Budding Solution:

The Nanobubble Effect

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Title: Budding Solution: The Nanobubble Effect

Question: Do varying levels of oxygen in water impact the growth of plants?

Hypothesis: "If I grow cress plants with tap water, 50% oxygen nanobubbles, or 100% oxygen nanobubbles, then the oxygen nanobubble-fed cress will have a longer root length and height than cress watered with tap water because oxygen is a crucial part of respiration—a part of a plant's metabolic process."

Background Research:

1.0 Introduction:

Nanobubbles are nanosized bubbles that are created through specific processes for specific reasons. This research focuses on creating and using Oxygen (O2) Nanobubbles. Exploring the impacts of Nanobubbles provides an understanding of its impacts and benefits to society. This includes how it works to eliminate water contamination and increase plant growth. The process in which plants exchange gasses, the chemistry and biology of nanobubbles, and plant interaction reveal the interaction of nanobubbles in agriculture. Although nanobubbles have been around since about 2010, institutions have only been conducting actual research since 2018. As part of the research, a review of fertilizer, how it works in agriculture practices, the history of fertilizers, and how it applies to our society today. It is important to understand what Cress is, how it grows, and its use in the food industry as it is the plant used in the experiment.

2.0 Nanobubbles:

Measuring 70-120 nanometers in size, nanobubbles are 2500 times smaller than a grain of salt. Nanobubbles are tiny bubbles of gas instilled in water, usually increasing gas concentration to 90% or more, that improve specific environmental conditions. Nanobubbles can be created with any gas in the liquid, but the main elements used are oxygen-filled bubbles in water, which I will be working with. Nanobubbles have many applications, including antiseptic abilities, with many applications inside that broad term, such as water treatment and removing unwanted buildup in wet environments. (SWAT Water Tech, n.d.)

2.1 Benefits:

The uses of superoxygenation through nanobubbles include;

- Destroy or inactivate bacteria and viruses
- Stop and lessen algae blooms
- Eliminate compounds that produce foul odours
- Degrade water contaminants
- Removes:
- Oil
- Fine Particles
- Colloids
- Solids
- Surfactants
- Fats and grease
- Prevention of biofilm growth in water
- Scale prevention
- Providing more oxygen in deprived underwater ecosystems

- Increases yield, growth rate, and size of crops/plants with no effect on taste (SWAT Water Tech. n.d.).
- Plant growth in space (Grooms, 2020)

2.2 Nanobubble technology in research settings and the business economy:

Nanobubble service is scarce, and only two companies in North America deal in nanobubbles, one in Canada and one in the United States. There are two main models for super-oxygenation: land-based and submersible. The two companies offer multiple versions, but they all have similar attributes, such as remote monitoring, choices of gas input, and flow-rate control (SWAT Water Tech, n.d.) (Moleaer, 2024).

The expansion and development of nanobubble technology are emerging scientific topics in universities, and research is starting worldwide. As an emerging field, the few research teams working in this field focus on production efficiency, nanobubble measurement, and scalability.

2.3 Unique Properties of Nanobubbles:

Its unique properties include its ability to survive in pHs far from the Isoelectric point. This increases stability and neutral buoyancy, allowing the nanobubble to stay in the water without floating to the top and dissipating. Nanobubbles also release hydroxyl radicals, which are natural oxidizers (ScienceDirect Topics, 2024).

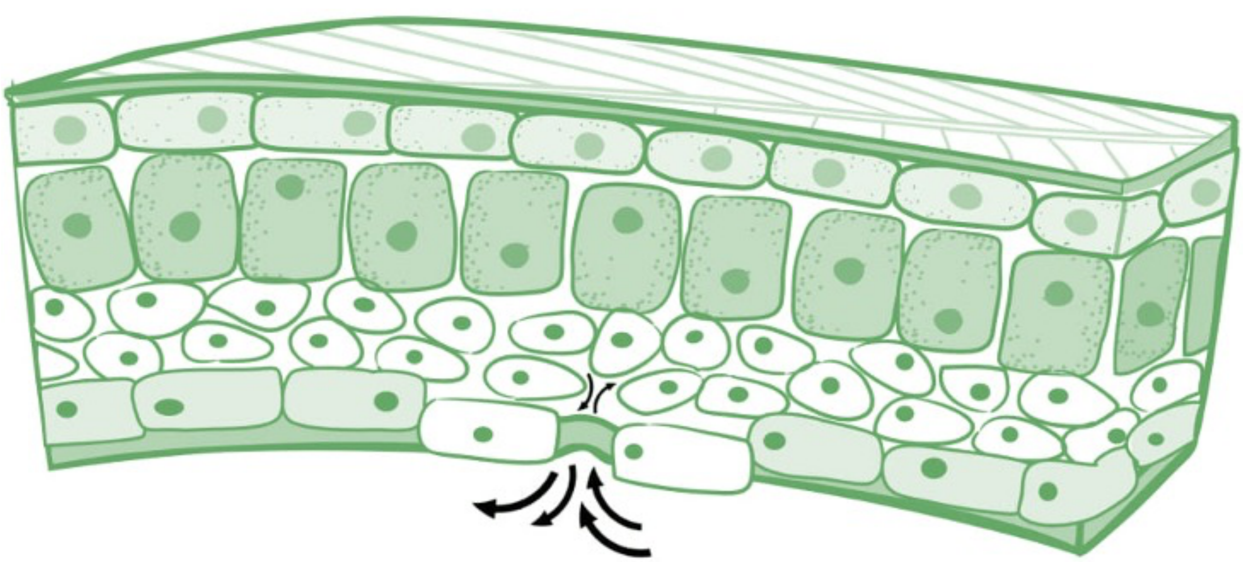
2.4 How it works:

2.4.1 Water contamination:

When stimulated, nanobubbles become unstable and implode, releasing a hydroxyl radical. The hydroxyl radical is one of the most effective natural oxidizers and kills bacteria. The contaminants are attracted to oxygen, then destroyed when the nanobubble implodes. It is very reactive and breaks apart most organic compounds (ScienceDirect Topics, 2024).

2.4.2 Agriculture:

Although plants do not have areas specified for exchanging gases, like lungs, they still breathe. Plants exchange gases in three places: leaves, stems, and roots. The most commonly known process is photosynthesis, in which CO2 from the atmosphere is processed by leaf and stem cells using solar energy to create sugar (C6H12O6). In leaves (and soft green stems), gases enter and exit through stomata, thousands of tiny pores found on the underside of most leaves. Stomata is also used to control water conservation through transpiration. A chemical signal from the roots to the leaves enables specialized cells, known as guard cells, to seal the pores and prevent water vapour from escaping when the roots sense the soil is dry. The bark is impermeable to gases in woody stems, so it is perforated by lenticels to exchange gases (Royal Horticultural Society, 2024).



(Image retrieved from Royal Horticultural Society, 2024).

