International Baccalaureate Diploma Program Biology Higher Level

Word count: 3932

Investigating the Effects of Adding Limestone on Plant Growth of Five Plant Species

Research question: What are the effects of adding different masses of limestone (0, 1.2, 1.4, 1.6, 1.8, 2g) on the rate of acid rain affected plants' (*Cucumis sativus*, *Tagetes erecta*, *Raphanus sativus*, *Solanum lycopersicum*, *Calendula officinalis*) vertical growth (mm/day), measured every second day for 15 days?

INTRODUCTION

Acid rain overview

Acid rain is characterized by a pH of about 5.2 or lower (Rafferty). It is caused by sulfur dioxide (SO_2) and nitrogen oxides (NO_X) reacting with atmospheric water and oxygen to form sulfuric and nitric acid ("What Is Acid"). Equations A and B outline the reactions in acid rain making.

$$(1)\ 2SO_2(g) + O_2(g)\ \rightarrow\ 2SO_3(g)$$

$$(2)\ SO_3(g) + H_2O(l)\ \rightarrow\ H_2SO_4(aq)$$

Eqn-1. *Consecutive reactions forming sulfuric acid*

$$(1)\ 2NO(g) + O_2(g)\ \rightarrow\ 2NO_2(g)$$

$$(2)\ 2NO_2(g) + H_2O(l)\ \rightarrow HNO_3(aq) + HNO_2(aq)$$

Eqn-2. *Consecutive reactions forming nitric acid*

SO_2 and NO_X gas are emitted naturally via volcanoes and other natural sources; however, a larger percentage comes from industrial activities. In Europe, 20% of SO2 gas emitted derives from the shipping of goods ("Utslipp Til Luft"). Acid rain threatens biodiversity by threatening species that depend on maintained pH and leaching vital nutrients from the soil (Rafferty).

Global context

Acid rain is a transnational issue and has been prevalent for a long time. An example was the Black Triangle which includes regions of the Czech Republic, Germany, and Poland. Due to heavy acid rain in the 1970s and 80s, the region was characterized by entire dead forests and corroded railroads. To mitigate the effects of acid rain, the coal-burning industries' emissions became strictly regulated under the 1979 Geneva Convention (Echolls). This proved to be successful in reducing acid rain. Today, acid rain most commonly occurs in the Northeast United States and Eastern Europe (Echolls). Globally, there have been efforts to control industries' emissions, including the United States Clean

Air Act of 1970, and technologies like limestone injection burners and flue gas desulfurizers. Despite this, acid rain has steadily increased since the 2000s due to rapid global industrialization (Echolls).

Norway is the country of focus because this is where the investigation is conducted. In Norway, major sources of NO_X emissions include energy production, road traffic, and water transport. Domestic shipping and fishing constitute 1/3 of the total emissions ("Utslipp Til Luft"). Although there are multiple policies and taxes in place, it is challenging to prevent acid rain from occurring.

Acid rain effects on plants

Acid rain produces morphological changes like the deformation of the margins, color change, and necrotic lesions to the leaves (Rodríguez-Sánchez et al.). It reduces the rate of photosynthetic activity by altering the electron transfer efficiency of the photosystem II, disrupting the chloroplast structure, and causing chlorosis (Zhang et al.). Acid rain can alter cuticle thickness, resulting in the occlusion of the stomata and loss of trichomes in the epidermis (Rodríguez-Sánchez et al.). It can also lead to a decrease in antioxidant enzyme (peroxidase and catalase) activity, making the plant more vulnerable to reactive oxidative species (ROS) (Zhang et al.). The culmination of all the adverse effects leads to slow growth or death of the plant (Fig-1).

Fig-1 *a) control pumpkin leaf b) chlorosis after pH 3 acid rain c) chronic injury after pH 3 acid rain* (Pflanzen)

pH 6.5 is optimum for nutrient availability. Low pH (< pH 7) can decrease the availability of secondary and macronutrients, while high pH (> pH 7) decreases the availability of micronutrients. Studies show that acid rain increases the solubility of elements; aluminum (Al), manganese (Mn), and iron (Fe), which are toxic in excess ("Competency Area"). Nutrient deficiency and high concentrations of toxic elements restrict plant growth and development. High concentrations of Al and Fe in soil can lead to phosphorus (P) fixation, limiting P availability. Furthermore, excess Al can inhibit cell elongation and restrict root growth, affecting water uptake needed for drought resistance and metabolic activity (Ejigu et al.).

Effect of adding limestone

Liming is a soil treatment in which liming materials, such as calcium carbonate ($CaCO_3$), hydrated lime ($Ca(OH)_2$), calcium oxide (CaO), and slag lime ($CaSiO_3$), are added to soil to reduce the effects of acid rain by neutralizing it. Adding limestone ($CaCO_3$) has been a standard agricultural practice throughout history. In practice, insoluble limestone is often crushed and ground into fine particles to increase water solubility. Limestone is also very pure (less than 5% chemical impurities) (Mahmud and Chong).

$$CaCO_3(s) + 2H^+ \leftrightarrow Ca^{2+} + CO_2(g) + H_2O(l)$$

Eqn-3 *Neutralizing reaction when limestone is added to acidic soil*

Limestone increases Ca^{2+} concentrations increasing soil ionic strength, benefiting the soil structure, and improving hydraulic conductivity. Liming raises earthworm activity increasing macroporosity allowing for water and air movement and providing room for root growth (Goulding). In addition, liming decreases Al levels and increases concentrations of essential nutrients like P, N, Ca, and Mg (Ejigu et al.).

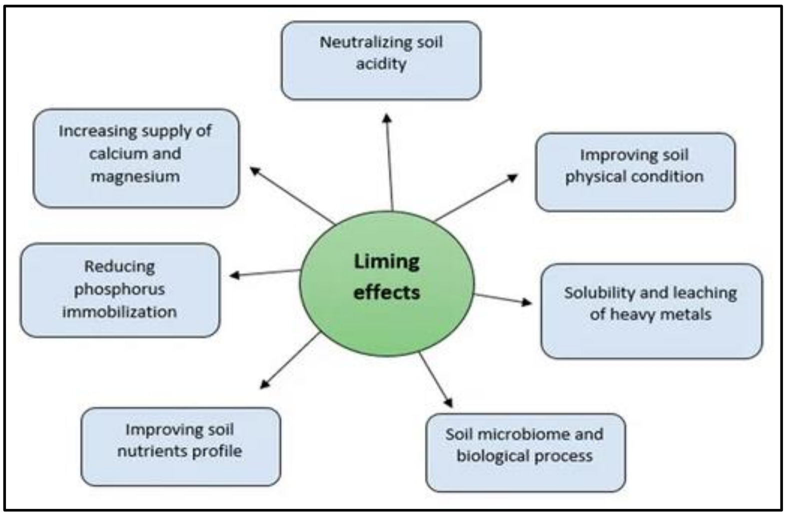


Fig-2 *Overview of liming effects* (Mahmud Chong)

Choice of test subjects and reacting chemicals

This investigation simulates acid rain with pH 4 sulfuric acid (H_2SO_4). Plant types were selected by their estimated germination time and pH tolerance range. Plants tolerate different pH levels depending on their biology and nutrient requirements (CANNA Research). Considering pH tolerance will further evaluate the effectiveness of limestone treatment on a variety of plants.

Table-1: The plants being tested ("Crop Guide") ("Nutritional Factsheet") (Masabni)(Slusher)(Hailey)

Plant	Binomial name	pH tolerance		Estimated time for germination
Cucumber	*Cucumis sativus*	5.1 - 5.7	low ↓ high	3 – 10 days
Marigold	*Tagetes*	5.8 - 6.2		4 – 10 days
Radishes	*Raphanus sativus*	6		5 – 10 days
Tomato	*Solanum lycopersicum*	6.2 - 6.8		5 – 10 days
Calendula	*Calendula officinalis*	6 - 7		7 – 14 days

RESEARCH DESIGN

Research question

What are the effects of adding different masses of limestone (0, 1.2, 1.4, 1.6, 1.8, 2g) on the rate of acid rain affected plants' (*Cucumis sativus, Tagetes erecta, Raphanus sativus, Solanum lycopersicum*, *Calendula officinalis*) vertical growth (mm/day), measured every second day for 15 days?

Hypothesis

Hypothesis: Increasing the mass of limestone added will increase the plant growth rate because limestone neutralizes acid rain and raises the availability of essential nutrients (Mahmud Chong).

Null hypothesis: There is no correlation between the rate of growth and the mass of limestone added.

Preliminary investigation

The preliminary investigation aimed to check the suitable pH for seed development and confirm that the seeds germinated within the experiment period.

Table-2: Preliminary test design

Equipment	Method
• 10x Petri dishes (⌀ 40mm) • Pure cotton as needed • Measuring cylinder (0.05mL) • 100 ml of (pH 4) 0.0001M H_2SO_4 • 100 ml of (pH 7) 1.2g of $CaCO_3$ and H_2SO_4 solution • Cucumber, marigold, radish, calendula, spinach seeds	1. Pick out enough cotton to line the petri dish 2. Place cotton in petri dish 3. Add a teaspoon of seeds to the petri dish, two petri dishes for every seed type 4. Add 10 ml of pH 4 solution to one dish and add pH 7 solution to the other *Excess solution was reused so no waste

