# Measuring the Effect of Voltage Exposure on Plant Growth

**IBDP HL Biology IA**

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**Background Information:**

Electroculture is a technique that utilizes electricity and magnetism in order to enhance plant growth. Studies done by Yannick Van Doorne, Ph.D. engineer in agriculture showed that electroculture could potentially increase harvest by 30% and increase vitamins and dry weight by 20% of almost all crops when compared to conventional non organic farming (Yannick Van Doorne, Natural Electro-Magnetic Influences on Plant Growth). However, there are many claims that go against electroculture as well. For instance, skeptics say that grass that grows under electric cables are fertilized by droppings from birds that sit on power lines, and that grass appears greener after a thunderstorm because the rain has washed them, and not because of the presence of electricity.

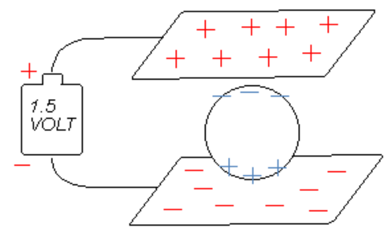



Figure 1: A battery and two metal plates are used to set up an electric field (Alphalab Inc., About Electromagnetism).

The reason why plants may grow when exposed to an electric field is because living cells and tissues utilize electrical charges to move needed materials both within the cells and in and out of cells (Khanacademy, Electrochemical gradients). Plant cells are constantly performing chemical reactions, requiring them to transfer substances such as oxygen, sugars, ATP, and $CO_2$ (Ann Murray, Hunker). An electric field will supply the electric charge that may assist in these reactions that help the plant grow. The electric stimulation causes an increase in metabolic activity (Agriculture Reference, What-when-how), which results in a faster rate of ion pumping. This at the same time allows for an increase in the intake of nutrients. Furthermore, the presence of an electric field has also been shown to have noticeable effects on the root apical meristem, which is responsible for the growth of the root and therefore the water and mineral intake as well as the structure of the plant. The electric field is able to disturb the structure of the closed meristem temporarily, and cause it to change into the open type, which allows for mitosis to occur more frequently (Wojciech Wawrecki, Annals of Botany). In addition, when exposed to an electric field, tissue tends to hold more calcium. Calcium is important in regulating membrane permeability, and when there is an abundance of calcium, the membrane becomes less permeable and many water-based molecules which would have otherwise leaked out of the cells, will be tightly stored within the cells (Agriculture Reference, What-when-how).

*Cucumis melo* plants should be planted in a sunny spot, in fertile, deep, sandy soil (University of Minnesota, Growing melons in the home garden). *Cucumis melo* seeds should be planted 2.5 cm deep into the soil, and they should be 2.5 cm apart from each other (harvesttotable, Melon Seed Starting Tips). Melons require warm climates which makes it perfect for planting during the summertime (almanac, growing watermelons). They need a significant amount of water, and their soil should be damp but not soaked (Burpee, All about watermelons). Therefore, watering them everyday in the Dubai heat will be necessary.

The way that the electric field's effect on the plants will be measured is by seeing how much the plants have grown under different electric field strengths. Plant growth is the process by which a plant's size grows. Growth in plants is affected by many variables, such as nutrients, light energy, water, and temperature.

This experiment is very relevant, because we have become the generation of technological advancements, where devices, and therefore electric fields are constantly surrounding us and our environment (Elizabeth Schulze, CNBC). This raises questions about the effect of these electric currents and their effect on one of the most valuable and necessary living things in our ecosystem: the plant. The plant is a vital part to the existence and survival of all living things. Thus, it is our duty to study the effect of our changing and technologically advancing lifestyles on the very living thing that keeps us alive.

If the effects of the electric current is seen to be harmful and detrimental to their growth, then ethical questions are raised, and concerns about the safety of plants in our changing environments will be inevitable. However, the electric current can be beneficial, and in that case, it can be seen as a helpful gardening tip, or perhaps even a revolutionary new agricultural technique. With this in mind, the results of our experiment are remarkably significant, as it can positively or negatively affect arguably the most crucial and essential living things in our ecosystem.

**Research Question:**
How does the voltage, ranging from 1.5 to 12 volts, of an electrical field in the soil affect the speed at which *Cucumis melo* seeds grow in millimeters, measured with a measuring tape, over a two week period (± 0.5 weeks)?

