CaCO ₃	0.04g CaCO ₃	0.05g CaCO ₃	
pH	5.32	5.64	5.88	5.73	6.03	
Conduct.	215.1	177.1	236.1	186.8	163.9	Day 1
Temp.	27.0	27	27.1	26.9	27.0	
pH	5.38	5.72	5.95	6.08	6.11	
Conduct.	230.2	183.3	209.3	212.8	215.6	Day 2
Temp.	27.6	27.7	27.7	27.6	27.6	
pH	5.44	6.04	6.21	6.32	6.50	
Conduct.	212.3	232.1	248.3	240.1	217.4	Day 3
Temp.	27.1	27.3	27.3	27.3	27.2	
pH	5.48	6.08	6.25	6.41	6.60	
Conduct.	200.3	203.5	239.7	227.7	221.8	Day 4
Temp.	27.1	27.1	27.1	27.1	27.1	
pH	5.52	6.08	6.26	6.39	6.60	
Conduct.	192.4	225.9	223.0	237.1	218.0	Day 5
Temp.	26.9	26.9	26.9	26.9	26.9	
pH	5.55	6.07	6.27	6.38	6.60	
Conduct.	178.6	222.3	230.4	234.1	217.2	Day 6
Temp.	27.1	27.0	27.1	27.1	27.0	
pH	5.54	6.08	6.27	6.37	6.60	
Conduct.	165.9	223.4	233.6	232.2	218.4	Day 7
Temp.	26.4	26.3	26.3	26.4	26.4	

pH over time (0.02g CaCO₃)



pH over time (0.03g CaCO₃)





7. Data Analysis

The more data available, the more accurate results will be and that is vital to the success of an experiment. The main purpose here is to find when a state of equilibrium was reached within the experiment as this is when the forward and backward reactions are equivalent and the pH value does not change, creating stability, an important factor in commercial farming.

Looking at the constant variables for all three trials a common pattern is seen where the pH gradually raises by itself. The rate at which this raises meets an average of about 0.06 pH each day. This was found by finding the average of all three trials and then the average of the three averages thereafter. The steady raise of the constant's pH shows an important factor, the loss of hydrogen gas and reactions between soil and water over a period of time without the addition of acid rain, can eventually heal the soil on its own. This, however, is not the most efficient or possible way, especially with 1,000 pounds of soil.

Onto the addition of CaCO_3 , within every trial the sample with the addition of 0.02g CaCO_3 never reached a point of equilibrium and the pH actually jumped around the point of 5.86pH on trials 2 and 3 leaving trial 1 to be only 5.77pH. The fluctuation of the unstable pH can be represented by a sine curve, however not depicted here. The trials with addition of 0.03g CaCO_3 experienced similar behaviors, however they were much more stable samples. After initially treated each trial had a major jump of over 0.40 units of pH value, at about day 4 equilibrium was almost met though there are changes either up or down of about 0.01 pH units. Trials with the addition of 0.04g CaCO_3 exhibited a jump of over 0.80 units of pH value, reaching lower instability at day 3, changing only 0.01 pH units thereafter. Finally, the prescribed 0.05g of CaCO_3 , the measurement that was to bring this soil's pH up to about 6.8. The behavior of these trials exhibited an automatic jump to the pH range of 6.03-6.19 upon

application and perfect stabilization and assumed equilibrium by day 4. Though the pH produced from each of these trials are very basic and optimal for plant growth, none of the trials reached the goal pH of 6.8.

It seems that the more CaCO_3 added, the faster the soil becomes basic and stable. Using less CaCO_3 produces instability for much longer than effective liming should take. Adding over half of the mathematically determined CaCO_3 , the pH jumped by 0.40 and this jump doubled thereafter with each addition of 0.01g CaCO_3 . The first measurement fluctuated by far too many pH units proving too little to be unstable, however with each addition the fluctuation lowered to about 0.01 pH units and ultimately, with the mathematically determined measurement, reached stability within the span of the experiment.



8. Conclusion

The amount of uncertainties with this experiment may affect the results. There are many components to soil as expected, however, due to lack of resources or sophisticated equipment, I was unable to pay attention to the concentration of constituent elements which may have led to further proof of CaCO_3 ability to reverse effects of pollution or further explain how liming affects the soil at all. On top of this, this experiment was run on a microscopic scale compared to how large practical application is, and with such small measurements, there is plenty room for error in the comparison of this experiment to comparison of commercial use. Done on a larger scale, this experiment may be more accurate as it is easier to measure 1mL of HCl versus 0.1mL and the agriculture industry must apply this to many square meters of soil.

Given more time, these results would be more reliable as I only produced three trials, the experiment could be more accurate. Repetition is important for accuracy and with more time I would have produced six trials or longer trials that show the change in pH and, hopefully, eventual equilibrium. Most measurements in this experiment did not have time to reach a comfortable stage of equilibrium and when the sample does reach this, it could express important data about liming missed by short experimental time.

Unfortunately, the conductivity measurements were far too inaccurate to consider in this experiment. The data for this can be found on the data collection tables and it is seen that this factor had a completely different measurement each time and due to this, it appears that the meter used was broken or poorly calibrated. I would like to have seen what proper conductivity readings could have lent to my analysis on the effect of liming.

Overall, from the research investigated here, lowering the amount of CaCO_3 used for liming is not beneficial. The intention was to produce a less tampered, stable environment at a lower cost, however, lowering the amount of lime proved to extend the period of instability in the soil and would ultimately cost the agricultural industry time. If assessed correctly, soil given the known measurements of lime should reach neutrality and stability within the first week if properly tilled and watered as both speed up the process. This research, however, did prove that it is possible to reverse the pH lowering effects that acid in the form of wet deposition eventually causes in soil through the liming process.

Works Cited

1. Ball, Jeff. "Understanding and Correcting Soil Acidity." Understanding and Correcting Soil Acidity. Samuel Roberts Noble Foundation, n.d. Web. 20 June 2014.
<<http://www.noble.org/ag/soils/soilacidity/>>.
2. Likens, Gene. "Acid rain." Acid rain. N.p., 7 Aug. 2010. Web. 17 July 2014.
<<http://www.eoearth.org/view/article/149814/>>.
3. Scott, Andrew. "What is an "Acre Furrow Slice of Soil?"" - PennStateTurf. N.p., ~~13 Apr.~~ 2010. Web. 18 July 2014.
<<http://www.personal.psu.edu/asm4/blogs/pennstateturf/2010/04/what-is-an-acre-furrow-slice-of-soil.html>>.
4. Sikora, Frank and Kissel, David. "Soil pH" N.p. 15 Dec. Web doc. 18 July 2014.
5. "Soil Electrical Conductivity." NRCS. USDA, n.d. Web. 18 June 2014.
<http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053280.pdf>.
6. Tisdale Samuel L., Nelson Werner L., Beaton James D., *Soil Fertility and Fertilizers*, fourth edition, USA, 1985.
7. Urbansky, Edward and Schock, Michael. "Understanding, Deriving and Computing Buffer Capacity." Journal of Chemical Education. American Chemical Society, n.d. Web. 3 July 2014. <<http://nepis.epa.gov/Adobe/PDF/300023>>
8. Woodford, Chris. "pH Meters." N.p. 6 Aug 2014. Web. 3 July 2014.
<http://www.explainthatstuff.com/how-ph-meters-work.html>