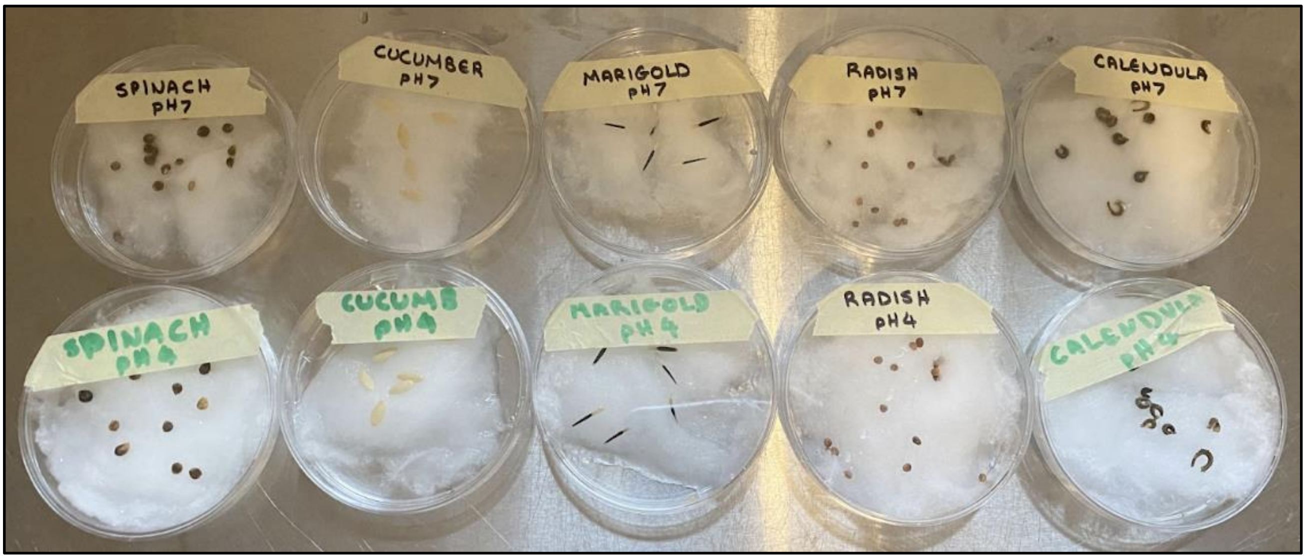


Fig-3 *Day 1* Photographed by Author

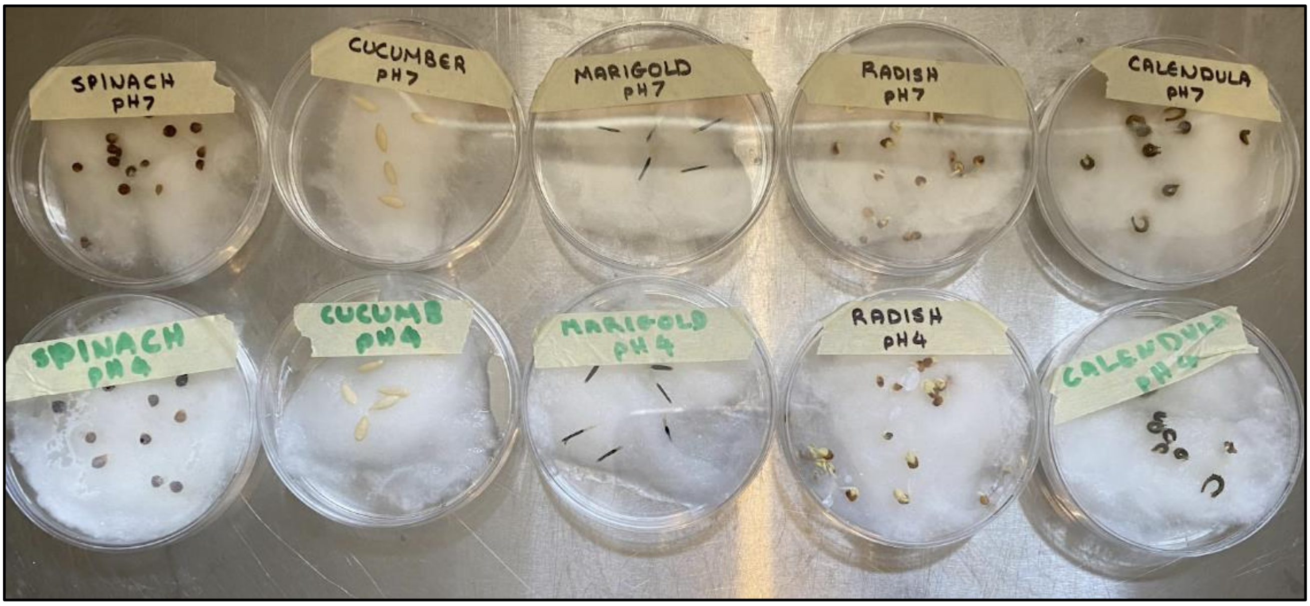


Fig-4 *Day 3* Photographed by Author

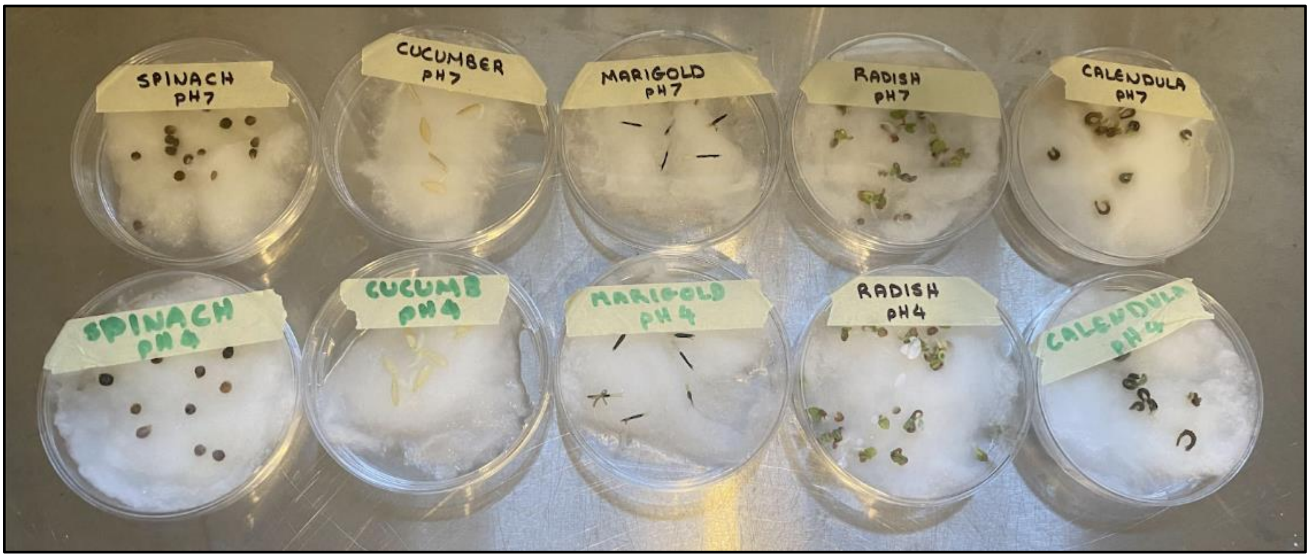


Fig-5 *Day 4* Photographed by Author

The seeds germinated in acidic and neutral conditions. The seeds developed faster at pH 7 than at pH 4; however, this is only an approximation. Radish pH 4 and calendula pH 7 were the first to germinate. The preliminary showed that the spinach needed to be replaced with tomato because the spinach seeds didn’t develop. The rest of the seeds developed, suggesting that the pH is suitable for seed development.

Variables

Table-3: Independent and dependent variables

Variable type	Description
Independent	Mass of limestone added; 0, 1.2, 1.4, 1.6, 1.8, 2g measured using a digital balance (±0.05g)
Dependent	Rate of plant growth (mm/day) calculated by measuring the shoot length (mm), using a ruler (±0.05), every other day for 15 days

Table-4: Controlled variables

Control	Method of control	Effect on results
Volume of water (±0.05mL)	50mL of water (±0.05mL) per pot using a measuring cylinder.	Varying the volume of water will affect plant growth, leading to incomparable data.
Pot size	Using same pot (7×7×7cm)	Different pot sizes can limit or encourage root growth resulting in incomparable data.
Room temperature (±0.5°C)	Maintaining room temperature at 20°C (±0.5°C) using an air conditioner.	Temperature affects plant metabolism and can influence growth independently.
Soil type and quality	Same prepackaged soil used.	Soil type and quality can influence the rate of plant growth and result in incomparable data.
Frequency of watering	Plants watered every other day.	Irregular watering can affect metabolism and yield inconsistent data.

Equipment

- 80x plant pots (7×7×7cm)
- 80L prepackaged soil
- Digital balance (±0.05g)
- 800g of powdered $CaCO_3$
- 4L (pH 4) 0.00025M H_2SO_4 solution
- 2x measuring cylinder (±0.5mL)
- Soil pH-probe (pH±0.005)
- 1x standard ruler (±0.5mm)
- 160x calendula, marigold, tomato, radish seeds
- 96x cucumber seeds
- 14x trays (38.7 × 29.2cm)

Procedure

Preparation of simulated acid rain:

0.01M solution used to prepare 4L of 0.00025M (pH 4) H_2SO_4

Dilution equation:

$$C_1V_1 = C_2V_2$$

C_1 = initial concentration (0.01M); V_1 = initial volume; C_2 = final concentration (0.00025M); V_2 = final volume (4L)

$$V_1 = \frac{C_2V_2}{C_1}$$

$$V_1 = \frac{0.00025M \times 4L}{0.01M}$$

$$V_1 = 0.1L$$

Therefore, 100 mL of 0.01M H_2SO_4 solution in total is needed.

$$Volume\ of\ water\ = V_2 - V_1$$

$$= 4L - 0.1L$$

$$= 3.9L$$

3900 mL of distilled water needed. Solutions stored in 8 bottles with 500 mL in each. pH double-checked using a pH probe.

Table-5: Conditions tested

	Condition	Day 1/15 - solution added to soil	Day 7/15 - mass (g) of $CaCO_3$ added
Control	1	50mL distilled H_2O	0
	2	50mL pH 4 H_2SO_4	0
	3		1.2
	4		1.4
	5		1.6
	6		1.8
	7		2
Control	8	50mL distilled H_2O	2

Experiment setup:

1) Allocate 16 pots for every plant type (2 per condition).
2) Label each pot with the plant type, condition number, and A or B to distinguish between pots of same condition.
3) Place trays under the pots to collect excess water that may leave the pots.
4) Elevate pots with stands for easier data collection.
5) Add 10 seeds (tomato, radish, calendula, marigold) and 6 cucumber seeds to each pot.

Fig-6 *Experiment setup* Photographed by Author

Table-6: Experiment timeline

Day		Description
Germinate	1	1. Using a clean soil pH probe, record the pH of each pot. 2. Add 50mL of simulated acid rain (0.00025M) using a measuring cylinder to the correct pot. 3. Add measured 50mL of distilled water to the untreated pots. 4. Use soil pH probe to measure and record soil pH.
	2, 3,4	Record which seeds have germinated.
Growth	1,3,5	1. Add 50 mL of water to every pot. 2. Measure and record plant growth using a standard ruler.
	7	1. Use a soil pH probe to record pH for every pot. 2. Use a digital balance to measure the correct mass of $CaCO_3$ and add to correct pot. 3. Add 50 mL distilled water to allow $CaCO_3$ to spread. 4. Use a soil pH probe to measure pH 5. Measure and record plant growth using a standard ruler
	9, 11, 13, 15	1. Add 50mL distilled water to every pot. 2. Measure and record plant growth using a standard ruler.

Risk assessment

Safety:

- Following guidelines on safe sulfuric acid handling are from the New Jersey Department of Health.
- Sulfuric acid is a carcinogen and is corrosive. Exercise the utmost caution by using gloves and goggles. Avoid contact with skin by wearing a protective coat (possibly supplied by the laboratory). Wear protective face gear for impermeable coverage.

    - Scientists have no safe level of exposure for carcinogens, so keep caution when handling diluted sulfuric acid as well.
- Sulfuric acid is a strong oxidizer, so keep away from open fires and do not use water directly on the acid.
- Water spills create slipping hazards. Keep the experiment area dry.

Ethical and environmental:

- After the experiment, the plants will be uprooted and replanted in a garden to minimize waste and help reduce carbon emissions.
- The soil will be disposed of appropriately following laboratory rules and local municipality guidelines.

RESULTS

Raw data

All the data is presented using Google Sheets 2024.

Table-7: Quantitative data of the soil pH before addition of limestone ($CaCO_3$) measured with pH probe

Soil pH (±0.005) before $CaCO_3$ added Day 7											
CONDITION		**TOMATO**		**RADISH**		**CALENDULA**		**MARIGOLD**		**CUCUMBER**	
		1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
1	*H_2O*	5.0	5.0	4.8	4.9	4.7	5.2	5.1	5.2	4.8	5.0
2	*Acid rain*	4.5	4.5	4.5	4.1	4.9	4.9	4.7	4.6	4.9	4.9
3		4.5	4.5	4.7	4.5	4.4	4.5	4.6	4.6	4.6	4.6
4		4.5	4.5	4.2	5.0	4.6	4.5	4.5	4.5	4.6	4.7
5		4.5	4.6	4.3	4.8	4.3	4.8	4.5	4.5	4.6	4.9
6		4.6	4.6	5.1	5.0	4.7	4.8	4.4	4.5	4.7	4.9
7		4.9	4.6	4.8	4.5	4.7	4.6	4.4	4.4	4.8	5.0
8	*H_2O*	5.3	5.2	5.1	4.7	4.8	5.2	5.2	5.3	5.1	5.2

Table-8: Quantitative data of the soil pH after addition of limestone ($CaCO_3$) measured with pH probe

Soil pH (±0.005) after $CaCO_3$ added Day 7												
CONDITION		**Mass of $CaCO_3$ added (±0.05g)**	**TOMATO**		**RADISH**		**CALENDULA**		**MARIGOLD**		**CUCUMBER**	
			1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
1	*H_2O*	*0.0*	5.2	5.8	5.0	5.1	5.7	5.5	4.8	4.7	4.8	4.6
2	*Acid rain*	*0.0*	5.6	5.6	5.1	5.1	4.9	4.8	4.9	4.8	4.8	4.8
3		*1.2*	6.6	6.5	6.9	6.5	5.9	6.1	6.6	6.3	6.9	6.9
4		*1.4*	6.8	7.0	6.4	5.9	6.9	6.8	6.4	6.5	7.0	7.2
5		*1.6*	7.0	6.5	5.8	5.7	6.2	6.2	6.7	6.7	5.6	5.7
6		*1.8*	7.3	7.1	5.4	6.8	6.6	6.7	6.7	6.7	5.4	5.0
7		*2.0*	7.2	7.0	6.8	6.9	7.5	7.4	5.3	5.5	4.8	5.2
8	*H_2O*	*2.0*	6.4	6.4	5.1	7.4	5.3	5.2	6.5	6.9	7.6	7.6

Refer appendix for plant growth.