**Hypothesis:**
If *Cucumis melo* seeds are exposed to a 12 voltage electric field, they will grow more quickly over a two week period than plants that are exposed to weaker voltage electric fields, because the electric charges will assist the plant cells to perform their natural chemical reactions and functions.

**Independent Variable:**
Battery voltage (V) of electric field (Variations are 0.0V, 1.5V, 3.0V, 9.0V, 12V) measured with a voltmeter.

**Dependent Variable:**
Growth of plant in centimeters ( ± 0.1 cm), measured with a measuring tape, over Two weeks. The growth will be measured from the bottom of the roots to the top of the leaf. Note that the uncertainty of the measuring tape is 1 mm, because that is the smallest value on the measuring device.

**Control Variables:**
**Figure 2: Control Variables Chart (1)**

| **Control variable** | **How it will be controlled** | **Why it needs to be Controlled** |
|---|---|---|
| Volume of water provided to each plant | The volume of water provided to each plant will be measured, previous to watering them. This way, all plants will receive the exact same amount of water. Every pot, which contains 5 seeds, will be given 0.12 liters (±0.01) every day. | If the soil in which a plant grows in has too much water, the roots can rot, and the plant will not be able to get sufficient amounts of oxygen from the soil. Furthermore, the nutrients will not be able to travel through the plant if there is not enough water (Missouri Botanical Garden, Overwatering). Therefore, ensuring that all plants receive the same amount of water will guarantee a balanced growth in all plants. |
| pH levels of water | The pH levels of the water must be the same for all plants, so all plants will be provided with the same water from the same hose. The hose water will have a consistent pH, as the source of the water is from one pipe. | The pH has a direct impact on the availability of nutrients to the plant. For instance, important soils such as potassium, nitrogen, and phosphorus will dissolve when the pH is out of the range of 5.5 to 7.0. *Cucumis melo* plants also prefer and prosper in this pH range. |
| Pot size | All pots will be of the same exact size and type to ensure equality across all plants. They will be 27 cm (± 0.1) in diameter and 24.4 cm (± 0.1 cm) deep. | The smaller the pot, the less soil. This means less nutrients available for the plant's roots. A small pot can constrict the roots of the plant, and may not be able to retain enough water for the plant, which hinders growth. Likewise, an overly sized pot may hold too much water in the soil, which can cause diseases like mold formation (Nicole Papagiorgio, hunker). |
| Sunlight exposure | All plants will be placed outside in the same general area, so that they all receive the same amount of sunlight. | Plants get energy from light, through photosynthesis. Sunlight is necessary for the plant to produce energy and grow. Thus, having different sunlight exposure with each plant will result in different amounts of growth, which is why it must be controlled. |

**Figure 3: Control Variables Chart (2)**

| Control variable | How it will be controlled | Why it needs to be Controlled |
|---|---|---|
| Type of plant | The *Cucumis melo* plant will be used for each trial. | Different plants have different abilities and needs. For instance, some plants require more acidic soil than others, higher temperatures than others, or lower volumes of water than others. Making sure that all plants have the same abilities to grow is significant, because it confirms that differences in growth levels in the plants is not due to the use of different plants. |
| Volume of soil in each pot | Each pot will be given 4185 grams of sandy soil (± 20 grams), so that no pot has more soil than another. The mass of the soil will be weighed on a scale prior to placement in the pots. | Soil holds the roots of plants, which provide the plant with support and stores nutrients. An imbalance between the pots in the amount of soil can mean that some plants have different levels of mineral and nutrient access, and have weaker or stronger roots than others. |
| Temperature | All plants will be placed in the same general area, allowing the plants to all be in the same temperature of around 30°C - 40°C. This temperature range is admittedly too broad, however, the plants must be placed outdoors because there must be adequate space between the pots so that their electric fields do not interfere with each other. This spacing could only be achieved outdoors, resulting in an unmanageable temperature range. | All plants have an optimum temperature, and typically, as the temperature increases the rate of growth of the plant increases, until a certain point. After that optimum point, growth begins to decline (gardeningknowhow). Therefore, all plants must be in the same temperature to guarantee that one does not have an unfair advantage over another because of the temperature it is in. |
| Soil type | All plants will be potted in 4185 grams of sandy soil (± 20 grams) from Shalimar Bio-tech potting soil. This soil is enriched with nutrients and has a high moisture content, which is good for growing *Cucumis melo* plants. | Different soils have different pH levels, and different plants will grow in more acidic or more alkaline soils. As previously stated, the pH has a direct link to the nutrients available to the plant. Thus, ensuring that all pH levels for every plant's soil will also ensure the availability of nutrients. |
| Distance of each pot | All pots will be placed an equal distance of 134 cm (±5 cm) from each other. | Since each pot will have a different voltage passing through it, it is important that the electric field of one pot does not interfere with the electric fields of other pots, as it may skew with the growth rates of the different seeds. |

