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The Effect of Climate Change on Seed Germination and Plant Growth

How does pH and water affect seed germination and plant growth in the context of climate change?

Chloe Yew **0445-012**

Scientific Report

Title

The Effects of Climate Change on Seed Germination and Plant Growth

Research Question

How does pH and water affect seed germination and plant growth in the context of climate change?

Background information

Seed germination is the fundamental embryonic phase of the plant life cycle that influences plant yield and quality (Science Facts, 2019; Tuan, 2014). Under optimal extrinsic and intrinsic conditions, a complex interplay of metabolic and cellular activities allows mature seeds to break dormancy and germinate through the development of the embryo axis into a seedling, as evidenced by the protrusion of the plumule and radicle (Tuan, 2014). Being genetically, physically, and chemically divergent, different seeds prefer different germination conditions (Tuan, 2014).

Once sufficient imbibition of water by the embryo is achieved, germination of fully developed seeds commences, allowing the activation of enzymes and metabolic processes including mobilisation of food reserves, respiration, and protein synthesis (Ali and Elozeiri, 2017). Seed germination is greatly affected by phytohormones, including gibberellins, which stimulate the enzymatic activities in the seeds and further facilitate metabolic activities such as cell divisions, which are catalysed by enzymatic reactions and expedited by water (Heslop-Harrison, 2022; Tuan, 2014). In the early growth of a plant, seeds typically initiate with the protrusion of the primary root, known as the radicle, or in some species, including coconut, the rudimentary stem, called the plumule, develops first (Figure 1) (Heslop-Harrison, 2022). During the post-germination phases, as the radicles and plumules continue to elongate and cotyledons develop, photosynthesis and energy metabolism promote final seedling establishment (Stivers and Dupont, 2019). When seeds are in conditions that exceed their stress tolerance limit, they remain dormant to maintain their ability to germinate (Tuan, 2014). However, in severe and extreme conditions, cell death may occur, resulting in a disruption in germination and growth.

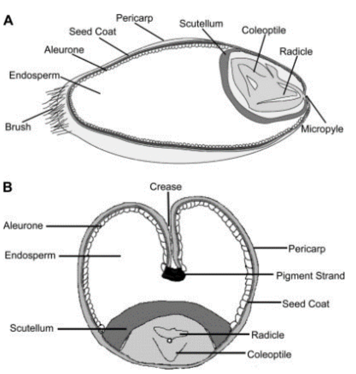


Figure 1a. Structure of a wheat seed (Sethi, 202)

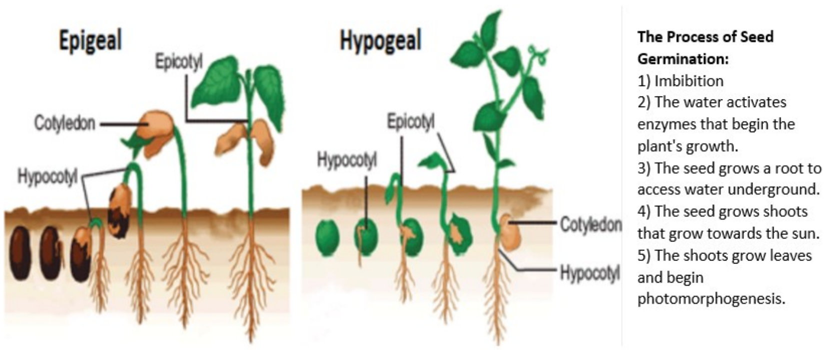


Figure 1b. The process of seed germination (Rathjen and Strounina, 2009)

Climate change is defined as the prolonged changes in temperature and weather patterns on Earth, predominantly caused by the emissions of greenhouse gases. The growth of plants is primarily influenced by extrinsic and intrinsic factors, which are eminently caused by climate change, resulting in greater stress and lower productivity (Hatfield & Prueger 2015). These factors include precipitation, soil pH, temperature, light, nutrients, humidity, UV radiation, and ozone. Climate change inflicts nutrient imbalances through the spread of invasive plants, vulnerability to pests, saltwater intrusion, and altered ecosystem structure (NPS, 2021). Therefore, climate change has been a detrimental stressor and disruption to plant resilience, forest structure, and ecosystems (NPS, 2021). While imposing more frequent and severe extreme weather conditions, including turbulent droughts, hurricanes, and thunderstorms, the rising temperatures have eminently affected soil erosion, organic carbon, nutrients, and alkalinity, therefore influencing plant production and growth or even leading to plant death (Hatfield & Prueger, 2015; Climate change impacts on our soils, 2023).

In this investigation, wheat, lettuce, grass, mung bean, red bean, and chia seeds were selected to investigate the effect of pH and water on seed germination and plant growth in the context of climate change. In experiment 1, seven pH groups were examined against seed germination and plant growth in hydroponics and soil environments. In experiment 2, five water conditions were used. PH formulation can be made using lemon juice, lye water, baking soda, sulphur, and garden lime. Additionally, qualitative and quantitative analyses were conducted to observe the effect of pH and moisture on the plants.

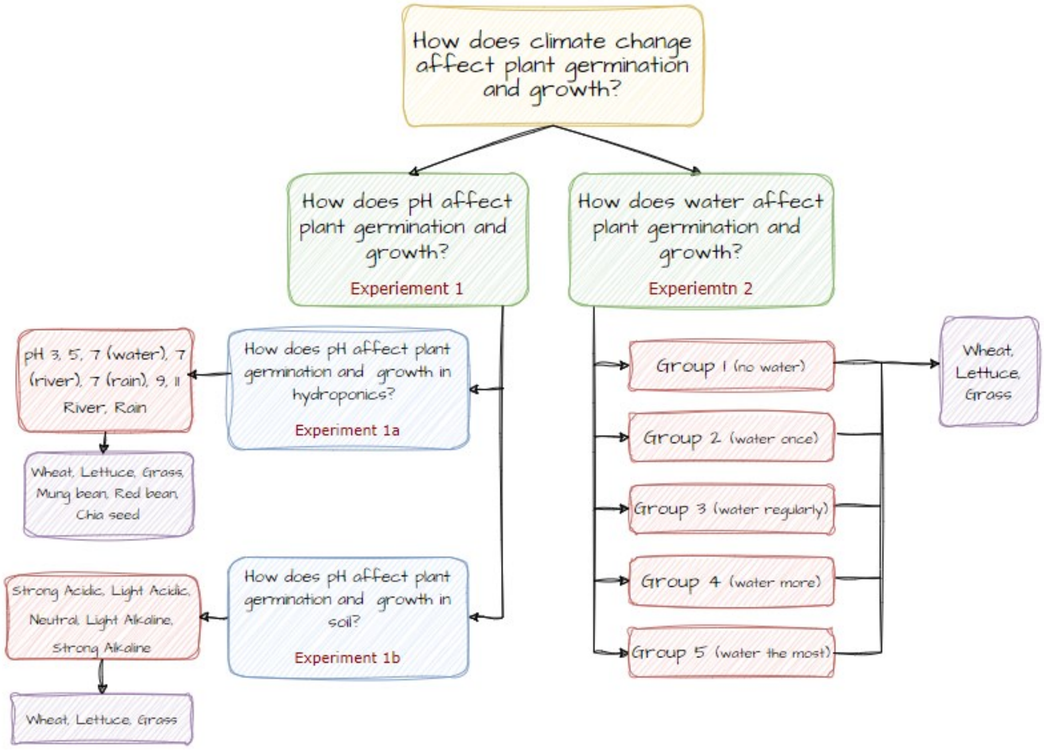
Aim

Climate change will affect the pH level and moisture of the soil. This experiment investigates the effect of extrinsic pH levels and water conditions on seed germination and plant growth by measuring the average length and number of germinated seeds of the chosen plants. This investigation also reflects on the impact of climate change on plant germination and growth as well as food production for our society.

Hypotheses

Hypothesis 1:	If the pH level of the solution is near neutral (pH 7 ± 10%), the germination of seeds will occur and the average height in plants will be the greatest.
Hypothesis 2:	If the amount of water given to the soil is below or above the optimum amount of water, the germination of the plant will be negatively impacted, and its growth rate will decrease.

Experiment flowchart



Variables

Independent and Dependent Variables

Independent Variables	**Experiment 1:** pH levels of solutions and soil **Experiment 2:** Water conditions
Dependent Variables	Plant germination and plant growth measured by number and average height of germinated seeds

Controlled Variables

Controlled variables are to ensure that this experiment is a 'fair test'.

Controlled variables	Method of Control	Reason
Weight of soil	The same amount of soil is placed in each plastic cup and measured with weighing scale. (50g for experiment 1 and 60g for experiment 2.)	The soil of the same weight is used across all samples. Different volume of soil may have varied nutrient supply and affect plant growth.
Number of seeds in each sample	Each cup is placed with 10 seeds using a tweezer.	Different number of seeds may influence degree of nutrient, solution and oxygen uptake. The number of seeds is controlled to ensure fair test.

Volume and size of plastic cups	The plastic cups of the same volume, size and of the same brand are used.	Plastic cups must be of the same size to ensure the same height of soil or solution for fair test.
Measurement/observation time	The data is collected at the specific time intervals.	The data must be collected at the same time for fair test.
Environment	All the experiments are conducted in the same environment. The temperature range is 8°C to 20°C.	Different environment, such as temperature and humidity, affects plant growth, e.g., Plant enzymes requiring an optimal temperature to function.
Weighing scale, ruler, PH test strips	The same equipment is used for measurement.	This is to minimise systematic errors and hence improve the accuracy of the data collected.
Number and volume of cotton balls	All cups were placed with only 3 cotton balls. The cotton balls were volumized in the same state. .	Different number and volume of cotton balls may affect the rate of plant growth.
Source of plant seeds	The seeds of each type of plants were sourced from the same brand and packet.	Different source of plant seeds has different viability which will affect the rate and quality of seed germination and seedling growth.
Volume of pH solution (for Experiment 1a)	Each cup was measured and placed with 50ml of pH solution using a 10ml syringe.	Water is a factor that results in different plant germination and growth rates. Therefore, volume of pH solution must be controlled for fair test.

Uncontrolled Variables

Uncontrolled variables	**Reason why it cannot be controlled and its effect on data**
The time lapse between measuring and observation time for each plant for both experiments, and the timing for watering each plant in Experiment 2	The time lapse for measuring and observation for each plant, and watering for each plant is different for merely few minutes since time is consumed when measuring. Its effect on data is insignificant since there is no rapid change in growth rate and number of germinated seeds in that short amount of time.
The quality of plant seeds	The quality of seeds can be genetically, physically, and chemically distinct from each other. Owing to varying ages, sizes and storage methods of each seed, seeds will have varied viability, manifesting intrinsic errors that affect the reliability of the data.

Equipment and Materials

Equipment and Materials (in all experiments)		
Materials	**Equipment**	**Personal Protective Equipment**
▪ 540g Buy Right All-Purpose Potting Mix ▪ 70 + 50 + 50 Wheat seeds (kernel) ▪ 70 + 50 + 50 D.T. Brown Iceberg Lettuce Seeds ▪ 70 + 50 + 50 Garden Basics Tough and Hardy Lawn Seeds ▪ 70 Mung beans ▪ 70 Red beans ▪ 70 Chia seeds ▪ Water ▪ Manutec Sulphur Fine Granules ▪ Richgro Natural Garden Lime ▪ Baking soda ▪ Lye water 4.78 mol ▪ Lemon juice	▪ Trojan Stainless-Steel Hand Trowel ▪ Soil sieve ▪ Plastic cups ▪ Plastic bags ▪ Plastic trays ▪ Weighing scale ▪ Ruler ▪ Scissors ▪ Forceps ▪ Trays ▪ Syringes ▪ PH test trips ▪ Glasses for mixing and storing PH solutions ▪ Barium sulphate ▪ Watch glass ▪ Universal Indicator	▪ Apron ▪ Safety glasses ▪ Safety gloves ▪ Surgical mask ▪ Enclosed footwear

Buy Right All-Purpose Potting Mix

Garden Basics Tough and Hardy Lawn Seeds

D.T. Brown Iceberg Lettuce Seeds


Wheat seeds


Mung Bean


Red Bean

Chia Seed

Richgro Natural Garden Lime

Manutec Sulphur Fine Granules


Water

Lye water


Lemon juice

Baking Soda


Trojan Stainless-Steel Hand Trowel


Soil sieve


Baking Soda


Masking tape


Ruler


Weighing scale


Forceps


Scissors


Surgical mask


Safety glasses


Apron


Safety gloves


Enclosed footwear

Risk Assessment

Safety Precautions Prudent laboratory safety practices were followed. Chemical contact was avoided by putting on personal protective equipment including an apron, safety glasses, safety gloves, enclosed footwear, and a surgical mask for preventing inhalation of chemicals. Hair was tied back so that hair did not contact with any chemicals. The experiment was handled with care as soil contains living microorganisms including bacteria, fungi and protozoa and can cause irritation in nose, throat and lungs, and illnesses from hay fever, asthma to pneumonia-like illnesses if inhaled (bioaerosols). During observation, personal protective equipment was used to reduce the risk of contamination and biohazards including mould growth. When cutting plastic bags and cardboard, scissors and cutter knives were carefully handled to prevent cuts. The equipment and apparatus used in this experiment were carefully handled to prevent any incidents.
Environmental Consideration The experiment was conducted in compliance with the control measures for preparation, usage of laboratory materials and disposal of chemical wastes. There were no significant environmental considerations as the equipment and actions used in this experiment presented no hazard or danger to the environment.
Ethical Consideration There were no significant ethical considerations as the equipment and actions used in this experiment presented no harm to society or any individual.

Experiment 1: pH

Procedure

Experiment 1a. Hydroponics

STEP 1: Prepare the plants

1. 42 cups were labelled appropriately (Table 1). 3 cotton balls were volumized and placed in each cup.

2. All the cups were placed with 50ml of their allocated solution.

3. Each cup was scattered evenly with 10 allocated plant seed using a tweezer (Table 1).

4. All the cups were arranged according to the type of plants in trays in the same environment.

Table 1a. The cups were labelled. The pH value was obtained by mixing the specific solution with water using dilution method and measure with PH test strips.

Experiment 1a. Label	Amount of solution	Solution
pH 3	50 ml	1.67% lemon water
pH 5	50 ml	0.67% lemon water
pH 7	50 ml	Tap water
pH 9	50 ml	0.03125% 4.78M lye water
pH 11	50 ml	2% 4.78M lye water
Rainwater PH 7	50 ml	Rainwater (from precipitation)
River water PH 7	50 ml	Surface river water (from Morialta Conservation Park)

STEP 2: Measure and record data and observations daily

1. The weight of each plant was measured using a weighing scale.

2. The height of each plant was measured using a ruler.

3. The number of germinated seeds of each plant was recorded.

Experiment 1b. Soil

STEP 1: Filter the soil

1. The plastic bag was cut to a flat plastic and placed flatly on the ground.

2. The soil sieve was placed on top of the plastic.

3. The soil was placed on the sieve using a trowel and sieved through. Large bark mulches were disposed of after sieving.

4. The sieved soil was placed in a thick clean reused plastic bag.

STEP 2: Prepare the plants

1. All materials and equipment were prepared, and 15 cups were labelled appropriately (Table 2).

2. 50g of soil and 50g of water was placed in each cup. Allocated supplements were added into the cups (Table 2).

3. Each cup was scattered evenly with 10 allocated plant seed using a tweezer (Table 2).

4. Each cup is placed with the assigned solution of 5ml every day (Table 2).

Table 1b. The cups were labelled.

Label	Supplement (Day 0)	Solution (Day 1 to 10)	Solution (Day 11 to 14)
Strong Acidic	20g sulphur	5ml (10% lemon juice)	5ml (33% lemon juice)
Light Acidic	10g sulphur	2ml (10% lemon juice) + 3ml water	2ml (33% lemon juice) + 3ml water
Neutral	None	5ml water	5ml water
Light Alkaline	10g garden lime	2ml (4% baking soda water) + 3ml water	2ml (10% baking soda water) + 3ml water
Strong Alkaline	20g garden lime	5ml (4% baking soda water)	5ml (10% baking soda water)

STEP 3: Measure and record data and observations daily

1. The weight of each plant was measured using a weighing scale.

2. The height of each plant was measured using a ruler.

3. The number of germinated seeds of each plant was recorded.

Table 1c. pH values for simulated soil samples impacted by climate change for 3 types of plant seeds were measured on Day 15.

Simulated soil sample	Soil pH for wheat	Soil pH for lettuce	Soil pH for grass
Strong Acidic	6	5.5	6
Light Acidic	6.5	6	6.5
Neutral	7	7	7
Light Alkaline	8	7.5	7.5
Strong Alkaline	8.5	8	8

Experiment 2: Water

Groups and Labels:

Groups	Water amount	Days of water intake	Total water intake (ml)
Group 1	No water at all.	-	0
Group 2	Water once.	Day 0: 50ml	50
Group 3	Water regularly.	Day 0: 50ml, Day 1, 2 & 7: 15ml	95
Group 4	Water more.	Day 0: 50ml, Day 1, 2 & 7: 30ml	140
Group 5	Water the most.	Day 0 & 1: 100ml	200

Procedure

STEP 1: Filter the soil

1. The plastic bag was cut to a flat plastic and placed flatly on the ground.

2. The soil sieve was placed on top of the plastic.

3. The soil was placed on a sieve using a trowel and sieved through. Large bark mulches were disposed of after sieving.

4. The sieved soil was placed in a thick clean reused plastic bag.

STEP 2: Prepare the plants

1. 12 cups was labelled appropriately (Table 1d). 60g of soil was placed in each cup using a weighing scale and a trowel.

2. All the cups except for L0, W0 and G0, were watered with 50 ml of water on Day 0.

3. Each cup was scattered evenly with 10 allocated-plant seeds (Table 1d). The seeds were gently pushed in and covered in the soil using fingers.

4. All the cups were watered with the allocated amount of water on Day 1 and the following days (Table 1d).

Table 1d. Labels.

Name	Plant	Group
W1	Wheat	1
W2	Wheat	2
W3	Wheat	3
W4	Wheat	4
W5	Wheat	5
L1	Lettuce	1
L2	Lettuce	2
L3	Lettuce	3
L4	Lettuce	4
L5	Lettuce	5
G1	Grass	1
G2	Grass	2
G3	Grass	3
G4	Grass	4
G5	Grass	5

STEP 3: Measure and record data and observations daily

1. The weight of each plant was measured using a weighing scale. → **2.** The height of each plant was measured using a ruler. → **3.** The number of germinated seeds of each plant was recorded.