Sample calculations

Average growth of cucumber – acid rain; day 3:

$$\frac{\Sigma x_n}{n}$$

$$= \frac{19 + 20 + 19 + 18 + 19 + 20 + 19 + 18 + 18 + 20 + 19 + 19}{20}$$

$$= 19\ mm$$

Standard deviation, σ, of cucumber - acid rain; day 3:

$$\sqrt{\frac{\sum_{i=1}^{k} f_i (x_i - \mu)^2}{n}}$$

$$= \sqrt{\frac{(20-19)^2 + (18-19)^2 + (20-19)^2 + (18-19)^2 + (18-19)^2 + (20-19)^2}{5}}$$

$$= 0.7$$

Logger Pro 3.16.2 was used to calculate growth rates. Rate of growth for tomato – H_2O; day 1 to 7:

$$\frac{Day\,7 \;-\; Day\,1}{7}$$

$$= \frac{49.3 - 0}{7}$$

$$= 7\ mm\ day^{-1}$$

Average soil pH of tomato - acid rain; day 7:

$$\frac{\Sigma x_n}{n}$$

$$= \frac{5.6 + 5.6}{2}$$

$$= pH\ 5.6$$

Percentage change between tomato growth rate in the first week and the second with 2g added limestone:

$$\frac{final - initial}{initial} \times 100$$

$$= \frac{10.7 - 6.5}{6.5} \times 100$$

$$= 64.6\%$$

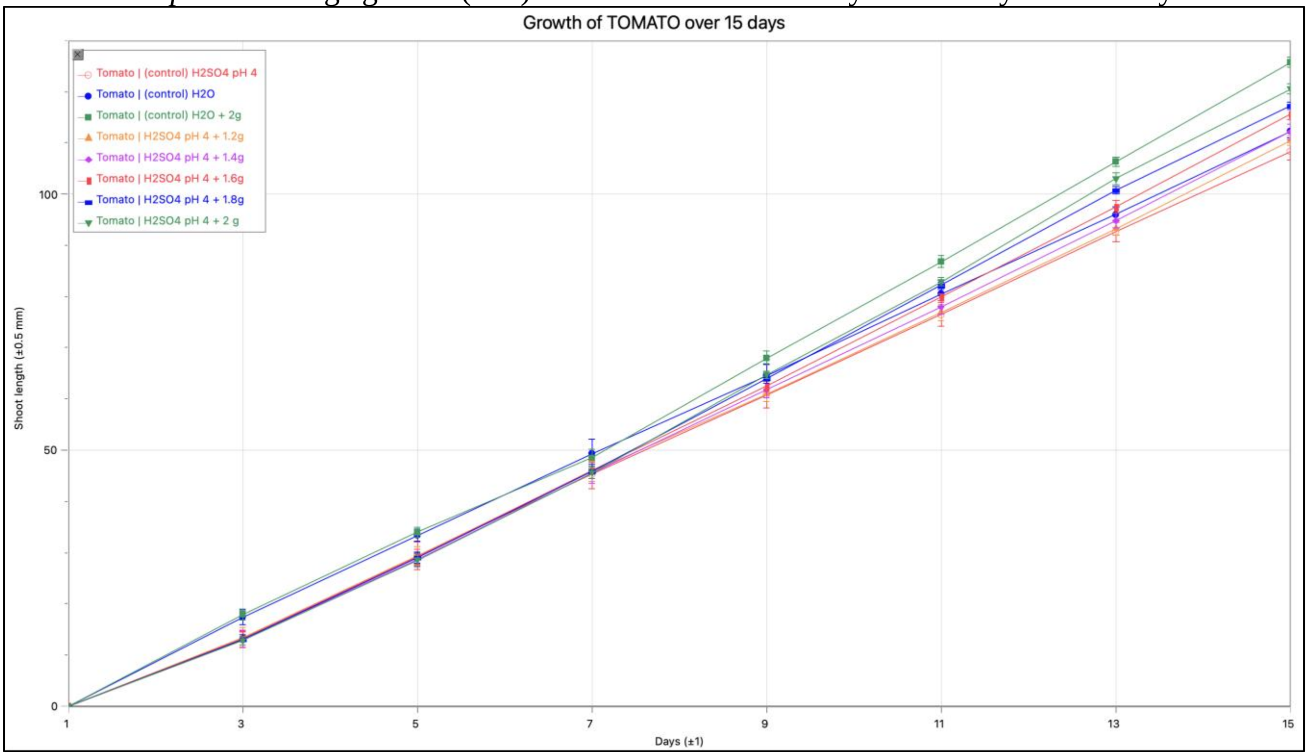
Processed data

Table-9: Average growth (mm) of tomato seeds for every second day over 15 days

avg. growth (±0.5mm) of TOMATO over 15 days																
Day (±1)	*Condition*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	12.9	1.5	17.4	1.4	17.9	1.0	13.5	1.9	13.1	1.7	13.3	1.4	13.0	1.0	12.8	0.8
5	29.3	2.7	33.4	1.1	34.0	1.0	29.4	1.8	28.7	1.3	29.2	1.5	29.0	1.1	28.5	1.2
7	45.3	2.8	49.3	2.9	48.5	1.6	45.9	2.0	45.6	2.0	46.0	1.6	45.9	1.4	45.6	1.1
9	60.8	2.6	64.6	2.3	68.0	1.4	60.9	1.4	61.8	1.6	62.5	1.0	64.0	0.9	64.7	0.8
11	76.5	2.3	80.5	2.3	86.8	1.2	76.9	1.6	77.9	1.3	79.9	0.6	82.2	0.9	82.9	0.8
13	92.6	1.9	96.0	1.6	106.3	0.9	93.2	1.2	94.8	1.4	97.5	1.2	100.8	0.7	103.0	1.2
15	108.8	1.7	112.3	1.3	125.7	1.0	110.4	0.9	112.2	1.5	115.6	1.0	117.2	0.7	120.5	1.0

Refer appendix for average plant growth and standard deviation.

Graph-1: Average growth (mm) of tomato seeds for every second day over 15 days

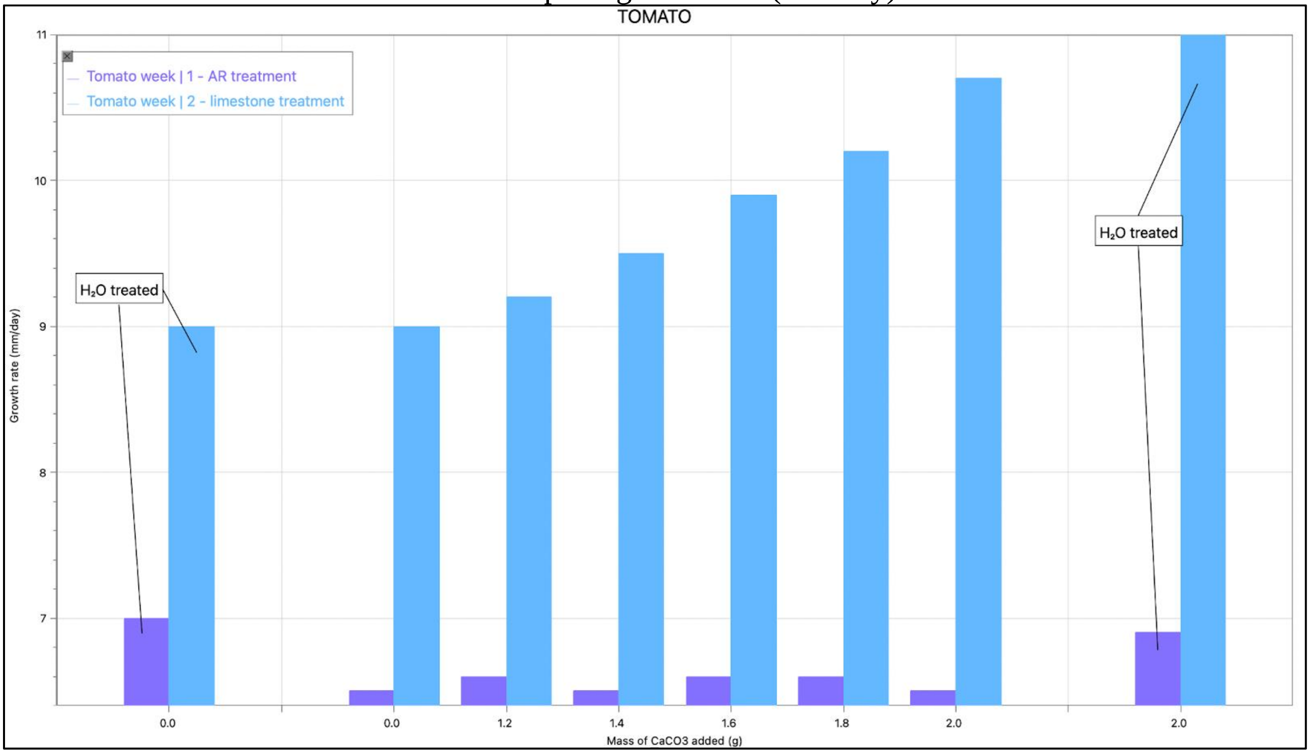


Mean shoot length was used to calculate growth rate in each condition using Logger Pro 3.16.2. Standard deviation (Table-9) is small hence the power of mean is high, suggesting the mean is an accurate reflection of the data. These average data points were used to calculate the average rates for every condition. Graphs-2 to 7 do not show error bars as the rates were calculated from single points (derived from the average growth on the specific day); however, this investigation does contain limitations that decrease the accuracy. The results may have been influenced by instrumental and human error. The uncertainties for the instruments have been noted, but human error cannot be quantified into a single uncertainty. Despite the standard deviation being low and the 20 trials for every condition (12 for cucumber), there will be a degree of uncertainty to the data interpretation. Calculating averages and conducting multiple trials are all measures to reduce uncertainty.

Table-10: Growth rate (mm/day) of tomato plants for week 1 (days 1-7) and week 2 (days 7-15), calculated by the average growth (mm) for every condition for 15 days

Growth rate (mm/day) TOMATO				**Percentage increase between week 1 and 2**
Soil treatment	Growth rate (mm/day) in week 1	Mass of $CaCO_3$ added	Growth rate (mm/day) in week 2	
H_2O	7.0	0	9.0	28.6%
Acid rain	6.5	0	9.0	38.5%
Acid rain	6.6	1.2	9.2	39.4%
Acid rain	6.5	1.4	9.5	46.2%
Acid rain	6.6	1.6	9.9	50.0%
Acid rain	6.6	1.8	10.2	54.5%
Acid rain	6.5	2	10.7	64.6%
H_2O	6.9	2	11.0	59.4%

Graph-2: Effect of adding simulated acid rain (week 1) and different masses of limestone (week 2) on tomato plant growth rate (mm/day)

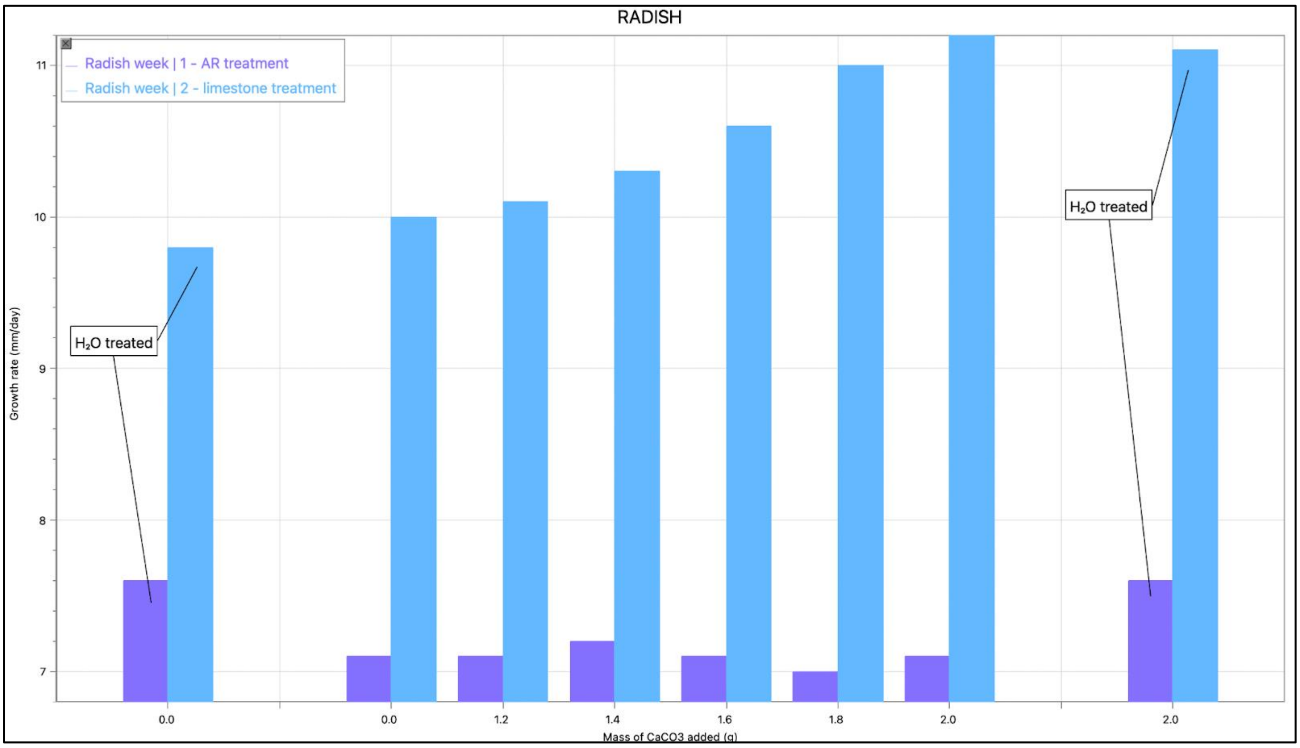


During week 1, tomato plants treated with water instead of acid rain have a greater growth rate. In week 2 there is a positive correlation between the mass of limestone added and the growth rate. This supports the hypothesis that adding more limestone will neutralize the effects of acid rain. The acid treated plants' growth rate increased by 38.5% without any added limestone in the second week. Acid treated plants with 1.2g added limestone in the second week increased growth rate by 39.4%. The percentage change differs by 7%, suggesting the effect of adding 1.2g of limestone is low. There is a greater difference between percentage increase when 1.8g of limestone is added (54.5%) and 2g added (64.6%); a 10% difference. The data demonstrates that adding more limestone does not correlate with a proportional increase in growth rate. More limestone is needed for a greater increase in tomato plant growth rate.

