Introduction

In this experiment, we hope to learn if bigger seeds germinate faster and produce bigger plants. We chose this topic because we had developed an interest in plants and we wanted to research plants further. We selected this idea, of seed size affecting growth performance, when one of us was planting pansies in her garden. She noticed that the seeds had different sizes and began to wonder if the little seeds would grow just as fast and as big as the bigger seeds. We hope our experiment will show a quick way to germinate seeds and to grow bigger plants.

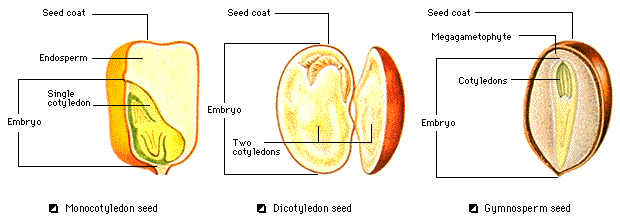
For our experiment, we used peas. We wanted a plant that could grow in the winter, grow fast, and grow under artificial light (Thiel). We found that peas need rich soil, constant moisture, and cool seasons to grow and develop well (Reid). Peas belong to the plant family called legumes, which also include beans, soybeans, peanuts, clover, and alfalfa. Legumes are of “great economic importance throughout the world” (Austin) serving as food and yielding medicine and other important products. Legumes take in nitrogen from the air to their roots. Bacteria called rhizobia live in nodules found along the roots of legumes. The rhizobia supply the legume with nitrogen, and the plant provides the bacteria with carbohydrates and other organic compounds. Both the legume and the bacteria benefit from this relationship (Campbell 722). Legumes are valuable in agriculture because farmers use them as manure and as crop covers to improve poor soil (Austin). Farmers rotate their crops between legumes and nonlegumes. Legumes are planted to restore the concentration of fixed nitrogen in the soil, and act as a “green manure” (Campbell 723).

In the National Corn Handbook, under the Seed Corn Quality and Size section, authors J.S. Burris of Iowa State University, D.R. Hicks of University of Minnesota, and Ivan Wikner believe that seed size, which is genetically controlled, may have an effect on plant performance. Smaller seeds usually have a smaller seed growth rate. In many instances, “seed size has significant consequences in the performance of a number of crop species” (Burris). Also, Gary E. Pepper of the University of Illinois believes that seed size may have an effect on plant performance. After his 1996 experiment with soybeans, Pepper found that “the overall effect of soybean seed size, on establishment, growth, and yield potential, appears to be minimal” (Pepper). However, he believed that a large seed, which has a greater amount of stored energy than smaller seeds, might grow greater in height than smaller seeds later in the season (Pepper).

Plants are an essential part in the environment of life. During the Paleozoic Era, over 430 million years ago, the first land plants appeared on earth. Plants, like animals, compete for sunlight, water and other necessities of life. Plants act as food for many organisms. Also, plants produce oxygen, which is essential for life on earth. Plants changed the physical environment of the earth on a global scale. One important effect was a great decrease in the amount of carbon dioxide in the atmosphere, which made the earth cooler. Therefore, other organisms could inhabit and survive in the new environment. Robert Berner of Yale University proposed that the relationship between the drop of carbon dioxide and the time plants colonized on land is not a coincidence. In the atmosphere, carbon dioxide contributes to the warming of the earth’s surface, which is also known as the green house effect. Carbon dioxide allows solar radiation to penetrate the earth’s atmosphere at a faster rate than it allows the heat to radiate back into space. Therefore, by lowering carbon dioxide concentration, the temperature of the earth is lowered, which allows more terrestrial locations to be habitable for plants and animals (Campbell 571).

Plants are also an essential part of human life. Studies have shown that the healthiest diets are loaded with plant foods, such as vegetables, fruits, beans, and grains. Walter Willett, chair of the nutrition department at the Harvard School of Public Health, says that “a diet rich in fruits and vegetables plays a role in reducing the risk of all major causes of illness and death” (Liebman). Statistics have shown that 800 million people in the world today, which is about one-third of the world’s population, are malnourished. Two billion people have a diet that lacks essential vitamins and minerals. 18 million people, mainly women and children, die of starvation each year (“Making a Meal of It!”). Therefore, if our experiment shows that bigger seeds do produce bigger plants, we can propose this to farmers as a new method of producing a greater crop yield. A greater crop yield would be able to feed more hungry people around the world. Seeds are the beginning of plants, which serve as a major source of food for millions of people around the world.

Seeds vary greatly in size and shape. Some seeds, such as the tobacco plant, are very small. On the other hand, some seeds, such as the coconut tree, may weigh more than twenty pounds. Seeds consist of three main parts called the seed coat, the embryo and the food storage tissue. The seed coat, also known as the outer skin, protects the embryo from injury, insects, and loss of water. The embryo contains all the parts, such as an immature root and stem, needed to form a mature plant. It also has one or more cotyledons, which are embryo leaves. A monocotyledon seed, such as a corn seed, has one cotyledon. A dicotyledon, such as a pea or bean seed, has two cotyledons. These cotyledons absorb food from the food storage tissue, which is also known as the endosperm in flowering plants. However, in some plants, such as peas, the embryo absorbs the endosperm and food is stored in the cotyledons. Once the seed becomes active, it goes through a process called germination (Byrne).