Conversely, respiration is the opposite process used by root cells. During respiration, plant roots absorb air, hence absorbing oxygen that breaks down simple sugars into carbon dioxide and water and releases energy in the form of ATP (Adenosine triphosphate), 'the source of energy for use and storage at the cellular level'. (Oak Ridge Institute for Science and Education, 2023)

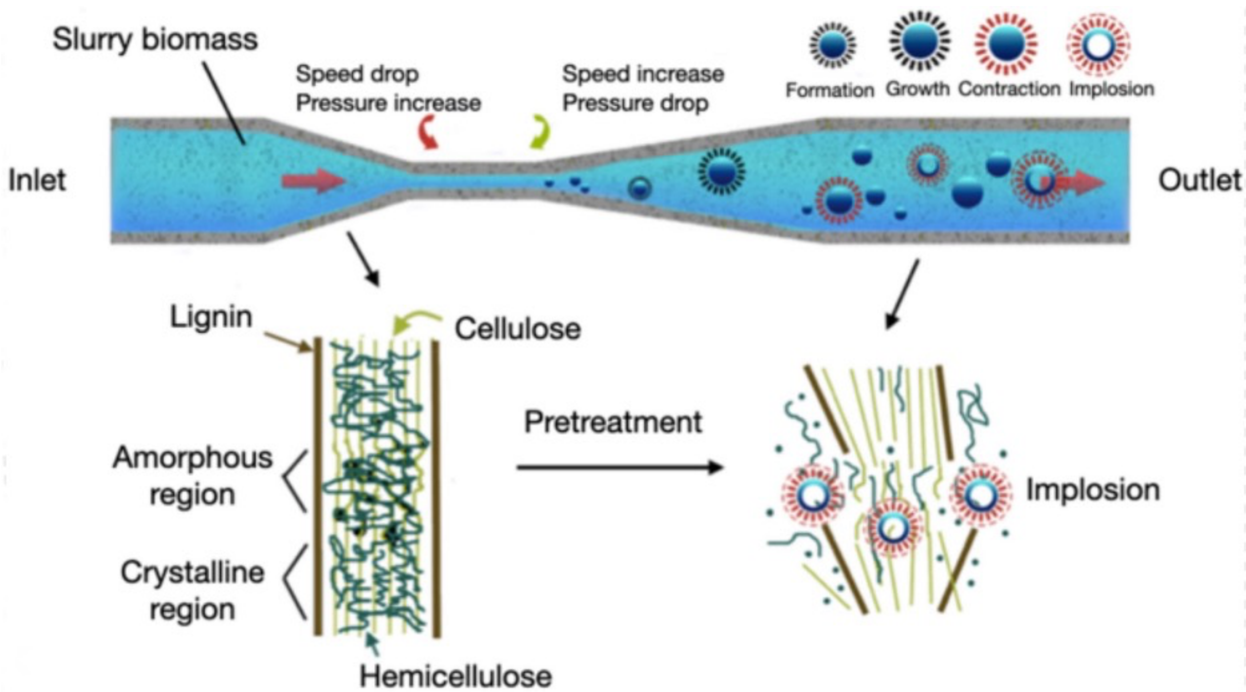
When nanobubble water is applied, plants have access to more oxygen, speeding up the respiration process. As these processes are connected, the overall health of plants is improved. When the respiration process is improved, root length increases, meaning the plant has more area to take in and process nutrients, further improving the health of the plant. Using nanobubble water also makes plants less likely to be overwatered, as they cannot drown. One study found that cucumber plants watered with nanobubbles grew 15% faster and had a 90% yield increase.

2.5 How nanobubbles are made:

There are four main ways nanobubbles are made: hydrodynamic cavitation, ultrasonic cavitation, electrolysis, and electric field assisted.

2.5.1 Hydrodynamic cavitation:

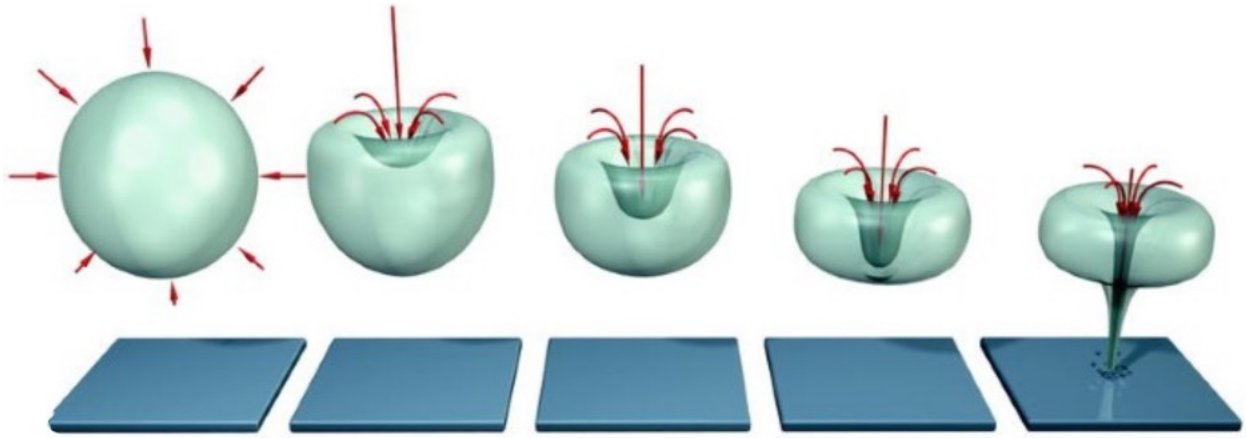
The local pressure inside the fluid drops dramatically during hydrodynamic cavitation, falling below the saturated vapour pressure of this state. The gas dissolves in the water to be separated out, causing cavitation bubbles to form and expand. As the fluid flows, the local pressure stabilizes, and the cavitation bubbles burst, causing the temperature and pressure to rise quickly. Speed cameras can record the cavitation bubble as it forms. This form of nanobubble formation is most effective for wastewater treatment, as the bubbles burst immediately, unlike plant growth. (Bimestre et al., 2022)



(Image retrieved from Bimestre et al., 2022)