Table-11: Growth rate (mm/day) of radish plants for week 1 (days 1-7) and week 2 (days 7-15), calculated by the average growth (mm) for every condition for 15 days

Growth rate (mm/day) RADISH				Percentage increase between week 1 and 2
Soil treatment	Growth rate (mm/day) in week 1	Mass of $CaCO_3$ added	Growth rate (mm/day) in week 2	
H_2O	7.6	0	9.8	29.0%
Acid rain	7.1	0	10.0	40.8%
Acid rain	7.1	1.2	10.1	42.3%
Acid rain	7.2	1.4	10.3	43.1%
Acid rain	7.1	1.6	10.6	49.3%
Acid rain	7.0	1.8	11.0	57.1%
Acid rain	7.1	2	11.2	57.7%
H_2O	7.6	2	11.1	46.1%

Graph-3: Effect of adding simulated acid rain (week 1) and different masses of limestone (week 2) on radish plant growth rate (mm/day)

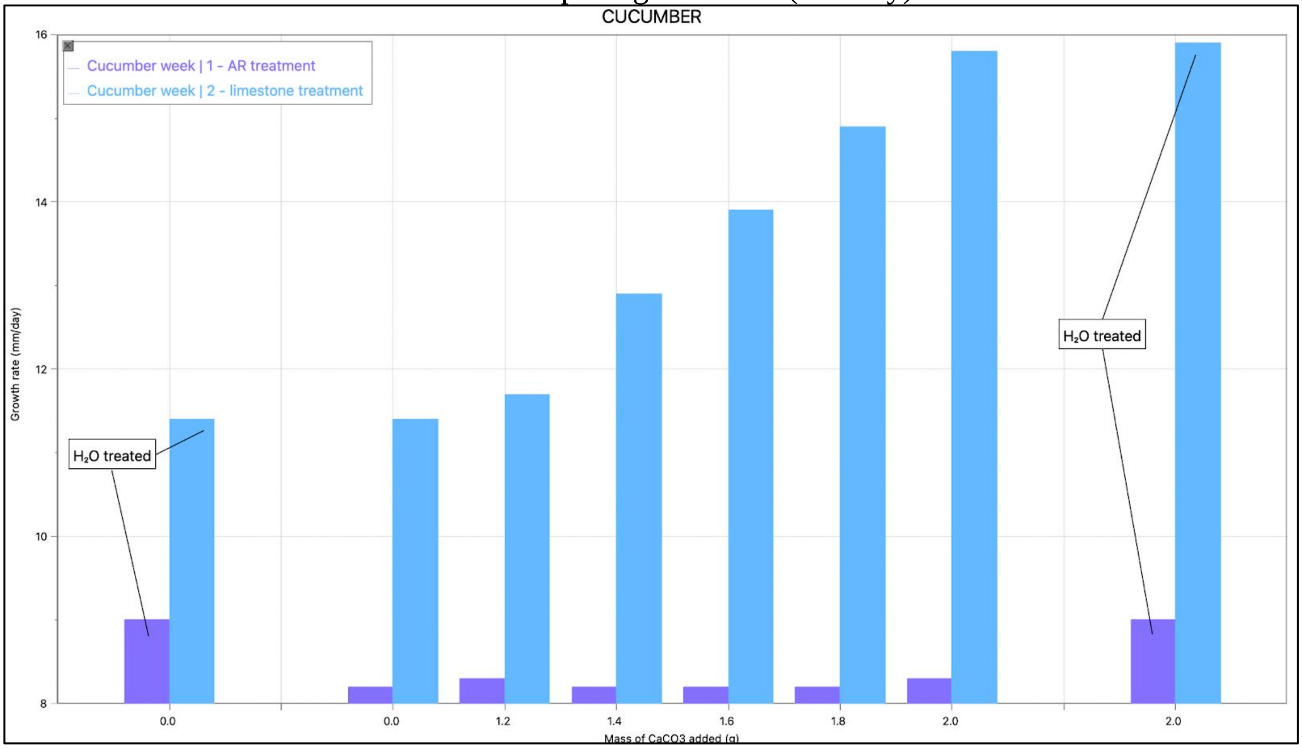


Adding limestone to acid treated radish increased the growth rate and aligns with the hypothesis. This is demonstrated by adding 2g of limestone increasing the growth rate by 57.7%, while plants with no added limestone only increased growth rate by 28.2%. However, the increments in percentage increase are small. 0g added to acid rain plants only produces an increase in rate that is 1% lower than that of 1.2g. Similarly, adding 1.4g only increases the rate by 1% compared to 1.2g added. The greatest difference in percentage increase in rate (8%) is between 1.6g (49%) and 1.8g (57.1%). This suggests that limestone treatment is only effective in larger masses. Additionally, only water plants with 2g of limestone show a lower growth rate (11.1mm/day) than acid rain plants with the same limestone treatment (11.2mm/day). The difference in rate is minute, but the percentage increase difference (11.6%) between the two is great. Adding more limestone to acid treated plants increases plant growth rate.

Table-12: Growth rate (mm/day) of cucumber plants for week 1 (days 1-7) and week 2 (days 7-15), calculated by the average growth (mm) for every condition for 15 days

Growth rate (mm/day) CUCUMBER				**Percentage increase between week 1 and 2**
Soil treatment	Growth rate (mm/day) in week 1	Mass of $CaCO_3$ added	Growth rate (mm/day) in week 2	
H_2O	9.0	0	11.4	26.7%
Acid rain	8.2	0	11.4	39.0%
Acid rain	8.3	1.2	11.7	41.0%
Acid rain	8.2	1.4	12.9	57.3%
Acid rain	8.2	1.6	13.9	69.5%
Acid rain	8.2	1.8	14.9	81.7%
Acid rain	8.3	2	15.8	90.4%
H_2O	9.0	2	15.9	79.7%

Graph-4: Effect of adding simulated acid rain (week 1) and different masses of limestone (week 2) on cucumber plant growth rate (mm/day)

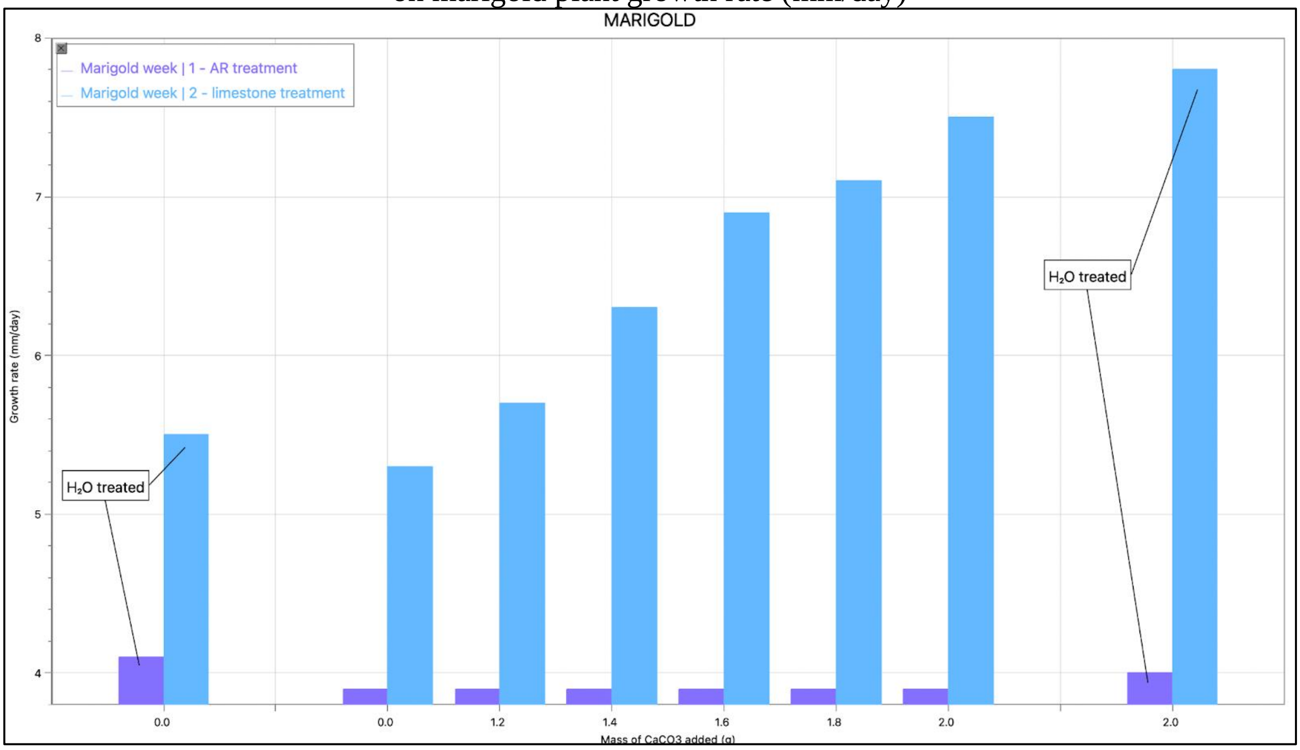


Adding limestone increases the plant growth rate in all cucumber plants. Adding 2g of limestone to acid treated plants produced a greater percentage increase (76.7%) than 0g of limestone added (26.7%). The results support the hypothesis. The difference between percentage increase in 1.4g and 1.6g added to acid rain plants is 16%. 2g of limestone is the most effective as the percentage increase between adding acid and limestone treatment is 90.4%. The percentage increase in growth rate increases significantly with more limestone being added. Limestone treatment is effective in increasing growth rate of acid treated cucumber plants.

Table-13: Growth rate (mm/day) of marigold plants for week 1 (days 1-7) and week 2 (days 7-15), calculated by the average growth (mm) for every condition for 15 days

Growth rate (mm/day) MARIGOLD				**Percentage increase between week 1 and 2**
Soil treatment	Growth rate (mm/day) in week 1	Mass of $CaCO_3$ added	Growth rate (mm/day) in week 2	
H_2O	4.1	0	5.5	34.1%
Acid rain	3.9	0	5.3	35.9%
Acid rain	3.9	1.2	5.7	46.2%
Acid rain	3.9	1.4	6.3	61.5%
Acid rain	3.9	1.6	6.9	76.9%
Acid rain	3.9	1.8	7.1	82.1%
Acid rain	3.9	2	7.5	92.3%
H_2O	4.0	2	7.8	95.0%

Graph-5: Effect of adding simulated acid rain (week 1) and different masses of limestone (week 2) on marigold plant growth rate (mm/day)

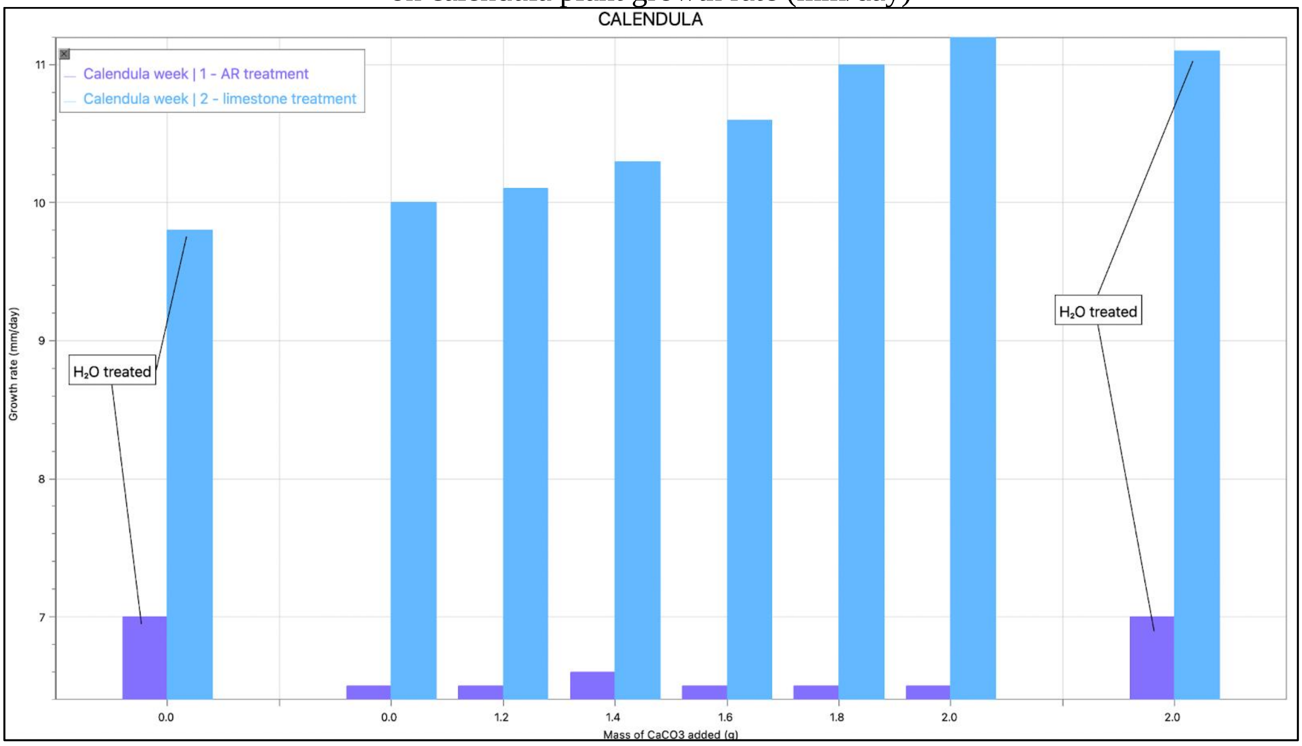


The percentage increase in acid treated marigold plants with 0g limestone added (35.9%) is less than 2g of limestone added (92.3%), aligning with the hypothesis that adding more limestone increases growth rate. The difference between the percentage increase between every subsequent mass is high. The difference between 1.2g and 1.4g is 15.4%. Limestone treatment for acid rain marigold plants is highly effective as adding 2g to acid rain plants increased growth rate by 92.3% as compared to when acid rain was added.