Processing and Analysing Data and Information:

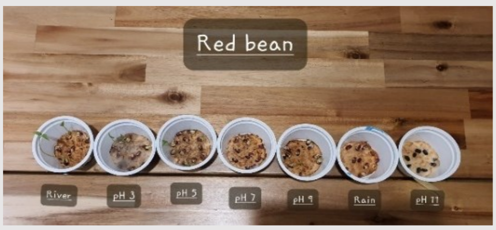
Experiment 1a: Wheat (on Day 14)

Experiment 1a: Lettuce (on Day 14)

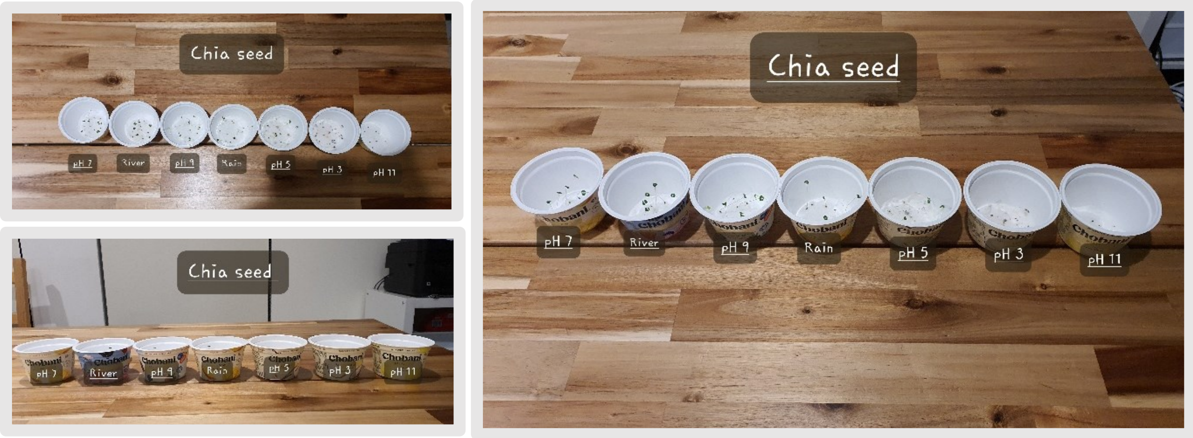
Experiment 1a: Grass (on Day 14)

Experiment 1a: Mung bean (on Day 14)

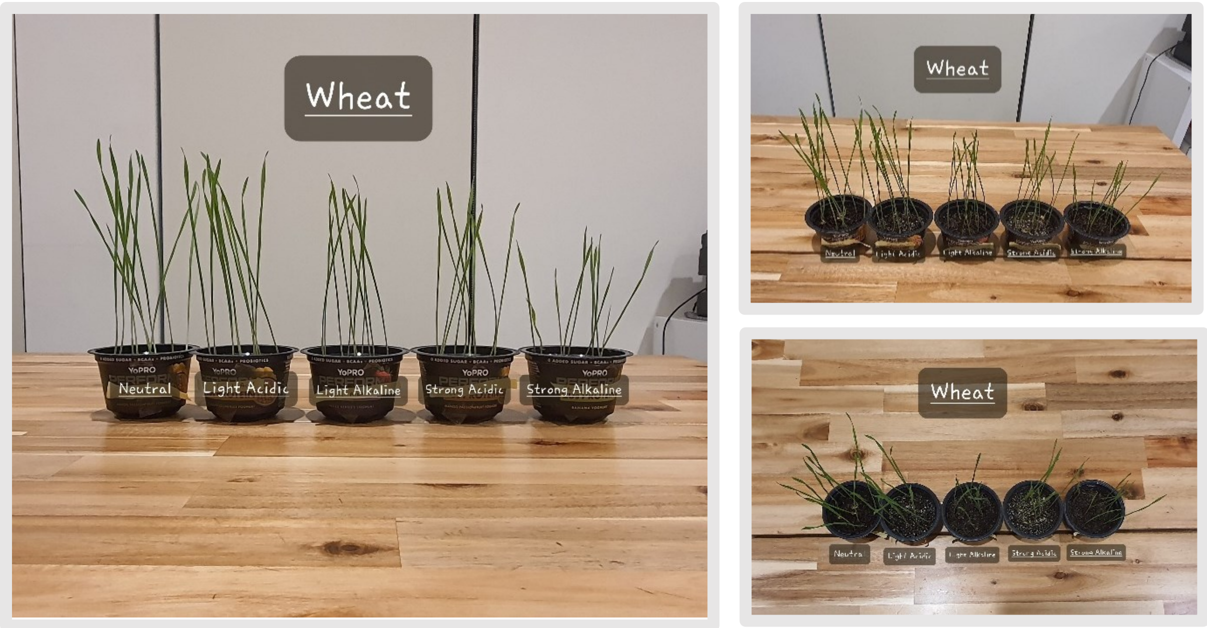
Experiment 1a: Red bean (on Day 14)



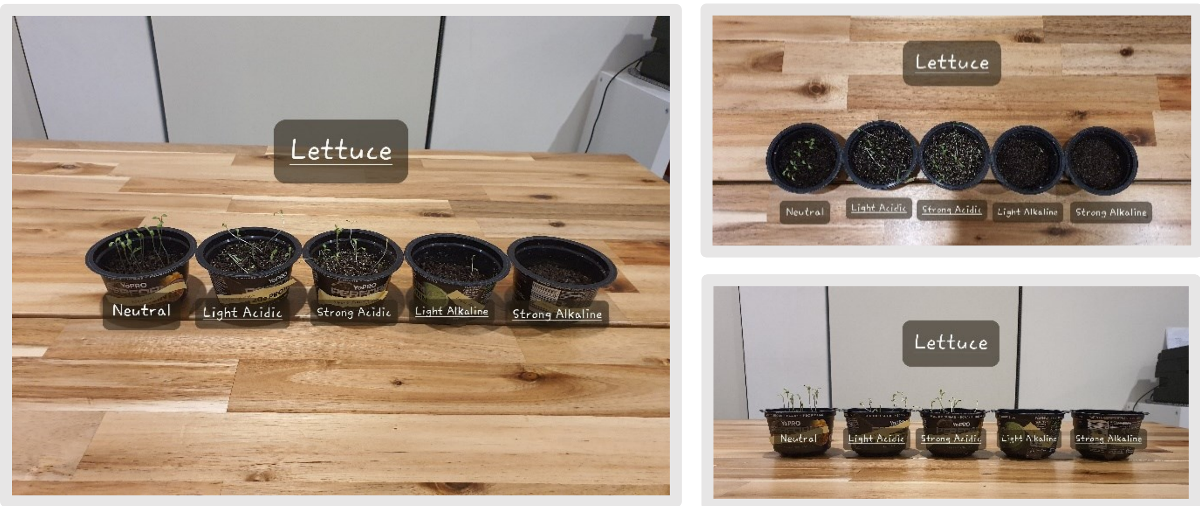
Experiment 1a: Chia seed (on Day 14)



Experiment 1b: Wheat (on Day 14)



Experiment 1b: Lettuce (on Day 14)



Experiment 1b: Grass (on Day 14)

Figure 2. The plants for observation Experiments 1a and 1b.

Experiment 1

Table 2. Number and average growth rate of 6 types of plant seeds in Experiment 1a during the period of 14 days. Table 2 comprises of Tables 2a to 2f.

Table 2a. Number and average length of germinated wheat seeds in Experiment 1a during the period of 14 days.

DAY	Wheat Growth Rate													
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	2.22	9/10	4.50	10/10	2.00	9/10	3.50	10/10	4.00	10/10	2.60	10/10	2.00	7/10
3	4.89	9/10	15.00	10/10	10.40	10/10	12.90	10/10	12.50	10/10	7.10	10/10	5.10	10/10
4	5.80	10/10	9.00	10/10	11.70	10/10	12.00	10/10	14.60	10/10	12.00	10/10	4.00	10/10
5	6.90	10/10	23.00	10/10	23.10	10/10	23.20	10/10	27.50	10/10	24.40	10/10	4.50	10/10
6	13.00	10/10	49.50	10/10	51.50	10/10	45.50	10/10	52.00	10/10	50.20	10/10	5.90	10/10
7	18.00	10/10	74.50	10/10	76.00	10/10	71.50	10/10	77.00	10/10	77.50	9/10	8.00	10/10
8	21.50	10/10	94.50	10/10	98.00	10/10	86.00	10/10	97.00	10/10	101.40	9/10	20.40	7/10
9	26.40	10/10	112.50	10/10	109.90	10/10	100.00	10/10	112.20	10/10	126.60	9/10	20.40	7/10
10	42.30	10/10	128.00	10/10	122.50	10/10	109.80	10/10	125.70	10/10	142.00	9/10	25.60	7/10
11	52.30	10/10	134.00	10/10	128.40	10/10	111.80	10/10	130.40	10/10	150.60	9/10	25.60	7/10
12	66.00	10/10	143.00	10/10	136.40	10/10	113.00	10/10	136.50	10/10	163.90	9/10	26.30	7/10
13	72.70	10/10	148.00	10/10	144.50	10/10	119.00	10/10	139.50	10/10	166.10	9/10	27.00	7/10
14	72.70	10/10	148.00	10/10	151.36	10/10	112.50	10/10	145.50	10/10	171.44	9/10	29.00	7/10

Table 2b. Number and average length of germinated lettuce seeds in Experiment 1a during the period of 14 days.

DAy	Lettuce Growth Rate													
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	3.00	10/10	5.00	10/10	6.00	10/10	6.00	8/10	6.00	10/10	6.00	10/10	2.00	4/10
3	7.00	10/10	8.22	9/10	10.00	9/10	10.00	9/10	10.00	9/10	10.00	10/10	2.50	8/10
4	4.7	10/10	6.90	10/10	14.67	9/10	11.44	8/10	18.67	9/10	15.20	10/10	1.875	8/10
5	6.00	10/10	10.80	10/10	20.00	9/10	22.75	8/10	28.11	9/10	23.33	10/10	5.00	8/10
6	6.00	10/10	22.78	9/10	41.67	9/10	36.25	8/10	41.50	10/10	37.00	10/10	5.00	8/10
7	6.00	10/10	30.70	10/10	44.44	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
8	6.00	10/10	31.20	10/10	46.67	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
9	5.00	10/10	34.50	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
10	5.00	10/10	37.00	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
11	5.00	10/10	42.50	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
12	5.00	10/10	42.50	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
13	5.00	10/10	42.50	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10
14	5.00	10/10	46.50	10/10	47.22	9/10	40.63	8/10	46.00	10/10	41.00	10/10	5.00	8/10

Table 2c. Number and average length of germinated grass seeds in Experiment 1a during the period of 14 day.

DAy	Grass Growth Rate													
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	1.00	2/10	1.00	5/10	1.00	7/10	1.00	7/10	1.00	4/10	0	0/10
3	2.00	3/10	1.00	10/10	1.70	10/10	1.86	7/10	1.25	8/10	1.00	6/10	0	0/10
4	3.33	3/10	5.40	10/10	5.10	10/10	5.50	8/10	6.13	8/10	4.29	7/10	1.00	2/10
5	5.80	5/10	9.90	10/10	15.90	10/10	11.80	10/10	14.11	9/10	14.10	10/10	1.00	2/10
6	13.00	8/10	28.60	10/10	39.50	10/10	33.00	10/10	28.67	9/10	38.00	10/10	1.00	2/10
7	23.65	8/10	51.10	10/10	58.00	10/10	50.70	10/10	70.56	9/10	57.50	10/10	1.00	2/10
8	35.13	8/10	66.30	10/10	69.00	10/10	58.20	10/10	80.22	9/10	75.30	10/10	2.80	5/10
9	49.75	8/10	82.00	10/10	89.70	10/10	70.50	10/10	100.89	9/10	90.00	10/10	2.50	6/10
10	42.89	9/10	102.50	10/10	93.00	10/10	80.00	10/10	109.22	9/10	100.80	10/10	5.17	6/10
11	55.78	9/10	111.40	10/10	104.00	10/10	83.00	10/10	122.78	9/10	106.50	10/10	7.00	6/10
12	59.78	9/10	121.50	10/10	115.00	10/10	91.00	10/10	126.56	9/10	113.50	10/10	8.00	6/10
13	63.78	9/10	130.00	10/10	119.00	10/10	92.30	10/10	135.00	9/10	120.00	10/10	8.00	6/10
14	69.44	9/10	137.00	10/10	124.00	10/10	98.50	10/10	152.22	9/10	122.50	10/10	8.00	6/10

Table 2d. Number and average length of germinated mung beans in Experiment 1a during the period of 14 days.

DAy	Mung Bean Growth Rate														
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	1.00	1/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	4.13	8/10	6.78	9/10	6.71	7/10	5.00	9/10	5.86	7/10	6.375	8/10	2.67	3/10
3	9.11	9/10	13.78	9/10	11.67	9/10	6.57	9/10	13.4	9/10	11.25	8/10	4.8	5/10
4	10.56	9/10	16.44	9/10	13.60	10/10	15.00	9/10	13.44	9/10	14.00	8/10	2.14	7/10
5	10.78	9/10	16.44	9/10	15.50	10/10	15.67	9/10	14.11	9/10	17.5	8/10	2.29	7/10
6	10.11	9/10	20.00	9/10	19.40	10/10	19.90	9/10	15.89	9/10	20.67	8/10	1.83	6/10
7	13.83	6/10	22.78	9/10	28.70	10/10	24.40	9/10	25.78	9/10	28.125	8/10	1.83	6/10
8	13.83	6/10	22.78	9/10	28.70	10/10	24.40	9/10	25.78	9/10	28.125	8/10	1.83	6/10
9	13.83	6/10	22.78	9/10	28.70	10/10	26.67	9/10	25.78	9/10	23.75	8/10	1.83	6/10
10	13.83	6/10	25.11	9/10	31.80	10/10	28.33	9/10	38.00	9/10	26.25	8/10	0	0/10
11	13.83	6/10	26.78	9/10	36.70	10/10	29.40	9/10	49.67	9/10	28.75	8/10	0	0/10
12	20.00	2/10	27.89	9/10	41.00	10/10	29.40	9/10	47.70	9/10	31.875	8/10	0	0/10
13	20.00	2/10	29.56	9/10	44.00	10/10	32.22	9/10	52.56	9/10	35.00	8/10	0	0/10
14	20.00	2/10	30.89	9/10	45.30	10/10	33.11	9/10	55.44	9/10	35.63	8/10	0	0/10

Table 2e. Number and average length of germinated red beans in Experiment 1a during the period of 14 days.

DAy	Red Bean Growth Rate													
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
3	1.00	3/10	3.25	4/10	2.00	3/10	1.00	1/10	3.67	3/10	3.00	1/10	0	0/10
4	1.25	8/10	5.33	6/10	5.50	4/10	1.67	3/10	5.00	6/10	2.50	4/10	0	0/10
5	3.75	8/10	5.375	8/10	5.83	6/10	1.80	5/10	5.75	8/10	3.57	7/10	0	0/10
6	4.78	9/10	7.00	10/10	5.25	8/10	3.20	5/10	6.89	9/10	5.43	7/10	0	0/10
7	5.33	9/10	8.10	10/10	8.13	8/10	3.17	6/10	11.11	9/10	5.44	9/10	0	0/10
8	5.33	9/10	8.10	10/10	8.13	8/10	3.17	6/10	11.11	9/10	5.44	9/10	0	0/10
9	6.56	9/10	11.90	10/10	9.00	8/10	3.17	6/10	10.11	9/10	6.22	9/10	0	0/10
10	9.90	10/10	11.90	10/10	10.25	8/10	3.17	6/10	11.78	9/10	6.22	9/10	0	0/10
11	10.40	10/10	11.90	10/10	10.25	8/10	3.17	6/10	12.33	9/10	6.22	9/10	0	0/10
12	10.40	10/10	11.90	10/10	10.25	8/10	3.17	6/10	14.00	9/10	6.22	9/10	0	0/10
13	12.70	10/10	11.90	10/10	10.25	8/10	3.17	6/10	18.44	9/10	6.22	9/10	0	0/10
14	13.70	10/10	11.90	10/10	10.25	8/10	3.17	6/10	19.78	9/10	6.22	9/10	0	0/10

Table 2f. Number and average length of germinated chia seeds in Experiment 1a during the period of 14 day.

DAy	Chia Seed Growth Rate													
	pH 3		pH 5		pH 7 (tap water)		pH 7 (rainwater)		pH 7 (river water)		pH 9		pH 11	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
3	0	0/10	3.00	5/10	4.00	5/10	3.67	3/10	3.17	6/10	3.00	1/10	0	0/10
4	2.00	1/10	9.20	5/10	6.57	7/10	8.40	5/10	7.00	6/10	4.00	3/10	0	0/10
5	2.00	1/10	5.13	5/10	9.14	7/10	8.70	5/10	7.67	6/10	4.00	8/10	0	0/10
6	2.00	1/10	6.20	5/10	11.71	7/10	9.00	5/10	8.33	6/10	4.38	8/10	0	0/10
7	2.00	1/10	9.60	5/10	17.00	7/10	14.40	5/10	16.33	6/10	9.14	7/10	0	0/10
8	2.00	1/10	14.80	5/10	34.29	7/10	23.33	6/10	34.17	6/10	22.71	7/10	0	0/10
9	2.00	1/10	17.80	5/10	36.43	7/10	24.33	6/10	35.83	6/10	27.42	7/10	0	0/10
10	2.00	1/10	22.40	5/10	42.14	7/10	27.83	6/10	41.00	6/10	32.43	7/10	0	0/10
11	2.00	1/10	23.40	5/10	42.14	7/10	30.83	6/10	41.00	6/10	32.43	7/10	0	0/10
12	2.00	1/10	26.20	5/10	42.14	7/10	31.83	6/10	41.67	6/10	33.14	7/10	0	0/10
13	2.00	1/10	29.20	5/10	43.57	7/10	34.00	6/10	43.00	6/10	35.29	7/10	0	0/10
14	2.00	1/10	29.20	5/10	45.00	7/10	36.00	6/10	43.00	6/10	36.86	7/10	0	0/10

Table 3. Number and average growth rate of 3 types of plant seeds in Experiment 1b during the period of 14 days. Table 3 comprises of Tables 3a to 3c.

Table 3a. Number and average length of germinated wheat seeds in Experiment 1b during the period of 14 days.

DAy	Wheat Growth Rate (Experiment 1b)									
	Strong Acidic		Light Acidic		Neutral		Light Alkaline		Strong Alkaline	
	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.	Avg. Length (mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
3	5.00	5/10	4.67	5/10	5.00	3/10	5.00	2/10	0	0/10
4	11.57	8/10	9.25	8/10	8.86	8/10	13.00	6/10	4.00	4/10
5	21.30	10/10	23.00	10/10	18.60	10/10	17.40	10/10	12.78	9/10
6	35.80	10/10	39.09	10/10	32.00	10/10	31.00	10/10	25.00	10/10
7	51.00	10/10	55.00	10/10	50.00	10/10	50.00	10/10	38.50	10/10
8	71.30	10/10	81.36	10/10	71.50	10/10	72.10	10/10	56.60	10/10
9	93.10	10/10	108.27	10/10	97.00	10/10	91.70	10/10	79.50	10/10
10	108.80	10/10	121.82	10/10	116.80	10/10	106.00	10/10	87.00	10/10
11	122.50	10/10	142.27	10/10	137.00	10/10	122.00	10/10	100.00	10/10
12	134.50	10/10	155.00	10/10	151.50	10/10	138.5	10/10	109.50	10/10
13	137.50	10/10	163.81	10/10	164.00	10/10	141.0	10/10	110.50	10/10
14	144.9	10/10	176.81	10/10	177.30	10/10	148.5	10/10	111.00	10/10

Table 3b. Number and average length of germinated lettuce seeds in Experiment 1b during the period of 14 days.

DAy	Lettuce Growth Rate (Experiment 1b)									
	Strong Acidic		**Light Acidic**		**Neutral**		**Light Alkaline**		**Strong Alkaline**	
	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	0	0/10	5.00	1/10	1.00	1/10	1.00	1/10
3	0	0/10	0	0/10	6.00	1/10	3.00	3/10	3.00	4/10
4	7.50	4/10	3.00	3/10	3.50	8/10	4.25	4/10	5.50	4/10
5	10.13	8/10	4.17	6/10	10.50	10/10	6.67	6/10	5.50	4/10
6	18.89	9/10	11.38	8/10	16.80	10/10	6.67	6/10	7.25	4/10
7	28.44	9/10	20.67	9/10	29.00	10/10	8.17	6/10	9.00	4/10
8	38.56	9/10	30.44	9/10	38.50	10/10	11.17	6/10	10.40	5/10
9	44.67	9/10	36.44	9/10	45.80	10/10	11.83	6/10	11.67	6/10
10	48.44	9/10	42.89	9/10	48.60	10/10	12.71	6/10	12.17	6/10
11	53.44	9/10	49.67	9/10	52.00	10/10	12.71	6/10	12.17	6/10
12	49.1	9/10	49.67	9/10	52.60	10/10	13.71	6/10	12.17	6/10
13	49.1	9/10	49.67	9/10	52.60	10/10	13.71	6/10	12.17	6/10
14	49.1	9/10	49.67	9/10	52.60	10/10	13.71	6/10	12.17	6/10

Table 3c. Number and average length of germinated grass seeds in Experiment 1b during the period of 14 days.

DAy	Grass Growth Rate (Experiment 1b)									
	Strong Acidic		**Light Acidic**		**Neutral**		**Light Alkaline**		**Strong Alkaline**	
	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.	Avg. Length(mm)	No.
0	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
1	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
2	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
3	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
4	0	0/10	0	0/10	0	0/10	0	0/10	0	0/10
5	0	0/10	4.00	1/10	7.00	4/10	0	0/10	0	0/10
6	9.60	5/10	11.14	7/10	12.33	9/10	0	0/10	0	0/10
7	13.33	6/10	20.00	9/10	23.00	10/10	20.00	1/10	8.67	3/10
8	26.67	6/10	36.67	9/10	43.10	10/10	35.00	1/10	18.33	3/10
9	31.13	8/10	49.22	9/10	57.40	10/10	40.00	1/10	26.67	3/10
10	44.38	8/10	63.11	9/10	72.50	10/10	50.00	1/10	29.25	4/10
11	50.50	8/10	77.00	9/10	85.6	10/10	60.00	1/10	35.00	4/10
12	57.50	8/10	84.56	9/10	100.2	10/10	63.00	1/10	37.75	4/10
13	64.88	8/10	96.00	9/10	109.4	10/10	63.00	1/10	33.20	5/10
14	72.50	8/10	104.78	9/10	115.9	10/10	66.00	1/10	36.60	5/10

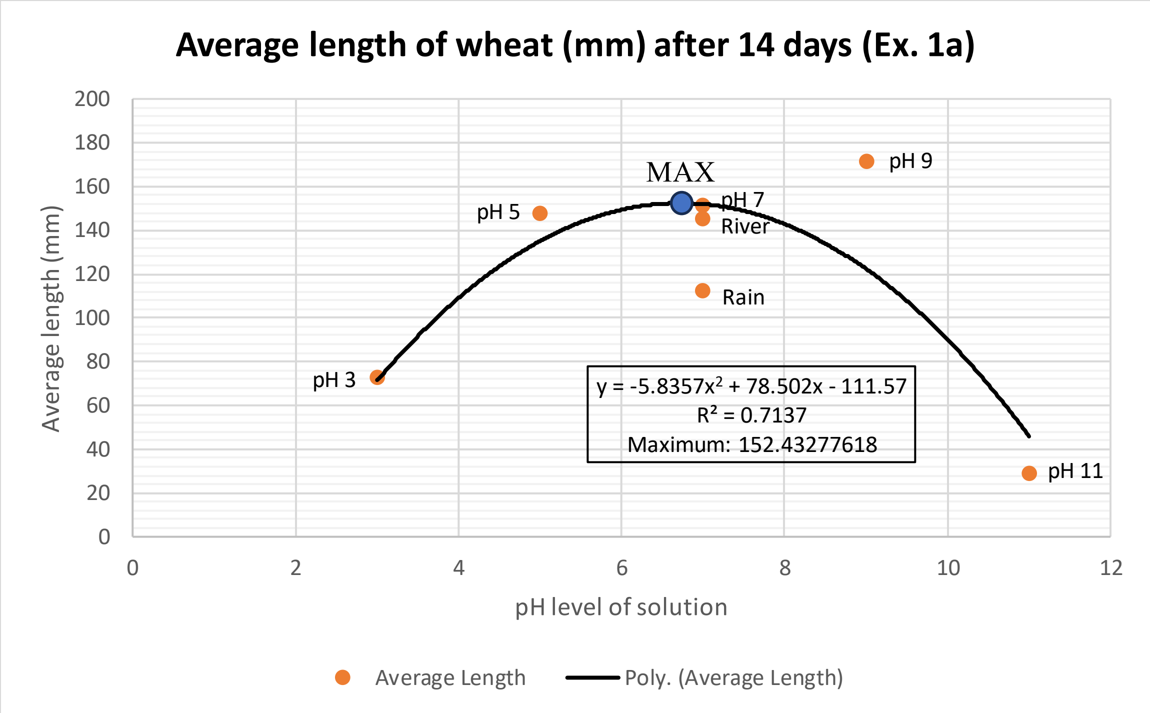


Figure 3a. This graph depicts the average length of wheat seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of wheat in Experiment 1a.