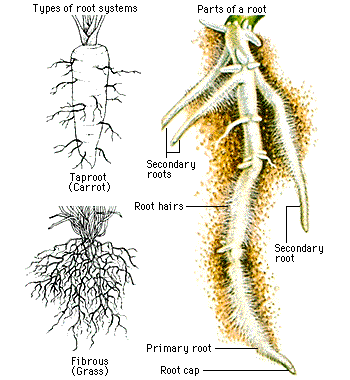
All seeds need moisture, oxygen and warmth to germinate. Seeds receive the moisture they need from the ground. The moisture softens the seed coat, which lets the growing parts to break through. If the seed receives too much water, it may rot. However, if the seed receives too little water, germination may take place slowly, or not even at all (Keating). The seed absorbs water, which makes it swell. The water triggers chemical changes that allow the embryo to change the stored food into energy needed for growth. The swelling splits the seed coat so that a tiny seedling shows. The lower part of the seedling is called the hypocotyls, which develops into the primary root. This root anchors the seedling into the ground, which later develops a root system that supplies water and minerals to the plants. In peas, the upper part of the seedling, also known as the epicotyl, carries the cotyledons above ground. After the seedling develops its own roots and leaves, it can develop its own food. Cotyledons are no longer needed for nourishment (Keating). 

Seeds may go through a period of dormancy, which is inactivity. Dormancy prevents seeds from sprouting when conditions are not favorable for growth. For instance, some dormant seeds must have its outer layer broken before they can germinate. Other dormant seeds need a period of cold weather or additional sunlight. For example, dormancy prevents seeds from germinating in the fall, which protects the seed from being killed in the winter (Keating). If the seed is not killed, it grows into a living plant.

Graduate fellow Marianne Ames and Assistant Professor Wayne S. Johnson, of the University of Nevada, define growth as “an irreversible change in the size of a cell, organ or whole organism” (Ames). Growth is commonly known as an increase of living material, which leads to an increase in cell size. In living cells, growth occurs by metabolic processes involved in protein nucleic acids, lipids and carbohydrate synthesis. Photosynthesis and respiration provide the metabolic energy (Ames). Plants make food through a process called photosynthesis. During photosynthesis, plants use carbon dioxide, water, and light energy, normally from the sun, to produce glucose, oxygen, and water. Glucose and water are the plant’s food source, and allows the plant to grow. Oxygen is an essential element used by organisms to function properly through cellular respiration. In the process of cellular respiration, oxygen is consumed along with organic fuel to produce carbon dioxide, water, and energy. Energy is essential to the organism’s survival. Plants are beneficial to the earth and the other living organisms that live in it (Campbell 171). Plant growth is commonly measured as a change in area, length, volume, height, and weight. The growth and development patterns of plants are usually used to classify plants into groups. Determinate plants, such as sweet corn and bush tomatoes, have its main and secondary axes terminated in a flower bud. On the other hand, indeterminate plants, such as peas, “are those whose main axes remain vegetative and in which flowers form buds” (Ames). Different plants grow at different rates.

There are many factors that influence plant growth. First, hereditary factors that influence plant growth are passed on from generation to generation. The genetic structure of a plant is acquired when the zygote is formed from the male and female gametes. The genetic information is copied and passed on through cell division. As the plant becomes bigger to its mature size, some of the genes are activated, while others are inactivated. Some genes are codes for the synthesis of enzymes that catalyze specific biochemical reactions needed for growth and differentiation (Ames). Differentiation is when cells turn off or on certain genes to develop different functions. Structural genes are involved in protein synthesis. Regulatory and operator genes regulate the activity of the structural genes. Growth hormones are also involved in the genetic and environmental control of growth and differentiation. In a plant, growth hormone distribution is controlled by interactions between the genetic factors in the plant and the environment. The growth hormones may be either growth inhibitors or growth promoters depending on the site of the action and the concentration of the substance of the growth hormone.

Also, there are environmental factors that influence plant growth. All plants need a suitable climate, light, and a continuous supply of water. Each individual plant cell holds a large amount of water. Most growing plants contain 90 percent water. Without water, the plant cells could not continue many of the processes that take place within a plant. Most water enters the plant through its roots. The hairs on these roots absorb moisture and minerals from the soil by a process called osmosis. Osmosis is the diffusion of water. Water is the medium of transfer within the plant. It is also the solvent system within the cell (Ames). In many plants, fungi grow on the roots and help the plant absorb water and nutrients. Plants grow well only within a limited temperature range, which varies from plant to plant. A plant requires at least eight hours of light everyday (Ames). Some plants that grow without light are called etiolated plants. They lack chlorophyll. Chlorophyll absorbs light energy that is necessary for photosynthesis. Photosynthetic rates are determined by light intensity, carbon dioxide levels, and temperature. Light can have an effect on the morphology of a plant. For example, leaves that are in the sun tend to be thicker with extra layers than leaves that are normally in the shade. A plant’s response to light will defer depending on the intensity of the light. It also depends on the duration and wavelength of the light it receives. Light intensity is the concentration of light waves that are shown on the leaf’s surface. Another environmental factor is temperature. The temperature range that supports the plant growth is normally 40 to 97 degrees Fahrenheit. The optimum temperature for plant growth can defer within species and the stage of development the plant is in (Ames). As temperature increases, respiration rate increases also.

For our experiment, we want to test if bigger seeds affect growth performance. Therefore, we will test germination rates between different seed sizes. We will observe which seed size starts to germinate faster than the other seed sizes. We will record the frequency of each seed sizes’ germination within the duration of the experimental period. We will also measure the length of radicles, which will become roots, and are essential for plants in absorbance of nutrients that help the plant to grow and survive. We also want to find out if bigger seeds have more knots than smaller seeds. Knots are premature root hairs. They will enable the plant to form roots with a bigger surface area, which will allow for more sufficient transportation and absorption of water and nutrients from its surroundings with a more efficient root system. Nodules, which are the bacteria filled parts of the roots that fixate nitrogen, which is an essential nutrient for the plant. Since nodules do not form until later, we will not be observing them throughout our experiment. We want to test if the actual stems of the bigger seeds are actually bigger than the smaller seeds. Bigger stems would lead to taller plants. Therefore, the primary stem length will be measured to observe if it is true. To measure plant height, we will plant seeds in soil and observe the height of the plant, from the top of the soil to the top of the pea plant. Furthermore, we will use vermiculite in our study of growth performance. Vermiculite will act as a control and allow the plant to grow naturally without nutrients from the environment. We would also like to explore if the embryos of bigger seeds are actually bigger than that of smaller seeds. However, Professor Lynne Elkin of California State University of Hayward suggests that embryos might “vary in shape and position, but the size is usually fairly small. Unless [one is] dealing with really tiny seeds like those of orchards or poppies, the difference in seed size is mainly a function of the amount of food stored” (Elkin). Therefore, we will not be studying embryo size because we do not believe we would be able to measure the exact embryo size of a pea, since the pea seed is fairly small. Also, we believe that we will not be able to find a valid method to compute the amount of food stored in a seed. We considered using a starch test, but that would only show that seeds have initial nutrients and food stored inside of it. Therefore, all the seeds would have a positive outcome by turning black. So, in our experiment, we will not be using any procedure to test our hypothesis that initial nutrient affects growth performance. The same is for embryo size. 