Table-14: Growth rate (mm/day) of calendula plants for week 1 (days 1-7) and week 2 (days 7-15), calculated by the average growth (mm) for every condition for 15 days

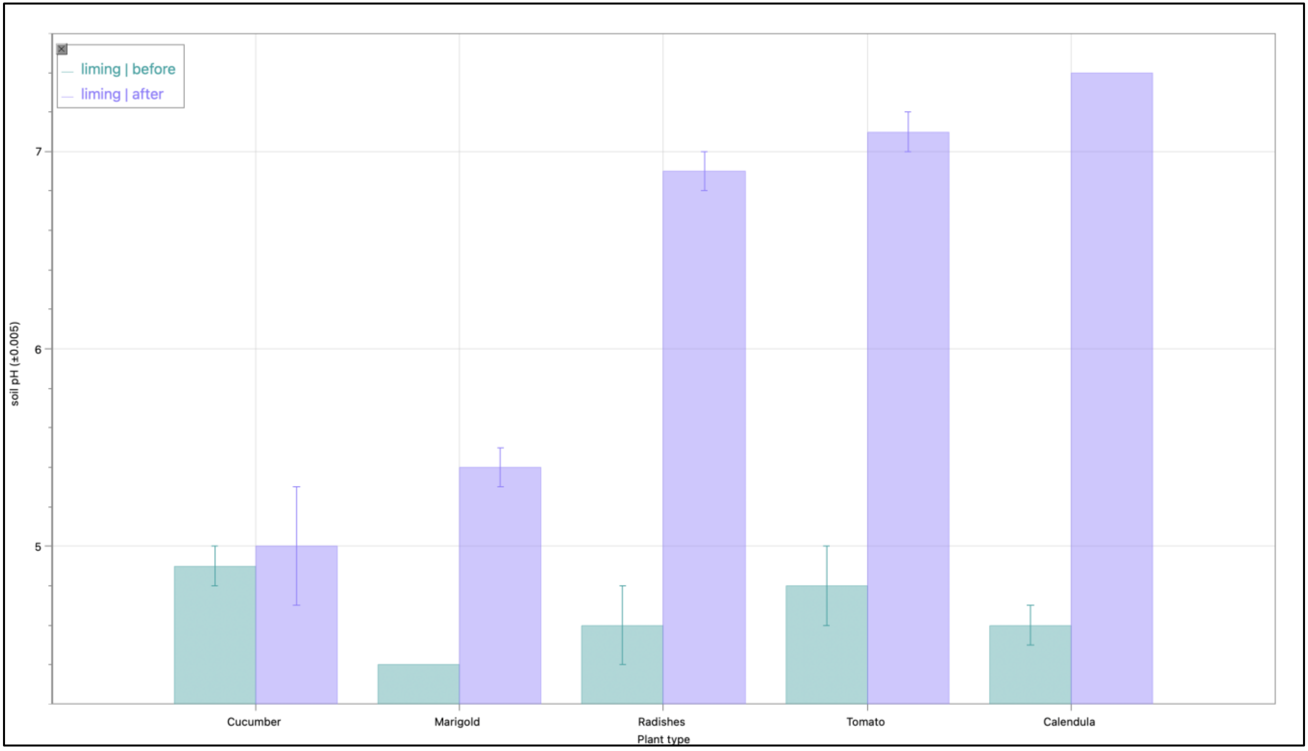
Growth rate (mm/day) CALENDULA				Percentage increase between week 1 and 2
Soil treatment	Growth rate (mm/day) in week 1	Mass of $CaCO_3$ added	Growth rate (mm/day) in week 2	
H_2O	7.0	0	9.8	40.0%
Acid rain	6.5	0	10.0	53.8%
Acid rain	6.5	1.2	10.1	55.4%
Acid rain	6.6	1.4	10.3	56.1%
Acid rain	6.5	1.6	10.6	63.1%
Acid rain	6.5	1.8	11.0	69.2%
Acid rain	6.5	2	11.2	72.3%
H_2O	7.0	2	11.1	58.6%

Graph-6: Effect of adding simulated acid rain (week 1) and different masses of limestone (week 2) on calendula plant growth rate (mm/day)



Adding limestone to acid treated calendula plants has increased plant growth rate and aligns with the hypothesis. The greatest percentage increase difference is between 1.6g and 1.8g (6.1%). Limestone treatment is most effective from 1.6g to 1.8g. The control experiment water plants with 2g limestone have a lower percentage increase (58.6%) than acid rain plants with 2g of limestone (72.3%). Limestone is more effective in acid treated plants.

Graph-7: Soil pH in acid rain treated plants before (green) and after (purple) adding 2g of limestone



The plant types are ordered in decreasing pH tolerance to acidity. Soil pH has increased after liming in all plants. There is no significant trend between pH tolerance and soil pH in week 1, but in week 2, soil pH increases as plants become less acid tolerant.

Statistical test

The unpaired T-test has been carried out to determine if there is a significant difference between total plant growth (mm) over 15 days of acid treated plants with no limestone (control) and 2g added (intervention). GraphPad T-test calculator has been used to find the following.

1.686 critical value

Plant type	Mean score (SD) of intervention	Mean score (SD) of control	Mean difference	df	t	p value	95% C.I.
Tomato	1.05	1.74	-12.20	38	26.8	>0.0001	(-13.12, -11.28)
Radish	0.55	0.79	-7.85	38	36.5	>0.0001	(-8.29, -7.41)
Marigold	0.51	0.76	-15.10	38	73.8	>0.0001	(-15.51, -14.69)
Calendula	0.55	0.79	-7.85	38	36.5	>0.0001	(-8.29, -7.41)

Table format from Presentation of T-test, Researchgate (Presentation of Independent)

1.717 critical value

Plant type	Mean score (SD) of intervention	Mean score (SD) of control	Mean difference	df	t	p value	95% C.I.
Cucumber	0.87	0.75	-31	22	93.5	>0.0001	(-31.69, -30.31)

The t-statistic is less than the critical value, so the difference is considered to be extremely statistically significant for all plant types, rejecting the null hypothesis.

CONCLUSION

Discussion

This experiment's purpose was to measure the effects of adding limestone acid treated plants, hence evaluate limestone treatment as a viable acid rain mitigating measure. Overall, the results support the hypothesis that adding limestone to acid rain exposed plants increases the plant growth rate. This is consistent within all the plant types as a positive correlation between mass of limestone added and growth rate produced is observable.

A key finding is the difference in limestone addition effectiveness between plant types. Liming had the least effect on plant growth rate. Unique biological factors are likely to cause this difference. New research on saline-alkali tolerance mechanisms of plants is still developing. It has been found that plants that are already alkaline soil tolerant (tomato is pH 6, slightly acidic) maintain their pH and Na^+ homeostasis (Cao et al.). Such adaptations can explain why limestone treatment was least effective in tomato plants. This result can also be attributed to human error in adding limestone, as it may have been improperly dispersed throughout the soil.

The results of this investigation are significant, evidenced by the T-test, which allowed for the rejection of the null hypothesis. However, this does not prove the hypothesis as human error, or any other unidentified variables, can influence plant growth rate. To reduce the chance of error, 20 trials for each plant type in every condition (and 12 trials for every cucumber condition) were used to calculate an average vertical growth for every measured day. The standard deviation is low so calculating rates from the average points is an accurate representation of the true growth rate. The results are supported by statistical tests and evaluation of standard deviations; however, uncertainty cannot be eliminated hence the hypothesis is not proven true, only supported.

Further analysis of the results showed that radish and calendula had a higher growth rate when 2g of limestone was added to acid rain, compared to 2g added to water. The difference in rate in both plants is 0.1mm/day and can be attributed to acid rain promoting growth. Acid rain contains sulfur, a vital nutrient required for nitrogen metabolism and protein synthesis ("Sulphur Fertilization"). The simulated acid rain (diluted sulfuric acid) may have increased sulfur availability in the experimental plants and promoted growth. This is an underdeveloped research area and can be a viable extension.

Furthermore, Graph-7 shows how soil pH increased after adding limestone. As mentioned in the background research, limestone neutralizes the acid present in acid affected soil. This neutralization reaction is what increases the soil pH towards alkaline levels. During week 1, there is no significant trend between soil pH and plant type. This can be linked to the composition of the packaged soil. Other than dirt particles, organic material in the soil can influence soil pH. Decarboxylation plays a key role in organic matter decomposition under aerobic soil conditions. Carboxylic groups are produced when carbohydrates undergo decomposition in a glycolytic pathway, decreasing soil pH (Yan et al.). Differing proportions of organic matter can skew the pH values obtained. During week 2, there is an observable positive correlation between increasing soil pH and greater tolerance of basic soil. This is likely caused by the unique biological variation of the plants. In terms of ion exchange, for every nitrate ion uptake, the plant exudes a hydroxide ion. This exchange ensures that the plant is electrochemically balanced, in addition to increasing soil pH due to the excess negative hydroxide ions in the soil (Currey). Although this does not explain the trend, it does provide insight into why soil pH increased significantly after limestone was added. pH tolerance has minimal impact on soil pH.

The results of this experiment suggest that liming is a viable practice to mitigate the effects of acid rain. Farmers should be attentive to the specific needs of the plants as there are adverse effects of liming. Soil has a limited amount of nutrient holding capacity. Excessive liming can increase calcium concentration leading to reduced holding capacity for other vital nutrients ("The Dangers"). This is detrimental to plant growth and development. Farmers should be mindful of the mass of limestone applied.

In the wider context, the results of this investigation encourage limestone addition. Limestone promoted plant growth in acid rain affected plants and in plants with only water. It is in the farmers' best interest to add limestone. The masses used in the experiment can be extrapolated further to suit the field area.

A similar study was conducted on the effects of lime rates on acidic soil. The study was conducted using different masses of lime and buffer pH methods. The experiment concluded that increasing lime mass and time increased wheat yield. This corresponds to my findings as well; however, the study also mentions that the maximum wheat yields were obtained a year after applying lime, suggesting that the efficiency of lime increases with time (Ejigu et al.). The timeframe in which I conducted my experiment is considerably smaller than the study's timeframe. In agricultural practice, it is more advisable to expect results over a longer period than 8 days.

Overall, this investigation encourages limestone treatment to plants. It also highlighted areas for further scientific inquiry. All the plants chosen are from Norway, so countries with similar climate and flora can benefit from the results of this investigation.

Evaluation

Table-15: Strengths of the investigation

Strengths
The temperature was controlled using an air conditioner. Controlling the temperature allowed for a fair test and reduced the influence of random errors on the results.
Using multiple seeds for each condition (20 seeds, 12 for cucumber) and 2 pots for each condition allowed for more reliable results, as multiple trials reduce the influence of random errors on the results.
Keeping variables such as pot size and volume of water and sulphuric acid added constant reduced the risk of random errors yielding unreliable results.

Table-16: Limitations and improvements

Limitations		
Name	Reasoning	Improvements
Source of soil	The soil composition affects the pH of the soil. There was bark and other dead organic plant matter in the soil. Organic matter and fertilizers reduce the pH of the soil (Yan et al.). Differing soil composition in each pot may result in random errors.	It is possible to filter the soil using a strainer to ensure that large organic matter doesn't enter the pot.
Number of cucumber seeds	6 instead of 10 used due to availability. Using a different number of seeds can skew the results.	Using 10 seeds
Experiment time frame	A previous study concluded that lime is most effective after a year of application (Ejigu et al.). A short timeframe would limit the scope of the results.	If possible, conducting the experiment for a month would increase the scope of the results substantially.
Density of soil added	Differing densities of soil would result in random errors as density affects the movement of solutions like simulated acid rain and water.	Difficult to control. Using a digital balance to measure the mass of soil being added.