2.5.2 Ultrasonic cavitation:

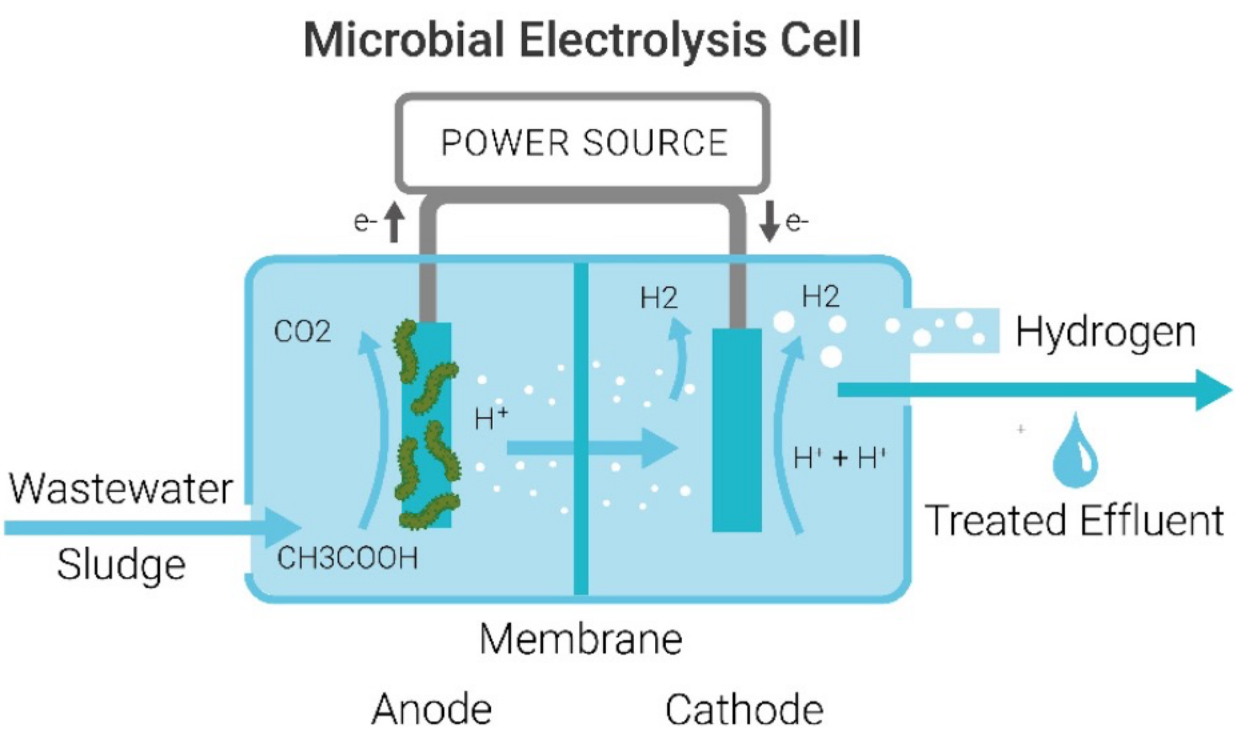
In fluid, mechanical vibration is produced by intense ultrasonic waves. Ultrasonic waves extrude the fluid molecules during the positive pressure phase, causing the molecules to collect. However, the fluid molecules experience the separation effect during the negative pressure phase, which causes the molecules to become distinct. Consequently, cavitation bubbles occur during the negative pressure stage when the average distance between liquid molecules exceeds the maximum distance when ultrasonic intensity reaches a specific threshold. Cavitation bubbles cannot exist if they escape negative pressure. Ultrasonic cavitation is the result of cavitation bubbles collapsing due to fluid pressure. (Song, Y. et al., 2022)



(Image retrieved from Barichard, T., 2012)

2.5.3 Electrolysis:

In electrolysis, the flow of ions required to run an otherwise non-spontaneous reaction is stimulated by sending an electric current through an electrolyte and into a solution (Postnikov et al., 2018). Gas bubbles are created on the electrode surface using the electrolysis process, and they gradually grow, separate, and float. (Song, K., 2023).



(Image retrieved from Fudge et al., 2021)

2.5.4 Electric field assisted:

Research has shown that low-power electric fields can produce bulk nanobubbles. When a low-energy, continuous direct current electric field is activated in water, the concentration of gas molecules in the solution increases significantly. Nanobubbles form as a result of the pressure drop caused by the increase in gas molecules (Jenzeh, S., n.d.). The oxygen nanobubbles used in this experiment were created using electric fields.

3.0 Fertilizer:

3.1 What it is:

Fertilizer is food for plants and provides the nutrients they need. Farmers use fertilizers on their crops to produce higher yields and better-quality products (Fertilizer Canada, 2020).

Fertilizers can come in many forms, including liquid, powder, and granular (All Green Pest Control And Lawn Care, n.d.).

3.2 How it works:

Plants require seventeen nutrients to grow, the four main nutrients being phosphorus, nitrogen, potassium, and sulphur (Fertilizer Canada, 2020).

3.2.1 Phosphorus

Phosphorous is essential for all life forms, is found in all living cells and concentrated in teeth and bones. Phosphorus is used in fertilizer from phosphate rock, primarily found in the US, North Africa, and China. (Fertilizer Canada, 2020).

3.2.2 Nitrogen

A significant portion of our air, is insoluble and inert, making it unsuitable for plants. To create fertilizer, nitrogen is removed from the air and combined with hydrogen, producing ammonia. Ammonia is used as a nitrogen fertilizer or a building block for other nitrogen fertilizer products. The products have varying properties and levels, which are effective for different climates and cropping patterns. (Fertilizer Canada, 2020).

3.2.3 Potassium

Potassium is found in our bodies, is essential for good health. Plants obtain it from potash fertilizers. Potash is mined from seawater-evaporated ore bodies, forming a mixture of potassium chloride and sodium chloride. The potassium chloride is separated and results in a granular fertilizer. Most potash deposits are located in Canada, Russia, Belarus, Germany, and the US. (Fertilizer Canada, 2020).

3.24 Sulphur

Sulphur is crucial for protein production through amino acid production and colour in crops like onion, mustard, and radishes. It is found naturally in soil but only sometimes in the form plants can use. (Fertilizer Canada, 2020). The soil is depleted of these nutrients after every growing season. Fertilizers supply the nutrients so your plants or crops will grow next harvest (Fertilizer Canada, 2020).

3.3 History of Fertilizer:

Fertilizer is now integral in modern farming; however, traditional fertilizer practices date back to 8,000 years ago, with the concept of fertilizer dating back 2,000 to 3,000 years. Researchers have found evidence of earlier fertilizer use in ancient times - manure. Manure would also be the most logical natural fertilizer due to its higher concentration of the nitrogen-15 isotope (N-15). Early farmers likely noticed enhanced crop growth in areas of dung accumulation where animals gathered, as farmers would have seen differences in productivity between their plots. Later, the Babylonians, Egyptians, Romans, and early Germans all used minerals or manure to increase yields on their farms. Still, manure was the prominent fertilizer source for the next few thousand years. (CropWatch, 2019)

Mycorrhizae Soil : What does mycorrhizae soil do? It permits the plant to obtain additional moisture and nutrients. This is particularly important in phosphorus uptake, one of the significant nutrients plants require. When mycorrhizae are present, plants are less susceptible to water stress.

3.4 Applications:

Fertilizers are essential to sustainable food production in Canada to feed our growing population. They also help reduce greenhouse gas emissions of nitrous oxide by allowing farmers to use nitrogen inside fertilizers. The fertilizer industry itself employs over 76,000 people directly in Canada, affecting food production industries and railroads. The industry also contributes twenty-three billion dollars to the Canadian economy, and domestic farm gate sales are about 4.2 billion a year (Fertilizer Canada, 2020).

4.0 Cress:

4.1 What it is:

The scientific name for garden cress is Lepidium sativum; Lepidium is derived from the Greek lepidion, which means "a little scale," referring to the fruit pods' form.

The Latin word "satum," from which the species name "sativum" is derived, means "that which is sown," suggesting that the plant is cultivated and grown for food (Seedaholic, 2023). Cress belongs to the Brassicaceae family and is a fast-growing herb. It grows in many places, including Africa, Northern and Southern America, Europe, Asia, and Australasia. (Hekmatshoar et al., 2022)

4.2 Use in Society:

Human Consumption: Cress has many medicinal uses, including lowering blood sugar and blood pressure. Large amounts of Cress can also decrease the amount of potassium in the body. Cress also slows blood clotting and increases the effects of Phenytoin, a drug used to prevent, control, and treat seizures. (WebMD, n.d.).

Cress also has some adverse effects. The above-ground parts of Cress are not proven to be safe for medicinal treatment yet and should be used with caution- especially if pregnant or breastfeeding. Cress can also increase the risk of bleeding and lower potassium levels- which could be harmful if you have a potassium deficiency. (WebMD, n.d.).