We hope that the information we find in this experiment will help farmers germinate seeds faster. This would also be useful in places like Alaska, which have a very short growing season. We hope that this experiment will give us insight on how to produce bigger and more bountiful plants. This would help farmers grow more crops, which would lead to more food for the hungry. Besides enhancing plant growth, our experiment could reveal ways to harvest and maximize crop yield (Thiel). We hope our experiment will be successful.

Hypothesis: The bigger the seed, the faster the germination rate.

Prediction: If the seed size is big, then the germination rate will be faster than the rate of smaller seeds.

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| Materials:  -peas  -small containers (6)  -paper towels  -distilled water  -micrometer  -ruler  -micropippette  -tweezers  Procedure:  1. Collect 2.5 oz packets of peas.  2. Measure length of axis on each pea with micrometer.  3. Put peas into groups according to size: groups in tenths of a millimeter.  4. Put one paper towel into each plastic, clear container (6).  5. Label containers: 5.0-5.4, 5.5-5.9, 6.0-6.4, 6.5-6.9, 7.0-7.4, 7.5-7.9.  6. Place two peas of each size in corresponding container (10 peas in each container).  7. Use micropippette to measure distilled water and put 20-mL in each container.  8. Place all containers on bare desk in corner of room.  9. Observe peas in containers everyday between 8 p.m. to 10 p.m. Record observations.  10. Water peas everyday with 5-mL of distilled water in every container. | Materials:  -plant tray  -soil  -vermiculite  -fluorescent light  -automatic timer  Procedure:  1. Fill first 36 squares with soil to rim.  2. Fill other 36 squares with vermiculite to rim.  3. Place one pea 3 cm deep in each square.  4. Water each square with 2-mL of distilled water.  5. Plug automatic timer in with light for 12 hours a day. Record observations.  6. Water each square 1-mL of distilled water every other day. |

Daily Journal

11/18/01-11/25/01: Research on plants, seeds, peas and growing techniques at library and on Internet. Email Biology teacher for advice (see Contacts section).

11/26/01: School resumes. Talk to Mr. Thiel at lunch about topic.

11/27/01: Talk to Mr. Simms, the botany teacher, about seeds, germination and to look at seed collection and borrowed a botany textbook.

11/30/01: Went to Mr. Simms’ room again and got three 2.5 oz. packets of pea seeds from him. Talked more about project idea and learned how to germinate and grow peas.

12/8/01: Went to Home Depot and bought vermiculite and soil.

12/14/01: Emailed Julie Glass of California State University, Hayward regarding any advice or access to a machine that could measure the size of a pea seed’s embryo.

12/15/01: Picked out defected peas from packets. Measured two packets of peas with micrometer. Started measuring length, width , height and mass – realized too many calculations to consider. Decided to measure length of pea along axis only.

12/16/01: Set up experiments. First, filled half of plant tray with soil and other half with vermiculite. Plant peas 3 cm deep into tray (one per square). Then, elevate fluorescent lamp 30-cm distance from the top of the plant tray. Watered each square with 2-mL of distilled water (used micropippette). Place setup against wall.

-Soil

-Vermiculite

Plant Tray Layout (size in mm)

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|  |  | 6.0 a | 6.0 b | 7.0 a | 7.0 b |  |  | 6.0 a | 6.0 b | 7.0 a | 7.0 b |
| 5.2 a | 5.2 b | 6.2 a | 6.2 b | 7.2 a | 7.2 b | 5.2 a | 5.2 b | 6.2 a | 6.2 b | 7.2 a | 7.2 b |
| 5.4 a | 5.4 b | 6.4 a | 6.4 b | 7.4 a | 7.4 b | 5.4 a | 5.4 b | 6.4 a | 6.4 b | 7.4 a | 7.4 b |
| 5.6 a | 5.6 b | 6.6 a | 6.6 b | 7.6 a | 7.6 b | 5.6 a | 5.6 b | 6.6 a | 6.6 b | 7.6 a | 7.6 b |
| 5.8 a | 5.8 b | 6.8 a | 6.8 b | 7.8 a | 7.8 b | 5.8 a | 5.8 b | 6.8 a | 6.8 b | 7.8 a | 7.8 b |
|  |  |  |  | 8.0 a | 8.0 b |  |  |  |  | 8.0 a | 8.0 b |

Set up germination containers (6). Place one paper towel in each container. Label containers: 5.0-5.4, 5.5-5.9, 6.0-6.4, 6.5-6.9, 7.0-7.4, and 7.5-7.9. Place two peas of each size in corresponding container (10 peas for each container). Water each container with 20-mL in each container. Place all containers on a bare desk in corner of room.

12/17/01-1/4/02: Begin observing (see Data section for results). Water each container 5-mL of water everyday (to keep peas moist) between 8 and 10 p.m. Water each square 1-mL every other day.