**Apparatus List:**

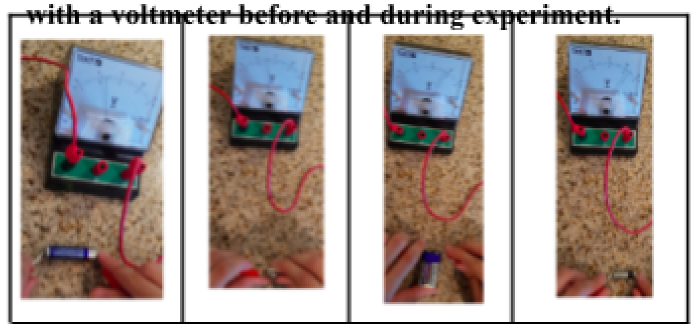
1 *Cucumis melo* Seed Packet
- 1 Measuring Tape
- 5 24.4 cm (±0.1 cm) Deep Plastic Pots
- 20,925 grams (± 20 grams) of Sandy Soil
- 1 Measuring Cup
- 12.4 Liters (± 0.1 Liters) of Room Temperature hose water
- 10 5 cm Copper Rods
- 1 1.5V Battery
- 1 Scotch Tape roll
- 1 3V Battery
- 1 9V Battery
- 1 12V Battery
- 8 Alligator Clips
- 1 Voltmeter
- 8 Wires

**Method:**

1. Fill 5 24.4 cm (±0.1 cm) pots, each with 4185 grams of sandy soil (± 20 grams). Use a scale to measure out the soil correctly.
2. Place the pots outside 134 cm (±5 cm) from each other, ensuring that they all get equal sunlight exposure. Use a measuring tape to guarantee equal distance between pots. This is important for making sure that the electric fields do not interact with the wrong plants (check figure 4).
3. Stick 2 5cm long copper rods 4 centimeters deep into the soil of 4 pots, leaving one pot. The rods should be on opposite sides of the pot.
4. Connect an alligator clip and a wire to each copper rod.
5. Connect the ends of the wires to the opposite ends of each different battery. Use tape. It is extremely important that the metal part of the wire makes contact with the metal part of the battery. After this, there should be one pot with a 12V battery, one with a 9V battery, one with a 3V battery, one with a 1.5V battery, and one with no battery, wires or copper rods.
6. Place five *Cucumis melo* seeds in each pot, ensuring that they are all of equal size and length (in this case, all seeds were 1.2 ± 0.1 cm long), 2.5 cm deep into the soil. The seeds should be 2.5 cm apart from each other.
7. Water each pot with 0.12 liters of hose water daily. Use a measuring cup to get accurate results.
8. Make sure that the batteries are still working everyday by connecting each one to a voltmeter. If not, replace the battery with the same voltage type immediately (check figure 5).
9. Throughout the 2 week process, take qualitative and quantitative data around every other day. Keep in mind things like color, growth, dimensions, and health of the growing plants.
10. After the 3 weeks, measure the growth of each of the *Cucumis melo* plants from root to tip, using a measuring tape.

Figure 4: Distance between pots

**Figure 5: Checking the voltages of each battery with a voltmeter before and during experiment.**

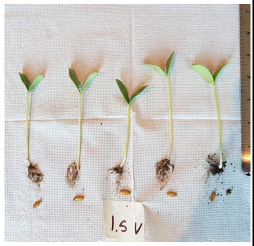
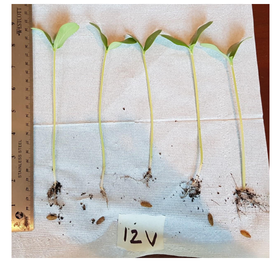