4.3 Growth stages:

The germination period for Cress is between 48 and 72 hours (two to three days) at a temperature of roughly 15-20°C. The young Cress is ready to be harvested when it reaches a height of around 2-3 inches (5-7 cm). The cress plant typically takes ten to fifteen days to reach a height of three inches. (Blackwood, 2022)

5.0 Summary:

Nanobubbles are 70-120 nanometers and can be made of any gas. Nanobubbles have many uses, including water treatment and improving plant growth. There are two types of nanobubble units, Land-based and submersible, and nanobubbles have many unique properties. Nanobubbles decontaminate water through hydroxyl radicals and increase plant growth through respiration. Moleaer Inc. (USA) and SWAT Water Tech. (Canada) are the leading nanobubble technology companies and are available for consultation.

Fertilizer is food for plants and provides the nutrients they need. Plants need seventeen different nutrients to grow; the four primary nutrients are potassium, sulphur, nitrogen, and phosphorus. Fertilizer, a natural resource, has been used since ancient times as manure. Farmers likely observed increased crop growth in dung accumulation areas where animals gathered. Fertilizers in Canada are crucial for sustainable food production, reducing greenhouse gas emissions, and employing over 76,000 people, contributing $23 billion to the Canadian economy.

Garden cress, scientifically Lepidium sativum, is a fast-growing herb found in various parts of the world, including Africa, Northern America, Europe, Asia, and Australasia. Cress has medicinal uses, including lowering blood sugar, blood pressure, and potassium levels. It slows blood clotting and enhances Phenytoin's effects. However, above-ground parts are not safe for medicinal use, increasing bleeding and potassium deficiency risks. Cress germination takes 48-

72 hours at 15-20°C, reaching 2-3 inches in height. Harvesting takes ten to fifteen days, with young plants reaching a possible 3-inch height within ten days.

Materials:

- Three Medium Pots
- Tap Water
- Oxygen Nanobubbles
- Miracle Grow Organic Fertilizer
- Grow Lights (Full Spectrum LED) (6400 Kelvin)
- Measuring Cup
- Cress Seeds
- Pencil
- Table
- Log Book
- Camera
- Data Table
- Mycorraizae Soil (Ingredients: Soy Protein Hydrolysate, Bone Meal, Sunflower Hull Ash, and Potassium Sulphate.)
- Glass Beads
- Water Drainage Trays
- Three Labels
- Ruler

Variables:

Manipulated variables: type of liquid used to water the Cress seed (tap water, 50% tap water/50% oxygen nanobubbles, and 100% oxygen nanobubble).

Responding variables: plant height, root length.

Controlled variables: grow lights, water volume, method of watering, growth pot and soil, time of watering, time of planting, environment, type of fertilizer, oxygen nanobubbles, tap water, glass beads, and ruler.

Procedure:

1. Label Pots
    a. Label the first pot 'A: Tap Water'
    b. Label the second pot 'B: 50% Nanobubble- 50% Tap Water'
    c. Label the third pot 'C: Nanobubbles'
2. Set up growing environment (recommended time 8:00 pm)
    a. Add 40.5 ml of fertilizer to 90 ml of tap water
    b. Shake until the fertilizer is dissolved
    c. Combine 90ml fertilizer mixture with 180g of soil in a large container
    d. Mix until all soil is damp
    e. Weigh 125g of glass beads and pour them into Pot A
    f. Weigh 125g of glass beads and pour them into Pot B
    g. Weigh 125g of glass beads and pour them into Pot C
    h. Weigh 60g of soil and fill Pot A
    i. Weigh 60g of soil and fill Pot B
    j. Weigh 60g of soil and fill Pot C
    k. Place pots into water drainage trays

l. Place seeds on the soil
    i. Spread 15 seeds evenly in each pot
m. Cover pots with a paper towel(no light) for 12 hours
n. After twelve hours, place pots under grow lights so they receive an equal amount of light
o. Set up grow lights for 16 hours lights on, 8 hours lights off (8:00 am - 12:00 am on, 12:00 am - 8:00 am off)

3. Day One
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot
        ii. Pot B:
            a. Measure 15 ml of tap water
            b. Pour tap water evenly around the pot
            c. Measure 15 ml nanobubble water
            d. Pour nanobubble water evenly around the pot
        iii. Pot C:
            a. Measure 30 ml of nanobubble water
            b. Pour evenly around the pot
    b. Write down any observations in the logbook
    c. Take pictures
        i. From the front of pots- even spacing from camera to pot

ii. At an above angle- even spacing from camera to pot

4. Day Two
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot
        ii. Pot B:
            a. Measure 15 ml of tap water
            b. Pour tap water evenly around the pot
            c. Measure 15 ml nanobubble water
            d. Pour nanobubble water evenly around the pot
        iii. Pot C:
            a. Measure 30 ml of nanobubble water
            b. Pour evenly around the pot
    b. Write down any observations in the logbook
    c. Take pictures
        i. From the front of pots- even spacing from camera to pot
        ii. At an above angle- even spacing from camera to pot

1. Day Three
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot

    ii. Pot B:
        a. Measure 15 ml of tap water
        b. Pour tap water evenly around the pot
        c. Measure 15 ml nanobubble water
        d. Pour nanobubble water evenly around the pot
    iii. Pot C:
        a. Measure 30ml of nanobubble water
        b. Pour evenly around the pot
  b. Write down any observations in the logbook
  c. Take pictures
    i. From the front of pots- even spacing from camera to pot
    ii. At an above angle- even spacing from camera to pot
2. Day Four
  a. Water each pot at 6:00 pm
    i. Pot A:
        a. Measure 30 ml of tap water
        b. Pour evenly around the pot
    ii. Pot B:
        a. Measure 15 ml of tap water
        b. Pour tap water evenly around the pot
        c. Measure 15 ml nanobubble water
        d. Pour nanobubble water evenly around the pot
    iii. Pot C:

            a. Measure 30ml of nanobubble water
            b. Pour evenly around the pot
    b. Write down any observations in the logbook
    c. Take pictures
        i. From the front of pots- even spacing from camera to pot
        ii. At an above angle- even spacing from camera to pot

3. Day Five
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot
        ii. Pot B:
            a. Measure 15 ml of tap water
            b. Pour tap water evenly around the pot
            c. Measure 15 ml nanobubble water
            d. Pour nanobubble water evenly around the pot
        iii. Pot C:
            a. Mesure 30ml of nanobubble water
            b. Pour evenly around the pot
    b. Write down any observations in the logbook
    c. Take pictures
        i. From the front of pots- even spacing from camera to pot
        ii. At an above angle- even spacing from camera to pot

4. Day Six
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot
        ii. Pot B:
            a. Measure 15 ml of tap water
            b. Pour tap water evenly around the pot
            c. Measure 15 ml nanobubble water
            d. Pour nanobubble water evenly around the pot
        iii. Pot C:
            a. Measure 30ml of nanobubble water
            b. Pour evenly around the pot
    b. Write down any observations in the logbook
    c. Take pictures
        i. From the front of pots- even spacing from camera to pot
        ii. At an above angle- even spacing from camera to pot
5. Day Seven
    a. Water each pot at 6:00 pm
        i. Pot A:
            a. Measure 30 ml of tap water
            b. Pour evenly around the pot
        ii. Pot B:

a. Measure 15 ml of tap water

b. Pour tap water evenly around the pot

c. Measure 15 ml nanobubble water

d. Pour nanobubble water evenly around the pot

iii. Pot C:

a. Measure 30ml of nanobubble water

b. Pour evenly around the pot

b. Write down any observations in the logbook

c. Take pictures

i. From the front of pots- even spacing from camera to pot

ii. At an above angle- even spacing from camera to pot

d. Measure Cress sprout growth

i. Harvested all 15 Cress sprouts from pot A and measured above soil growth, root growth and overall sprout length.

a. Record measurements in the logbook

ii. Harvested all 15 Cress sprouts from pot B and measured above soil growth, root growth and overall sprout length.

a. Record measurements in the logbook

iii. Harvested all 15 Cress sprouts from pot C and measured above soil growth, root growth and overall sprout length.

a. Record measurements in the logbook

Observations:

Trial one

-(Feb 21st) Day one; Seeds in pots are spread evenly, no growth.