1/4/02: Got email from Dr. Lynne Osman Elkin, Professor of Biological Sciences at California State University, Hayward.

1/7/02: Begin second germination experiment for repetition (exactly like first germination setup).

1/8/02-1/21/02: Observe experiment. Water each container 5-mL of water everyday, between 8 and 10 p.m.

Data

Experiment 1 Trial1

B = bulge up from dormant state C = seed coat split R = radicle poking out

r = primary root ss = seed split k = has knobs

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| Day 1 | 12/17 | 63 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | B | B | B | B | B | B | B | B | B |
| 5.5-5.9 | B | B | B | B | B | B | B | B | B | B |
| 6.0-6.4 | B | B | B | B | B | B | B | B | B | R |
| 6.5-6.9 | B | B | B | B | B | B | B | B | C | R |
| 7.0-7.4 | B | B | B | B | B | B | B | B | B | C |
| 7.5-7.9 | B | B | B | B | B | B | B | B | C | R |

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| Day 2 | 12/18 | 62 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | B | B | B | B | R | R | R | R | R |
| 5.5-5.9 | B | B | B | B | R | R | R | R | R | R |
| 6.0-6.4 | B | B | B | B | B | B | R | R | R | R |
| 6.5-6.9 | B | B | R | R | R | R | R | R | R | R |
| 7.0-7.4 | B | B | R | R | R | R | R | R | R | R |
| 7.5-7.9 | B | B | R | R | R | R | R | R | R | R |

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| Day 3 | 12/19 | 65 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | B | B | B | B | R | R | R | R | R |
| 5.5-5.9 | B | B | B | R | R | R | R | R | R | R |
| 6.0-6.4 | B | B | B | B | C | R | R | R | R | R |
| 6.5-6.9 | B | R | R | R | R | R | R | R | R | R |
| 7.0-7.4 | B | R | R | R | R | R | R | R | R | R |
| 7.5-7.9 | B | B | R | R | R | R | R | R | R | R |

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| Day 4 | 12/20 | 63 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | B | B | B | B | R | R | R | R | R |
| 5.5-5.9 | B | B | B | R | R | R | R | R | R | R |
| 6.0-6.4 | B | B | B | B | C | R | R | R | R | R |
| 6.5-6.9 | B | R | R | R | R | R | R | R | R | R |
| 7.0-7.4 | B | R | R | R | R | R | R | R | R | R |
| 7.5-7.9 | B | B | R | R | R | R | R | R | R | R |

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| Day 5 | 12/21 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | B | B | B | R | R | R | R | R | R |
| 5.5-5.9 | B | B | B | R | R | R | R | R | R | R |
| 6.0-6.4 | B | B | B | B | C | R | R | R | R | R |
| 6.5-6.9 | B | R | R | R | R | R | R | R | R | R |
| 7.0-7.4 | B | R | R | R | R | R | R | R | R | R |
| 7.5-7.9 | B | R | R | R | R | R | R | R | R | R |

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| Day 6 | 12/22 | 68 F |  |  |  |  |  |  |  |  |

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| Day 7 | 12/23 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | C | R | R | R r | R r | R r | R r | R r | R r(ss) |
| 5.5-5.9 | B | B | B | R | R r | R r | R r(ss) | R r(ss) | R r(ss) | R r(ss) |
| 6.0-6.4 | B | B | B | B | R | R | R | R r | R r(ss) | R r(ss) |
| 6.5-6.9 | B | R r | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r(ss-k) |
| 7.0-7.4 | B | R | R | R r | R r (ss) | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) |
| 7.5-7.9 | B | R | R | R | R | R | R r (k) | R r (k) | R r (k) | R r (k) |

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| Day 8 | 12/24 | 62 F |  |  |  |  |  |  |  |  |

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| Day 9 | 12/25 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | R | R | R r | R r (ss) | R r (ss) | R r (k) | R r (k) | R r (k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | B | B | B | B | R | R | R r | R r(k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | B | R r | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r (k) | R r ( ss-k) |
| 7.0-7.4 | B | R | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | B | R | R | R | R | R | R r (k) | R r (k) | R r (ss-k) | R r (ss-k) |

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| Day 10 | 12/26 | 64 F |  |  |  |  |  |  |  |  |

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| Day 11 | 12/27 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | B | R | R | R r (ss) | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | B | B | B | C | R | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | B | R r | R r (k) | R r (k) | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.0-7.4 | B | R | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | B | R | R | R | R | R r (k) | R r (k) | R r(ss-k) | R r (ss-k) | R r (ss-k) |

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| Day 12 | 12/28 | 64 F |  |  |  |  |  |  |  |  |

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| Day 13 | 12/29 | 65 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | C | R | R | R r (ss) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | B | B | B | C | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | B | R r | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.0-7.4 | B | R | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | B | R | R | R | R r (ss) | R r (k) | R r(ss-k) | R r(ss-k) | R r (ss-k) | R r (ss-k) |

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| Day 14 | 12/30 | 64 F |  |  |  |  |  |  |  |  |

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| Day 15 | 12/31 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | C | R | R | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | B | R r | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.0-7.4 | B | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | R | R | R | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r (ss-k) | R r (ss-k) |

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| Day 16 | 1/1 | 64 F |  |  |  |  |  |  |  |  |

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| Day 17 | ½ | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | R | R | R | R | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | R | R r | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.0-7.4 | B | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | R | R | R | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r (ss-k) | R r (ss-k) |

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| Day 18 | 1/3 | 66 F |  |  |  |  |  |  |  |  |

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| Day 19 | 1/ 4 | 64 F |  |  |  |  |  |  |  |  |
| 5.0-5.4 | R | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 5.5-5.9 | B | B | B | R r (ss-k) | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.0-6.4 | R r | R r | R r (k) | R r (ss-k) | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 6.5-6.9 | R | R r (ss-k) | R r (ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.0-7.4 | R | R r | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) |
| 7.5-7.9 | R | R | R | R r (k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r(ss-k) | R r (ss-k) | R r (ss-k) |