**Qualitative Data:**

**Figure 6: Progress of the Plants Throughout Experiment (1)**

| Day | No Battery | 1.5 Volt Battery | 3 Volt Battery | 9 Volt Battery Pot | 12 Volt Battery Pot |
|---|---|---|---|---|---|
| Day 7 |  Growth is clear on two plants. Still not all plants are visible. They are a very nice green color, and they are all roughly a little less than two centimeters out of the soil. |  Significant improvements in growth. There are four very clear and visible plants sprouting. They are not very long, and they do not poke out from the soil very far. One plant is significantly larger than the others. |  A lot of growth is visible. Three much larger plants are now visible, and they are all a nice green color. There is a fourth smaller plant visible as well. They are still rather small, but improvement is noticeable. |  A lot more growth in the plants. Long healthy plants can be seen and there are many more visible seeds growing. One plant is not growing perfectly vertically straight, and is slanting to the bottom left. |  A lot of visible growth. Plants have lengthened tremendously, and the ratio of green to brown in the picture is significant. The plants have grown very long and are looking a healthy bright green color. |

**Figure 7: Progress of the Plants Throughout Experiment (2)**

| Day | No Battery | 1.5 Volt Battery | 3 Volt Battery | 9 Volt Battery Pot | 12 Volt Battery Pot |
|---|---|---|---|---|---|
| Day 14 |  <br>Not all seeds grew out of the soil. One of them (far left) never poked itself out of the ground. The other four are all around the same size and have long roots relative to the rest of their size. |  <br>All roughly the same size. Leaves are pretty large (about half the size of the stem). The stems are light green while the leaves are darker green. They all stand vertically upwards and don't have any bends or kinks in them. |  <br>A lot of variance in height. One of the plants is significantly smaller than the rest (middle plant). Likewise, the stems, root length, and leaf sizes all vary dramatically. |  <br>Much longer plants. Colors are identical to each other and to the rest of the trial variations. Plants don't vary in height or size by a lot, although there is a visible difference between the shortest and the longest plant. |  <br>Very long plants have grown from the 12V battery pot. They are all very vertical, and don't bend or twist. This may suggest strong stems. The leaves' size is also remarkably large. The roots are very short compared to the rest of the plant. |

**Quantitative Data:**
**Figure 8: Growth of Each Plant in Centimeters (± 0.1 cm) From Each Pot with Different Voltages (±0.1 V)**

| | Growth of Plants From Root to Tip in Centimeters (± 0.1 cm) After Two Weeks | | | | |
|---|---|---|---|---|---|
| Battery Voltage in Pot (±0.1 V) | Plant 1 | Plant 2 | Plant 3 | Plant 4 | Plant 5 |
| 0 | 8.7 | 11.0 | 12.2 | 11.1 | 2.1 |
| 1.5 | 14.9 | 15.4 | 12.8 | 13.3 | 13.8 |
| 3 | 15.3 | 15.4 | 12.3 | 15.0 | 16.7 |
| 9 | 18.3 | 15.8 | 16.0 | 18.5 | 20.3 |
| 12 | 21.3 | 20.5 | 18.7 | 20.1 | 20.4 |

**Processed Data:**

**Figure 9: Justification of Processed Data Techniques**

| **Processed Data Type** | **Formula** | **Reason Behind Method** |
|---|---|---|
| **Percent change in height (cm) of plants in each pot** | $\frac{Final\ height - Initial\ height}{Initial\ height} \times 100$ | By changing the data into a percentage change, the data will clearly show how the voltage has allowed some plants to grow greater than others, and by what magnitude of growth. |
| **Standard deviation of height (cm) of plants in the same pot** | Found using excel<br>Equation: $\sigma = \sqrt{\frac{\Sigma (X - \bar{X})^2}{n-1}}$ | The standard deviation will show how the plants' height varied from the mean height for each pot. With this, the precision and the consistency of the numbers can be identified, and it will be known how reliable and exact the data for plant height is. |
| **Correlation Coefficient** | Found using excel<br>Equation: $r = \frac{1}{n-1} \Sigma \left(\frac{x - \bar{x}}{s_x}\right)\left(\frac{y - \bar{y}}{s_y}\right)$ | A correlation coefficient is used to measure how strong a relationship between two variables is. This will show with clarity the relationship and its strength between the height of the plants and the voltage they are exposed to. |
| **T-test** | Found using excel<br>Equation: $t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$<br>$s^2 = \frac{\sum_{i=1}^{n_1}(x_i - \bar{x}_1)^2 + \sum_{j=1}^{n_2}(x_j - \bar{x}_2)^2}{n_1 + n_2 - 2}$ | A t-test determines if there is a significant difference between the means of two groups, which allows for the comparison of the mean values of two data sets and determine if they came from the same population. Essentially, it will indicate the likelihood of the results that were found to be by chance or for them to be a consequence of the change in voltage. |