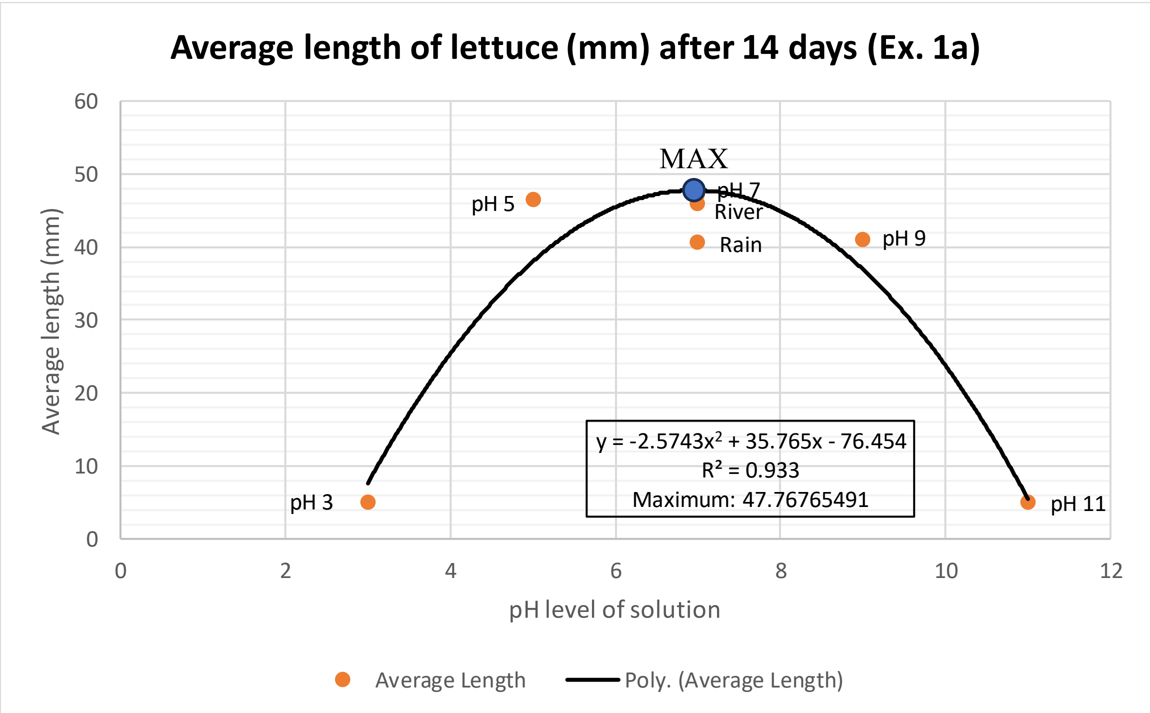


Figure 3b. This graph depicts the average length of lettuce seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of lettuce in Experiment 1a.

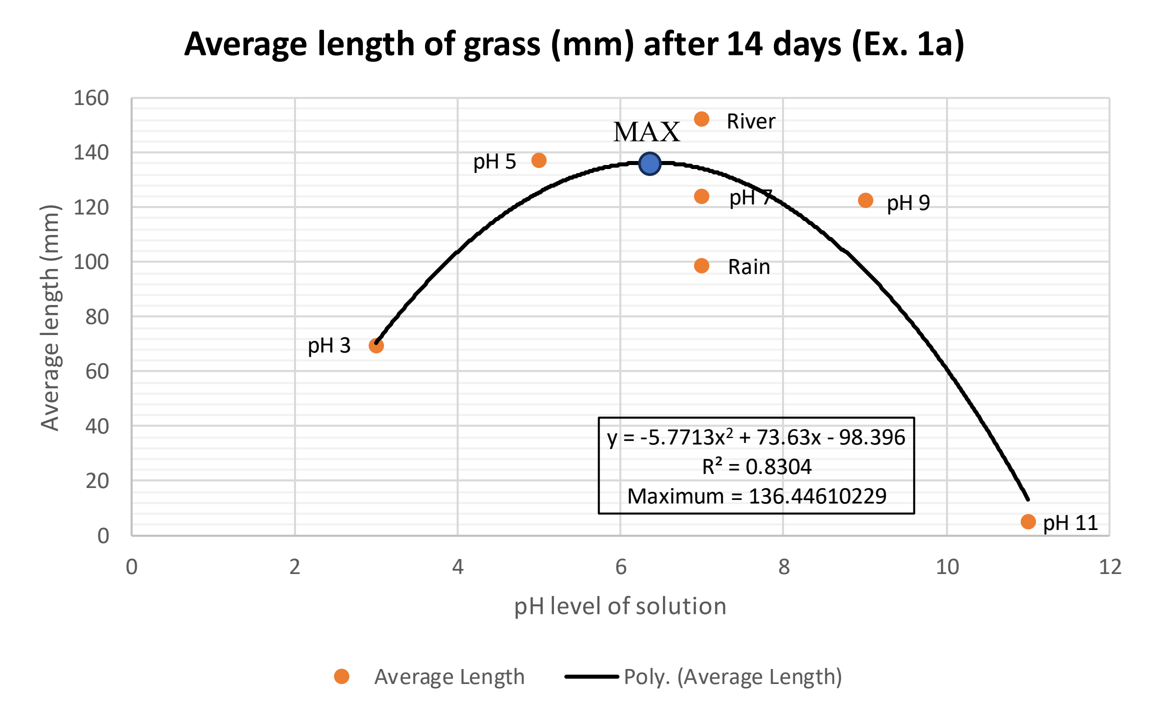


Figure 3c. This graph depicts the average length of grass seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of grass in Experiment 1a.

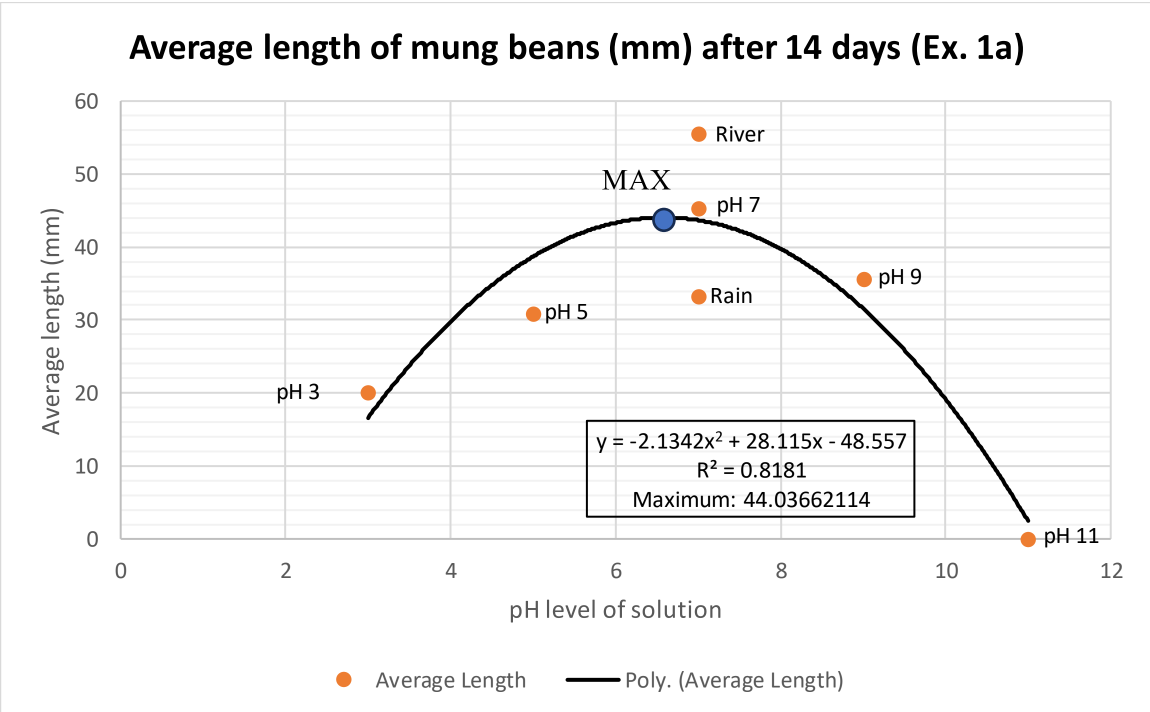


Figure 3d – This graph depicts the average length of mung beans in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of mung beans in Experiment 1a.

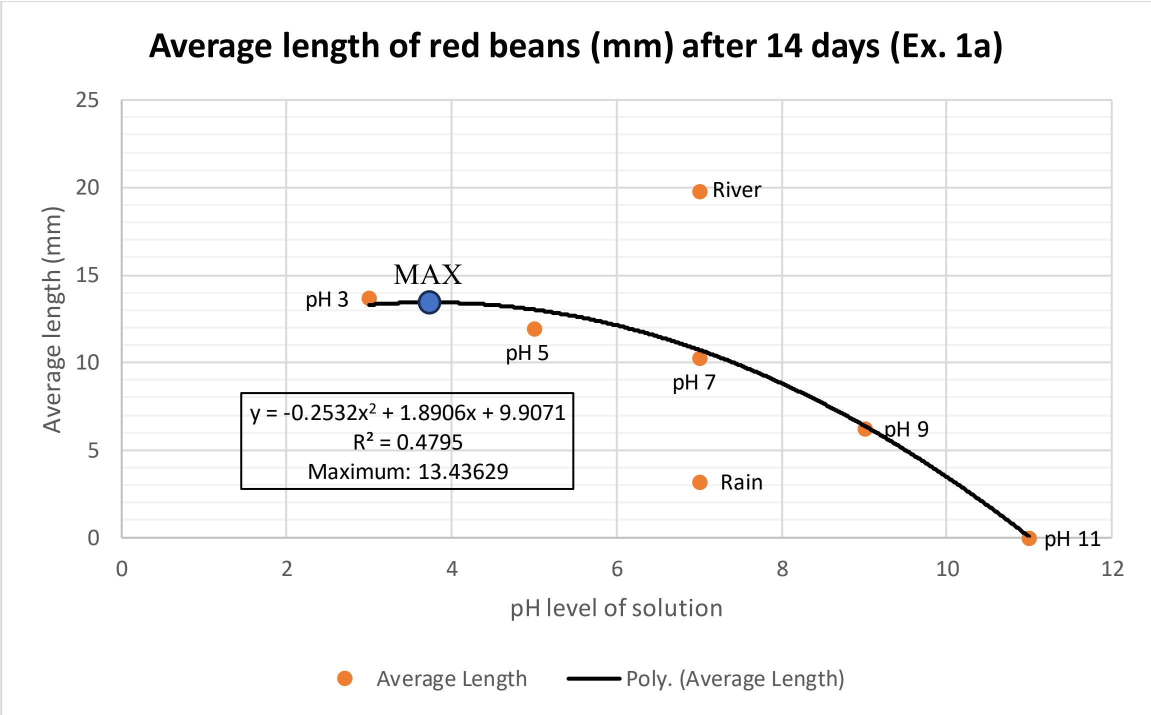


Figure 3e. This graph depicts the average length of red beans in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of red beans in Experiment 1a.

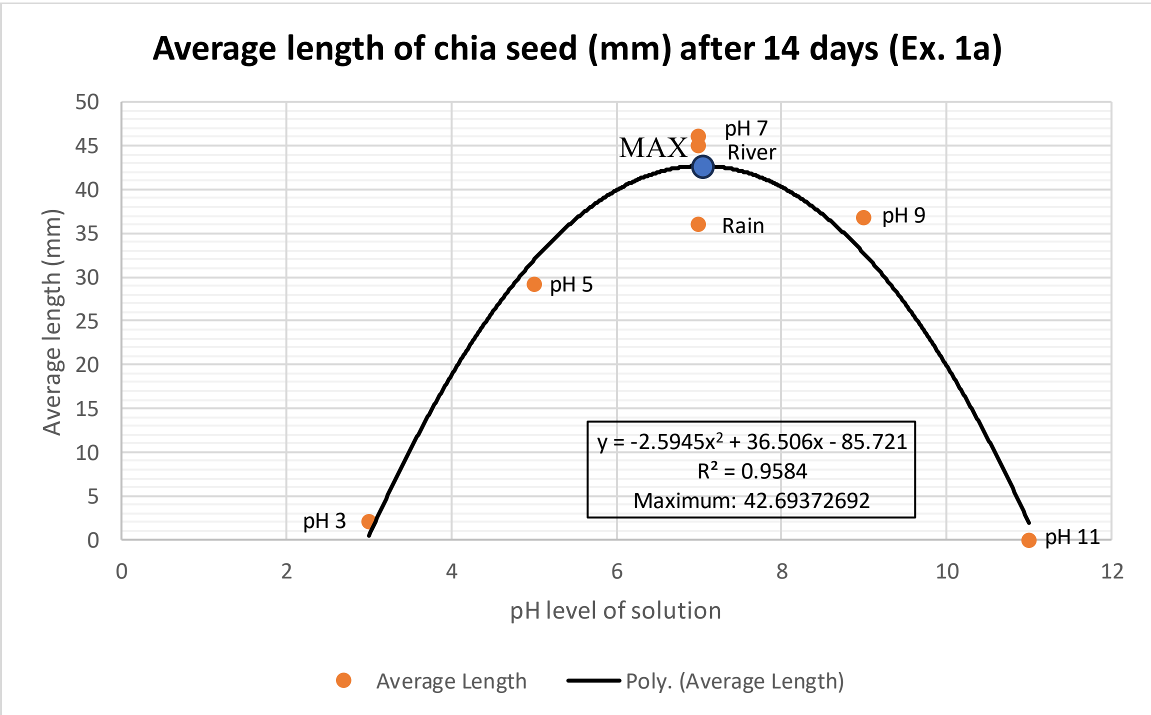


Figure 3f. This graph depicts the average length of chia seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of chia seed in Experiment 1a.

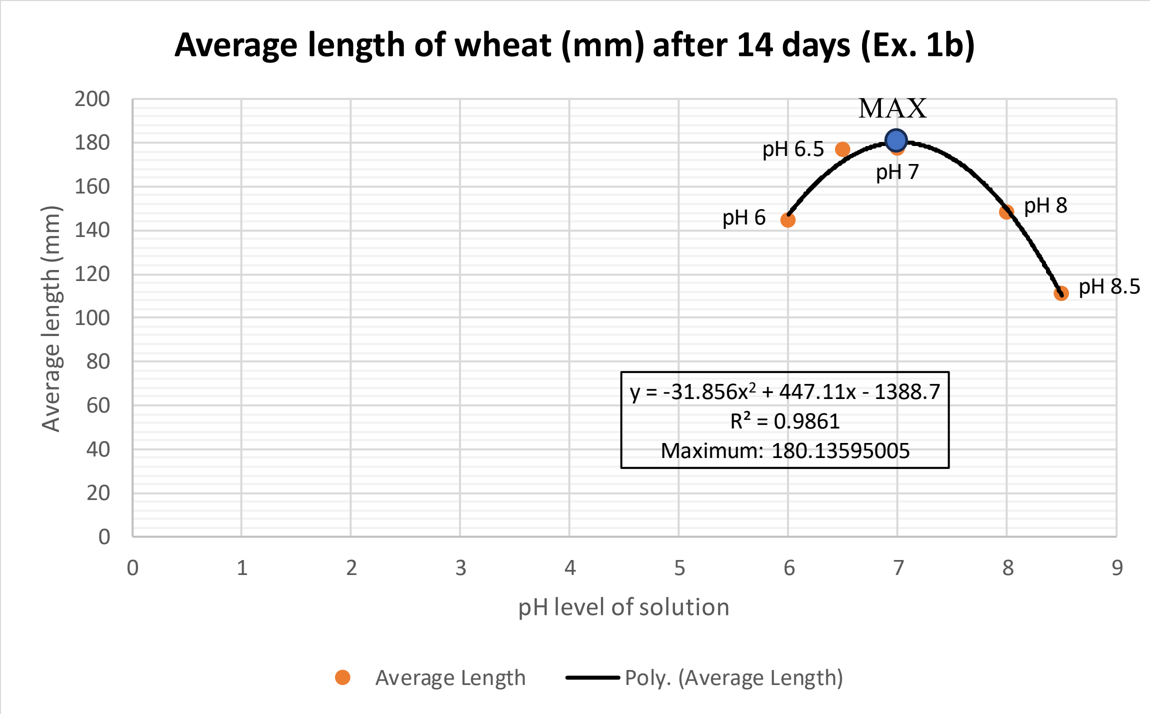


Figure 4a. This graph depicts the average length of wheat seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and growth rate of wheat in Experiment 1b.

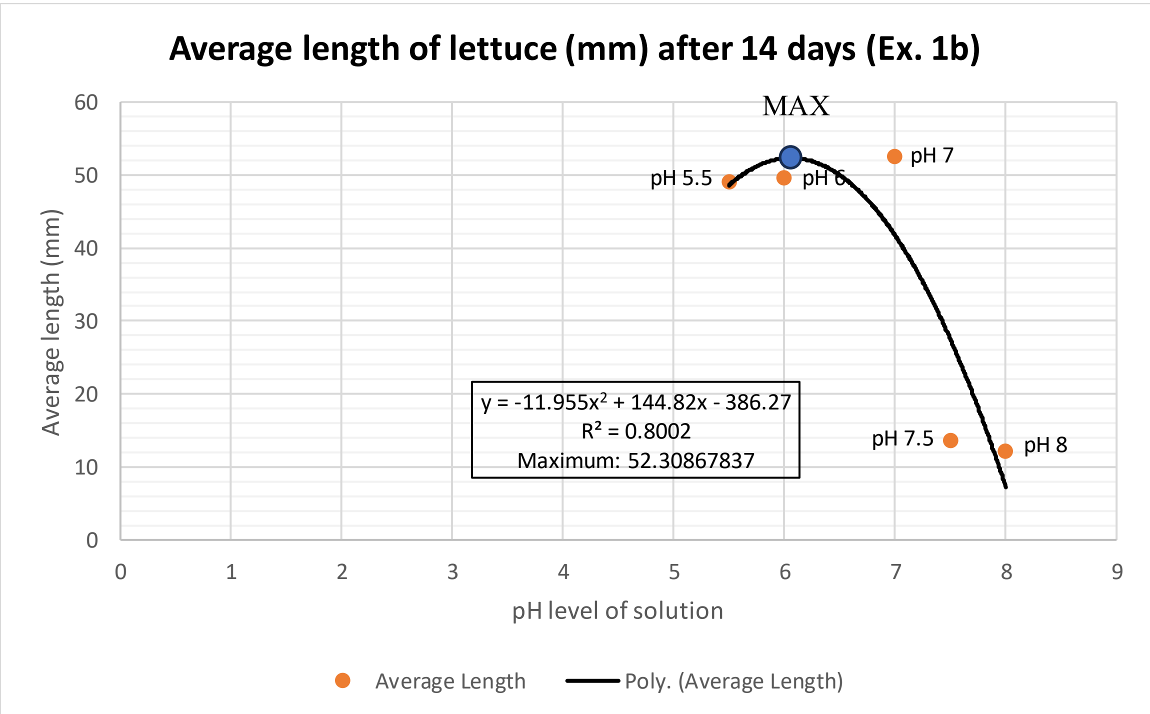


Figure 4b. This graph depicts the average length of lettuce seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and average growth rate of lettuce in Experiment 1b.

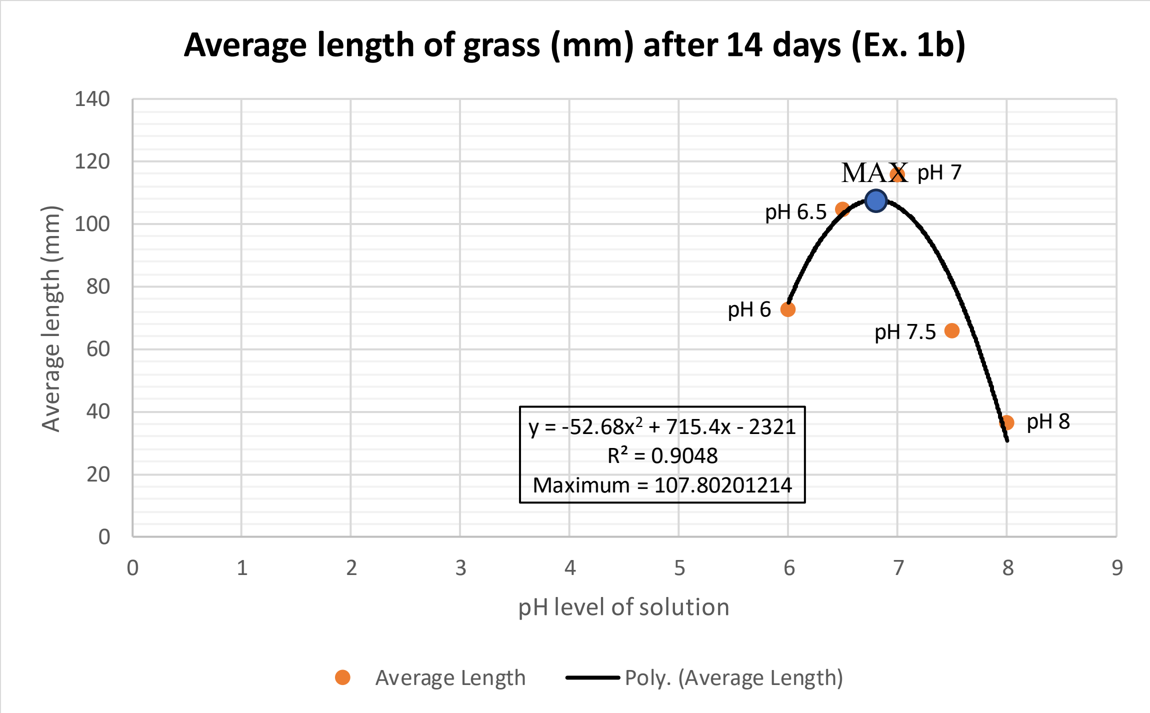


Figure 4c. This graph depicts the average length of grass seeds in millimetres over a period of 14 days with a curve of best fit illustrating the relationship between pH levels and average growth rate of grass in Experiment 1b.