STEM LENGTH (mm)

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| Day 1 | 12/17 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 |  |  |  |  |  |  |  |  |  |  |
| 5.5-5.9 |  |  |  |  |  |  |  |  |  |  |
| 6.0-6.4 | 1 |  |  |  |  |  |  |  |  |  |
| 6.5-6.9 | 1 |  |  |  |  |  |  |  |  |  |
| 7.0-7.4 | 1 |  |  |  |  |  |  |  |  |  |
| 7.5-7.9 | 1 | 2 |  |  |  |  |  |  |  |  |

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| Day 2 | 12/18 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 8 | 9 | 10 | 10 |  |  |  |  |  |
| 5.5-5.9 | 2 | 7 | 11 | 12 | 12.5 | 13 |  |  |  |  |
| 6.0-6.4 | 2 | 9 | 10 | 10 |  |  |  |  |  |  |
| 6.5-6.9 | 3 | 11 | 11 | 11 | 11.5 | 12 | 13 | 14 |  |  |
| 7.0-7.4 | 1 | 5 | 7 | 8 | 9 | 10.5 | 11.5 | 16 |  |  |
| 7.5-7.9 | 3.5 | 5 | 6 | 7 | 8 | 11 | 11 | 13 |  |  |

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| Day 3 | 12/19 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 11 | 12 | 13 | 14 |  |  |  |  |  |
| 5.5-5.9 | 4 | 6 | 13 | 14 | 14 | 15 | 16 |  |  |  |
| 6.0-6.4 | 4 | 7 | 10 | 11 | 12 |  |  |  |  |  |
| 6.5-6.9 | 5 | 11 | 11 | 12 | 13 | 13 | 14 | 16 | 20 |  |
| 7.0-7.4 | 6 | 7 | 10 | 12 | 13 | 13 | 14 | 16 | 21 |  |
| 7.5-7.9 | 6 | 10 | 10 | 11 | 11 | 11 | 12 | 15 |  |  |

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| Day 4 | 12/20 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 10 | 11 | 12 | 13 | 14 |  |  |  |  |  |
| 5.5-5.9 | 5 | 6 | 14 | 14 | 15 | 16 | 16 |  |  |  |
| 6.0-6.4 | 5 | 7 | 10 | 11 | 12 |  |  |  |  |  |
| 6.5-6.9 | 5 | 11 | 11 | 12 | 13 | 14 | 16 | 16 | 20 |  |
| 7.0-7.4 | 7 | 8 | 10 | 13 | 13 | 13 | 14 | 16 | 21 |  |
| 7.5-7.9 | 7 | 10 | 10 | 11 | 11 | 11 | 12 | 16 |  |  |

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| Day 5 | 12/21 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 10 | 11 | 12 | 13 | 14 |  |  |  |  |
| 5.5-5.9 | 6 | 7 | 14 | 14 | 15 | 16 | 16 |  |  |  |
| 6.0-6.4 | 6 | 9 | 10 | 12 | 15 |  |  |  |  |  |
| 6.5-6.9 | 7 | 10 | 12 | 13 | 13 | 15 | 16 | 16 | 20 |  |
| 7.0-7.4 | 8 | 9 | 10 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 16 |  |  |

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| Day 7 | 12/23 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 7 | 8 | 9 | 11 | 11 | 14 | 14 | 16 | 17 |  |
| 5.5-5.9 | 8 | 9 | 14 | 14 | 16 | 17 | 17 |  |  |  |
| 6.0-6.4 | 6 | 7 | 9 | 10 | 12 | 15 |  |  |  |  |
| 6.5-6.9 | 9 | 11 | 12 | 13 | 13 | 15 | 16 | 16 | 20 |  |
| 7.0-7.4 | 8 | 9 | 10 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 13 | 16 |  |

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| Day 9 | 12/25 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 8 | 10 | 11 | 12 | 13 | 14 | 14 | 16 |  |  |
| 5.5-5.9 | 8.5 | 9 | 14 | 14 | 16 | 17 | 17 |  |  |  |
| 6.0-6.4 | 6 | 7 | 9 | 10 | 12 | 15 |  |  |  |  |
| 6.5-6.9 | 9 | 11 | 12 | 13 | 13 | 15 | 16 | 18 | 20 |  |
| 7.0-7.4 | 10 | 11 | 11 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 13 | 16 |  |

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| Day 11 | 12/27 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 10 | 11 | 12 | 13 | 14 | 14 | 16 |  |  |
| 5.5-5.9 | 8.5 | 10 | 14 | 14 | 16 | 17 | 19 |  |  |  |
| 6.0-6.4 | 6 | 8 | 9 | 11 | 12 | 15 |  |  |  |  |
| 6.5-6.9 | 9 | 11 | 12 | 13 | 13 | 15 | 16 | 18 | 20 |  |
| 7.0-7.4 | 10 | 11 | 11 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 13 | 16 |  |

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| Day 13 | 12/29 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 14 | 16 |  |
| 5.5-5.9 | 8.5 | 10 | 14 | 14 | 16 | 17 | 19 |  |  |  |
| 6.0-6.4 | 8 | 8 | 9 | 11 | 12 | 15 |  |  |  |  |
| 6.5-6.9 | 9 | 11 | 12 | 13 | 13 | 15 | 16 | 18 | 21 |  |
| 7.0-7.4 | 10 | 11 | 12 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 13 | 16 |  |

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| Day 15 | 12/31 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |  |
| 5.5-5.9 | 8.5 | 11 | 14 | 14 | 16 | 17 | 20 |  |  |  |
| 6.0-6.4 | 4 | 8 | 8 | 9 | 11 | 12 | 12 | 13 | 15 |  |
| 6.5-6.9 | 9 | 12 | 12 | 13 | 13 | 15 | 18 | 18 | 22 |  |
| 7.0-7.4 | 10 | 11 | 12 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 1 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 15 | 21 |