**Figure 10: Percent Change in Height (±0.1) cm of Plants in each Pot Depending on the Voltage Supplied (±0.1V)**

| | Percent Change in Height (%) | | | | | |
|---|---|---|---|---|---|---|
| Voltage of Electric Field (±0.1 V) | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Mean |
| 0 | 625 | 817 | 916 | 825 | 75* | 652 |
| 1.5 | 1140 | 1180 | 967 | 1008 | 1050 | 1070 |
| 3.0 | 1175 | 1183 | 925 | 1150 | 1292 | 1145 |
| 9.0 | 1425 | 1217 | 1233 | 1442 | 1592 | 1382 |
| 12 | 1425 | 1608 | 1458 | 1575 | 1600 | 1583 |

Uncertainty of ±0.1 for battery voltage because this is the accuracy level that all of the battery producers claim to have.
Uncertainty of ±0.1 cm for height because that is the smallest value on the measuring stick used.

Percent Change in height sample calculation:

$\frac{Final\ height - Initial\ height}{Initial\ height} \times\ 100$ = Percent change
Initial height = 0.8
Final height = 0.9
((0.9-0.8)/0.8) × 100 = 12.5%
Mean change in height = Sum of percent change for each trial divided by number of trials.

*Trial 5 for the 0 voltage pot is an anomaly, and clearly has a very significant difference in comparison to the other trials.

**Figure 11: Standard Deviation and Correlation Coefficient of Mean Percent Change in Height (±0.1) cm for Each Plant Depending on the Voltage (±0.1V) Supplied by Each Battery**

| Voltage of Electric Field (±0.1) V | Standard Deviation (±0.1) cm | Correlation Coefficient |
|---|---|---|
| 0 | 339.3 | 0.929 |
| 1.5 | 89.2 | |
| 3.0 | 134.5 | |
| 9.0 | 157.3 | |
| 12 | 85.4 | |

Note: Standard deviation has the same uncertainty as the height, because that is the origin of the data.
Excel and calculator used to calculate standard deviation and correlation coefficient.

**Figure 12: T-test Displaying the Significance of the Changes in Height (±0.1) cm Based on the Change in Voltage (±0.1) V**
Null Hypothesis: There is not a significant difference between the two groups; any observed differences may be due to chance and sampling error.

Alternative Hypothesis: There is a significant difference between the two groups; the observed differences are most likely not due to chance or sampling error.