Table 4. The order of average length for wheat, lettuce, grass, mung bean, red bean, and chia seed on Day 14 in Experiment 1a.

Placement	Mung bean	Red bean	Wheat	Lettuce	Grass	Chia seed
1st	River	River	pH 9	pH 7	River	pH 7
2nd	pH 7	pH 3	pH 7	pH 5	pH 5	River
3rd	pH 9	pH 5	pH 5	River	pH 7	pH 9
4th	Rain	pH 7	River	pH 9	pH 9	Rain
5th	pH 5	pH 9	Rain	Rain	Rain	pH 5
6th	pH 3	Rain	pH 3	pH 3	pH 3	pH 3
7th	pH 11	pH 11	pH 11	pH 11	pH 11	pH 11

Table 5. The order of average length for wheat, lettuce, and grass on Day 14 in Experiment 1b.

Placement	Wheat	Lettuce	Grass
1st	Neutral	Neutral	Neutral
2nd	Light acidic	Light acidic	Light acidic
3rd	Light alkaline	Strong acidic	Strong acidic
4th	Strong acidic	Light alkaline	Light alkaline
5th	Strong alkaline	Strong alkaline	Strong alkaline

Table 6. The optimal pH value and maximum length calculated from model function of the polynomial graphs of average lengths of wheat, lettuce, grass, mung bean, red bean, and chia seed in Experiments 1a and 1b. Table 6 comprises of Tables 6a and 6b.

Table 6a. For experiment 1a.

Graphs	Mathematical Model Equation	Optimal pH value
Figure 3a – Average length of **wheat** after 14 days (Experiment 1a)	$y = -5.8357x^2 + 78.502x - 111.57$	**Model Function:** $y = -5.8357x^2 + 78.502x - 111.57$ **Derivative Function:** $\frac{dy}{dx} = -11.6714x + 78.502$ **X value when derivative function equals 0:** $x \approx pH\ 6.70$ **Y value for x value above:** $y \approx 152.43\ mm$
Figure 3b – Average length of **lettuce** after 14 days (Experiment 1a)	$y = -2.5743x^2 + 35.765x - 76.454$	**Model Function:** $y = -2.5743x^2 + 35.765x - 76.454$ **Derivative Function:** $\frac{dy}{dx} = -4.2684x + 28.115$ **X value when derivative function equals 0:** $x \approx pH\ 6.60$ **Y value for x value above:** $y \approx 47.77\ mm$
Figure 3c – Average length of **grass** after 14 days (Experiment 1a)	$y = -5.7713x^2 + 73.63x - 98.396$	**Model Function:** $y = -5.7713x^2 + 73.63x - 98.396$ **Derivative Function:** $\frac{dy}{dx} = -11.5426x + 73.63$ **X value when derivative function equals 0:** $x \approx pH\ 6.38$ **Y value for x value above:** $y \approx 136.45\ mm$
Figure 3d – Average length of **mung bean** after 14 days (Experiment 1a)	$y = -2.1342x^2 + 28.115x - 48.557$	**Model Function:** $y = -2.1342x^2 + 28.115x - 48.557$ **Derivative Function:** $\frac{dy}{dx} = -4.2684x + 28.115$ **X value when derivative function equals 0:** $x \approx pH\ 6.60$ **Y value for x value above:** $y \approx 44.04\ mm$
Figure 3e – Average length of **red bean** after 14 days (Experiment 1a)	$y = -0.2532x^2 + 1.8906x + 9.9071$	**Model Function:** $y = -0.2532x^2 + 1.8906x + 9.9071$ **Derivative Function:** $\frac{dy}{dx} = -0.5064x + 1.8906$ **X value when derivative function equals 0:** $x \approx pH\ 3.73$ **Y value for x value above:** $y \approx 13.44\ mm$
Figure 3f – Average length of **chia seed** after 14 days (Experiment 1a)	$y = -2.5945x^2 + 36.506x - 85.721y$	**Model Function:** $y = -2.5945x^2 + 36.506x - 85.721y$ **Derivative Function:** $\frac{dy}{dx} = -5.189x + 36.506$ **X value when derivative function equals 0:** $x \approx pH\ 7.04$ **Y value for x value above:** $y \approx 42.69\ mm$

Table 6b. For experiment 1b.

Graphs	Mathematical Model Equation	Optimal pH value
Figure 4a – Average length of **wheat** after 14 days (Experiment 1b)	$y = -31.856x^2 + 447.11x - 1388.7$	**Model Function:** $y = -31.856x^2 + 447.11x - 1388.7$ **Derivative Function:** $\frac{dy}{dx} = -63.712x + 447.11$ **X value when derivative function equals 0:** $x \approx pH\ 7.00$ **Y value for x value above:** $y \approx 180.14\ mm$
Figure 4b – Average length of **lettuce** after 14 days (Experiment 1b)	$y = -11.955x^2 + 144.82x - 386.27$	**Model Function:** $y = -11.955x^2 + 144.82x - 386.27$ **Derivative Function:** $\frac{dy}{dx} = -23.91x + 144.82$ **X value when derivative function equals 0:** $x \approx pH\ 6.05$ **Y value for x value above:** $y \approx 52.31\ mm$
Figure 4c – Average length of **grass** after 14 days (Experiment 1b)	$y = -52.68x^2 + 715.4x - 2321$	**Model Function:** $y = -52.68x^2 + 715.4x - 2321$ **Derivative Function:** $\frac{dy}{dx} = -105.36x + 715.4$ **X value when derivative function equals 0:** $x \approx pH\ 6.79$ **Y value for x value above:** $y \approx 107.80\ mm$

Experiment 2

Table 7. Number and average growth rate of germinated wheat seeds in different water content on Day 7 and Day 14. Table 7 comprises of Tables 7a to 7c.

Table 7a. Number and average length of germinated wheat seeds on Day 7 &14.

Name	Average length on Day 7 (mm)	Number of germinated seeds on Day 7	Average length on Day 14 (mm)	Number of germinated seeds on Day 14
W1	0	0	0	0
W2	15	10	80	10
W3	35	10	170	10
W4	0	0	0	0
W5	0	0	0	0

Table 7b. Number and average length of germinated lettuce seeds on Day 7 & 14.

Name	Average length on Day 7 (mm)	Number of germinated seeds on Day 7	Average length on Day 14 (mm)	Number of germinated seeds on Day 14
L1	0	0	0	0
L2	20	9	45	10
L3	30	8	50	10
L4	20	5	40	5
L5	0	0	0	0

Table 7c. Number and average length of germinated grass seeds on Day 7 & 14.

Name	Average length on Day 7 (mm)	Number of germinated seeds on Day 7	Average length on Day 14 (mm)	Number of germinated seeds on Day 14
G1	0	0	0	0
G2	20	10	70	10
G3	20	10	90	10
G4	20	3	40	4
G5	0	0	30	3

Table 8. The order of average length for wheat, lettuce, grass, on Day 14 in Experiment 2.

Placement	Group	Days of water intake	Total water intake (ml)
1st	3	Day 0: 50ml, Day 1, 2 & 7: 15ml	95
2nd	2	Day 0: 50ml	50
3rd	4	Day 0: 50ml, Day 1, 2 & 7: 30ml	140
4th	5	Day 0 & 1: 100ml	200
5th	1	-	0

Experiment 1a

Data analysis (Table 2, Figure 2)

Day 14 is selected as a reference time for analysis. On Day 14, wheat presents the optimal growth of an average length of 171.44mm at pH 9, followed by pH 7 (tap water), pH 5, pH 7 (river water), pH 7 (rainwater), pH 3, and pH 11 with the least increase of 29mm. Comparatively, for lettuce, the greatest growth occurs at pH 7 (tap water) with an average length of 47.22m, followed by pH 5, pH 7 (river water), pH 9, pH 7 (rainwater), pH 3, and pH 11 with the least growth of 5mm. For grass, pH 7 (river water) works the best (152.22mm), followed by pH 5, pH 7 (water), pH 9, pH 7 (rainwater), pH 3, and pH 11 (8mm). Mung beans show the greatest growth at pH 7 (River water) (55.44mm), followed by pH 7 (tap water), pH 9, pH 7 (Rainwater), pH 5, pH 3, and pH 11. Relatively, red beans display the maximum increase at pH 7 (river) (19.78mm), followed by pH 3, pH 5, pH 7 (tap water), pH 9, pH 7 (rainwater), and pH 11. Similarly, chia seeds depict optimal growth at pH 7 (tap water) (45mm), followed by pH 7 (River water), pH 9, pH 7 (rainwater), pH 5, pH 3, and pH 11.

The order of average growth rate (Table 4)

All plants in pH 11 conditions perform the worst, of which either have no growth (0mm for mung bean, red bean, and chia seed) or minimal growth (8mm for grass, 5mm for lettuce, and 29mm for wheat on Day 14). PH 3 is the second-worst condition occurs in five out of six plants. PH 7 (rainwater) keeps fifth place in wheat, lettuce, and grass. Comparatively, plants in pH 7 (tap water) conditions performed second best out of other pH groups.

The optimum pH values of all six plants (Table 2, Figure 3)

On Day 14, grass, mung beans, and red beans achieved the greatest growth in pH 7 (river water). Lettuce and chia seeds grow best in pH 7 group (tap water). In contrast, wheat grow fastest at pH 9 with 171.44mm and a difference of 20.08mm and 25.94mm compared with pH 7 (tap water and river water). The results conclude that pH 7 solutions (tap water and river water) are the optimum pH to achieve the best growth in plants.

The calculated optimal pH values (Table 6a)

Results show that the optimal pH range is between 6.05 and 7.04 for all plants except for red beans which presents a significant outlier illustrating an optimum pH of 3.73 and a downward curve.

The number of germinated seeds (Table 2)

None of the red beans or chia seeds germinated in the pH 11 solution. For wheat, lettuce, grass, and mung bean, a significantly lesser number of seeds germinated at a slower rate in the pH 11 solution than in other pH conditions. For example, 7 wheat seeds and 3 lettuce seeds germinated in pH 11 groups on day 2, respectively. Only 4 lettuce seeds germinated in pH 3 setting on day 2. For grass, 2 and 4 germinated seeds were observed in pH 5 and pH 9 solutions on day 2, whereas 3 germinated seeds in pH 3 solution on day 3, and 2 germinated seeds in pH 11 solution on day 4. This finding implies that both the numbers of germinated seeds as well as the germination and growth rates of all plants decrease in unfavourable pH conditions. Plant seeds tend to grow at a slower rate in both extreme acidity and alkalinity.

Most of the germinated seeds stop growing in extremely acidic environment and are susceptible to early death and invasion by fungus and other microorganisms. Red beans in an acidic environment became mouldy from Day 4, being worse in pH 3 solution than in pH 5 solution. Similarly, chia seeds suffered from some pinkish fungus in both acidic settings, from day 4 in pH 3 solution and from day 5 in pH 5 solution. Fungal invasion was apparent across all acidic and alkaline environments for wheat seeds and mung beans, with the worst being in pH 3 solutions, followed by pH 5, pH 11, and pH 9 solutions, with the earliest occurring from day 3. Fungi tend to habitat more intensively and grow at a faster rate in acidic lemon water than in alkaline lye water.

Experiment 1b.

Data analysis and the order of average growth rate (Tables 3 and 5, Figures 2 and 4)

The number and average growth rate of germinated seeds of three plants at five pH groups in soil are compared. All plants perform best in the pH condition of 7 (neutral), in which wheat grew 177.3mm, lettuce grew 52.6mm, and grass grew 115.9mm. Relatively, the light acidic condition of pH 6.5 is displayed as the second optimal pH condition for wheat, followed by light alkaline (pH 8), strong acidic (pH 6), and strong alkaline (pH 8.5). Contrastingly, lettuce and grass performed similarly with an order of neutral (pH 7), light acidic (pH 6 and 6.5), strong acidic (pH 5.5 and 6), light alkaline (pH 7.5), and strong alkaline (pH 8). It is evident that pH 7 is the optimum pH condition for wheat, lettuce, and grass.

The calculated optimum pH values (Table 6b)

Results show that the optimal pH value of wheat is 7, lettuce is pH 6.05, and grass is pH 6.76, respectively, all of which are near neutral.

The number of germinated seeds (Table 3)

Wheat germinated lesser and slower in alkaline soil than in neutral and acidic soils, with 6 germinated seeds in light alkaline soil and 4 in strong alkaline soil compared to 8 germinated seeds in neutral and acidic soils on Day 4. For lettuce on day 9, 10 seeds germinated in neutral soil, 9 in acidic soils, and 6 in alkaline soils, respectively. For grass on Day 13, 10 seeds germinated in neutral soil, 9 in light acidic soil, 8 in strong acidic soil, 1 in light alkaline soil, and 5 in strong alkaline soil, respectively. The finding strongly supports that soil pH affects the viability and quality of germination.

Graphs (Experiments 1a and 1b) (Figures 3 and 4)

The graph illustrates that plant growth rates decrease as extrinsic pH levels exceed the optimum pH range, represented by parabolic-shaped curves.

Experiment 2 (Tables 7 and 8)

All Groups 3 performs the best, followed by Group 2, Group 4, Group 5, and Group 1. Groups 4 and 5 show that plants with excessive amounts of water uptake will decrease their growth. Contrastingly, Group 1 shows no growth for all plants due to insufficient water imbibition to activate enzymes for germination. Group 5 demonstrate no growth for wheat and lettuce. Comparatively, Group 2 shows more growth than Group 4 due to sufficient water intake to germinate, but insufficient enough to perform its fullest potential to grow as compared to Group 3.

Discussion and Evaluation

Data discussion

The results of Experiment 1 support the hypothesis that if the extrinsic pH is near neutral (pH 7 ± 10%), seed germination will take place and the average plant height will be the greatest. Chemical reactions that occur during germination are controlled by enzymes. All enzymes have an optimum pH at which they can work best (Table 9). The experiment finding supports that enzymes usually function well within an optimum range of pH values. The impacted plant growth in unfavourable acidic and alkaline environments is caused by denaturation of essential enzymes in the plants, such as hydrolytic enzymes, amylase, and protease. Denaturation of enzymes is permanent, irreversible, and owing to the breaking of the hydrogen and ionic bonds that maintain the three-dimensional shape and active site of the enzyme. Once an enzyme is denatured, its biological functions are lost, causing damage to the plant and increased vulnerability to diseases, leading to a disruption in germination and growth or even cell death.

Table 9. Recent studies showing the optimum pH range for each plant.

Plant	pH	Reference
Wheat	6.5	(Cornell University Cooperative Extension, n.d.)
Lettuce	6-6.5	(UC IPM, 2017)
Grass	6-6.5	(Beyond Pesticides, 2017)
Mung bean	6.2-7.2	(Ryczkowski, 2018)
Red bean	6-7	(Heirloom Organics, 2019)
Chia seed	6.5-8.5	(Benetoli da Silva et al., 2020)

The results of Experiment 2 support the hypothesis that if the amount of water given to the soil is below or above the optimum amount of water, the germination of the plant will not occur, and its growth rate will decrease. Once the embryo of a plant receives the optimum amount of water imbibition, germination of seeds commences, allowing the activation of enzyme-mediated metabolic processes. Seeds with insufficient water imbibition will not commence germination. Adversely, excessive imbibition of water will cause increased turgor pressure, water stress and excessive osmosis in plant cells, causing vacuoles to burst, leading to a disruption in germination and growth or even cell death (Biology Online Editors, 2019).

Soil acidification

Soil acidification is naturally caused by leaching from increased amounts of rainfall. Soil acidity influences plant growth, production, and water use as it results in nutrient deficiencies in soil and plants and increases the impact of toxic elements, especially aluminium and manganese, affecting essential bacteria, earthworms, and other soil organisms (Agriculture Victoria, 2020). In addition, soil acidity affects essential soil biological functions including nitrogen fixation, and increases vulnerability to soil structure decline and erosion (Agriculture Victoria, 2020).

Soil alkalinity

Soil alkalinity commonly occurs in semiarid regions where there is poor rainfall distribution or within irrigated areas with poor water delivery, usually associated with salinity (A. Msimbira & Smith, 2020). Alkaline soils hinder root development by limiting water access to the roots, which diminishes plant growth. It causes deficiencies in phosphorus, zinc, and potentially iron, as well as boron toxicity (A. Msimbira & Smith, 2020). The high sodium content commonly results in soil structural problems, which can impact aerobic or highland crop systems (A. Msimbira & Smith, 2020).

Effects of climate change to agriculture and food production

Climate change certainly exerts a detrimental impact on agricultural production in regions of the world that are already experiencing water shortages due to declining water supplies, a rise in extreme weather phenomena including floods and severe storms, heat stress, and an increase in pests and diseases. This investigation simulates the impact of climate change on plants. It is evident that pH and water conditions inflicted by the exacerbation of climate change affect the germination and growth of plants. The burgeoning global food demand has urged more food production to feed the rising population, and climate change has been an adverse factor to our food supply. Increased temperatures and more turbulent weather patterns caused by climate change affect the soil pH and water levels. The accelerated evapotranspiration from plants and soils caused by rising temperatures influences the amount of water plants needed to thrive. Heat waves, extreme rainfalls, and droughts have caused severe disruptions in food production and availability, causing crop failures and rising prices of food commodities, hence inflicting populations in food insecurities and poverty.

Sustainable agriculture for soil management

Soil is a fundamental aspect of terrestrial ecosystems and agriculture. Climate change affects soil properties through changes in rainfall and temperature, which can cause soil erosion, organic carbon, nutrients, and pH, hence impacting our vegetation, water quality, and agricultural production (Gelybó et al., 2018). This investigation raises awareness and supports that managing soil pH and water levels in their optimal range is crucial for sustainable agriculture practises to obtain optimum plant growth and hence maximise crop yield for our society. Sustainable soil management principles, including selecting appropriate crops, managing nutrients, water cycles, and reforestation, can be used to maximise soil health (AdaptNSW, 2023).

Random errors

1. Human error specifically parallax errors in which measurements of each plant may not be exactly accurate.
2. Red beans and mung beans were purchased from supermarket and their viability was uncertain. Seeds have a shell life and lose their viability quickly; therefore, germination rates will reduce as time goes on.

Systematic Error

PH test strips cannot provide accurate pH values as they change colour in vast ranges. Systematic error can be minimised by using calibrated equipment that are reliable and functioning accurately including digital pH meter and weighing scale.

Limitation and improvement

1. Digital pH meter can be used for accurate and reliable reading for soil and liquids.
2. More trials of the experiment involving more pH ranges can be done to obtain average values whilst reduce random errors to increase reliability of results.
3. Alternative to manually measuring the length of each stem of plant repeatedly with a ruler, calibrated image measurement utilising cameras and software programmes can obtain data more accurately and efficiently (Figure 5).

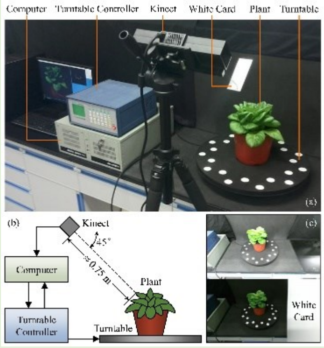


Figure 5. An example of measuring plant growth using software programs and calibrated digital imaging (Hu et al. 2018)

Conclusion

The experiment supports the hypotheses that If the pH level of the solution is near neutral (pH 7 ± 10%), seed germination will take place and the growth rate in plants will be the greatest, and if the amount of water given to the soil is below or above the optimum amount of water, the germination of the plant will be negatively impacted, and its growth rate will decrease. Climate change affects soil pH and water level, and hence influencing seed germination and growth. As a result, our food production and security will be afflicted. Sustainable agricultural practices for soil management are crucial for optimum plant growth to maximise food yield for our society.

Word Count

- 2188 words
- Headings, titles, figure captions, tables, references, and logbook/journal are not included in the word count.

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OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☑ Scientific Inquiry

This must be included with your report, log book or entry. One form per entry.

NAME: Chloe Yaan Yuit Yew ID: 0445-012

SCHOOL: Norwood International High School

Activity: Give a brief outline of what you are planning to do.

This experiment investigates the effect of extrinsic pH levels and water conditions on seed germination and plant growth by measuring the average length and number of germinated seeds of the chosen plants. This investigation also reflects on the impact of climate change on seed germination and plant growth as well as food production for our society.