-(Feb 22nd) Day two; Seeds in pots are spread evenly, no growth.

-(Feb 23rd) Day three; Pot A, B and C sprouted.

-(Feb 24th) Day four; Pot A, B and C growth started.

-(Feb 25th) Day five; Density of plants increases with concentration nanobubbles.

-(Feb 26th) Day six; Few cress from Pot A and Pot B are curved, but still healthy. Pot C cress are straight.

-(Feb 27th) Day seven; There are a few bent but otherwise healthy cress from Pots A and B. Pot C cress is straight.

-Final observations & numbers: The average height of Pot A is 3.94cm, Pot B is 3.77cm, and Pot C is 4.63cm. The average root length of Pot A is 5.47cm, Pot B is 5.5cm, and Pot C is 7.72cm. The average total length of Pot A is 9.29cm, Pot B is 9.27cm, and Pot C is 12.36cm. Using the average total length, A is 0.21% longer than B, C is 28.36% longer than A and 28.57% longer than B.

Trial two

-(Feb 28th) Day one; No growth.

-(Mar 1st) Day two; No growth.

-(Mar 2nd) Day three; Pot A, B and C sprouted.

-(Mar 3rd) Day four; Growth in all pots.

-(Mar 4th) Day five; Growth in all pots. Pots B and C appear taller then Pot A

-(Mar 5th) Day six; Growth in all pots .

-(Mar 6th) Day seven; Growth in all pots.

-Final observations & numbers: The average height of Pot A is 2.07cm, Pot B is 3.65cm, and Pot C is 3.8cm. The average root length of Pot A is 2.21cm, Pot B is 6.11cm, and Pot C is 6.45cm. The average total length of Pot A is 4.41cm, Pot B is 9.76cm, and Pot C is 10.22cm. Using the average total length, B is 75.51% longer than A, C is 79.42% longer than A and 4.6% longer than B.

Trial three:

-(Mar 6th) Day one; No growth

-(Mar 7th) Day two; No growth

-(Mar 8th) Day three; Small sprouts in pots B and C. No growth in A.

-(Mar 9th) Day four; Plant growth started in B and C. Growth also started in A.

-(Mar 10th) Day five; Growth is more abundant.

-(Mar 11th) Day six; Growth in all pots. Density increases with concentration of nanobubble

-(Mar 12th) Day seven; Growth in all pots.

-Final observations & numbers: The average height of Pot A is 3.5cm, Pot B is 4.3cm, and Pot C is 4.77cm. The average root length of Pot A is 5.4cm, Pot B is 6.6cm, and Pot C is 7.2cm. The average total length of Pot A is 8.5cm, Pot B is 11.2cm, and Pot C is 11.95cm. Using the average total length, B is 27.41% longer than A, C is 33.74% longer than A and 6.48% longer than B.

Results:

Trial one:

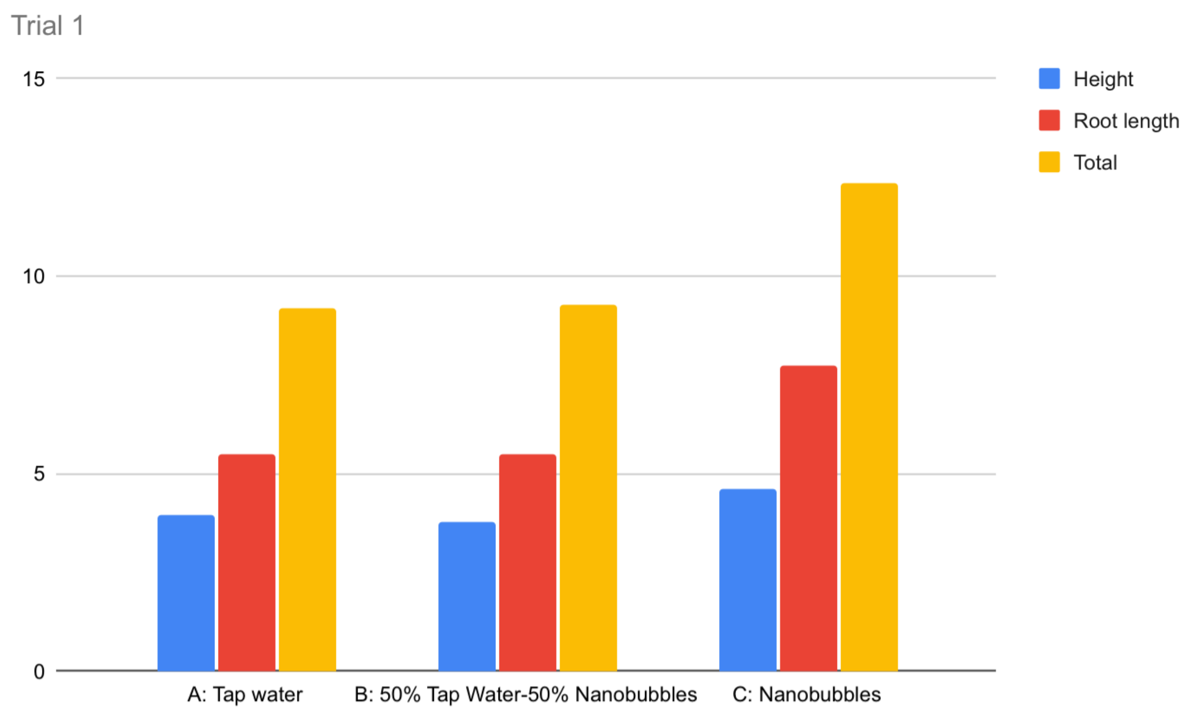
		Height	**Root Length**	**Total Length**
A: Tap Water				
	1	5.5 cm	6.1 cm	11.6 cm

	2	4.5 cm	5.3 cm	9.8 cm
	3	4.3 cm	5.7 cm	10 cm
	4	3.2 cm	7.5 cm	10.7 cm
	5	2.9 cm	5.6 cm	8.5 cm
	6	3 cm	4.8 cm	7.8 cm
	7	4.8 cm	5.9 cm	10.7 cm
	8	3.2 cm	3.3 cm	6.5 cm
	9	5.2 cm	4.2 cm	9.4 cm
	10	4.3 cm	4.8 cm	9.1 cm
	11	4.7 cm	7.5 cm	12.2 cm
	12	4.1 cm	7.2 cm	11.3 cm
	13	4 cm	7.6 cm	11.6 cm
	14	3.6 cm	6.6 cm	10.2 cm
	15	0 cm	0 cm	0 cm
	Total	**59.1 cm**	**82.1 cm**	**139.4 cm**
	Average	**3.94 cm**	**5.47 cm**	**9.29 cm**