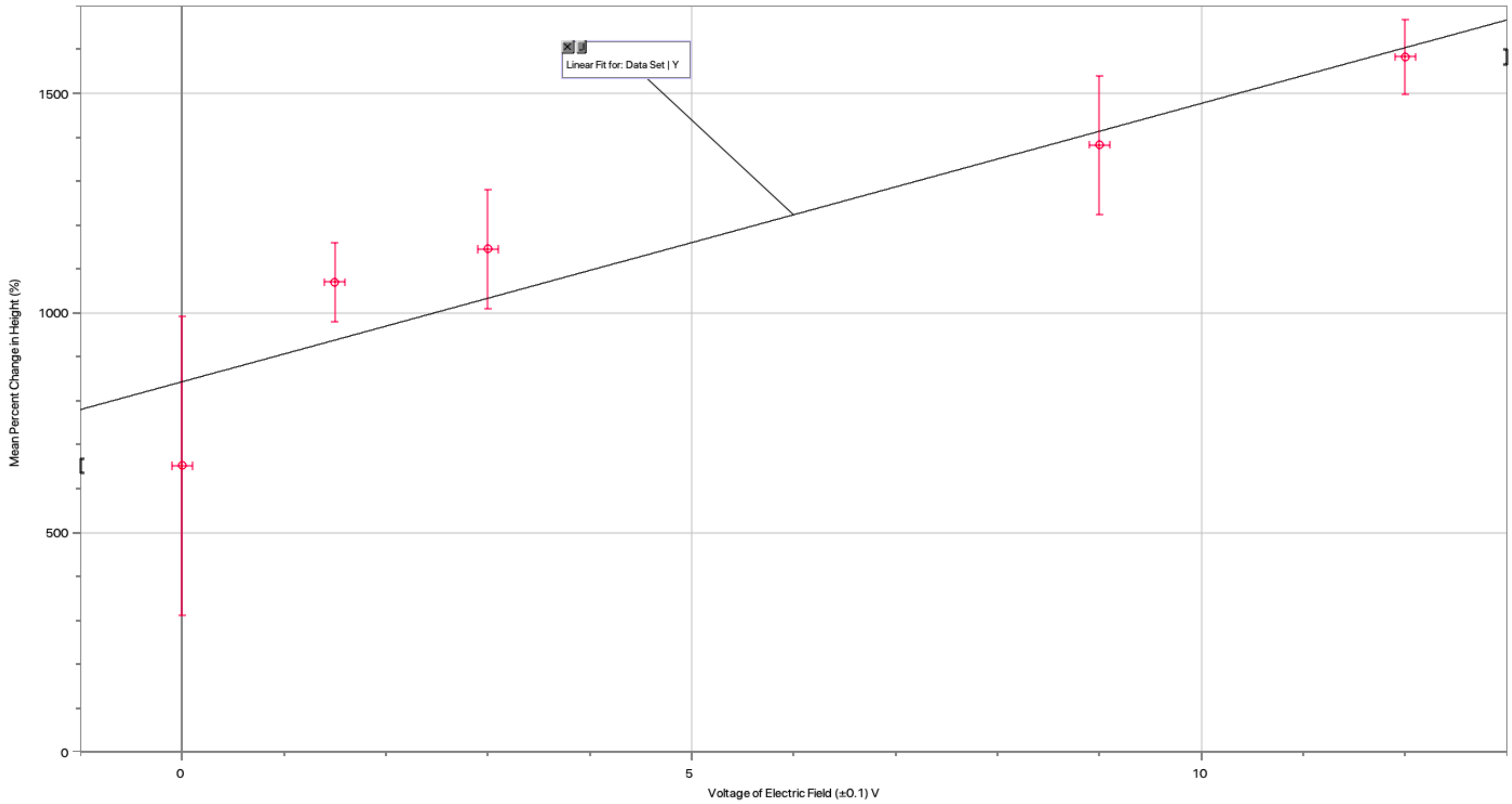
| Voltage of Electric Field (±0.1) V | P-Value | Accept/Reject Null Hypothesis |
|---|---|---|
| 0 - 1.5 | 0.02879274502 | Reject |
| 0 - 3.0 | 0.01649117608 | Reject |
| 0 - 9.0 | 0.002393938188 | Reject |
| 0 - 12 | 0.0004903276363 | Reject |

With this data it can be concluded that for all of the comparisons, the P-value is below 0.05, which means that the null hypothesis is rejected and the differences between the data sets is most likely not due to random chance, and is instead too significant. A P-value below 0.05 means that there is less than a 5 percent chance that the difference in the means of the 2 compared sets of data is due to random chance. Thus, when recognizing that all of our comparisons have P-values less than 0.05, it shows that the difference in the growth of the plants is exceptional and not ignorable. In other words, the presence of an electric field, be it 1.5 volts or 12 volts, does significantly change the growth of the plants.

T-test was calculated using excel and a TI-nspire calculator.

**Graph:**

**Figure 13: Mean Percent Change in Height (%) Versus Voltage of Electric Field (±0.1) V**




Black line is the line of best fit (slope of 63.38). All error bars for voltage are the same, as all the batteries have an uncertainty of ±0.1 V. The error bars for the percent change in height (%) are unique, because they all have a unique standard deviation based on each of their individual trials.

The trend that can be seen is that as the voltage provided to each group of plants increases, so does the mean percent change in height, which demonstrates that the growth of the plant is heightened when the plants are exposed to a stronger voltage.

The line of best fit passes through both the first and last error bars, which shows a strong amount of accuracy. This is because it shows that the trend in the data can be supported by a line that demonstrates the accuracy and reliability of the trend.

The first error bar for percent growth is very large, for example, which means that there is a compromise of accuracy. However, this was the one voltage variation that had one seed that did not grow out of the soil, so it included an anomaly. The rest of the error bars are not nearly as drastic and are much more reasonable and, because of that, accurate.