Are there possible risks? Consider the following:

- **Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.**
- **Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?**
- **Biological risks: Are you working with micro-organisms such as mould and bacteria?**

Risks	How I will control/manage the risk
Chemical risks	Prudent laboratory safety practices were followed. Chemical contact was avoided by putting on personal protective equipment including an apron, safety glasses, safety gloves, enclosed footwear, and a surgical mask for preventing inhalation of chemicals. Hair was tied back so that hair did not contact with any chemicals.
Biological risks	The experiment was handled with care as soil contains living microorganisms including bacteria, fungi and protozoa and can cause irritation in nose, throat and lungs, and illnesses from hay fever, asthma to pneumonia-like illnesses if inhaled (bioaerosols). During observation, personal protective equipment was used to reduce the risk of contamination and biohazards including mould growth.
Sharp risks	When cutting plastic bags and cardboard, scissors and cutter knives were carefully handled to prevent cuts. The equipment and apparatus used in this experiment were carefully handled to prevent any incidents.

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out.

RISK ASSESSMENT COMPLETED BY (student name(s)): Chloe Yaan Yuit Yew

SIGNATURE(S): Chloe Yew

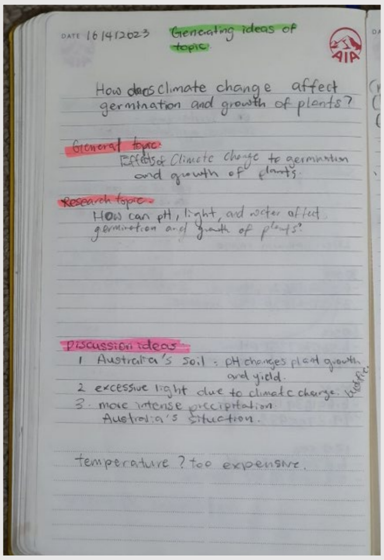
☑ **By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.**

TEACHER'S NAME: Wenting Yu

SIGNATURE: Wenting Yu DATE: 27/5/2023

Scientific Journal

Jan 2023 till 16/4/2023



Generating topic of interest:

General topic: How does climate change affect germination and growth rate of plant?

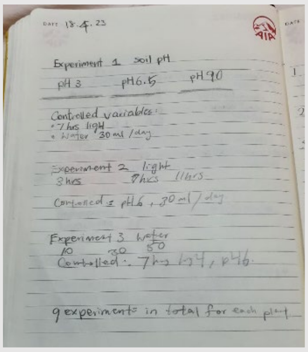
Research topic: How do pH, light, water and temperature affect plant germination and growth in the context of climate change?

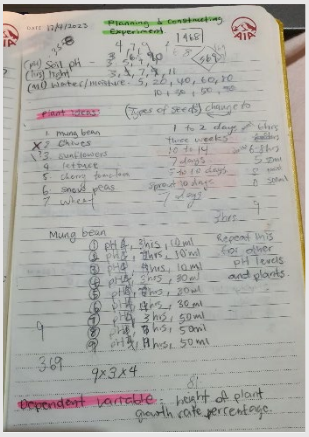
Discussion of ideas & reading:

Australian soils: pH changes due to climate change affecting plant growth and crop yield – flooding in NSW & Queensland 2022, bushfires in Sep 2019 - Mar 2020, dry climate etc.

Excessive light due to climate change, more intense precipitation.

17/4/2023 till 18/4/2023



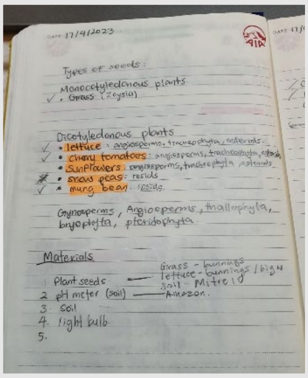


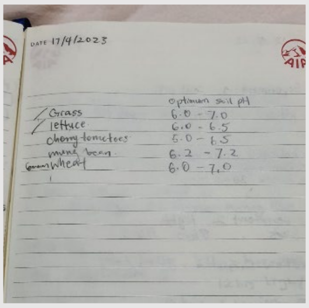
Independent variables to investigate:

- **pH:** 3, 5, 7, 9, 11
- **light:** 4hrs, 8hrs, 12hrs, 16hrs, 20hrs, 24hrs
- **water:** 5, 10, 20, 30, 40, 50ml

Plant ideas: Mung bean, chives, sunflowers, lettuce, cherry tomatoes, snow peas, wheat, grass etc.

Types of seeds: Monocotyledonous, dicotyledonous, angiosperms, gymnosperms





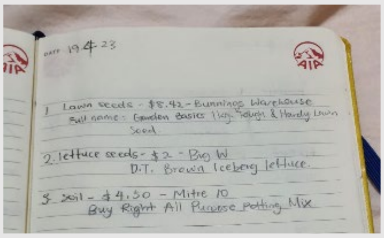
Optimum pH for different plants:

Wheat: pH 6 – 7
Lettuce: pH 6 – 6.5
Grass: pH 6 –7
Cherry tomatoes: pH 5 – 6.5
Mung bean: pH 6.2 – 7.2

Thinking critically for temperature experiment about its procedure, materials and equipment required. The idea of investigating the effect of temperature on plant growth is not realistic or practical having considered lacking reliable methods due to limited resources including incubators and so on. Therefore, the temperature experiment is eliminated.

19/4/23

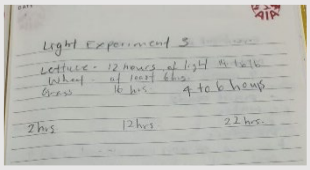
Purchased materials from stores and websites:

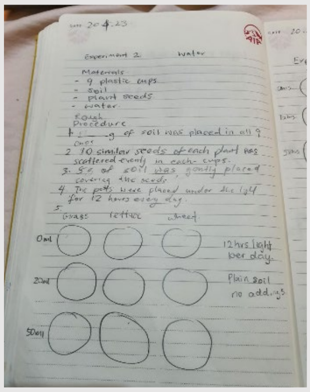


1. **Lawn seeds** - $8.42 – Bunnings Warehouse
   Brand: Garden Basics 1kg Tough & Hardy Lawn Seeds
2. **Lettuce seeds** - $2 – Big W
   Brand: D.T. Brown Iceberg lettuce
3. **Soil** - $4.50 – Mitre 10
   Brand: Buy Right All-Purpose Potting Mix
4. **Digital pH meter** - $14.99 – Amazon AU
   Brand: Techvida Digital pH Meter Tester

Independent Variables	**Experiment 1:** pH levels (using water, different concentrations of lemon juice and lye water) **Experiment 2:** Water conditions (control group, water regularly, excessive amount of water)
Dependent Variables	Germination and growth rate, measuring weight, plant height, number of germinated seeds

20/4/23





Developing ideas for Experiment 2: Water

Materials: 9 clean yogurt plastic cups, soil, plant seeds, water

3 types of plant seeds: Wheat, lettuce, grass

Procedure:

1. 60g of soil was placed in all 9 cups.
2. 10 seeds of each plant were scattered evenly in each cup.
3. 5g of soil was gently placed covering the seeds.
4. Each pot was watered with the set amount of water every day.

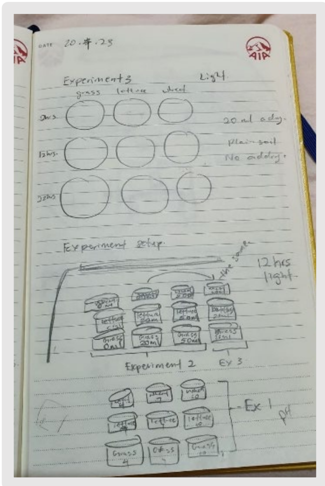
Developing ideas for Experiment 3: Light

- Materials: 9 clean yogurt plastic cups, soil, plant seeds, water, 3 grow light lamps ($25 x3), cardboard, 3 *socket timers ($8 x3)*, cord extension ($14), hot glue gun, glue sticks, masking tape, scissors





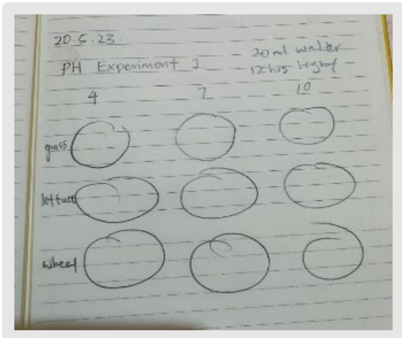

3 types of plant seeds: Wheat, lettuce, grass



Procedure:

1. 60g of soil was placed in all 9 cups.
2. 10 seeds of each plant were scattered evenly in each cup.
3. 5g of soil was gently placed covering the seeds.
4. Three pots of different plants were placed under lighting for 2 hours for 14 days.
5. Three pots of different plants were placed under lighting for 12 hours for 14 days.
6. Three pots of different plants were placed under lighting for 24 hours for 14 days.

Developing ideas for Experiment 1: pH



Materials: 9 clean yogurt plastic cups, soil, plant seeds, water

3 types of plant seeds: Wheat, lettuce, grass

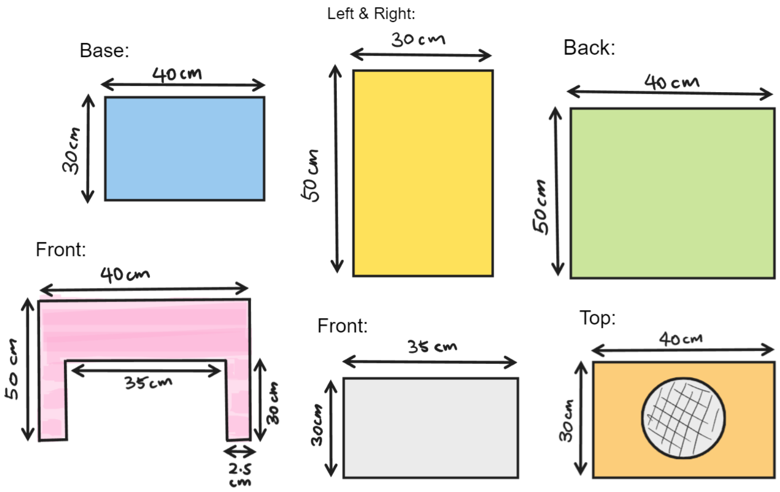
5 PH conditions: Low pH x2, neutral, high pH x2

Procedures:

1. 60g of soil was placed in all 9 cups.
2. 10 seeds of each plant were scattered evenly in each cup.
3. 5g of soil was gently placed covering the seeds.
4. Each pot was watered with the set amount of water every day.

21/4/23

Making boxes to keep plants for Experiment 3: Light



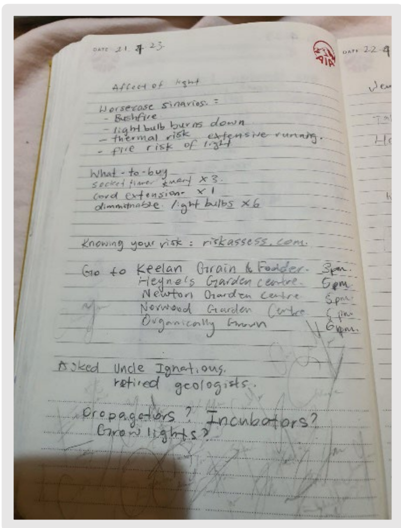
Developing ideas for Experiment 3: Light:

Worst case scenarios: Bushfires in plants, light bulb burns out, thermal and fire risks from extensive running light bulbs.

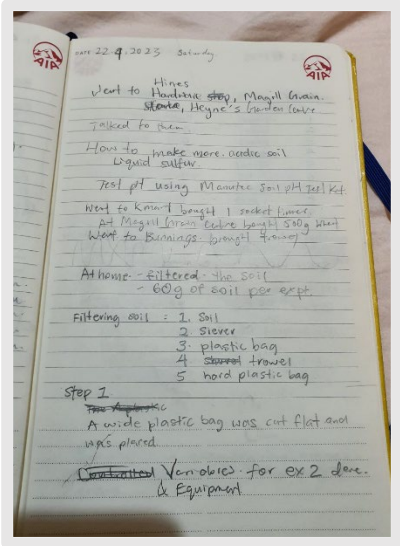
What to buy: Socket timer x3, cord extension, dimmable light bulbs x3, grow lights x3

Propagators and incubators may be needed.

Discussion with a retired geologist: How to alter soil pH, soil chemistry, borrow self-made soil sieve.



22/4/23



Visiting garden centres and grain stores: Magill Grain Store, Heyne's Garden Centre

Discussion with garden workers: Methods & toolkits of measuring and changing pH soil.

Results:

- use sulphur to decrease soil pH
- use garden lime to increase soil pH
- use Manutec Soil pH Test Kit to obtain pH of soil, $27.42 - Bunnings Warehouse

Purchased materials and equipment from stores:

1. Trowel - $5.30 - Bunnings Warehouse
   Full name: Trojan Stainless Steel Hand Trowel
2. Socket timer - $8 - Kmart
   Full name: 3 Arlec Slimline 24 hour Analogue Timer
3. Cord extension - $14 - Kmart
   Full name: Arlec 4 Outlet Surge Protected Powerboard


Filtering soil using a sieve to remove large mulches that may prevent plant growth.

Materials: Soil, sieve, soft plastic bag, trowel, hard plastic bag

Procedure: Filtering soil

1. The plastic bag was cut to a flat plastic and placed flatly on the ground.

2. The soil sieve was placed on top of the plastic.

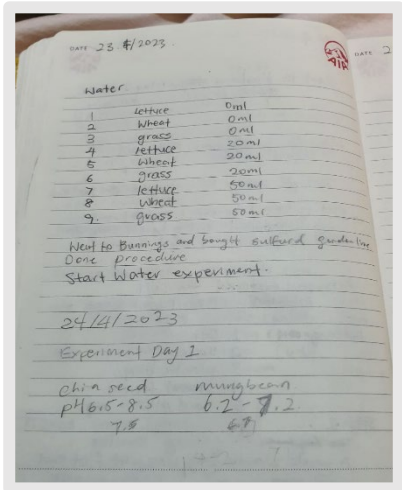
3. The soil was placed on the sieve using a trowel and sieved through. Large bark mulches were disposed of after sieving.

4. The sieved soil was placed in a thick clean reused plastic bag.


23/4/23 till 24/4/23

Purchasing materials from Bunnings Warehouse:

1. Manutec Sulphur Fine Granules - $16.95
2. Richgro Natural Garden Lime - $7.18



Paperwork: Working on procedures and adding on the materials and equipment list. Setting out layout and flowchart, and designing framework/components in the scientific report.

Conducting pilot study for Experiment 2: Water - to decide the amount and frequency of water needed to mimic climate change.

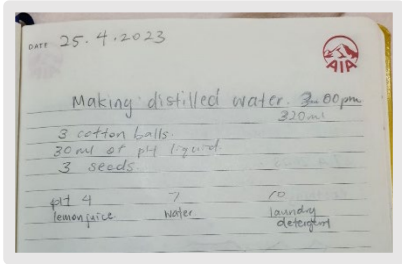
25/4/23

Producing distilled water using distillation method:

1. A metal rack and water were placed in the pot with the lid placed upside down on the pot. A bowl was placed on the rack and the water was set to boil.
2. Once water boils, ice cubes and a pair of long chopsticks was placed on the pot's lid with an ice bottle balanced securely on top of the chopsticks.
3. Distilled water was slowly obtained through this time-consuming process of evaporation.
4. Repeat the steps 1-3 until the desired amount of distilled water was obtained.



Calibration of digital pH meter:
The distilled water made was mixed with the provided solutes **to calibrate the purchased digital pH tester.** However, despite multiple times of calibration were attempted, the tester did not work, presenting false and unreliable data.



Solution: Consider using traditional pH test strips, may not be perfect. Despite reduced accuracy, it will still be able to differentiate the effect of pH to germination and growth rate.

Developing ideas to increase and decrease pH in soil and hydroponics:

Acids: Lemon juice, vinegar, lime juice, sulphur liquid/powder etc.

Alkali: Laundry detergent, lye water, alkaline water from supermarket, baking soda, garden lime etc.

Neutral: Is there any difference in pH among tap water, rainwater, and river water?

26/4/23 – 28/5/23

Continue working on data collection, developing ideas, researching for more information, and drafting report.

Thinking critically about the investigation.

The idea of Experiment 3: Light - is just not practical since there are insufficient resources and limited budget to conduct this experiment at home. Reluctantly, the idea is abandoned.

28/4/23

Purchased Alkaline water - $3.50

Full name: Alka Power Alkaline Water 1.5L, Coles.
The alkaline water is labelled as pH 9 -10, however, the solution was repeatedly tested to be pH 8 using pH test strips.

29/4/23

Conducting Experiment 2: Water

Groups and Labels:

Groups	Water amount	Days of water intake	Total water intake (ml)
Group 1	No water at all.	- (dry climate, desert)	0
Group 2	Water once.	Day 0: 50ml	50
Group 3	Water regularly.	Day 0: 50ml, Day 1, 2 & 7: 15ml	95
Group 4	Water more.	Day 0: 50ml, Day 1, 2 & 7: 30ml	140
Group 5	Water the most.	Day 0 & 1: 100ml (flooding)	200

Procedure

STEP 1: Filter the soil

1. The plastic bag was cut to a flat plastic and placed flatly on the ground.

2. The soil sieve was placed on top of the plastic.

3. The soil was placed on the sieve using a trowel and sieved through. Large bark mulches were disposed of after sieving.

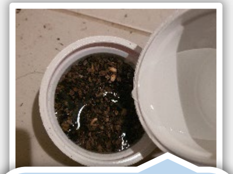
4. The sieved soil was placed in a thick clean reused plastic bag.

STEP 2: Prepare the plants

1. 12 cups were labelled appropriately (Table). 60g of soil was placed in each cup using a weighing scale and a trowel.

2. All the cups except for L0, W0 and G0, were watered with 50 ml of water on Day 0 except Group 1.

3. Each cup was scattered evenly with 10 allocated-plant seeds (Table). The seeds were gently pushed in and covered in the soil using fingers.



4. All the cups were watered with the allocated amount of water on Day 1 and the following days.

Table. Labels.

Name	Plant	Group
W1	Wheat	1
W2	Wheat	2
W3	Wheat	3
W4	Wheat	4
W5	Wheat	5
L1	Lettuce	1
L2	Lettuce	2
L3	Lettuce	3
L4	Lettuce	4
L5	Lettuce	5
G1	Grass	1
G2	Grass	2
G3	Grass	3
G4	Grass	4
G5	Grass	5

STEP 3: Measure and record data and observations daily				
1. The weight of each plant was measured using a weighing scale.	→	**2.** The height of each plant was measured using a ruler.	→	**3.** The number of germinated seeds of each plant was recorded.

29/4/23 till 2/5/23

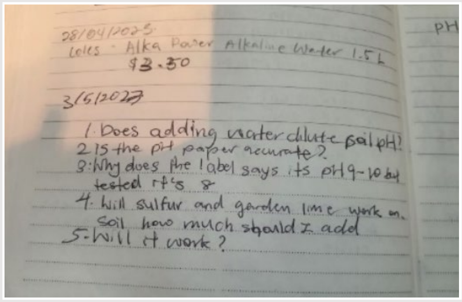
Developing ideas and working on report. Completing risk assessment:

Risks	**Control/management**
Chemical risks	Prudent laboratory safety practices were followed. Chemical contact was avoided by putting on personal protective equipment including an apron, safety glasses, safety gloves, enclosed footwear, and a surgical mask for preventing inhalation of chemicals. Hair was tied back so that hair did not contact with any chemicals. The equipment and apparatus were carefully handled to prevent any incidents.
Biological risks	The experiment was handled with care as the soil contains living microorganisms including bacteria, fungi and protozoa which can cause irritation in nose, throat and lungs, and illnesses from hay fever or asthma to pneumonia-like illnesses if inhaled (bioaerosols). During observation, personal protective equipment was used to reduce the risk of contamination and biohazards including mould growth.
Sharp risks	When cutting plastic bags and cardboard, scissors and cutter knives were carefully handled to prevent cuts.

3/5/23

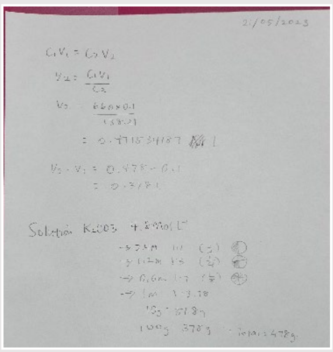
Curiosity - questioning:

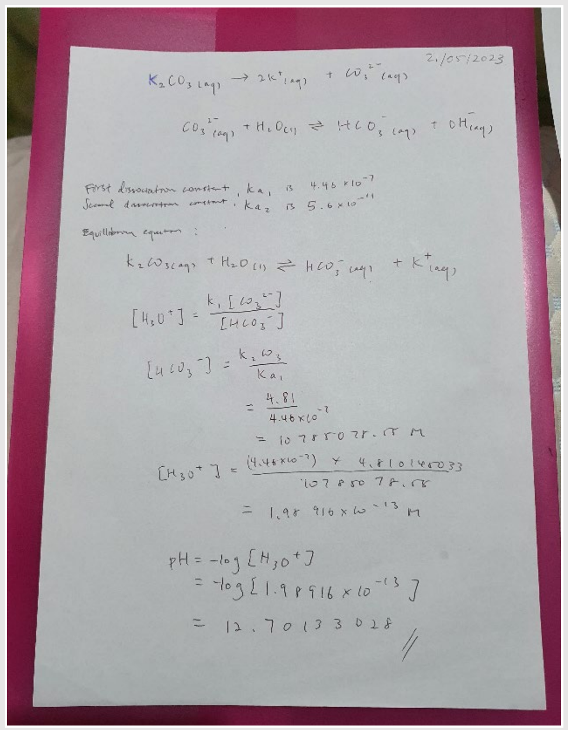
1. Does adding water dilute soil pH?
2. Is pH test strip accurate and reliable?
3. Will sulphur and garden lime work on soil?