B: 50% Tap Water-50% Nanobubbles				
	1	4.3cm	6.2cm	10.5cm
	2	3.3cm	5.1cm	8.4cm
	3	3.8cm	5.8cm	9.6cm
	4	4cm	6cm	10cm
	5	3.5cm	6.9cm	10.4cm
	6	3.8cm	5.6cm	9.4cm
	7	2.8cm	5.4cm	8.2cm
	8	3.4cm	3cm	6.4cm
	9	4.4cm	5.7cm	10.1cm
	10	3.8cm	5.9cm	9.7cm
	11	4.5cm	5.6cm	10.1cm
	12	4cm	5.5cm	9.5cm
	13	2.2cm	5cm	7.2cm
	14	4.6cm	3.4cm	8cm

	15	4.2cm	5.4cm	9.6cm
	Total	**56.6 cm**	**82.5 cm**	**139.1 cm**
	Average	**3.773 cm**	**5.5 cm**	**9.273 cm**
C: Nanobubbles				
	1	3.6cm	9.2cm	12.8cm
	2	3.9cm	3.5cm	7.4cm
	3	4.3cm	5.7cm	10cm
	4	5.1cm	9.5cm	14.6cm
	5	4.1cm	7cm	11.1cm
	6	4.2cm	10cm	14.2cm
	7	4.7cm	6.2cm	10.9cm
	8	5cm	9.5cm	14.5cm
	9	5.5cm	9.5cm	15cm
	10	4.9cm	5.9cm	10.8cm
	11	5.3cm	10.6cm	15.9cm
	12	4.2cm	9.8cm	14cm

	13	4.2cm	6.7cm	10.9cm
	14	5.4cm	5.8cm	11.2cm
	15	5.1cm	7cm	12.1cm
	Total	**69.45 cm**	**115.89 cm**	**185.4 cm**
	Average	**4.63 cm**	**7.726 cm**	**12.36 cm**



Trial two:

		Height	Root Length	Total Length
A: Tap Water				
	1	3.5cm	2.4cm	5.9cm

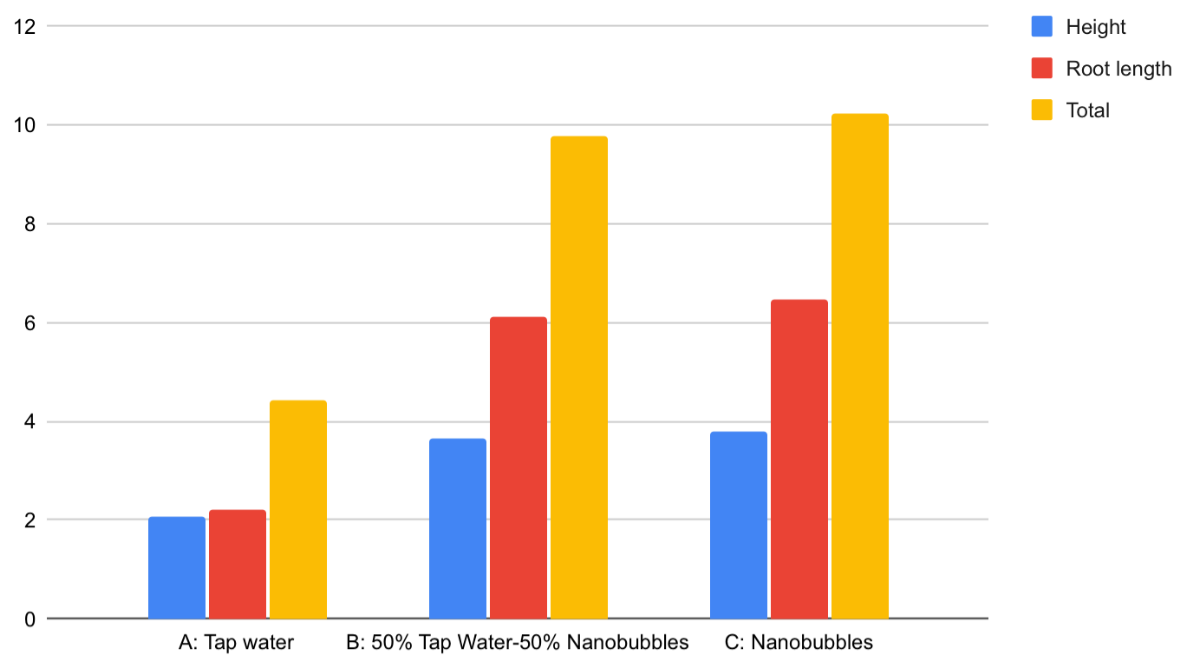
	2	3.8cm	1.1cm	4.9cm
	3	2.4cm	2.2cm	4.6cm
	4	3.2cm	3.5cm	6.7cm
	5	3.5cm	6.3cm	9.8cm
	6	3.6cm	2cm	5.6cm
	7	3cm	6cm	9cm
	8	2.8cm	6.5cm	9.3cm
	9	3.8cm	2.5cm	6.3cm
	10	1.5cm	0.6cm	2.1cm
	11	1cm	1cm	2cm
	12	0cm	0cm	0cm
	13	0cm	0cm	0cm
	14	0cm	0cm	0cm
	15	0cm	0cm	0cm
	Total	**31.09 cm**	**33.19 cm**	**66.19 cm**
	Average	**2.073 cm**	**2.213 cm**	**4.413 cm**

B: 50% Tap Water-50% Nanobubbles				
	1	3.5cm	10cm	13.5cm
	2	3.8cm	3.6cm	7.4cm
	3	3cm	7.7cm	10.7cm
	4	4cm	2cm	6cm
	5	4.1cm	7.1cm	11.2cm
	6	4.5cm	7.4cm	11.9cm
	7	3.4cm	8.3cm	11.7cm
	8	3.5cm	7.2cm	10.7cm
	9	3.8cm	8cm	11.8cm
	10	3.7cm	7.5cm	11.2cm
	11	4cm	5.6cm	9.6cm
	12	4cm	7cm	11cm
	13	3cm	1.8cm	4.8cm
	14	3cm	6cm	9cm

	15	3.5cm	2.5cm	6cm
	Total	**54.79 cm**	**91.69 cm**	**146.4 cm**
	Average	**3.653cm**	**6.113cm**	**9.76cm**
C: Nanobubbles				
	1	3.9m	10.6cm	14.5cm
	2	4.5cm	6.5cm	11cm
	3	4.7cm	7.6cm	12.3cm
	4	3.6cm	2.2cm	5.8cm
	5	4.5cm	2cm	6.5cm
	6	4.8cm	2cm	6.8cm
	7	4.1cm	6.6cm	10.7cm
	8	4.4cm	9cm	13.4cm
	9	2cm	2cm	4cm
	10	2cm	1.8cm	3.8cm
	11	3.3cm	10.5cm	13.8cm
	12	3.4cm	7.5cm	10.9cm

	13	3.9cm	9.1cm	13cm
	14	3.3m	7.5cm	10.8cm
	15	4.4cm	11.6cm	16cm
	Total	**69.45 cm**	**96.79 cm**	**153.3 cm**
	Average	**4.63cm**	**6.453cm**	**10.22cm**