**Conclusion:**

In conclusion, the hypothesis was supported by the data and therefore accepted, as the *Cucumis melo* seeds that were exposed to a 12 voltage electric field grew more quickly over a two week period than the plants that were exposed to weaker voltage electric fields. As can be seen in figure 13 and in figure 10,  the voltages of 0, 1.5, 3.0, 9.0, and 12 V had the mean percentage increase in size of 652, 1070, 1145, 1383, and 1583 percent respectively. Thus, it is clear that as the voltage increased, the plant size also increased at a remarkably noticeable rate.

The reasons behind why the plants were able to grow larger when exposed to higher voltage are plenty. For instance, according to a study done by Elizabeth Aleman at the National Center of Applied Bioelectromagnetism, meristem cells exposed to electric fields observed significant increase in metabolism and mitosis. This means that the central location for plant growth performs all of its chemical reactions at a heightened rate, which allow for it to grow and perform mitosis. Regeneration rate, plant fresh and dry weight, leaf number, shoot number, and rooting rate increased as well (Elizabeth Aleman, National Center of Applied Bioelectromagnetism). Leaf number is important because that is where photosynthesis takes place, which is responsible for energy creation for the plant. Likewise, another study was conducted by Muniza Riaz at the Federal Urdu University of Arts, Science, and Technology, and it showed that both germination rate and the presence of chlorophyll increased when *Vigna radiata* plants were exposed to electromagnetic fields (Muniza Riaz, Federal Urdu University of Arts, Science, and Technology). Chlorophyll is responsible for absorbing sunlight to create energy in photosynthesis, so it is crucial for plant growth.

The reliability of the data is strong. Performing 5 trials for 5 variations all of which leads to the same conclusion that a higher voltage leads to increased growth suggests that there is great reliability and integrity with that claim. The differences in growth was experienced by every single trial, resulting in a clear distinction between the effect the voltages had on the plants. There was however one anomaly in the data, wherein the 5th trial of the 0 voltage pot had not grown out of the soil. This most likely was an issue with the plant being too deep into the soil, and not being provided the proper sunlight to be exposed to light energy.

The fact that the conclusion was accepted is very significant, because it means that the use of electroculture can be very beneficial to plants and can result in up to 2144% more growth. This number comes from the percent increase from the smallest percent change in height (75%) in the 0 V trial to the greatest percent change in height (1608%) in the 12 V trial. This shows the potential for this technique on a global scale, and how it could potentially promote a new wave of agriculture that results in quicker growing, and more reliable plant growth.

**Evaluation:**

**Figure 14: Identification of Strengths:**

| **Strength:** | **Explanation:** |
|---|---|
| Simple procedure | This experiment is very easy to replicate, and very safe as well. The planting process can be done anywhere with sunlight, making it very accessible. Not many tools are needed, and the tools that are needed are very basic and can be found in any lab or even in the home. The results are also very easy to quantify, and the procedure does not require a lot of difficult technical skill. |
| *Cucumis melo* plants are very quick to grow | Because they grow so fast, it is very easy to get quick results, especially over a period of Two weeks. The plants have had ample time to grow, and the results can be seen from the first week. Furthermore, they do not require a lot of attention to grow. Checking in on them and watering them once a day is enough for them to grow. |
| Easy to control the control variables | Variables such as source of water, sunlight exposure, plant type, soil volume, pot size, soil type, and volume of water were all very easy to control. By just using the same source for all plants, for all different variables, it made it very easy to ensure that the data collected was reliable and dependable. |

**Figure 15: Identification of Weaknesses (1):**

| **Weakness:** | **Explanation:** | **Possible Improvement:** |
|---|---|---|
| Tools were not as accurate as possible | The voltmeter used, for instance, seemed to be off by up to half a volt at times. This uncertainty in the voltages is significant, because the project depends heavily on having accurate voltages so that it can be compared with the growth of the plants. An inaccuracy in such vital tools means that the integrity of the data collected is highly questionable. | Using multiple different tools to measure can help get a more accurate reading. For instance, having more than one voltmeter can allow for unusual readings to be double checked and confirmed. |