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| Day 17 | ½ |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 9 | 10 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |  |
| 5.5-5.9 | 8.5 | 11 | 14 | 14 | 16 | 17 | 21 |  |  |  |
| 6.0-6.4 | 4 | 9 | 9 | 10 | 11 | 12 | 13 | 13 | 16 |  |
| 6.5-6.9 | 3 | 9 | 12 | 13 | 13 | 15 | 15 | 18 | 18 | 22 |
| 7.0-7.4 | 10 | 12 | 12 | 14 | 14 | 15 | 15 | 18 | 21 |  |
| 7.5-7.9 | 2 | 8 | 10 | 10 | 12 | 12 | 12 | 13 | 15 | 21 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 19 | ¼ |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 9 | 10 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 5.5-5.9 | 8.5 | 12 | 14 | 14 | 16 | 17 | 21 |  |  |  |
| 6.0-6.4 | 9 | 10 | 10 | 12 | 12 | 13 | 13 | 16 | 17 | 22 |
| 6.5-6.9 | 8 | 9 | 12 | 13 | 13 | 15 | 15 | 18 | 19 | 22 |
| 7.0-7.4 | 8 | 11 | 12 | 12 | 14 | 14 | 15 | 15 | 18 | 21 |
| 7.5-7.9 | 9 | 9 | 10 | 10 | 12 | 12 | 12 | 13 | 16 | 21 |

PRIMARY ROOT LENGTH (mm)

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| Day 1 | 12/17 | NONE |  |  |  |  |  |  |  |  |

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| Day 3 | 12/19 | NONE |  |  |  |  |  |  |  |  |

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| Day 5 | 12/21 | NONE |  |  |  |  |  |  |  |  |

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| Day 7 | 12/23 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 3 | 5 | 5 | 5 | 5 | 8 |  |  |  |  |
| 5.5-5.9 | 3 | 4 | 5 | 5 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 3 | 4 | 5 |  |  |  |  |  |  |  |
| 6.5-6.9 | 3 | 3 | 5 | 5 | 5 | 6 | 6 | 7 | 9 |  |
| 7.0-7.4 | 3 | 3 | 4 | 4 | 4 | 5 | 5 |  |  |  |
| 7.5-7.9 | 3 | 3 | 4 | 4 |  |  |  |  |  |  |

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| Day 9 | 12/25 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 4 | 4 | 5 | 5 | 5 | 5 | 8 |  |  |  |
| 5.5-5.9 | 3 | 5 | 5 | 6 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 3 | 4 | 5 |  |  |  |  |  |  |  |
| 6.5-6.9 | 5 | 5 | 5 | 5 | 6 | 7 | 7 | 8 | 9 |  |
| 7.0-7.4 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 6 |  |  |
| 7.5-7.9 | 3 | 4 | 5 | 6 |  |  |  |  |  |  |

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| Day 11 | 12/27 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 5 | 5 | 5 | 5 | 6 | 9 |  |  |  |
| 5.5-5.9 | 3 | 5 | 6 | 7 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 4 | 5 | 6 |  |  |  |  |  |  |  |
| 6.5-6.9 | 5 | 5 | 5 | 5 | 6 | 7 | 7 | 8 | 9 |  |
| 7.0-7.4 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 6 |  |  |
| 7.5-7.9 | 3 | 5 | 5 | 6 |  |  |  |  |  |  |

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| Day 13 | 12/29 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 5 | 5 | 5 | 5 | 8 | 9 |  |  |  |
| 5.5-5.9 | 4 | 5 | 6 | 7 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 5 | 5 | 5 | 5 | 6 |  |  |  |  |  |
| 6.5-6.9 | 5 | 5 | 5 | 5 | 6 | 7 | 7 | 8 | 9 |  |
| 7.0-7.4 | 3 | 4 | 5 | 5 | 5 | 6 | 6 | 6 |  |  |
| 7.5-7.9 | 4 | 4 | 5 | 5 | 6 |  |  |  |  |  |

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| Day 15 | 12/31 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 8 | 9 |  |
| 5.5-5.9 | 4 | 6 | 6 | 7 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 2 | 5 | 5 | 5 | 5 | 6 |  |  |  |  |
| 6.5-6.9 | 4 | 5 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 9 |
| 7.0-7.4 | 4 | 4 | 5 | 5 | 6 | 6 | 6 | 6 | 6 |  |
| 7.5-7.9 | 3 | 5 | 5 | 5 | 5 | 6 |  |  |  |  |

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| Day 17 | 1/2 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 5 | 5 | 5 | 5 | 6 | 7 | 8 | 8 | 10 |
| 5.5-5.9 | 4 | 6 | 7 | 7 | 8 | 9 |  |  |  |  |
| 6.0-6.4 | 2 | 5 | 5 | 6 | 6 | 7 |  |  |  |  |
| 6.5-6.9 | 7 | 7 | 8 | 8 | 8 | 9 | 10 | 10 | 11 |  |
| 7.0-7.4 | 5 | 5 | 5 | 6 | 6 | 6 | 7 | 7 | 7 |  |
| 7.5-7.9 | 5 | 5 | 5 | 5 | 6 | 7 |  |  |  |  |

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| Day 19 | 1/4 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 5 | 6 | 6 | 6 | 6 | 6 | 7 | 8 | 9 | 10 |
| 5.5-5.9 | 1 | 5 | 6 | 7 | 7 | 9 | 9 |  |  |  |
| 6.0-6.4 | 2 | 3 | 4 | 5 | 5 | 6 | 6 | 7 | 8 | 9 |
| 6.5-6.9 | 2 | 7 | 8 | 8 | 8 | 9 | 9 | 10 | 11 | 11 |
| 7.0-7.4 | 5 | 5 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 9 |
| 7.5-7.9 | 2 | 5 | 6 | 6 | 6 | 6 | 9 |  |  |  |