Trial 2



Trial three:

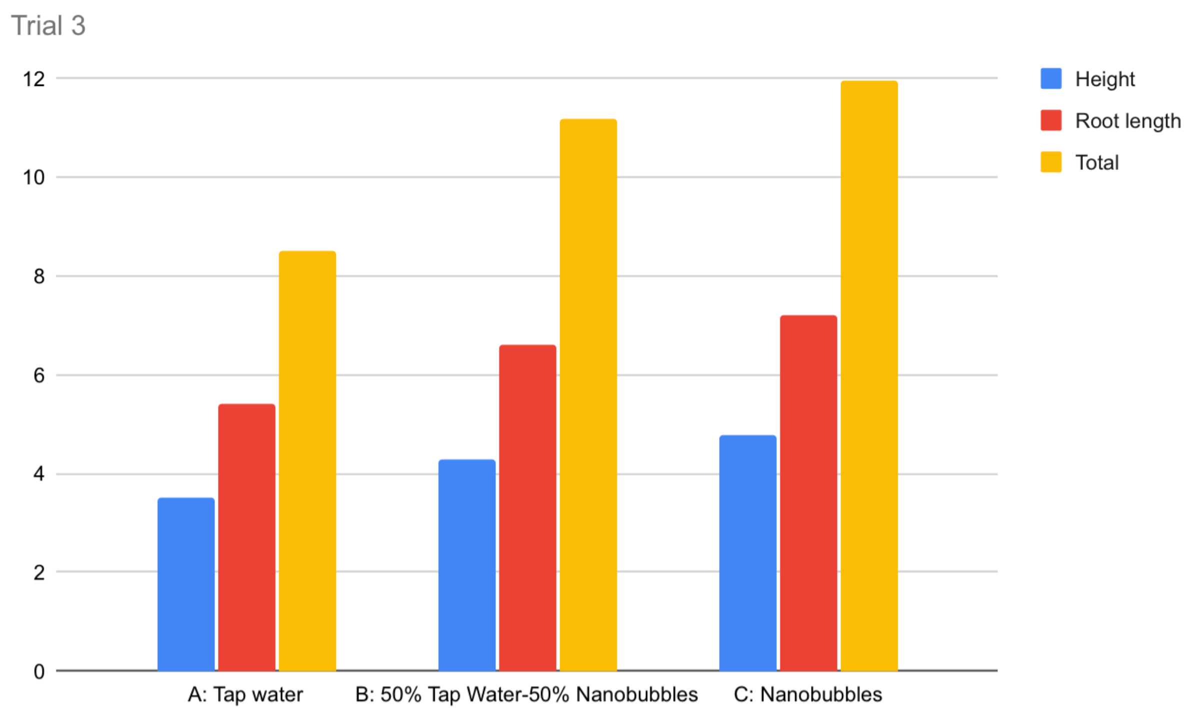
		Height	Root Length	Total Length
A: Tap Water				
	1	4.5 cm	9.7 cm	14.2 cm

	2	3.3 cm	2.5 cm	5.8 cm
	3	4.9 cm	3.3 cm	8.2 cm
	4	3.2 cm	7.3 cm	10.5 cm
	5	3.7 cm	4.2 cm	7.9 cm
	6	2.6 cm	2.9 cm	5.5 cm
	7	4.2 cm	2.8 cm	7.0 cm
	8	4.2 cm	6.1 cm	10.3 cm
	9	3.7 cm	7.0 cm	10.7 cm
	10	3.8 cm	7.5 cm	11.3 cm
	11	3.1 cm	7.1 cm	10.2 cm
	12	2.7 cm	5.2 cm	7.9 cm
	13	4.7 cm	7.0 cm	11.7 cm
	14	4.0 cm	1.7 cm	5.7 cm
	15	0 cm	0 cm	0 cm
	Total	**52.6 cm**	**81 cm**	**127.5 cm**
	Average	**3.5 cm**	**5.4 cm**	**8.5 cm**

B: 50% Tap Water-50% Nanobubbles				
	1	3.5 cm	4.0 cm	7.5 cm
	2	5.6 cm	12.5 cm	18.1 cm
	3	5.1 cm	7.5 cm	12.6 cm
	4	4.6 cm	9.8 cm	14.4 cm
	5	4.3 cm	11.6 cm	15.9 cm
	6	4.1 cm	7.6 cm	11.7 cm
	7	4.7 cm	3.6 cm	8.3 cm
	8	3.7 cm	4.7 cm	8.4 cm
	9	4.8 cm	4.6 cm	9.4 cm
	10	4.3 cm	6.6 cm	16.0 cm
	11	3.5 cm	5.8 cm	9.3 cm
	12	4.2 cm	6.3 cm	10.5 cm
	13	3.9 cm	6.5 cm	10.4 cm
	14	3.6 cm	4.8cm	8.4 cm

	15	4.2 cm	3.0 cm	7.2 cm
	Total	**64 cm**	**98.9 cm**	**168.1 cm**
	Average	**4.3 cm**	**6.6 cm**	**11.2 cm**
C: Nanobubbles				
	1	4.9 cm	7.2 cm	12.1 cm
	2	4.3 cm	7.7 cm	12 cm
	3	5.2 cm	3.9 cm	9.1 cm
	4	5.9 cm	7.7 cm	13.6 cm
	5	4.4 cm	9.6 cm	14 cm
	6	4.1 cm	5.9 cm	10 cm
	7	3.8 cm	4.2 cm	8.0 cm
	8	4.6 cm	3.1 cm	7.7 cm
	9	4.5 cm	5.1 cm	9.6 cm
	10	5.7 cm	4.6 cm	10.3 cm
	11	4.0 cm	6.2 cm	10.2 cm
	12	5.0 cm	7.5 cm	12.5 cm

	13	5.3 cm	10.6 cm	15.9 cm
	14	5.4 cm	12.7 cm	18.1 cm
	15	4.4 cm	11.7 cm	16.1 cm
	Total	**71.6 cm**	**108 cm**	**179.27 cm**
	Average	**4.77 cm**	**7.2 cm**	**11.95 cm**



Analysis:

Trial one:

-(Feb 21st) Day one; No growth, and I infer this is because the plants are still germinating since they have just been planted.

-(Feb 22nd) Day two; There is no growth, this is most likely because the plants have not germinated and have just been planted.

-(Feb 23rd) Day three: Pots A, B and C sprouted the same, this is most likely because the smaller difference in concentration does not show in the early stages of growth.

-(Feb 24th) Day four: Pot A, B and C growth started, this shows the plants are healthy.

-(Feb 25th) Day five; Density of plants increases with the concentration of nanobubbles. I infer this is due to the effect of nanobubbles, includes increasing growth rate.

-(Feb 26th) Day six: Few cress from Pot A and Pot B are curved, but still healthy. Pot C cress is straight. This is most likely because the plants should be harvested soon, but the effect of the nanobubbles on Pot C includes stronger stems.