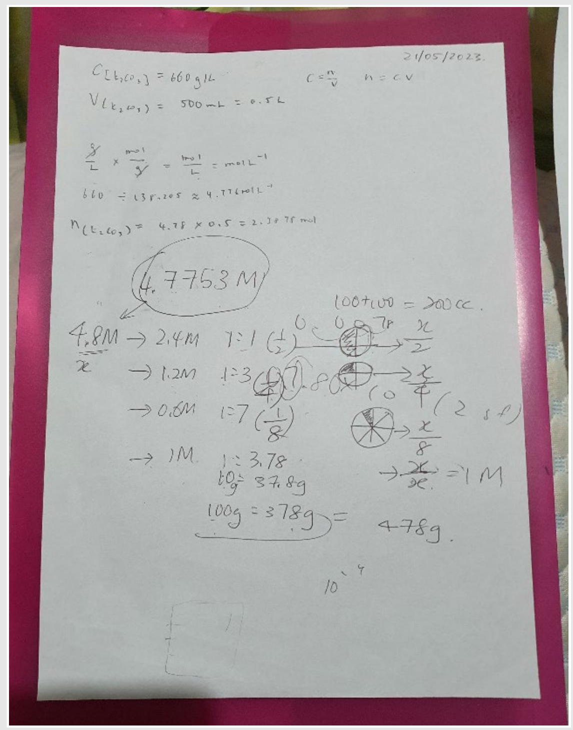


21/5/23

Determining the pH and molar of lye water:







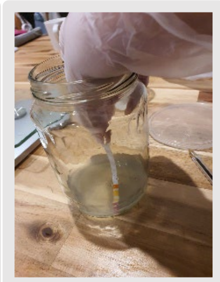
28/5/23

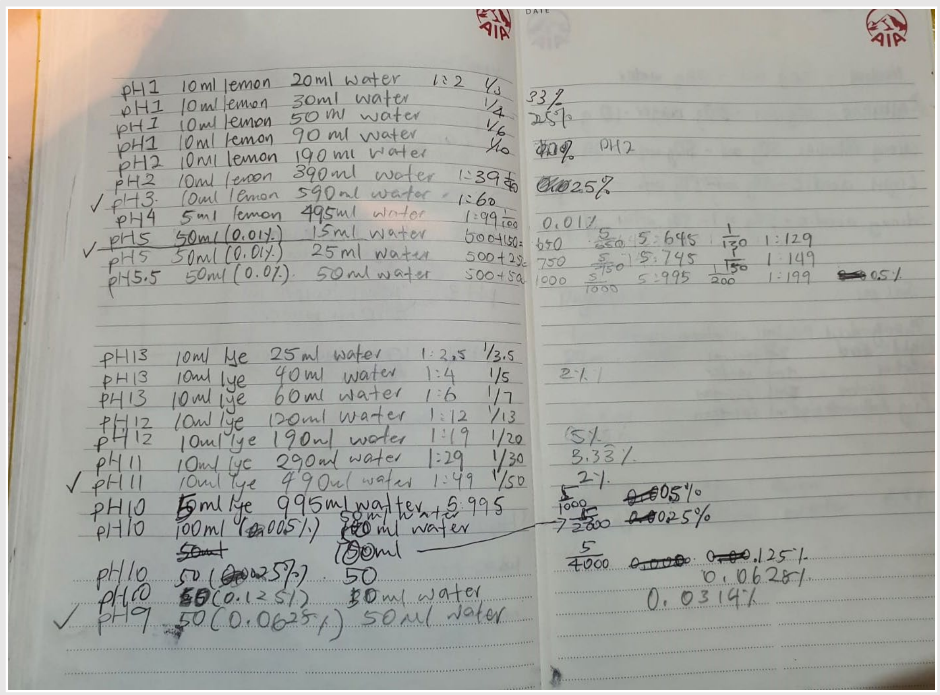
Determining the pH of various solutions using pH test strips.

Ingredients to produce the pH solutions: Water, lemon juice, and lye water.

Making solution using dilution method

☒ = selected pH solutions for experiment





pH	Ingredients of solution	Concentration (%)
PH 1	10ml lemon, 20ml water	33.33
PH 1	10ml lemon, 30ml water	25
PH 1	10ml lemon, 50ml water	16.67
PH 1	10ml lemon, 90ml water	10
PH 2	10ml lemon, 190ml water	5
PH 2	10ml lemon, 390ml water	2.5
☒ PH 3	10ml lemon, 590ml water	1.67
PH 4	5ml lemon, 495ml water	1
PH 5	50ml (1%) lemon, 15ml water	0.77
☒ PH 5	50ml (1%) lemon, 25ml water	0.67
PH 5.5	50ml (1%) lemon, 50ml water	0.5
PH 13	10ml lye water, 25ml water	28.57
PH 13	10ml lye water, 40ml water	25
PH 13	10ml lye water, 60ml water	14.28
PH 12	10ml lye water, 120ml water	7.69
PH 12	10ml lye water, 190ml water	5
PH 11	10ml lye water, 290ml water	3.33
☒ PH 11	10ml lye water, 490ml water	2
PH 10	5ml lye water, 995ml water	0.5
PH 10	100ml (0.5%) lye water, 100ml water	0.25

PH 10	50ml (0.25%) lye water, 50ml water	0.125
PH 10	50ml (0.125%) lye water, 50ml water	0.0625
☒ PH 9	50ml (0.0625%) lye water, 50ml water	0.03125

Potential error: pH test strips cannot provide very accurate pH values.

Better option is a digital pH tester which was not available at the time of experiment. The purchased pH tester was not functioning despite many times of calibration.

28/5/23 – 11/6/23

Conducting Experiment 1a: Wheat, lettuce, grass, mung bean, red bean, and chia seed

Control Trial

A control trial was conducted for both experiments to assess the effects of pH levels and water conditions on seed germination and growth.

STEP 1: Prepare the plants

1. 42 cups were labelled appropriately (Table). 3 cotton balls were volumized and placed in each cup.

2. All the cups were placed with 50ml of their allocated solution.

3. Each cup was scattered evenly with 10 allocated plant seed using a tweezer (Table).

4. All the cups were arranged according to the type of plants in trays in the same environment.

Table. The cups were labelled. The pH value was obtained by mixing the specific solution with water using dilution method and measure with PH test strips.

Table 1. **Label**	**Amount of solution**	**Solution**
pH 3	50 ml	1.67% lemon water
pH 5	50 ml	0.67% lemon water
pH 7	50 ml	Tap water
pH 9	50 ml	0.03125% 4.78M lye water
pH 11	50 ml	2% 4.78M lye water
Rainwater PH 7	50 ml	Rainwater (from precipitation)
River water PH 7	50 ml	Surface river water (from Morialta Conservation Park)

STEP 2: Measure and record data and observations daily

1. The weight of each plant was measured using a weighing scale. → **2.** The height of each plant was measured using a ruler. → **3.** The number of germinated seeds of each plant was recorded.

Label	Plant	Amount of solution	Solution
pH 3	Mung Bean	50 ml	1.67% lemon water
pH 5	Mung Bean	50 ml	0.67% lemon water
pH 7	Mung Bean	50 ml	Tap water
pH 9	Mung Bean	50 ml	0.03125% 4.78M lye water
pH 11	Mung Bean	50 ml	2% 4.78M lye water
Rain PH 7	Mung Bean	50 ml	Rainwater (from precipitation)
River PH 7	Mung Bean	50 ml	Surface river water (from Morialta Conservation Park)
pH 3	Red Bean	50 ml	1.67% lemon water
pH 5	Red Bean	50 ml	0.67% lemon water
pH 7	Red Bean	50 ml	Tap water
pH 9	Red Bean	50 ml	0.03125% 4.78M lye water
pH 11	Red Bean	50 ml	2% 4.78M lye water
Rain	Red Bean	50 ml	Rainwater (from precipitation)
River	Red Bean	50 ml	Surface river water (from Morialta Conservation Park)
pH 3	Wheat	50 ml	1.67% lemon water
pH 5	Wheat	50 ml	0.67% lemon water
pH 7	Wheat	50 ml	Tap water
pH 9	Wheat	50 ml	0.03125% 4.78M lye water
pH 11	Wheat	50 ml	2% 4.78M lye water
Rain	Wheat	50 ml	Rainwater (from precipitation)
River	Wheat	50 ml	Surface river water (from Morialta Conservation Park)
pH 3	Lettuce	50 ml	1.67% lemon water
pH 5	Lettuce	50 ml	0.67% lemon water
pH 7	Lettuce	50 ml	Tap water
pH 9	Lettuce	50 ml	0.03125% 4.78M lye water
pH 11	Lettuce	50 ml	2% 4.78M lye water
Rain	Lettuce	50 ml	Rainwater (from precipitation)
River	Lettuce	50 ml	Surface river water (from Morialta Conservation Park)
pH 3	Grass	50 ml	1.67% lemon water
pH 5	Grass	50 ml	0.67% lemon water
pH 7	Grass	50 ml	Tap water
pH 9	Grass	50 ml	0.03125% 4.78M lye water
pH 11	Grass	50 ml	2% 4.78M lye water

Rain	Grass	50 ml	Rainwater (from precipitation)
River	Grass	50 ml	Surface river water (from Morialta Conservation Park)
pH 3	Chia Seed	50 ml	1.67% lemon water
pH 5	Chia Seed	50 ml	0.67% lemon water
pH 7	Chia Seed	50 ml	Tap water
pH 9	Chia Seed	50 ml	0.03125% 4.78M lye water
pH 11	Chia Seed	50 ml	2% 4.78M lye water
Rain	Chia Seed	50 ml	Rainwater (from precipitation)
River	Chia Seed	50 ml	Surface river water (from Morialta Conservation Park)

4/6/23 – 19/6/2023

Conducting Experiment 1b:

STEP 1: Filter the soil

1. The plastic bag was cut to a flat plastic and placed flatly on the ground.

2. The soil sieve was placed on top of the plastic.

3. The soil was placed on the sieve using a trowel and sieved through. Large bark mulches were disposed of after sieving.

4. The sieved soil was placed in a thick clean reused plastic bag.

STEP 2: Prepare the plants

1. All materials and equipment were prepared, and 15 cups were labelled appropriately (Table 2).

2. 50g of soil and 50g of water was placed in each cup. Allocated supplements were added into the cups (Table 2).

3. Each cup was scattered evenly with 10 allocated plant seed using a tweezer (Table 2).

4. Each cup is placed with the assigned solution of 5ml every day (Table 2).

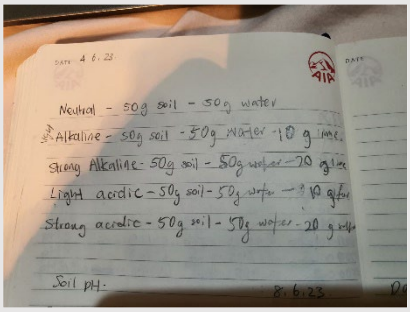
Table 2. The cups were labelled.

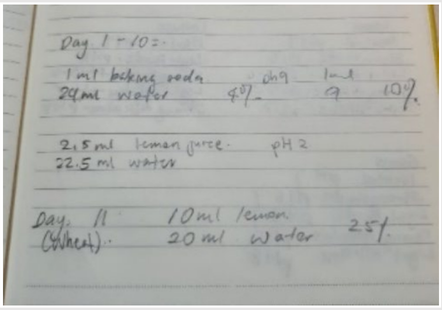
Label	Supplement (Day 0)	Solution (Day 1 to 10)	Solution (Day 11 to 14)
Strong Acidic	20g sulphur	5ml (10% lemon juice)	5ml (33% lemon juice)
Light Acidic	10g sulphur	2ml (10% lemon juice) + 3ml water	2ml (33% lemon juice) + 3ml water
Neutral	None	5ml water	5ml water

Light Alkaline	10g garden lime	2ml (4% baking soda water) + 3ml water	2ml (10% baking soda water) + 3ml water
Strong Alkaline	20g garden lime	5ml (4% baking soda water)	5ml (10% baking soda water)

STEP 3: Measure and record data and observations daily

1. The weight of each plant was measured using a weighing scale.
2. The height of each plant was measured using a ruler.
3. The number of germinated seeds of each plant was recorded.



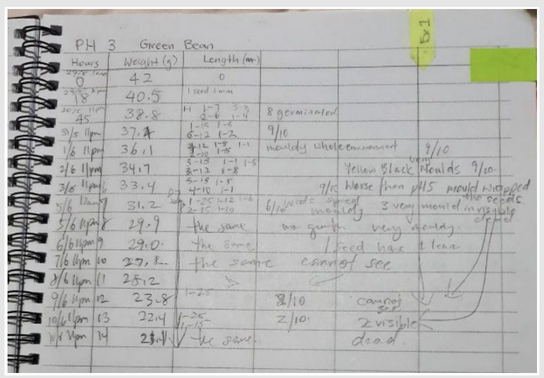


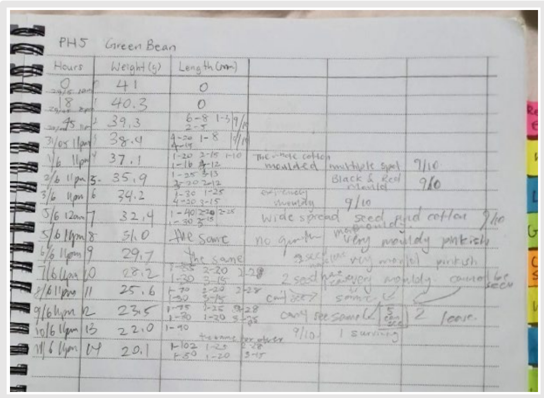
Label	Plant	Supplement (Day 0)	Solution (Day 1 to 10)	Solution (Day 11 to 14)
Strong Acidic	Wheat	20g sulphur	5ml (10% lemon juice)	5ml (33% lemon juice)
Light Acidic	Wheat	10g sulphur	2ml (10% lemon juice) + 3ml water	2ml (33% lemon juice) + 3ml water
Neutral	Wheat	None	5ml water	5ml water
Light Alkaline	Wheat	10g garden lime	2ml (4% baking soda water) + 3ml water	2ml (10% baking soda water) + 3ml water
Strong Alkaline	Wheat	20g garden lime	5ml (4% baking soda water)	5ml (10% baking soda water)
Strong Acidic	Lettuce	20g sulphur	lemon juice)	5ml (33% lemon juice)
Light Acidic	Lettuce	10g sulphur	2ml (10% lemon juice) + 3ml water	2ml (33% lemon juice) + 3ml water
Neutral	Lettuce	None	5ml water	5ml water
Light Alkaline	Lettuce	10g garden lime	2ml (4% baking soda water) + 3ml water	2ml (10% baking soda water) + 3ml water
Strong Alkaline	Lettuce	20g garden lime	5ml (4% baking soda water)	5ml (10% baking soda water)
Strong Acidic	Grass	20g sulphur	lemon juice)	5ml (33% lemon juice)
Light Acidic	Grass	10g sulphur	2ml (10% lemon juice) + 3ml water	2ml (33% lemon juice) + 3ml water
Neutral	Grass	None	5ml water	5ml water

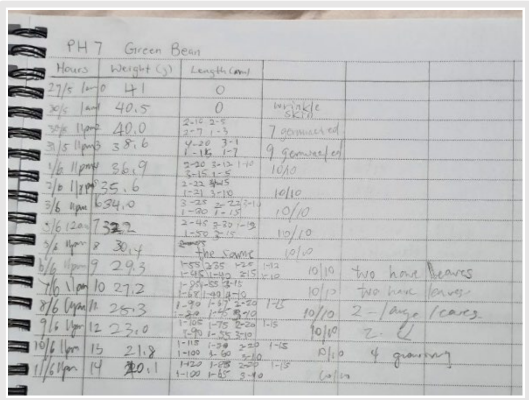
Light Alkaline	Grass	10g garden lime	2ml (4% baking soda water) + 3ml water	2ml (10% baking soda water) + 3ml water
Strong Alkaline	Grass	20g garden lime	5ml (4% baking soda water)	5ml (10% baking soda water)

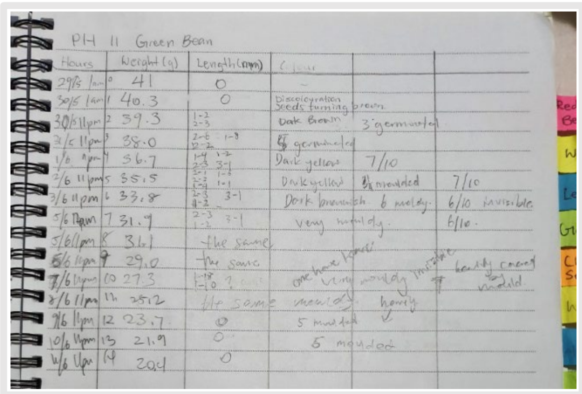
Results: Experiment 1a.

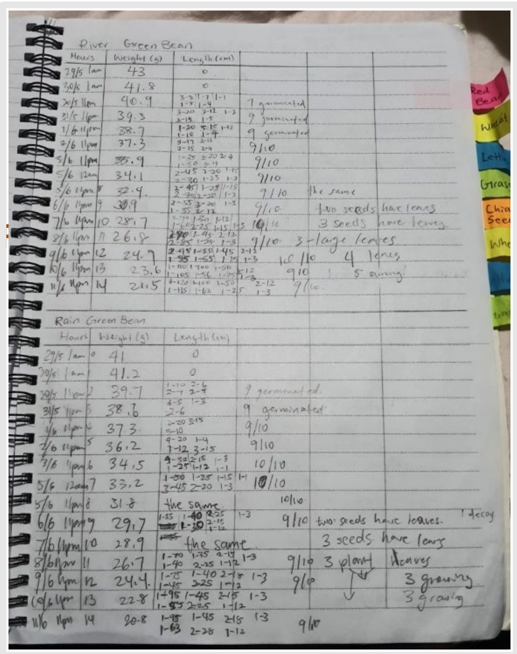
Mung bean:

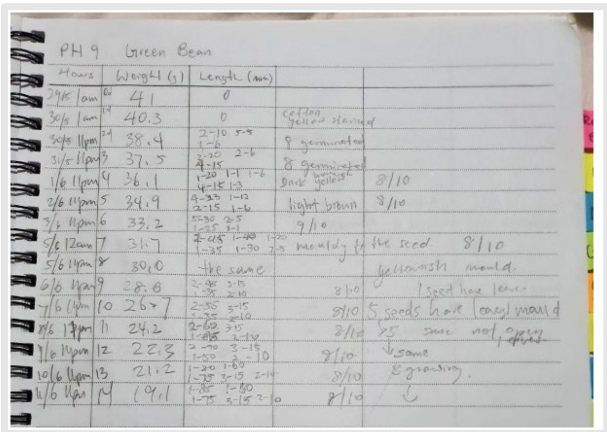




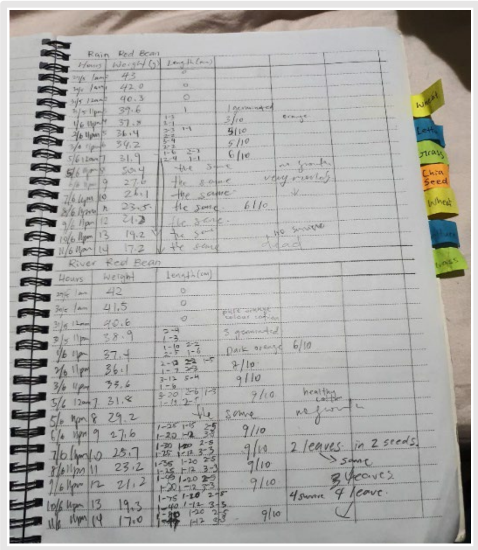


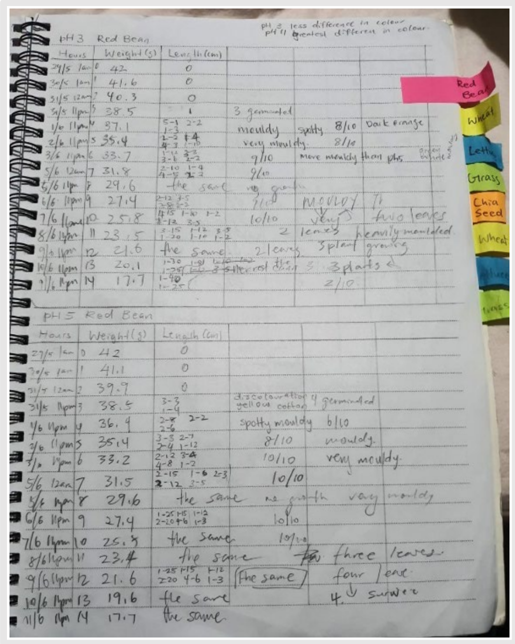


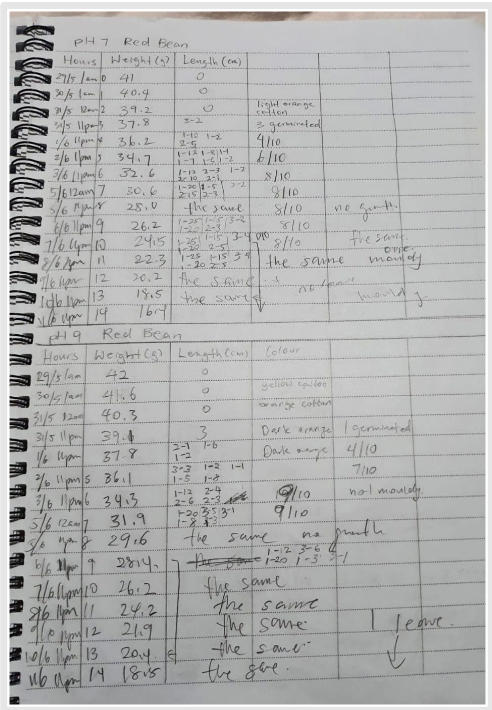


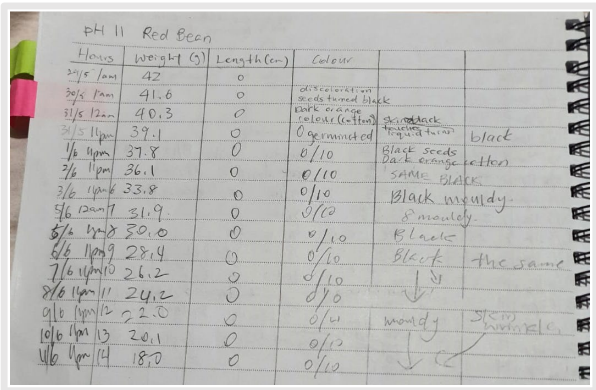


Red bean:

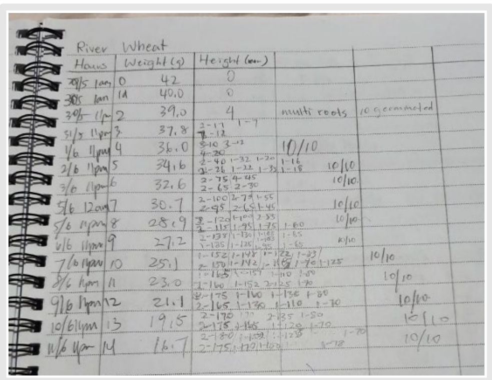


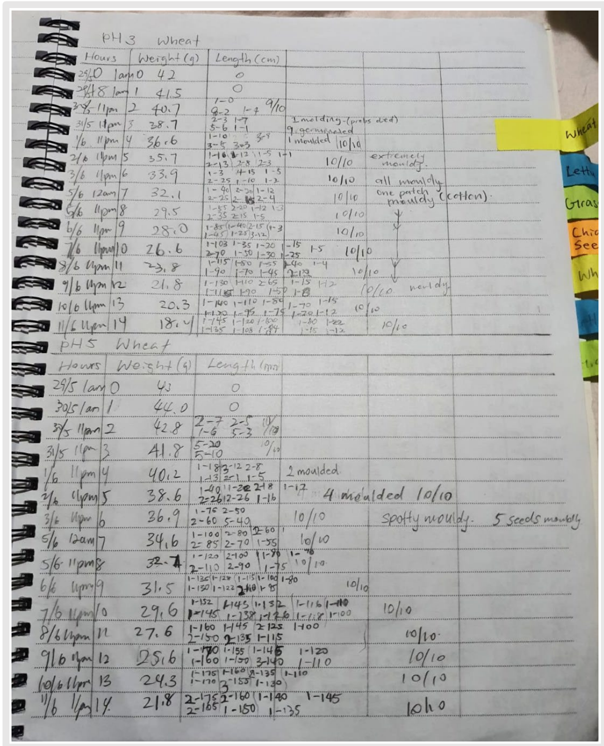


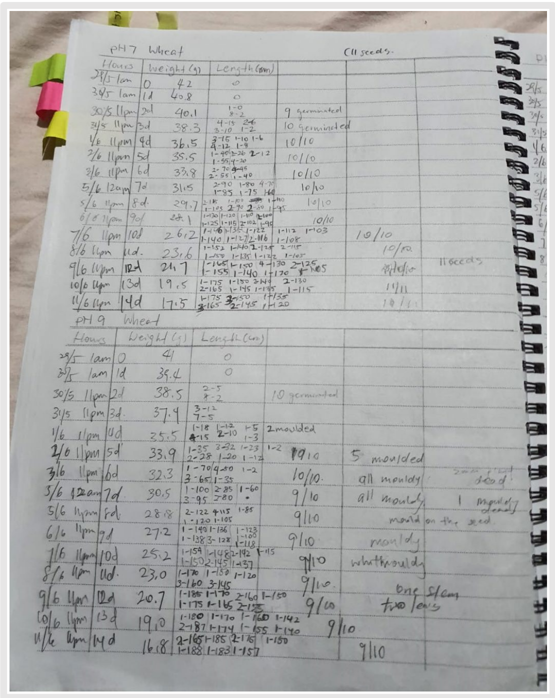


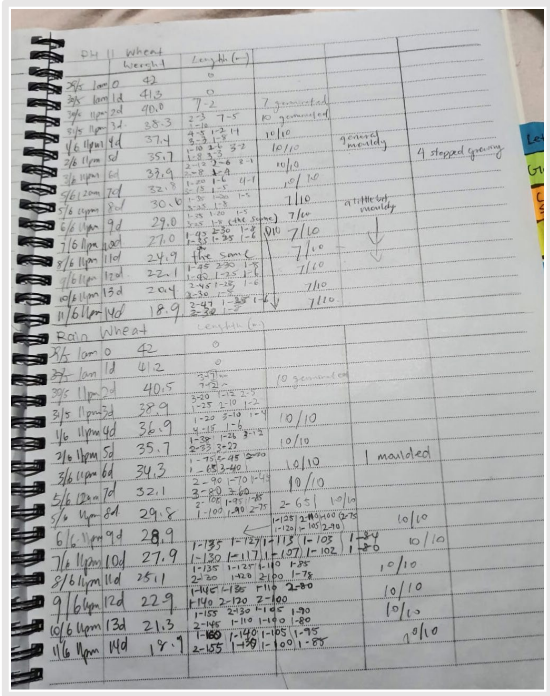


Wheat:

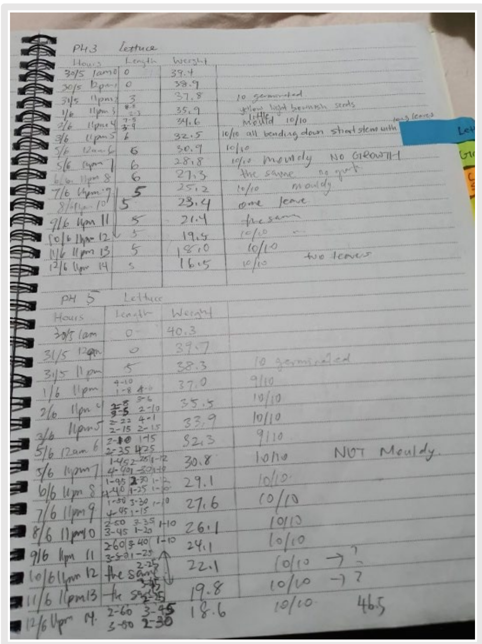


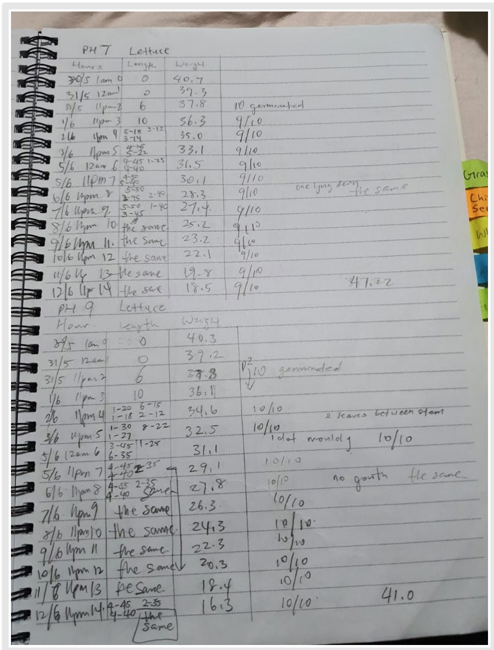


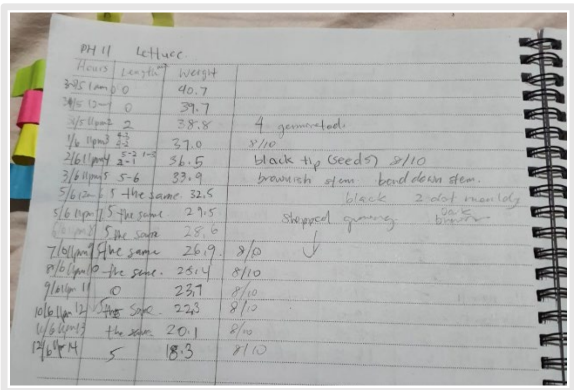

PH 7 Wheat
PH 9 Wheat


PH 11 Wheat
Rain Wheat

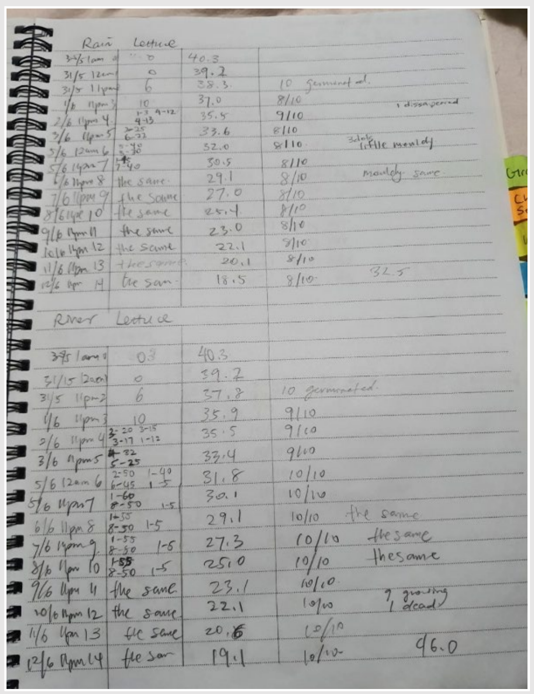
Lettuce:

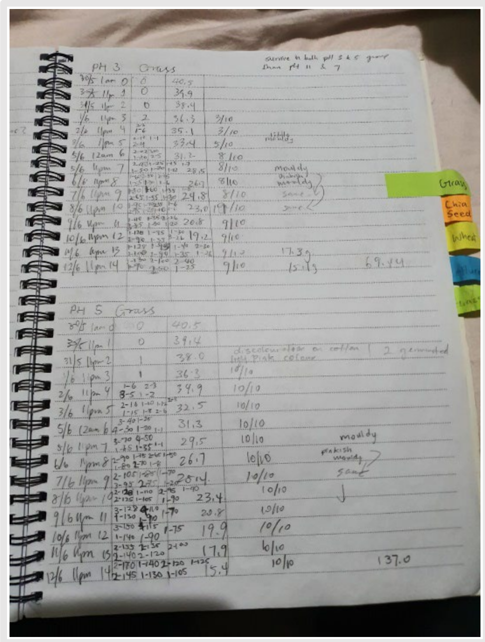

PH 3 Lettuce
PH 5 Lettuce

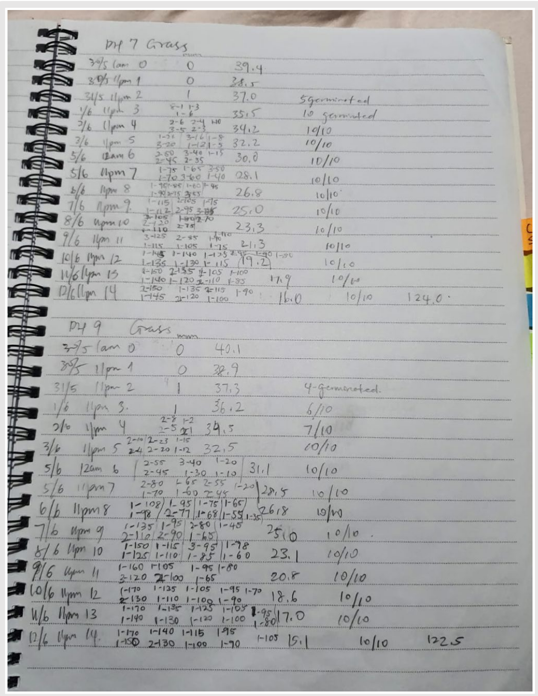

PH 7 Lettuce
PH 9 Lettuce

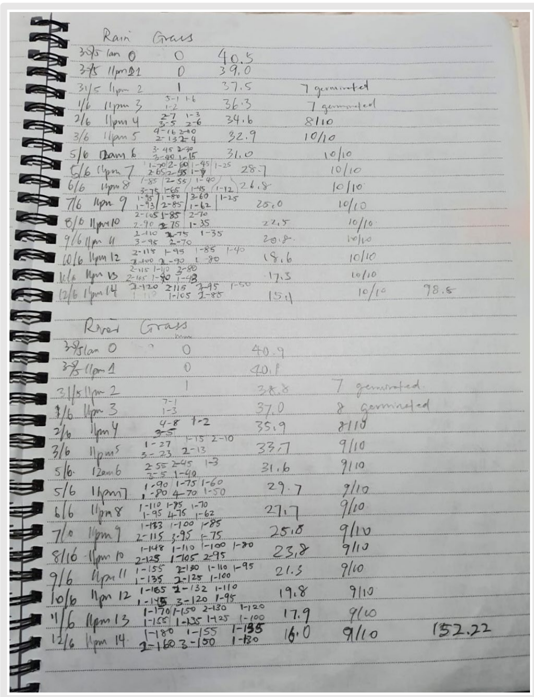

PH 11 Lettuce

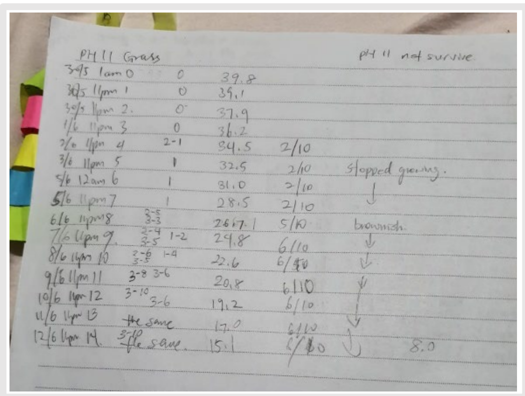
Grass:



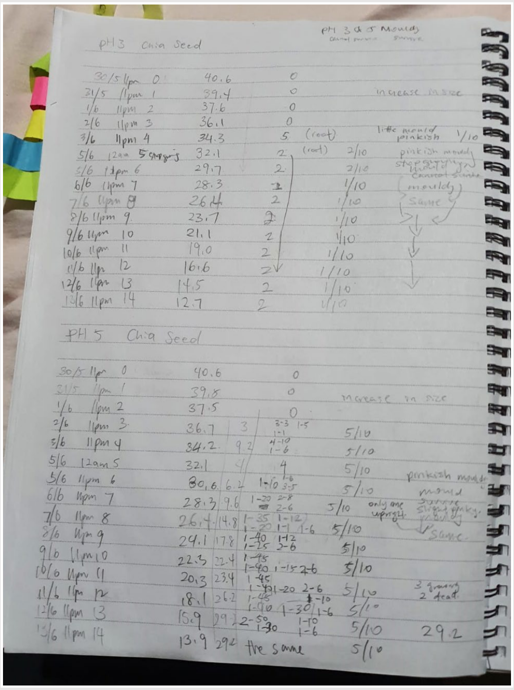








Chia seed:



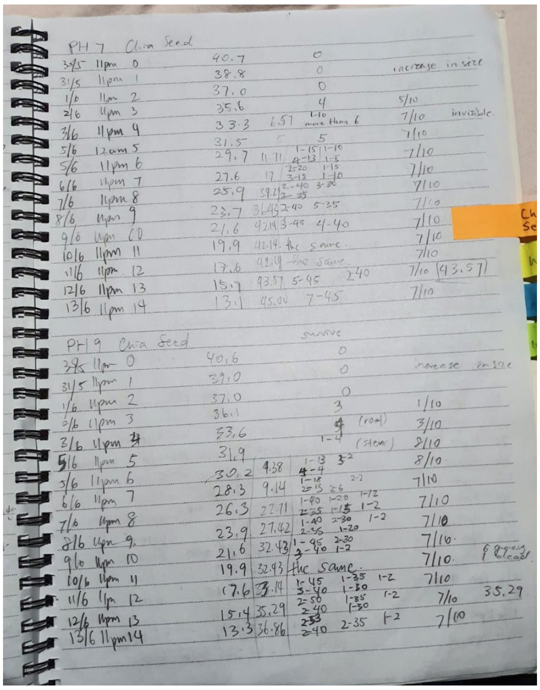
pH 3 & 5 Mouldy

pH3 Chia Seed

30/5 11pm 0	40.6	0			
31/5 11pm 1	39.4	0			increase in size
1/6 11pm 2	37.6	0			
2/6 11pm 3	36.1	0			
3/6 11pm 4	34.3	5	(root)		little mould pinkish 1/10
5/6 12am 5	32.1	2	(root)	2/10	pinkish mould
5/6 11pm 6	29.7	2		2/10	
6/6 11pm 7	28.3	2		1/10	mouldy
7/6 11pm 8	26.4	2		1/10	same
8/6 11pm 9	23.7	2		1/10	
9/6 11pm 10	21.1	2		1/10	
10/6 11pm 11	19.0	2		1/10	
11/6 11pm 12	16.6	2		1/10	
12/6 11pm 13	14.5	2		1/10	
13/6 11pm 14	12.7	2		1/10	

PH 5 Chia Seed

30/5 11pm 0	40.6		0		
31/5 11pm 1	39.8		0		increase in size
1/6 11pm 2	37.5		0		
2/6 11pm 3	36.7	3	3-3 1-5 1-1	5/10	
3/6 11pm 4	34.2	9.2	4-10 1-6	5/10	
5/6 12am 5	32.1	4	4	5/10	
5/6 11pm 6	30.6	6.2	1-10 1-6 3-5	5/10	pinkish mould
6/6 11pm 7	28.3	9.6	1-20 2-8 2-6	5/10	only one upright. mould
7/6 11pm 8	26.4	14.8	1-35 1-12 1-20 1-1 1-6	5/10	
8/6 11pm 9	24.1	17.8	1-40 1-12 1-25 2-6	5/10	same
9/6 11pm 10	22.3	22.4	1-45 1-40 1-15 2-6	5/10	
10/6 11pm 11	20.3	23.4	1-45 1-40 1-20 2-6	5/10	
11/6 11pm 12	18.1	26.2	1-45 1-40 1-30 1-10	5/10	3 growing 2 dead
12/6 11pm 13	15.9	29.2	2-50 1-30 1-10 1-6	5/10	
13/6 11pm 14	13.9	29.2	the same	5/10	29.2

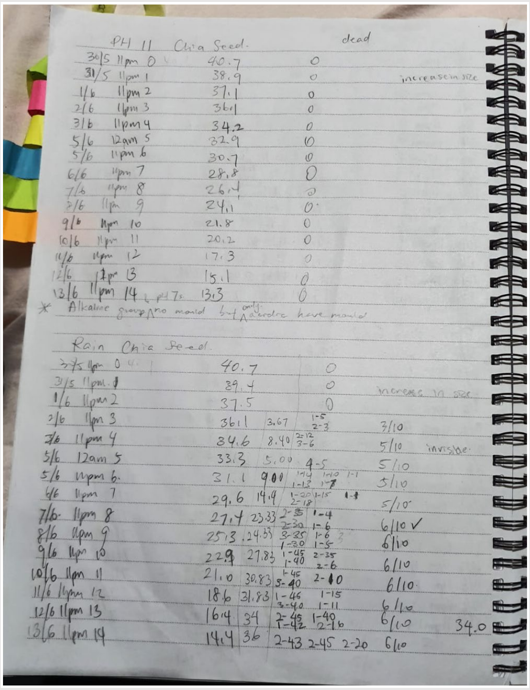


PH 7 Chia Seed

30/5 11pm 0	40.7		0		
31/5 11pm 1	38.8		0		increase in size
1/6 11pm 2	37.0		0		
2/6 11pm 3	35.6		4	5/10	
3/6 11pm 4	33.3	6.57	1-10 more than 6	7/10	invisible
5/6 12am 5	31.5		5	7/10	
5/6 11pm 6	29.7	11.71	1-15 1-10 4-13 1-5	7/10	
6/6 11pm 7	27.6	17	2-20 1-15 3-18 1-10	7/10	
7/6 11pm 8	25.9	34.29	2-40 3-30 2-35	7/10	
8/6 11pm 9	23.7	36.43	2-40 5-35	7/10	
9/6 11pm 10	21.6	42.14	3-45 4-40	7/10	
10/6 11pm 11	19.9	42.14	the same	7/10	
11/6 11pm 12	17.6	42.14	the same 2-40	7/10	43.57
12/6 11pm 13	15.7	43.57	5-45	7/10	
13/6 11pm 14	13.1	45.00	7-45		

PH 9 Chia Seed — survive

30/5 11pm 0	40.6		0		
31/5 11pm 1	39.0		0		increase in size
1/6 11pm 2	37.0		0		
2/6 11pm 3	36.1		3	1/10	
3/6 11pm 4	33.6		4 (root) 1-4 (stem)	3/10	
5/6 11pm 5	31.9			8/10	
5/6 11pm 6	30.2	4.38	1-13 3-2 4-4	8/10	
6/6 11pm 7	28.3	9.14	1-18 2-2 2-13 2-6	7/10	
7/6 11pm 8	26.3	22.71	1-40 1-20 1-12 2-35 1-15 1-2	7/10	
8/6 11pm 9	23.9	27.42	1-40 2-30 1-2 2-35 1-20	7/10	
9/6 11pm 10	21.6	32.43	1-45 2-30 3-40 1-2	7/10	
10/6 11pm 11	19.9	32.43	the same	7/10	[illegible]
11/6 11pm 12	17.6	33.14	1-45 1-35 1-2 3-40 1-30	7/10	
12/6 11pm 13	15.4	35.29	2-50 1-35 1-2 2-40 1-30	7/10	35.29
13/6 11pm 14	13.3	36.86	2-53 2-40 2-35 1-2	7/10	