Extension

Conducting the experiment for a longer period would increase the scope of the results, and further observations regarding the effect of acid rain and liming can be investigated. Another extension is testing more plants, and masses of limestone to check when the mass added becomes detrimental.

Inspired by a study investigating the effects of Acid rain stress on leaf anatomy (Rodríguez-Sánchez et al.), an extension would be to investigate the changes in leaf structure using a microscope, where stomatal and photosynthetic pigment alterations could be observed.

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APPENDIX

Table-17: Quantitative data of the soil pH before limestone treatment ($CaCO_3$) measured with pH probe

Soil pH (±0.005) before $CaCO_3$ added Day 7											
CONDITION		**TOMATO**		**RADISH**		**CALENDULA**		**MARIGOLD**		**CUCUMBER**	
		1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
1	*H2O*	5.0	5.0	4.8	4.9	4.7	5.2	5.1	5.2	4.8	5.0
2	*Acid rain*	4.5	4.5	4.5	4.1	4.9	4.9	4.7	4.6	4.9	4.9
3		4.5	4.5	4.7	4.5	4.4	4.5	4.6	4.6	4.6	4.6
4		4.5	4.5	4.2	5.0	4.6	4.5	4.5	4.5	4.6	4.7
5		4.5	4.6	4.3	4.8	4.3	4.8	4.5	4.5	4.6	4.9
6		4.6	4.6	5.1	5.0	4.7	4.8	4.4	4.5	4.7	4.9
7		4.9	4.6	4.8	4.5	4.7	4.6	4.4	4.4	4.8	5.0
8	*H2O*	5.3	5.2	5.1	4.7	4.8	5.2	5.2	5.3	5.1	5.2

Table-18: Quantitative data of the soil pH after limestone treatment ($CaCO_3$) measured with pH probe

Soil pH (±0.005) after $CaCO_3$ added Day 7												
CONDITION		**Mass of $CaCO_3$ added (±0.05g)**	**TOMATO**		**RADISH**		**CALENDULA**		**MARIGOLD**		**CUCUMBER**	
			1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
1	*H_2O*	*0.0*	5.2	5.8	5.0	5.1	5.7	5.5	4.8	4.7	4.8	4.6
2	*Acid rain*	*0.0*	5.6	5.6	5.1	5.1	4.9	4.8	4.9	4.8	4.8	4.8
3		*1.2*	6.6	6.5	6.9	6.5	5.9	6.1	6.6	6.3	6.9	6.9
4		*1.4*	6.8	7.0	6.4	5.9	6.9	6.8	6.4	6.5	7.0	7.2
5		*1.6*	7.0	6.5	5.8	5.7	6.2	6.2	6.7	6.7	5.6	5.7
6		*1.8*	7.3	7.1	5.4	6.8	6.6	6.7	6.7	6.7	5.4	5.0
7		*2.0*	7.2	7.0	6.8	6.9	7.5	7.4	5.3	5.5	4.8	5.2
8	*H_2O*	*2.0*	6.4	6.4	5.1	7.4	5.3	5.2	6.5	6.9	7.6	7.6

Table-19: Quantitative raw data for growth of tomato seeds over 15 days in each condition

growth of TOMATO over 15 days (±0.5 mm)																
Day/condition	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
	1	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	r	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	17	17	14	11	11	10	14	12	14	15	11	12	13	14	18	16
	18	16	11	11	16	13	14	11	12	15	14	12	14	13	18	18
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	18	18	14	13	11	15	14	14	13	15	11	14	12	12	17	19
5	33	33	33	25	27	27	30	28	30	31	27	28	28	30	34	32
	34	32	25	25	31	29	30	27	28	31	31	28	31	29	34	34
	31	34	32	31	28	32	29	28	28	28	29	29	30	28	35	34
	34	35	26	32	29	31	29	30	29	27	30	30	29	28	34	35
	35	33	26	32	29	32	26	30	30	29	30	30	27	28	35	34
	34	35	26	29	31	29	26	29	28	28	30	28	31	27	33	33
	33	34	29	31	30	28	28	28	33	28	28	29	29	28	34	34
	33	33	29	30	30	26	28	29	29	28	29	29	29	28	35	32
	31	33	30	31	30	31	29	30	28	32	28	29	27	27	34	34
	34	34	32	31	26	31	30	30	29	29	27	30	29	27	33	36
7	47	49	50	41	43	43	47	43	46	48	43	45	45	47	48	47

	49	47	41	41	47	45	47	42	45	48	47	45	47	46	48	49
	45	48	48	47	45	49	45	46	44	44	45	46	47	45	49	48
	49	50	42	48	46	47	46	49	47	44	46	48	46	46	48	51
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	48	48	48	46	43	48	48	47	46	47	43	47	44	45	47	51
9	63	65	65	57	60	59	63	59	63	63	64	64	64	65	69	67
	65	63	57	57	61	59	63	59	63	63	66	64	66	64	68	68
	63	64	64	64	60	65	61	64	61	62	63	65	66	64	68	68
	65	66	58	64	61	62	61	64	63	62	64	66	66	65	68	70
	70	64	58	64	61	61	60	64	63	63	64	65	64	65	69	67
	64	70	57	60	61	61	59	61	63	61	64	63	66	64	66	66
	64	69	60	61	61	59	61	61	64	60	64	64	64	65	67	67
	65	66	60	61	61	59	62	62	63	61	64	63	64	64	72	67
	61	63	62	62	62	62	63	62	62	64	64	64	64	64	68	68
	64	64	61	61	61	62	64	62	63	62	62	63	64	65	67	70
11	79	82	80	73	76	74	79	76	80	80	81	82	82	84	86	87
	81	78	74	73	78	74	79	76	80	80	84	82	83	82	87	87
	78	79	80	79	76	79	78	79	79	80	80	83	83	82	87	87
	80	80	74	79	78	79	78	80	80	80	81	83	83	83	88	88
	84	79	74	79	78	79	76	80	80	81	82	83	84	83	89	86
	80	86	73	76	76	77	76	77	80	79	82	82	85	82	85	85
	80	85	76	77	76	75	77	77	81	79	82	82	83	83	86	85
	82	81	76	77	76	75	77	78	80	79	82	82	82	82	89	85
	78	78	77	78	78	78	79	78	79	81	83	83	83	83	88	86
	80	79	77	77	77	78	80	78	80	80	81	83	83	83	87	88
13	95	98	95	90	93	91	96	93	98	98	100	100	101	105	105	106
	97	93	90	90	94	91	96	93	98	98	102	100	103	101	106	106
	94	94	94	95	93	95	94	95	97	98	99	101	103	101	106	107
	96	96	91	95	93	95	94	97	97	98	100	101	103	104	107	107
	95	97	91	95	94	95	93	97	97	99	101	101	104	104	108	106
	96	97	89	93	93	93	93	94	98	97	101	101	104	102	105	105

	96	96	92	94	93	92	94	94	99	97	101	101	103	103	106	105
	98	97	92	93	93	92	94	95	97	97	101	101	103	101	108	106
	93	96	93	94	93	94	95	95	93	98	102	101	103	104	107	106
	96	99	92	93	92	94	98	95	98	98	101	101	103	104	107	107
15	111	113	110	105	110	109	113	110	116	116	117	117	119	121	124	125
	112	110	105	106	111	109	113	110	116	116	118	117	121	119	125	125
	110	111	110	110	110	112	112	112	115	116	115	118	121	119	125	127
	113	112	107	110	110	112	112	113	115	116	117	118	122	121	126	127
	112	113	107	110	111	112	111	113	115	116	117	118	122	121	128	125
	113	114	106	109	110	110	110	112	116	115	117	117	121	119	125	125
	112	113	108	110	110	110	111	112	117	115	117	117	120	119	125	125
	113	113	108	110	110	110	111	113	115	115	117	117	121	119	126	126
	110	114	109	109	110	111	113	113	112	116	118	117	121	121	126	127
	112	115	108	108	109	111	117	113	117	116	117	117	121	121	126	126

Table-20: Quantitative raw data for growth of radish seeds over 15 days in each condition

growth of RADISH over 15 days (±0.5 mm)																
Day/condition	**2**		**1**		**4**		**5**		**6**		**7**		**8**		**3**	
	1	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	18	17	14	14	15	15	14	14	14	15	15	14	14	14	18	18
	19	19	15	16	16	14	16	15	15	15	14	16	14	16	20	18
	19	19	16	15	15	16	15	14	15	15	16	15	14	15	19	18
	18	19	15	15	14	15	15	17	16	16	14	14	16	15	18	19
	19	18	15	16	15	16	16	17	14	15	14	14	15	13	18	18
	19	19	15	15	15	16	15	15	15	14	14	15	14	15	20	19
	18	18	16	14	15	15	14	15	16	14	15	15	15	14	18	18
	19	19	16	16	14	15	16	16	15	15	14	15	15	14	18	18
	19	19	15	16	14	16	16	14	14	16	15	14	14	15	19	20
	19	18	15	15	16	15	16	14	14	15	15	14	14	16	18	20
5	35	33	31	32	32	32	30	30	30	31	32	31	31	30	34	34
	37	35	31	32	34	31	34	31	32	31	31	33	31	33	36	34
	36	36	32	33	32	32	31	30	32	32	34	32	31	32	35	34
	36	35	31	31	33	31	32	33	33	34	30	31	34	32	34	35
	37	35	33	32	33	33	34	33	30	33	30	31	32	30	35	35
	36	35	31	32	32	33	32	32	32	30	30	32	31	32	35	34
	33	34	32	32	32	32	30	32	33	31	32	32	32	32	34	34
	36	34	32	32	30	31	33	34	32	31	31	32	32	31	34	34
	35	35	31	33	31	34	33	30	31	32	32	31	32	32	35	36
	35	34	32	31	33	31	32	30	31	32	32	31	31	33	34	36
7	53	50	49	49	48	49	49	49	49	49	50	49	49	48	53	52

	55	54	49	47	50	47	53	50	50	48	49	51	49	51	55	52
	54	55	49	50	49	50	50	49	50	50	51	50	49	50	53	52
	54	53	49	50	49	50	50	51	51	51	48	49	51	50	52	54
	54	53	52	49	49	51	54	51	47	50	49	48	50	48	54	53
	52	54	49	51	49	51	50	50	50	49	48	50	48	50	54	52
	50	53	52	50	49	51	49	49	51	49	50	50	49	49	51	52
	54	52	52	50	49	50	51	52	50	49	49	49	49	48	51	52
	54	53	48	52	50	52	51	49	49	49	50	48	49	50	54	54
	55	53	48	48	51	48	49	49	49	50	49	48	49	51	53	54
9	69	69	67	67	68	68	67	69	70	69	71	70	73	70	75	74
	71	71	67	68	69	67	69	67	71	67	71	71	73	74	76	74
	70	73	67	68	69	69	68	69	71	71	70	71	73	72	74	74
	71	71	67	68	68	69	68	69	71	70	71	70	74	73	74	75
	71	71	70	67	69	69	71	69	69	71	72	70	74	70	75	75
	70	71	66	69	68	69	68	69	70	69	70	71	73	73	76	74
	71	69	69	67	68	68	67	68	71	68	71	71	73	70	73	74
	71	69	70	67	69	68	69	70	71	69	70	70	73	70	73	74
	72	72	68	68	69	69	69	68	69	69	72	70	72	71	75	75
	72	72	67	67	69	67	68	68	69	70	70	70	72	74	74	75
11	88	86	85	85	87	87	89	89	90	90	91	90	91	89	93	91
	89	88	85	86	89	86	89	88	91	89	91	91	91	93	94	91
	87	88	84	86	87	88	88	89	90	90	90	90	90	92	93	92
	89	88	85	86	87	88	88	89	90	90	91	90	90	92	93	93
	88	87	86	85	88	88	90	89	90	91	92	90	91	92	94	93
	86	86	85	86	87	86	88	89	90	89	90	91	91	92	93	93
	87	87	85	85	87	87	87	88	91	89	90	91	91	90	93	92
	87	87	86	85	88	87	89	89	90	89	90	90	91	90	93	92
	88	88	86	86	88	89	89	88	89	91	92	90	91	92	93	94
	87	90	85	85	88	87	87	88	90	90	90	90	90	92	91	94
13	105	103	101	102	103	102	105	104	105	105	107	106	109	108	111	109
	106	104	102	102	104	101	105	103	107	103	107	107	109	109	111	109
	104	104	101	103	103	103	104	105	105	106	105	107	108	108	110	112
	105	103	102	103	103	103	103	103	105	106	107	107	109	110	110	112
	105	105	102	101	103	103	105	103	105	107	107	107	109	109	111	112
	104	103	102	102	102	101	104	104	105	104	107	107	109	109	111	112