-(Feb 27th) Day seven: There are a few bent but otherwise healthy cress from Pots A and B. Pot C cress is straight. This is probably because the plants are ready to be harvested, but Pot C benefits from the stronger stems that the nanobubbles have created. In the final numbers, using the average root length B is 0.54% longer than A, C is 34.11% longer than A and 33.58% longer than B. I surmise that this is so that the plant can absorb and utilize more water and nutrients, which will improve its overall health since the oxygen in the nanobubbles has a beneficial effect on the roots. Using the average height, A is 4.4% taller than B, C is 16.1% taller than A and 20.47% taller than B. I surmise this is due to the roots in C having greater access to oxygen via the nanobubbles—an essential component of all plants' metabolic activities, including cress. Since A is also slightly taller than B, I conclude that the energy used in the plant focused on the roots rather than the stem, as the roots in B were higher than A. Using the average total length, A is 0.21% longer than B, C is 28.36% longer than A and 28.57% longer than B. This is most likely caused by the soil's increased oxygen content (due to the nanobubbles), which supports the plant's general health through respiration.

Trial two:

-(Feb 28th) Day one: There is no growth; this is most likely because the plants have not germinated and have just been planted.

-(Mar 1st) Day two: No growth, and I infer this is because the plants are still germinating since they have just been planted.

-(Mar 2nd) Day three; Pots A, B, and C sprouted at the same time, most likely due to the concentration difference not being noticeable in the early stages of growth.

-(Mar 3rd) Day four; Plant growth has begun in Pots A, B, and C, indicating their good health.

(Mar 4th) Day five: Growth in all pots shows healthy plants. Pots B and C appear taller than Pot A. I infer this is due to the effect of nanobubbles, which includes an increasing growth rate.

-(Mar 5th) Day six; Plants in every pot demonstrate healthy growth.

-(Mar 6th) Day seven; Each pot contains plants that are growing healthily. In the final numbers, using the average root length B is 93.75% longer than A, C is 97.92% longer than A and 5.41% longer than B. I surmise that this is so that the plant can absorb and utilize more water and nutrients, which will improve its overall health since the oxygen in the nanobubbles has a beneficial effect on the roots. Using the average height, B is 55.24% taller than A, C is 58.94% taller than A and 4.02% taller than B. I surmise this is due to the roots in B and even more in C having greater access to oxygen via the nanobubbles—an essential component of all plants' metabolic activities, including cress. Using the average total length, B is 75.51% longer than A, C is 79.42% longer than A and 4.6% longer than B. This is most likely caused by the soil's increased oxygen content (due to the nanobubbles), which supports the plant's general health through respiration.

Trial three:

-(Mar 6th) Day one; No growth, and I infer this is because the plants are still germinating since they have just been planted.

-(Mar 7th) Day two; There is no growth, this is most likely because the plants have not germinated and have just been planted.

-(Mar 8th) Day three; Small sprouts in pots B and C. No growth in A. I infer this is due to the effect of nanobubbles, which includes an increasing growth rate.

-(Mar 9th) Day four; Plant growth started in B and C. Pot A sprouted. This is most likely because of the impact of nanobubbles, which involves a faster rate of growth.

-(Mar 10th) Day five; Growth is more abundant-this demonstrates healthy plants.

-(Mar 11th) Day six; Growth in all pots shows that plants are progressing heathily. Density increases with concentration of nanobubble. The influence of nanobubbles, which include a higher rate of expansion, is most likely the reason of this.

-(Mar 12th) Day seven; Growth in all pots shows healthy plants.

In the final numbers, using the average root length B is 20% longer than A, C is 28.57% longer than A and 36.83% longer than B. I surmise that this is so that the plant can absorb and utilize more water and nutrients, which will improve its overall health since the oxygen in the nanobubbles has a beneficial effect on the roots. Using the average height, B is 20.51% taller than A, C is 30.71% taller than A and 10.36% taller than B. I surmise this is due to the roots in B and even more in C having greater access to oxygen via the nanobubbles—an essential component of all plants' metabolic activities, including cress. Using the average total length, B is

27.41% longer than A, C is 33.74% longer than A and 6.48% longer than B. This is most likely caused by the soil's increased oxygen content (due to the nanobubbles), which supports the plant's general health through respiration.

Conclusions:

Hypothesis: "If I grow cress plants with tap water, 50% oxygen nanobubbles, or 100% oxygen nanobubbles, then the oxygen nanobubble-fed cress will have a longer root length and height than cress watered with tap water because oxygen is a crucial part of respiration—a part of a plant's metabolic process."

My hypothesis, stated above, was correct, as my results showed that at the end of the experiment, Pot A cress and Pot C cress had an average 47.17 % difference in total length, an average 53.53% difference in root length, and an average 35.25% difference in height, C longer than A in each average. This shows that the nanobubble water positively affected Cress and, therefore, plants.

Nanobubbles affect cress growth positively because pots watered with a higher concentration of nanobubble water grew taller and longer than pots with less or no nanobubbles. When I watered the trays with tap water, 50% tap water - 50% nanobubbles, and 100% nanobubbles, the total length, root length, and height were incrementally taller with the higher concentration of nanobubbles, with pot C being the longest and pot A being the shortest.

Possible Sources of Error:

In the morning, sometimes the plants were not turned on by 8:00 AM but by 8:15-8:20 AM.

Next Steps:

1. A next step could be to use a different seed to test on, perhaps a slower-growing vegetable or fruit.

2. Another step could be to test what 25% nanobubble-75% tap water or 75% nanobubble-25% tap water as well as the tap water, 50% nanobubble-50% tap water and nanobubble concentrations to observe and compare the more minor differences.
3. Moving forward, I could test growing the Cress on trays or hydroponics and see how that affects the results and compare them to the growth in soil.
4. The next step could be to keep growing and watering the plants past the best harvesting date and observe and compare the health of the plants.

Applications:

Nanobubbles have a wide range of applications, including destroying or inactivating bacteria and viruses, stopping and lessening algae blooms, eliminating compounds that produce foul odours, and degrading water contaminants. Nanobubbles also remove oil, fine particles, colloids, solids, surfactants, fats, and grease from bodies of water. Nanobubbles also prevent biofilm growth in water, scale prevention, and provide oxygen in deprived underwater ecosystems.

In my experiment, I worked with nanobubbles' effects on plants, and through both my experiment and research, I have found nanobubbles increase yield, growth rate, and size of crops/plants. This is a crucial next step in the food industry for multiple reasons.

Firstly, industries and companies are constantly improving aspects of their growing methods to produce more food; as they make more money, the more they can produce, and as this is a way to do that, nanobubbles can contribute significantly to the economy.

Secondly, around the world, about 783 million people go to bed hungry regularly, and although the numbers are falling in the last decade, they started going up again in 2017. Many factors contribute to world hunger, but the principal cause is poverty. Growing food faster and with a higher yield with nanobubbles can reduce prices of much-needed food and provide more food, in general, to be sold. Climate is the second most contributing factor to world hunger, as in severe heat and floods. As nanobubbles are proven to improve a plant's resiliency, due to the better health of the plant, severe heat is less likely to damage food. Even after a natural disaster such as a flood, using nanobubbles improves the growth rate of plants, growing back food and re-establishing farms and food supply. Another contributing factor to world hunger is economic shocks, such as job loss or surging prices, and as stated earlier, the introduction of nanobubbles improves the economy. (Owen, 2023)

Thirdly, the use of nanobubbles can also replace harmful chemicals. About 6% of the world's disease burden and 8% of deaths are attributed to chemical causes (European Environmental Agency, 2023). If implemented, nanobubbles can lower the use of chemicals, as they won't be necessary to produce large amounts of food.

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