KNOTS

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| Day 1 | 12/17 | NONE |  |  |  |  |  |  |  |  |

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| Day 3 | 12/19 | NONE |  |  |  |  |  |  |  |  |

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| Day 5 | 12/21 | NONE |  |  |  |  |  |  |  |  |

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| Day 7 | 12/23 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 |  |  |  |  |  |  |  |  |  |  |
| 5.5-5.9 |  |  |  |  |  |  |  |  |  |  |
| 6.0-6.4 |  |  |  |  |  |  |  |  |  |  |
| 6.5-6.9 | 1 | 1 | 1 | 2 | 2 | 2 |  |  |  |  |
| 7.0-7.4 | 1 | 1 | 2 | 2 | 3 |  |  |  |  |  |
| 7.5-7.9 | 1 | 2 | 2 | 2 |  |  |  |  |  |  |

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| Day 9 | 12/25 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 2 | 3 | 3 | 4 |  |  |  |  |  |  |
| 5.5-5.9 | 1 | 2 | 2 | 2 | 2 | 2 |  |  |  |  |
| 6.0-6.4 | 2 | 2 | 2 |  |  |  |  |  |  |  |
| 6.5-6.9 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |  |  |
| 7.0-7.4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |  |  |  |
| 7.5-7.9 | 1 | 2 | 2 | 3 |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 11 | 12/27 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 2 | 3 | 3 | 4 | 4 |  |  |  |  |
| 5.5-5.9 | 1 | 2 | 2 | 2 | 2 | 2 |  |  |  |  |
| 6.0-6.4 | 2 | 2 | 2 | 3 |  |  |  |  |  |  |
| 6.5-6.9 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 4 |  |  |
| 7.0-7.4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |  |  |  |
| 7.5-7.9 | 2 | 3 | 3 | 3 |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 13 | 12/29 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 3 | 3 | 3 | 4 | 4 |  |  |  |  |
| 5.5-5.9 | 1 | 2 | 2 | 2 | 2 | 3 |  |  |  |  |
| 6.0-6.4 | 1 | 2 | 2 | 4 | 4 |  |  |  |  |  |
| 6.5-6.9 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 5 |  |  |
| 7.0-7.4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |  |  |  |
| 7.5-7.9 | 2 | 2 | 3 | 3 | 3 |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 15 | 12/31 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 1 | 1 | 3 | 3 | 4 | 4 | 4 | 5 |  |
| 5.5-5.9 | 2 | 2 | 3 | 3 | 3 | 3 |  |  |  |  |
| 6.0-6.4 | 2 | 2 | 2 | 4 | 4 | 4 |  |  |  |  |
| 6.5-6.9 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 7 |  |  |
| 7.0-7.4 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 |  |  |
| 7.5-7.9 | 2 | 3 | 3 | 3 | 3 | 3 |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 17 | 1/2 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 5 |  |
| 5.5-5.9 | 2 | 3 | 3 | 3 | 3 | 3 |  |  |  |  |
| 6.0-6.4 | 2 | 2 | 3 | 4 | 4 | 4 |  |  |  |  |
| 6.5-6.9 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 7 |  |  |
| 7.0-7.4 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 |  |  |
| 7.5-7.9 | 2 | 3 | 3 | 4 | 4 | 4 |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day 19 | 1/4 |  |  |  |  |  |  |  |  |  |
| 5.0-5.4 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 5 | 6 |  |
| 5.5-5.9 | 2 | 3 | 3 | 3 | 4 | 4 |  |  |  |  |
| 6.0-6.4 | 2 | 2 | 3 | 3 | 4 | 4 | 4 |  |  |  |
| 6.5-6.9 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 7 |  |
| 7.0-7.4 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 |  |  |
| 7.5-7.9 | 1 | 2 | 3 | 3 | 4 | 6 | 6 |  |  |  |

Experiment 1 Trial 2

Germination

|  |  |
| --- | --- |
| 1/7/02 64F | SET UP CONTAINERS |

|  |  |
| --- | --- |
| Day 1 1/8/02 64F |  |
| 5.0-5.4 | All seeds swell up |
| 5.5-5.9 | All seeds swell up |
| 6.0-6.4 | All seeds swell up |
| 6.5-6.9 | All seeds swell up |
| 7.0-7.4 | All seeds swell up |
| 7.5-7.9 | All seeds swell up |

|  |  |
| --- | --- |
| Day 2 1/9/02 66F |  |
| 5.0-5.4 | 3 have sprout stems |
| 5.5-5.9 | 1 seed coat split and 3 have sprout stems |
| 6.0-6.4 | 1 seed coat split and 5 have sprout stems |
| 6.5-6.9 | 2 seed coat split and 4 have sprout stems |
| 7.0-7.4 | 4 have sprout stems |
| 7.5-7.9 | 1 seed coat split and 2 have sprout stems |

|  |  |
| --- | --- |
| Day 3 1/10/02 64F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 9 have sprout stems |
| 7.0-7.4 | 7 have sprout stems |
| 7.5-7.9 | 7 have sprout stems |

|  |  |
| --- | --- |
| Day 4 1/11/02 61F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 9 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 5 1/12/02 63F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 6 1/13/02 64F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 7 1/14/02 64F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 8 1/15/02 64F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 9 1/16/02 64F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 10 1/17/02 65F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 9 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 9 have sprout stems |

|  |  |
| --- | --- |
| Day 11 1/18/02 66F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 10 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 1 seed coat split and 9 have sprout stems |

|  |  |
| --- | --- |
| Day 12 1/19/02 63F |  |
| 5.0-5.4 | 9 have sprout stems |
| 5.5-5.9 | 10 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 1 seed coat split and 9 have sprout stems |

|  |  |
| --- | --- |
| Day 13 1/20/02 65F |  |
| 5.0-5.4 | 1 seed coat split and 9 have sprout stems |
| 5.5-5.9 | 10 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 1 seed coat split and 9 have sprout stems |

|  |  |
| --- | --- |
| Day 14 1/21/02 65F |  |
| 5.0-5.4 | 1 seed coat split and 9 have sprout stems |
| 5.5-5.9 | 10 have sprout stems |
| 6.0-6.4 | 10 have sprout stems |
| 6.5-6.9 | 10 have sprout stems |
| 7.0-7.4 | 10 have sprout stems |
| 7.5-7.9 | 1 seed coat split and 9 have sprout stems |