	106	103	102	102	103	102	102	103	107	104	107	107	109	108	111	110
	106	103	102	102	103	102	104	104	105	104	107	106	109	108	111	110
	105	104	103	103	103	104	104	103	104	106	108	106	108	109	111	112
	105	107	102	103	103	103	102	103	105	105	107	106	108	109	112	112
15	123	121	119	119	120	120	123	123	123	122	126	125	127	127	132	129
	124	122	120	119	121	119	123	122	126	122	126	126	128	127	132	129
	122	122	119	121	120	122	122	124	123	123	125	126	128	128	131	131
	122	121	121	121	120	122	122	123	123	123	126	126	128	129	131	130
	124	123	120	120	121	122	122	123	125	124	127	126	128	128	131	131
	121	121	120	119	120	119	123	123	124	123	127	126	128	128	130	131
	123	121	120	119	120	120	121	122	126	123	127	126	128	127	131	130
	122	121	121	120	120	120	123	123	125	123	127	125	128	127	131	130
	122	122	120	120	120	121	123	122	122	126	128	125	128	128	131	131
	122	124	119	121	121	121	121	122	123	125	127	126	127	128	132	130

Table-21: Quantitative raw data for growth of marigold seeds over 15 days in each condition

growth of MARIGOLD over 15 days (±0.5 mm)																
Day/condition	**2**		**1**		**4**		**5**		**6**		**7**		**8**		**3**	
	1	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	10	10	9	8	11	10	9	10	9	8	11	10	10	9	11	12
	11	12	10	8	9	10	9	11	10	8	9	10	9	10	11	11
	10	11	10	8	10	9	10	10	10	10	10	10	9	10	12	11
	11	10	8	10	10	8	10	8	10	11	9	9	10	10	12	12
	12	10	8	9	10	9	11	8	9	10	9	9	10	10	11	11
	11	12	8	9	8	10	11	10	10	10	9	10	9	10	11	11
	10	11	8	10	10	10	10	10	9	10	10	10	10	10	11	11
	10	11	9	8	9	11	10	10	10	10	9	10	10	10	12	12
	10	10	9	10	9	9	10	9	10	9	10	9	10	11	11	11
	11	11	8	8	11	8	9	9	10	8	11	9	10	10	12	12
5	19	19	18	17	19	18	18	18	18	18	19	18	18	18	20	20
	20	20	19	17	18	18	18	19	18	18	18	18	18	18	20	19
	19	20	19	17	18	18	18	18	18	18	19	18	18	18	20	19
	20	20	17	19	18	18	18	18	18	19	18	18	18	18	20	19
	20	20	17	18	18	18	19	18	18	18	18	18	18	19	19	19
	20	20	17	18	18	18	19	18	18	18	18	19	18	18	20	19
	19	19	17	19	18	18	18	18	18	18	18	19	18	18	20	19
	19	19	18	17	18	19	18	18	18	18	18	18	18	18	21	20
	19	19	18	18	18	18	18	18	18	18	18	18	18	19	20	19
	20	20	18	17	19	18	18	18	18	18	19	18	18	19	20	20
7	28	28	28	27	28	27	27	27	27	27	28	27	27	27	29	29

	29	29	28	27	27	27	27	28	27	27	27	27	27	27	29	28
	28	29	28	27	27	27	27	27	27	27	28	27	27	27	29	28
	29	29	27	28	27	27	27	27	27	28	27	27	27	27	29	28
	29	29	27	28	27	27	28	27	27	27	27	27	27	28	28	28
	29	29	27	27	27	27	28	27	27	27	27	28	27	27	29	28
	28	28	27	28	27	27	27	27	27	27	27	28	27	27	29	28
	28	28	27	27	27	28	27	27	27	27	27	27	27	27	18	29
	28	28	28	27	27	27	27	27	27	27	27	27	27	28	29	28
	29	29	28	27	28	27	27	27	27	27	28	27	27	28	29	29
9	38	38	37	36	39	38	39	39	41	40	43	42	44	44	46	46
	39	39	37	36	38	38	39	40	41	40	42	42	44	43	46	45
	38	39	37	36	38	38	39	39	40	40	43	42	44	43	46	45
	39	39	36	37	38	38	39	39	40	41	42	42	44	43	46	45
	39	39	36	37	38	38	40	39	40	40	42	42	43	43	45	45
	39	39	36	36	38	38	40	39	40	40	42	43	44	43	46	45
	38	38	36	38	38	38	39	39	40	40	42	43	44	43	46	45
	38	38	37	36	38	39	39	39	40	41	42	42	43	44	45	46
	38	38	37	37	38	38	39	39	40	40	42	42	44	43	46	45
	39	39	37	36	39	38	39	39	41	40	43	42	44	44	46	46
11	48	48	46	45	46	44	49	46	50	50	51	52	54	54	58	58
	48	48	46	45	48	44	49	46	50	50	54	52	54	53	58	57
	49	49	46	46	46	49	48	49	49	50	50	53	54	53	58	57
	49	49	45	46	48	49	48	49	50	50	51	53	54	53	58	57
	49	49	45	46	48	49	46	49	50	51	52	53	53	53	57	57
	48	49	45	45	46	47	46	47	50	49	52	52	54	53	58	57
	48	48	45	48	46	45	47	47	51	49	52	52	54	53	58	57
	48	48	46	45	46	45	47	48	50	49	52	52	53	54	57	58
	49	49	46	46	48	48	49	48	49	51	53	53	54	53	58	57
	49	49	46	45	47	48	49	48	50	50	51	53	54	54	58	58
13	57	57	56	54	56	54	59	57	61	60	62	62	67	67	70	70
	57	57	56	54	58	54	59	57	60	60	65	62	67	66	70	69
	58	58	56	56	56	59	59	59	60	60	61	63	67	66	70	69
	58	58	54	56	58	59	59	59	60	61	62	63	67	66	70	69
	58	58	54	56	58	59	57	59	60	62	63	63	66	66	69	69
	57	58	54	54	56	57	57	58	61	60	63	63	67	66	70	69

	57	57	54	58	56	55	58	58	62	60	63	62	67	66	70	69
	57	57	56	54	56	55	58	59	61	60	63	62	66	67	69	70
	58	58	56	56	58	58	59	59	61	62	63	63	67	66	70	69
	58	58	56	54	57	58	59	59	60	61	61	63	67	67	70	70
15	66	66	65	64	66	66	72	70	76	76	77	77	80	80	83	83
	66	66	65	64	68	67	72	70	76	76	78	77	80	79	83	82
	68	68	64	64	68	68	71	72	75	76	75	78	80	79	83	82
	68	68	64	65	68	68	71	72	75	76	77	78	80	79	83	82
	68	68	64	65	68	68	70	72	75	76	77	78	79	79	82	82
	66	68	64	64	66	67	70	71	76	75	77	77	80	79	83	82
	66	66	64	67	67	65	70	71	77	75	77	77	80	79	83	82
	66	66	64	64	67	65	70	71	75	75	77	77	79	80	82	83
	68	68	65	64	68	68	72	72	72	76	78	77	80	79	83	82
	68	68	65	64	68	68	71	72	77	76	77	77	80	80	83	83

Table-22: Quantitative raw data for growth of calendula seeds over 15 days in each condition

growth of CALENDULA over 15 days (±0.5 mm)																
Day/condition	**2**		**1**		**4**		**5**		**6**		**7**		**8**		**3**	
	1	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	14	13	10	10	11	11	10	10	10	11	11	10	10	10	14	14
	15	15	11	12	12	10	12	11	11	11	10	12	10	12	16	14
	15	15	11	11	11	12	11	10	11	11	12	11	10	11	15	14
	14	15	11	11	10	11	11	13	12	12	10	10	12	11	14	15
	14	14	11	12	11	12	12	13	10	11	10	10	11	9	14	14
	15	15	11	11	11	12	11	11	11	10	10	11	10	11	16	15
	14	14	12	10	11	11	10	11	12	10	11	11	11	10	14	14
	15	15	12	11	10	11	12	12	11	11	10	11	11	10	14	14
	14	15	10	12	10	12	12	10	10	12	11	10	10	11	15	16
	15	14	11	11	12	11	12	10	10	11	11	10	10	12	14	16
5	31	29	27	28	28	28	26	26	26	27	28	27	27	26	30	30
	33	31	27	28	30	27	30	27	28	27	27	29	27	29	32	30
	32	32	28	29	28	28	27	26	28	28	30	28	27	28	31	30
	32	31	27	27	29	27	28	29	29	30	26	27	30	28	30	31
	33	31	29	28	29	29	30	29	26	29	26	27	28	26	31	31
	32	31	27	28	28	29	28	28	28	26	26	28	27	28	31	30
	29	30	28	28	28	28	26	28	29	27	28	28	28	28	30	30
	32	30	28	28	26	27	29	30	28	27	27	28	28	27	30	30
	31	31	27	29	27	30	29	26	27	28	28	27	28	28	31	32
	31	30	28	27	29	27	28	26	27	28	28	27	27	29	30	32
7	49	46	45	45	44	45	45	45	45	45	46	45	45	44	49	48

	51	50	45	43	46	43	49	46	46	44	45	47	45	47	51	48
	50	51	45	46	45	46	46	45	46	46	47	46	45	46	49	48
	50	49	45	46	45	46	46	47	47	47	44	45	47	46	48	50
	50	49	48	45	45	47	50	47	43	46	45	44	46	44	50	49
	48	50	45	47	45	47	46	46	46	45	44	46	44	46	50	48
	46	49	48	46	45	47	45	45	47	45	46	46	45	45	47	48
	50	48	48	46	45	46	47	48	46	45	45	45	45	44	47	48
	50	49	44	48	46	48	47	45	45	45	46	44	45	46	50	50
	51	49	44	44	47	44	45	45	45	46	45	44	45	47	49	50
9	65	65	63	63	64	64	63	65	66	65	67	66	69	66	71	70
	67	67	63	64	65	63	65	63	67	63	67	67	69	70	72	70
	66	69	63	64	65	65	64	65	67	67	66	67	69	68	70	70
	67	67	63	64	64	65	64	65	67	66	67	66	70	69	70	71
	67	67	66	63	65	65	67	65	65	67	68	66	70	66	71	71
	66	67	62	65	64	65	64	65	66	65	66	67	69	69	72	70
	67	65	65	63	64	64	63	64	67	64	67	67	69	66	69	70
	67	65	66	63	65	64	65	66	67	65	66	66	69	66	69	70
	68	68	64	64	65	65	65	64	65	65	68	66	68	67	71	71
	68	68	63	63	65	63	64	64	65	66	66	66	68	70	70	71
11	84	82	81	81	83	83	85	85	86	86	87	86	87	85	89	87
	85	84	81	82	85	82	85	84	87	85	87	87	87	89	90	87
	83	84	80	82	83	84	84	85	86	86	86	86	86	88	89	88
	85	84	81	82	83	84	84	85	86	86	87	86	86	88	89	89
	84	83	82	81	84	84	86	85	86	87	88	86	87	88	90	89
	82	82	81	82	83	82	84	85	86	85	86	87	87	88	89	89
	83	83	81	81	83	83	83	84	87	85	86	87	87	86	89	88
	83	83	82	81	84	83	85	85	86	85	86	86	87	86	89	88
	84	84	82	82	84	85	85	84	85	87	88	86	87	88	89	90
	83	86	81	81	84	83	83	84	86	86	86	86	86	88	87	90
13	101	99	97	98	99	98	101	100	101	101	103	102	105	104	107	105
	102	100	98	98	100	97	101	99	103	99	103	103	105	105	107	105
	100	100	97	99	99	99	100	101	101	102	101	103	104	104	106	108
	101	99	98	99	99	99	99	99	101	102	103	103	105	106	106	108
	101	101	98	97	99	99	101	99	101	103	103	103	105	105	107	108
	100	99	98	98	98	97	100	100	101	100	103	103	105	105	107	108

	102	99	98	98	99	98	98	99	103	100	103	103	105	104	107	106
	102	99	98	98	99	98	100	100	101	100	103	102	105	104	107	106
	101	100	99	99	99	100	100	99	100	102	104	102	104	105	107	108
	101	103	98	99	99	99	98	99	101	101	103	102	104	105	108	108
15	119	117	115	115	116	116	119	119	119	118	122	121	123	123	128	125
	119	118	116	115	117	115	119	118	122	118	122	122	124	123	128	125
	118	118	115	117	116	118	118	120	119	119	121	122	124	124	127	127
	118	117	117	117	116	118	118	119	119	119	122	122	124	125	127	126
	118	119	116	116	117	118	118	119	121	120	123	122	124	124	127	127
	117	117	116	115	116	115	119	119	120	119	123	122	124	124	126	127
	119	117	116	115	116	116	117	118	122	119	123	122	124	123	127	126
	118	117	117	116	116	116	119	119	121	119	123	121	124	123	127	126
	118	118	116	116	116	117	119	118	118	122	124	121	124	124	127	127
	118	120	115	117	117	117	117	118	119	121	123	122	123	124	128	126