**Figure 16: Identification of Weaknesses (2):**

| Weakness: | Explanation: | Possible Improvement: |
|---|---|---|
| Hard to constantly manage the plants | One of the problems with this experiment is that because every pot needs a lot of space and the pots can't be placed right next to each other because of the electric field interferences, they must be placed outside to have enough room and still receive the same amount of sunlight. However, by placing all of the pots outside, they are being exposed to many potentially harmful things. There are a lot of cats that roam around in the area where this experiment was performed, and it could have been that these cats had messed with the pots, the wires, and the plants while no one saw. This uncertainty makes it hard to fully know how reliable the data that was collected is. | A possible solution would be to place a tall gate around the plants. This way no animals can mess with the experiment, playing with the equipment, and potentially tarnishing the reliability of the experiment. A gate would allow the plants to be completely isolated, while still being in a natural environment, with sunlight, water, and all of the resources they need. |
| Hard to guarantee an electric current is running through at all times | Because the electric current is not something physical that can be seen, it is not easy to guarantee that there is indeed an electric field in each pot. Testing the batteries everyday to see if they work does not ensure that when the wires are connected to the rods, and the rods are placed in the soil, that the electric field is definitively working. | Having a voltmeter for each pot that connects in a parallel circuit will be able to show the presence of an electric field by showing whether or not there is a voltage. |
| Tools were not as accurate as possible | The voltmeter used, for instance, seemed to be off by up to half a volt at times. This uncertainty in the voltages is significant, because the project depends heavily on having accurate voltages so that it can be compared with the growth of the plants. An inaccuracy in such vital tools means that the integrity of the data collected is highly questionable. | Using multiple different tools to measure can help get a more accurate reading. For instance, having more than one voltmeter can allow for unusual readings to be double checked and confirmed. |
| Lack of control over temperature | Ideally, *Cucumis melo* plants grow in a somewhat cool, spring climate, so growing them in Dubai heat in September is not the best way for them to grow to their maximum potential. Although all of the plants experienced the same temperature, and were all therefore inhibited in the same way, it is always best to grow plants in their ideal climate. | Planting seeds of a plant that fits the current season is a better and easier solution. This will also help get better results, because the plants will be able to grow faster, and possibly stronger. |
| Rust on copper rods | Some of the copper rods had rust on them while other rods were significantly and noticeably much cleaner. This could have raised a big problem, because rust is a poor conductor of electricity (Lynn Yarris, Rust Never Sleeps), meaning that some of the electric fields may have not worked as well as others, due to the amount of rust on the copper rods. | Buying brand new copper rods is the best way to guarantee the best and most equal conductivity for all electric fields in each pot. This will allow for greater certainty in the electric fields actually working, which will therefore make the data more reliable. |

**Figure 17: Identification of Weaknesses (3):**

| Weakness: | Explanation: | Possible Improvement: |
|---|---|---|
| Distance of seeds in the same pot from each copper rod | The individual seeds within each pot had a different distance from the copper rods, which could mean a different electric field strength was available to different plants. Although the difference would be infinitesimal, the fact that some seeds grew faster than other could lead to this being one of the reasons why. | Ensuring that the seeds are all equidistant to the copper rods would eliminate this concern, and make it so that they are without a doubt experiencing the same electric field strength. This can be accomplished by placing all of the seeds along the center of the pot. However, it is important that the pot is long enough, as each seed would need 2.5 cm of separation from the other seeds for optimum growth. |

**Safety and Ethical Considerations:**

It is significant that throughout this lab, precautions are taken and safety is always prioritized. Since the lab deals with batteries, electricity, and heat, it is important that whoever performs this experiment is vigilant of the batteries throughout the entire procedure. Making sure that the batteries are not getting too hot, and connecting them to a voltmeter every other day is a good way to ensure that the batteries are safe and still working, and that the plants and you are not in any harm or danger. There is also the potential of harmful microbes and ticks in the soil, so it is important that gloves are worn during the gardening portion of the lab, so that diseases do not spread.

There are also some ethical concerns within this lab. The IB is very strict when it comes to testing and studying other living things for scientific research, and rightly so. Because this experiment involves plants, it is of high importance that the plants are treated with care and respect during the entire experiment. Making sure that the plants are safe and healthy by providing them with the needed water and sunlight, allowing them to grow strong under humane conditions, and being gentle with the plants are all duties of the scientists who perform this lab. If one wishes to comprehend how essential and vital plants are to all ecosystems, it is of great importance that they also understand that plants are living beings, that must be taken care of and treated well in order to live and grow. This idea of taking care of the plant should be thought of even after the experiment has concluded. Replanting the plants in a garden is a good way to keep the plant safe after the experiment is finished. This makes sure that the plant is safe and is not disposed of incorrectly.

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