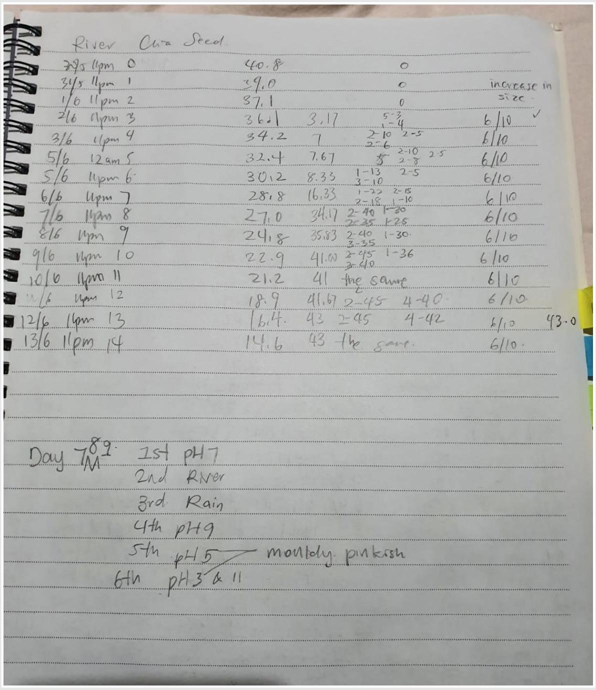
PH 11 Chia Seed — dead

30/5 11pm 0	40.7	0	
31/5 11pm 1	38.9	0	increase in size
1/6 11pm 2	37.1	0	
2/6 11pm 3	36.1	0	
3/6 11pm 4	34.2	0	
5/6 12am 5	32.9	0	
5/6 11pm 6	30.7	0	
6/6 11pm 7	28.8	0	
7/6 11pm 8	26.4	0	
8/6 11pm 9	24.1	0	
9/6 11pm 10	21.8	0	
10/6 11pm 11	20.2	0	
11/6 11pm 12	17.3	0	
12/6 11pm 13	15.1	0	
13/6 11pm 14	13.3	0	

* Alkaline group no mould but only acidic have mould

Rain Chia Seed

30/5 11pm 0	40.7		0		
31/5 11pm 1	39.4		0		increase in size
1/6 11pm 2	37.5		0		
2/6 11pm 3	36.1	3.67	1-5 2-3	3/10	
3/6 11pm 4	34.6	8.40	2-12 3-6	5/10	invisible
5/6 12am 5	33.3	5.00	4-5	5/10	
5/6 11pm 6	31.1	9.00	1-14 1-10 1-1 1-13 1-7	5/10	
6/6 11pm 7	29.6	14.4	1-20 1-15 1-8 2-18	5/10	
7/6 11pm 8	27.4	23.33	2-35 1-4 2-30 1-6	6/10 ✓	
8/6 11pm 9	25.3	24.33	3-35 1-6 1-30 1-5	6/10	
9/6 11pm 10	22.9	27.83	1-45 2-35 1-40 2-6	6/10	
10/6 11pm 11	21.0	30.83	1-45 2-40 3-40	6/10	
11/6 11pm 12	18.6	31.83	1-46 1-15 3-40 1-11	6/10	
12/6 11pm 13	16.4	34	2-45 1-40 1-42 2-16	6/10	34.0
13/6 11pm 14	14.4	36	2-43 2-45 2-20	6/10	



River Chia Seed

30/5 11pm 0	40.8		0		
31/5 11pm 1	39.0		0		increase in size
1/6 11pm 2	37.1		0		
2/6 11pm 3	36.1	3.17	5-3 1-4	6/10 ✓	
3/6 11pm 4	34.2	7	2-10 2-5 2-6	6/10	
5/6 12am 5	32.4	7.67	5 2-10 2-8 2-5	6/10	
5/6 11pm 6	30.2	8.33	1-13 2-5 3-10	6/10	
6/6 11pm 7	28.8	16.33	1-22 2-15 2-18 1-10	6/10	
7/6 11pm 8	27.0	34.17	2-40 1-30 2-35 1-26	6/10	
8/6 11pm 9	24.8	35.83	2-40 1-30 3-35	6/10	
9/6 11pm 10	22.9	41.00	2-45 1-36 3-40	6/10	
10/6 11pm 11	21.2	41	the same	6/10	
11/6 11pm 12	18.9	41.67	2-45 4-40	6/10	
12/6 11pm 13	16.4	43	2-45 4-42	6/10	43.0
13/6 11pm 14	14.6	43	the same	6/10	

Day 7 8 9 M

1st pH7

2nd River

3rd Rain

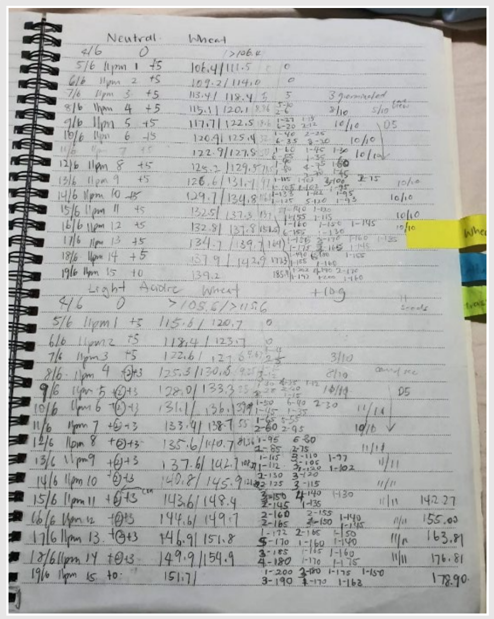
4th pH9

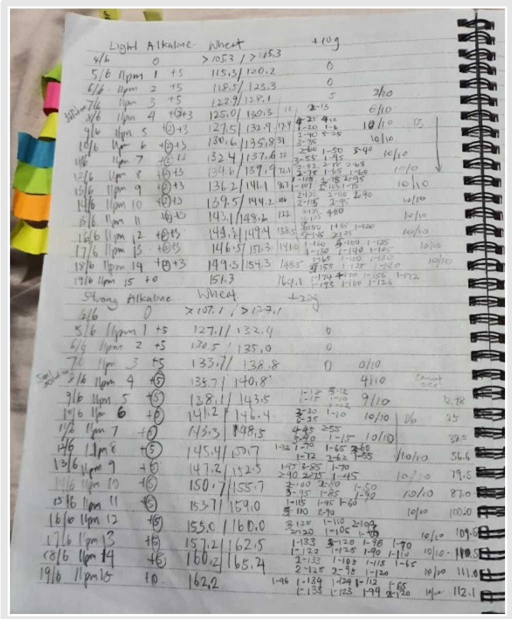
5th pH5 — mouldy pinkish

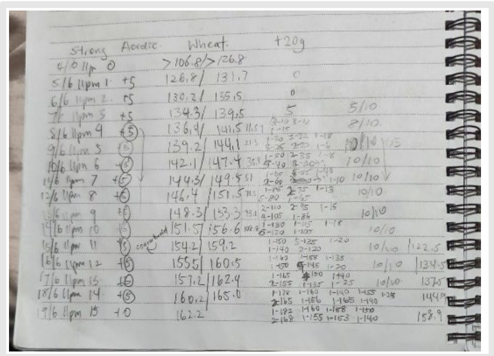
6th pH3 & 11

Results: Experiment 1b.

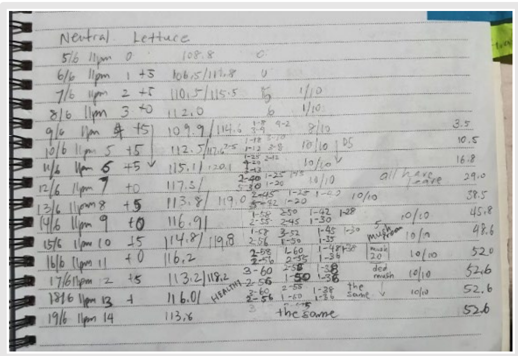
Wheat:

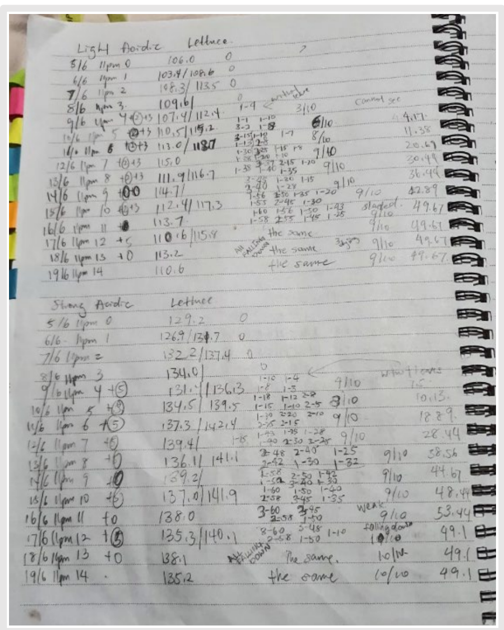


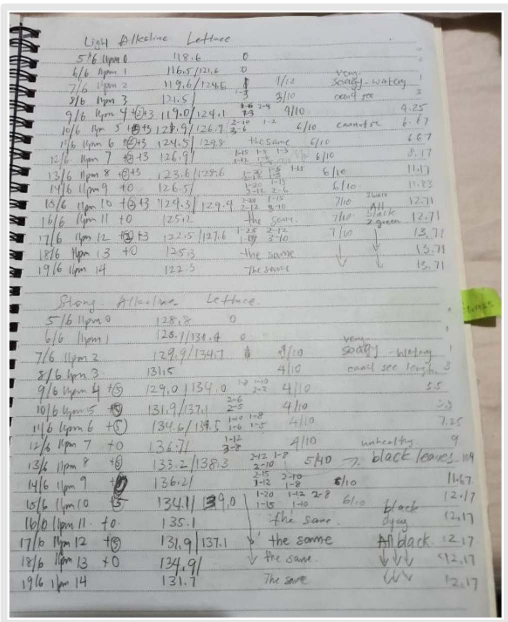




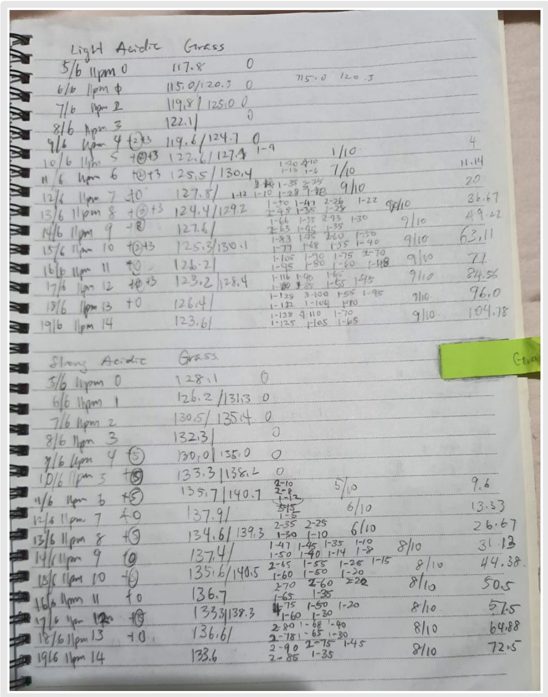
Lettuce:







Grass:

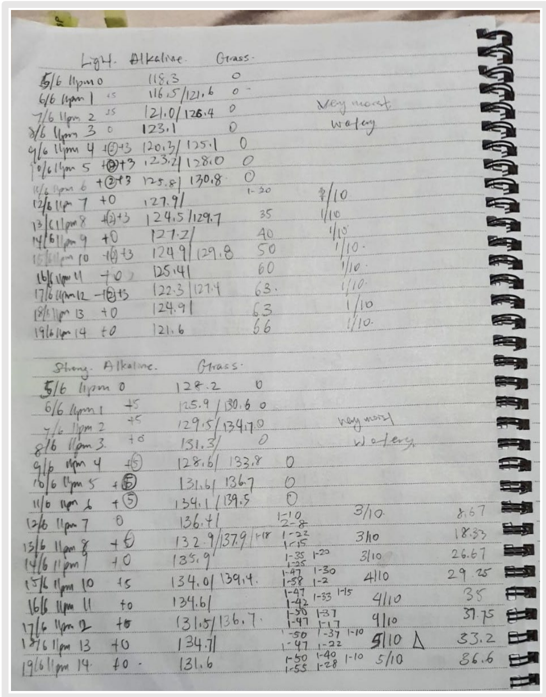


Light Acidic Grass

5/6 11pm 0		117.8	0		
6/6 11pm 1		115.0/120.3	0	115.0 120.3	
7/6 11pm 2		119.8/125.0	0		
8/6 11pm 3		122.1/	0		
9/6 11pm 4	+(2)+3	119.6/124.7	0		
10/6 11pm 5	+(2)+3	122.6/127.4	1-4	1/10	4
11/6 11pm 6	+(2)+3	125.5/130.4		7/10	11.14
12/6 11pm 7	+0	127.8/		9/10	20
13/6 11pm 8	+(2)+3	124.4/129.2		9/10	36.67
14/6 11pm 9	+(2)	127.6/		9/10	49.22
15/6 11pm 10	+(2)+3	125.3/130.1		9/10	63.11
16/6 11pm 11	+0	126.2/		9/10	72
17/6 11pm 12	+(2)+3	123.2/128.4		9/10	84.56
18/6 11pm 13	+0	126.4/		9/10	96.0
19/6 11pm 14		123.6/		9/10	104.78

Strong Acidic Grass

5/6 11pm 0		128.1	0		
6/6 11pm 1		126.2/131.3	0		
7/6 11pm 2		130.5/135.4	0		
8/6 11pm 3		132.3/	0		
9/6 11pm 4	(5)	130.0/135.0	0		
10/6 11pm 5	+(5)	133.3/138.2	0		
11/6 11pm 6	+(5)	135.7/140.7	2-10 2-8	5/10	9.6
12/6 11pm 7	+0	137.9/		6/10	13.33
13/6 11pm 8	+(5)	134.6/139.3	2-35 2-25 1-30 1-10	6/10	26.67
14/6 11pm 9	+(0)	137.4/	1-47 1-45 1-35 1-10 1-50 1-40 1-14 1-8	8/10	31.13
15/6 11pm 10	+(5)	135.6/140.5	2-65 1-55 1-25 1-15 1-60 1-50 1-20	8/10	44.38
16/6 11pm 11	+0	136.7	2-70 2-60 2-20 1-65 1-35	8/10	50.5
17/6 11pm 12	+(5)	133.3/138.3	4-75 1-50 1-20 1-60 1-30	8/10	57.5
18/6 11pm 13	+0	136.6/	2-80 1-68 1-40 2-78 1-65 1-30	8/10	64.88
19/6 11pm 14		133.6	2-90 2-75 1-45 2-85 1-35	8/10	72.5

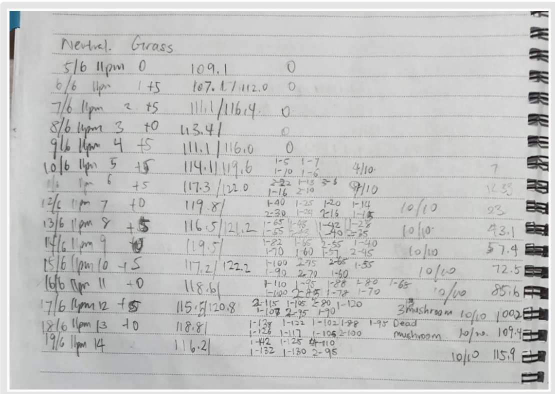


Light Alkaline Grass

5/6 11pm 0		118.3	0		
6/6 11pm 1	+5	116.5/121.6	0		
7/6 11pm 2	+5	121.0/126.4	0	Very moist watery	
8/6 11pm 3	0	123.1	0		
9/6 11pm 4	+(2)+3	120.3/125.1	0		
10/6 11pm 5	+(2)+3	123.2/128.0	0		
11/6 11pm 6	+(2)+3	125.8/130.8	0		
12/6 11pm 7	+0	127.9/	1-30	1/10	
13/6 11pm 8	+(2)+3	124.5/129.7	35	1/10	
14/6 11pm 9	+0	127.2/	40	1/10	
15/6 11pm 10	+(2)+3	124.9/129.8	50	1/10	
16/6 11pm 11	+0	125.4/	60	1/10	
17/6 11pm 12	+(2)+3	122.3/127.4	63	1/10	
18/6 11pm 13	+0	124.9/	63	1/10	
19/6 11pm 14	+0	121.6	66	1/10	

Strong Alkaline Grass

5/6 11pm 0		128.2	0		
6/6 11pm 1	+5	125.9/130.6	0		
7/6 11pm 2	+5	129.5/134.7	0	very moist watery	
8/6 11pm 3	+0	131.3/	0		
9/6 11pm 4	+(5)	128.6/133.8	0		
10/6 11pm 5	+(5)	131.6/136.7	0		
11/6 11pm 6	+(5)	134.1/139.5	0		
12/6 11pm 7	0	136.4/	1-10 2-8	3/10	8.67
13/6 11pm 8	+(5)	132.9/137.9	1-18 1-22 1-15	3/10	18.33
14/6 11pm 9	+0	135.9	1-35 1-20 1-25	3/10	26.67
15/6 11pm 10	+5	134.0/139.4	1-47 1-30 1-58 1-2	4/10	29.25
16/6 11pm 11	+0	134.6/	1-47 1-33 1-15 1-42	4/10	35
17/6 11pm 12	+5	131.5/136.7	1-50 1-37 1-47 1-17	4/10	37.75
18/6 11pm 13	+0	134.7/	1-50 1-37 1-10 1-47 1-22	5/10 △	33.2
19/6 11pm 14	+0	131.6	1-50 1-40 1-10 1-55 1-28	5/10	86.6



Neutral. Grass

5/6 11pm 0		109.1	0			
6/6 11pm 1	+5	107.1/112.0	0			
7/6 11pm 2	+5	111.1/116.4	0			
8/6 11pm 3	+0	113.4/	0			
9/6 11pm 4	+5	111.1/116.0	0			
10/6 11pm 5	+5	114.1/119.6	1-5 1-7 1-10 1-6		4/10	7
11/6 11pm 6	+5	117.3/122.0	2-22 1-13 3-6 1-16 2-10		9/10	12.33
12/6 11pm 7	+0	119.8/	1-40 1-25 1-20 1-14 2-30 1-24 2-16 1-15		10/10	23
13/6 11pm 8	+5	116.5/121.2	1-65 1-48 1-42 1-28 1-55 2-43 1-40 2-35		10/10	43.1
14/6 11pm 9	+0	119.5/	1-82 1-65 2-55 1-40 1-70 1-60 1-57 2-45		10/10	57.4
15/6 11pm 10	+5	117.2/122.2	1-100 2-75 2-65 1-55 1-90 2-70 1-60		10/10	72.5
16/6 11pm 11	+0	118.6/	1-110 1-95 1-88 1-80 1-65 1-100 2-85 1-78 1-70		10/10	85.6
17/6 11pm 12	+5	115.[illegible]/120.8	2-115 1-105 2-80 1-120 1-107 2-95 1-90	3 mushroom	10/10	100.2
18/6 11pm 13	+0	118.8/	1-138 1-122 1-102 1-88 1-95 1-126 1-117 1-105 2-100	Dead mushroom	10/10	109.4
19/6 11pm 14		116.2/	1-142 1-125 4-110 1-132 1-130 2-95		10/10	115.9

Observations:

Mung bean

Epigeal germination occurs.

9/6/23

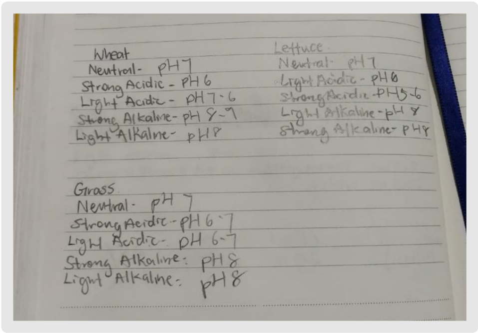
Borrowed garden pH meter from teacher.

10/6/23 – 21/6/2023

Working on report.

22/6/2023

Measuring soil pH on day 15 with lab assistance.



Procedure:

1. A decent amount of each type of soil was placed on different watch glasses using a spoon. The spoon was rinsed between intervals so that soil did not contaminate each other.
2. A decent amount of universal indicator was placed on each soil samples on the watch glasses.
3. Barium sulphate was placed on each soil sample.
4. The pH of each soil samples was indicated using a pH colour tool.

Results:

Wheat	**pH**
Strong Acidic	6
Light Acidic	6.5
Neutral	7
Light Alkaline	8
Strong Alkaline	8.5

Lettuce	**pH**
Strong Acidic	5.5
Light Acidic	6
Neutral	7
Light Alkaline	7.5
Strong Alkaline	8

Grass	**pH**
Strong Acidic	6
Light Acidic	6.5
Neutral	7
Light Alkaline	7.5
Strong Alkaline	8

Conclusion:

1. If the pH level of the solution is near neutral (pH 7 ± 10%), the germination of seeds will occur and the growth rate in plants will be the greatest.
2. if the amount of water given to the soil is below or above the optimum amount of water, the germination of the plant will be negatively impacted, and its growth rate will decrease.
3. Climate change affects soil pH and water level, and hence affect seed germination and growth. As a result, our food production and security will be affected.
4. Sustainable agricultural practices for soil management are crucial for optimum plant growth to maximise food yield for our society.

23/6/2023 - 30/6/2023

Working and finishing report and journal.

Submit:

1. Cover sheet
2. Risk assessment form
3. Scientific Journal
4. Scientific Report

🚀 Mission completed! 🥳