Table-23: Quantitative raw data for growth of cucumber seeds over 15 days in each condition

growth of CUCUMBER over 15 days (±0.5 mm)																
Day/condition	**2**		**1**		**4**		**5**		**6**		**7**		**8**		**3**	
	1	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***	***1***	***2***
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	23	21	19	19	19	19	21	19	20	22	21	21	21	20	24	23
	24	23	20	18	21	19	20	19	22	20	22	23	20	20	24	23
	23	23	19	18	19	20	21	21	21	21	21	19	20	21	22	24
	22	24	18	20	19	21	20	20	21	21	19	20	19	21	22	24
	23	22	19	19	19	20	21	19	20	20	20	21	19	20	24	21
	23	22	20	19	21	20	19	19	20	20	20	19	21	20	23	24
5	42	42	39	39	38	38	39	39	39	41	39	39	41	39	45	44
	45	44	39	37	40	38	38	39	41	40	41	41	40	39	44	44
	44	43	38	37	38	39	38	40	39	40	38	38	40	40	43	44
	43	44	37	39	38	39	38	41	39	40	38	39	39	40	43	45
	43	44	38	38	38	39	39	39	39	38	39	41	38	39	44	42
	43	43	38	38	40	39	39	39	39	38	39	39	40	39	42	44
7	61	62	58	58	58	58	59	57	58	59	57	57	59	57	64	63
	62	63	57	56	59	58	57	57	58	58	58	59	58	57	63	63
	62	63	57	57	57	59	57	59	57	57	57	57	58	58	63	64
	62	64	57	58	58	58	57	58	57	59	57	57	57	59	63	64
	62	63	57	57	57	59	57	57	58	56	58	58	57	57	64	63
	62	63	58	56	59	59	58	57	58	56	58	57	59	57	63	63
9	83	81	78	77	80	80	83	82	85	85	85	85	89	88	96	97
	83	83	77	77	79	80	82	82	85	84	86	87	89	88	95	97
	84	83	78	76	79	81	82	83	83	83	85	85	88	89	95	98
	83	84	76	77	79	80	81	82	82	85	85	86	88	90	96	98
	83	83	77	77	79	81	81	81	84	83	86	86	87	88	97	97
	83	83	77	76	81	80	82	82	84	84	86	86	90	87	95	97
11	101	101	97	98	101	101	107	106	110	109	115	116	118	120	126	125

	102	102	97	97	100	101	105	106	110	109	116	116	119	119	127	125
	102	102	98	97	101	102	106	107	109	110	115	115	120	120	126	127
	102	103	97	98	100	100	105	107	110	110	115	115	118	119	125	126
	102	102	97	98	100	101	105	106	111	109	115	115	118	118	126	125
	102	102	98	97	101	101	107	106	110	109	116	116	119	118	126	125
13	122	123	117	117	120	120	126	125	130	130	136	136	139	141	148	148
	124	123	116	116	118	120	126	125	132	130	136	136	141	139	149	148
	124	124	118	116	119	120	124	126	129	131	135	136	139	139	148	149
	123	123	116	117	119	119	125	127	131	131	136	135	139	141	145	149
	124	122	117	116	119	120	126	125	131	131	137	135	139	139	148	148
	124	122	118	116	120	120	126	125	131	131	135	135	140	138	148	148
15	141	143	138	138	141	139	148	148	155	155	162	162	168	169	174	175
	142	140	137	136	139	140	148	148	155	154	162	162	169	167	175	175
	140	141	138	137	139	140	147	148	153	156	161	161	169	168	175	176
	143	144	137	137	140	139	147	149	155	155	163	161	168	170	172	175
	142	143	138	137	140	141	149	146	154	155	163	162	167	168	175	175
	143	143	138	136	141	141	149	147	154	154	162	162	168	168	176	176

Table-24: Number of tomato seeds germinated

Number of seeds germinated TOMATO (20 seeds total)								
G. Day	H_2O	Acid rain						H_2O
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	3	0	5	2	0	0	0	2

Table-25: Number of radish seeds germinated

Number of seeds germinated RADISH (20 seeds total)								
G. Day	H_2O	Acid rain						H_2O
1	0	0	0	0	0	0	0	0
2	0	0	3	7	0	0	2	2
3	20	20	20	20	20	20	20	20
4	20	20	20	20	20	20	20	20

Table-26: Number of calendula seeds germinated

Number of seeds germinated CALENDULA (20 seeds total)								
G. Day	H_2O	Acid rain						H_2O
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	20	20	10	0	10	20	10	20
4	20	20	14	18	17	20	15	20

Table-27: Number of marigold seeds germinated

Number of seeds germinated MARIGOLD (20 seeds total)								
G. Day	H_2O	Acid rain						H_2O
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	2
3	20	20	20	20	0	0	0	20
4	20	20	20	20	20	20	18	20

Table-28: Number of cucumber seeds germinated

Number of seeds germinated CUCUMBER (6 seeds total)								
G. Day	H_2O	Acid rain						H_2O
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	1	3	2	1	0	1	1	2
4	4	5	6	6	4	5	5	5

Table-29: Average growth of tomato seeds over 15 days with standard deviation, σ, calculated

avg. growth of TOMATO over 15 days																
Day	*Condition (mm)*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	17.4	1.4	12.9	1.5	13.5	1.9	13.1	1.7	13.3	1.4	13.0	1.0	12.8	0.8	17.9	1.0
5	33.4	1.1	29.3	2.7	29.4	1.8	28.7	1.3	29.2	1.5	29.0	1.1	28.5	1.2	34.0	1.0
7	49.3	2.9	45.3	2.8	45.9	2.0	45.6	2.0	46.0	1.6	45.9	1.4	45.6	1.1	48.5	1.6
9	64.6	2.3	60.8	2.6	60.9	1.4	61.8	1.6	62.5	1.0	64.0	0.9	64.7	0.8	68.0	1.4
11	80.5	2.3	76.5	2.3	76.9	1.6	77.9	1.3	79.9	0.6	82.2	0.9	82.9	0.8	86.8	1.2
13	96.0	1.6	92.6	1.9	93.2	1.2	94.8	1.4	97.5	1.2	100.8	0.7	103.0	1.2	106.3	0.9
15	112.3	1.3	108.3	1.7	110.4	0.9	112.2	1.5	115.6	1.0	117.2	0.7	120.5	1.0	125.7	1.0

Table-30: Average growth of radish seeds over 15 days with standard deviation, σ, calculated

avg. growth of RADISH over 15 days																
Day	*Condition (mm)*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	18.6	0.6	15.2	0.7	15.1	0.7	15.2	1.0	14.9	0.7	14.6	0.7	14.6	0.8	18.6	0.8
5	35.1	1.1	31.8	0.7	32.1	1.0	31.8	1.4	31.7	1.1	31.5	1.0	31.7	1.0	34.6	0.7
7	53.3	1.4	49.7	1.5	49.6	1.2	50.3	1.4	49.5	1.0	49.3	0.9	49.4	1.0	52.9	1.1
9	70.8	1.1	67.7	1.1	68.5	0.7	68.5	1.0	69.8	1.1	70.6	0.7	72.4	1.4	74.5	0.8
11	87.6	1.0	85.4	0.6	87.5	0.8	88.5	0.7	90.0	0.7	90.5	0.7	91.1	1.0	92.8	0.9
13	104.5	1.2	102.1	0.6	102.7	0.8	103.7	0.9	105.2	1.1	106.8	0.6	108.7	0.6	111.0	1.0
15	122.2	1.0	119.9	0.8	120.5	0.9	122.5	0.7	123.7	1.3	126.2	0.8	127.8	0.5	130.7	0.8

Table-31: Average growth of cucumber seeds over 15 days with standard deviation, σ, calculated

avg. growth of CUCUMBER over 15 days																
Day	*Condition (mm)*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	22.6	0.8	19.0	0.7	19.8	0.8	19.9	0.9	20.7	0.7	20.5	1.2	20.2	0.7	23.2	1.0
5	43.2	0.8	38.1	0.8	38.7	0.7	39.0	0.8	39.4	1.0	39.3	1.1	39.5	0.8	43.7	0.9
7	62.7	0.8	57.2	0.7	58.3	0.7	57.5	0.8	57.6	1.0	57.5	0.6	57.8	0.8	63.3	0.5
9	82.9	0.7	76.9	0.6	79.9	0.8	81.9	0.6	83.9	1.0	85.7	0.6	88.4	1.0	96.5	1.0
11	102.0	0.5	97.4	0.5	100.8	0.6	106.1	0.8	109.7	0.6	115.4	0.5	118.8	0.8	125.8	0.7
13	123.1	0.8	116.7	0.7	119.5	0.6	125.5	0.8	130.7	0.7	135.7	0.6	139.5	1.0	148.0	1.0
15	142.4	1.3	137.3	0.7	140.0	0.8	147.8	0.9	154.6	0.8	161.9	0.6	168.3	0.8	174.9	1.0

Table-32: Average growth of marigold seeds over 15 days with standard deviation, σ, calculated

avg. growth of MARIGOLD over 15 days																
Day	*Condition (mm)*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
3	10.7	0.7	8.8	0.8	9.6	0.9	9.7	0.8	9.6	0.8	9.7	0.7	9.9	0.5	11.4	0.5
5	19.6	0.5	17.8	0.8	18.2	0.4	18.2	0.4	18.1	0.2	18.3	0.4	18.2	0.4	19.7	0.6
7	28.6	0.5	27.4	0.5	27.2	0.4	27.2	0.4	27.1	0.2	27.3	0.4	27.2	0.4	28.1	2.4
9	38.6	0.5	36.6	0.6	38.2	0.4	39.2	0.4	40.3	0.4	42.3	0.4	43.6	0.5	45.6	0.5
11	48.6	0.5	45.7	0.7	46.9	1.6	47.8	1.1	49.9	0.6	52.2	0.9	53.6	0.5	57.6	0.5
13	57.6	0.5	55.2	1.2	56.9	1.6	58.4	0.8	60.6	0.7	62.6	0.9	66.6	0.5	69.6	0.5
15	67.1	1.0	64.5	0.7	67.2	1.0	71.1	0.8	75.6	1.0	77.2	0.7	79.6	0.5	82.6	0.5

Table-33: Average growth of calendula seeds over 15 days with standard deviation, σ, calculated

avg. growth of CALENDULA over 15 days																
Day	*Condition (mm)*															
	1	σ	2	σ	3	σ	4	σ	5	σ	6	σ	7	σ	8	σ
1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
3	14.5	0.6	11.1	0.7	11.1	0.7	11.2	1.0	10.9	0.7	10.6	0.7	10.6	0.8	14.6	0.8
5	31.1	1.1	27.8	0.7	28.1	1.0	27.8	1.4	27.7	1.1	27.5	1.0	27.7	1.0	30.6	0.7
7	49.3	1.4	45.7	1.5	45.6	1.2	46.3	1.4	45.5	1.0	45.3	0.9	45.4	1.0	48.9	1.1
9	66.8	1.1	63.7	1.1	64.5	0.7	64.5	1.0	65.8	1.1	66.6	0.7	68.4	1.4	70.5	0.8
11	83.6	1.0	81.4	0.6	83.5	0.8	84.5	0.7	86.0	0.7	86.5	0.7	87.1	1.0	88.8	0.9
13	100.5	1.2	98.1	0.6	98.7	0.8	99.7	0.9	101.2	1.1	102.8	0.6	104.7	0.6	107.0	1.0
15	118.0	0.8	115.9	0.8	116.5	0.9	118.5	0.7	119.7	1.3	122.2	0.8	123.8	0.5	126.7	0.8

Table-34: Average soil pH before and after limestone treatment in all conditions

CONDITION	TOMATO		RADISH		CUCUMBER		MARIGOLD		CALENDULA	
	before	*after*	*before*	*after*	*before*	*after*	*before*	*after*	*before*	*after*
H_2O + 0g	5.0	5.5	4.9	5.1	4.9	4.7	5.2	4.7	5.0	5.6
AR + 0g	5.0	5.6	4.3	5.1	4.9	4.8	4.7	4.9	4.9	4.9
AR + 1.2g	4.5	6.5	4.6	6.7	4.6	6.9	4.6	6.4	4.5	6.0
AR + 1.4g	4.5	6.9	4.6	6.2	4.7	7.1	4.5	6.4	4.5	6.8
AR + 1.6g	4.6	6.7	4.6	5.7	4.8	5.6	4.5	6.7	4.5	6.2
AR + 1.8g	4.6	7.2	5.0	6.1	4.8	5.2	4.4	6.7	4.7	6.7
AR + 2g	4.8	7.1	4.6	6.9	4.9	5.0	4.4	5.4	4.6	7.4
H_2O + 2g	5.3	6.4	4.9	6.3	5.2	7.6	5.3	6.7	5.0	5.2

*AR = acid rain