GERMINATION

Experiment 1 Trial 1

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 5.0-5.4 | 0 | 5 | 5 | 5 | 5 | 5 | 9 | 9 | 9 | 9 |
| 5.5-5.9 | 0 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| 6.0-6.4 | 1 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 6.5-6.9 | 2 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 7.0-7.4 | 1 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 7.5-7.9 | 2 | 8 | 8 | 8 | 8 | 8 | 9 | 9 | 9 | 9 |
|  |  |  |  |  |  |  |  |  |  |  |
| DAY | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |  |
| 5.0-5.4 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |  |
| 5.5-5.9 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |  |
| 6.0-6.4 | 7 | 7 | 7 | 7 | 10 | 10 | 10 | 10 | 10 |  |
| 6.5-6.9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 |  |
| 7.0-7.4 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 |  |
| 7.5-7.9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 |  |

MEAN STEM LENGTH

(millimeters)

Experiment 1 Trial 1

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 5.0-5.4 | 0 | 4.2 | 5.9 | 6 | 6.9 | 6.9 | 9 | 9 | 9.8 | 9.8 |
| 5.5-5.9 | 0 | 5.75 | 8.2 | 8.6 | 8.8 | 8.8 | 9.5 | 9.5 | 9.55 | 9.55 |
| 6.0-6.4 | 0.1 | 3.1 | 4.4 | 4.5 | 5.2 | 5.2 | 5.9 | 5.9 | 5.9 | 5.9 |
| 6.5-6.9 | 0.1 | 8.65 | 11.5 | 11.8 | 12.2 | 12.2 | 12.5 | 12.5 | 12.7 | 12.7 |
| 7.0-7.4 | 0.1 | 6.8 | 11.1 | 11.5 | 12.4 | 12.4 | 12.4 | 12.4 | 12.9 | 12.9 |
| 7.5-7.9 | 0.3 | 6.45 | 8.6 | 8.8 | 9.3 | 9.3 | 10.6 | 10.6 | 10.6 | 10.6 |
|  |  |  |  |  |  |  |  |  |  |  |
| DAY | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |  |
| 5.0-5.4 | 9.9 | 9.9 | 11.8 | 11.8 | 11.9 | 11.9 | 12 | 12 | 12.1 |  |
| 5.5-5.9 | 9.85 | 9.85 | 9.85 | 9.85 | 10.05 | 10.05 | 10.15 | 10.15 | 10.25 |  |
| 6.0-6.4 | 6.1 | 6.1 | 6.3 | 6.3 | 9.2 | 9.2 | 9.7 | 9.7 | 13.4 |  |
| 6.5-6.9 | 12.7 | 12.7 | 12.8 | 12.8 | 13.2 | 13.2 | 13.8 | 13.8 | 14.4 |  |
| 7.0-7.4 | 12.9 | 12.9 | 13 | 13 | 13 | 13 | 13.1 | 13.1 | 14 |  |
| 7.5-7.9 | 10.6 | 10.6 | 10.6 | 10.6 | 11.4 | 11.4 | 11.5 | 11.5 | 12.4 |  |

PRIMARY ROOT LENGTH

(millimeters)

Experiment 1 Trial 1

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DAY | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
| 5.0-5.4 | 0 | 0 | 0 | 3.1 | 3.6 | 4 | 4.2 | 5.4 | 6.4 | 6.9 |
| 5.5-5.9 | 0 | 0 | 0 | 3.4 | 3.6 | 3.8 | 3.9 | 4 | 4.1 | 4.4 |
| 6.0-6.4 | 0 | 0 | 0 | 1.2 | 1.2 | 1.5 | 2.6 | 2.8 | 3.1 | 5.5 |
| 6.5-6.9 | 0 | 0 | 0 | 5 | 5.7 | 5.7 | 5.7 | 6.2 | 7.8 | 8.3 |
| 7.0-7.4 | 0 | 0 | 0 | 2.8 | 3.5 | 3.7 | 4 | 4.8 | 5.4 | 6.4 |
| 7.5-7.9 | 0 | 0 | 0 | 1.4 | 1.8 | 1.9 | 2.4 | 2.9 | 3.3 | 4 |

KNOTS

Experiment 1 Trial 1

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DAY | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 |
| 5.0-5.4 | 0 | 0 | 0 | 0 | 1.2 | 1.7 | 1.8 | 2.6 | 2.9 | 3.2 |
| 5.5-5.9 | 0 | 0 | 0 | 0 | 1.1 | 1.1 | 1.2 | 1.6 | 1.7 | 1.9 |
| 6.0-6.4 | 0 | 0 | 0 | 0 | 0.6 | 0.9 | 1.3 | 1.8 | 1.9 | 2.2 |
| 6.5-6.9 | 0 | 0 | 0 | 0.9 | 1.5 | 2.1 | 2.7 | 3.6 | 3.9 | 4.3 |
| 7.0-7.4 | 0 | 0 | 0 | 0.9 | 1.5 | 1.5 | 1.5 | 2.3 | 2.3 | 2.3 |
| 7.5-7.9 | 0 | 0 | 0 | 0.7 | 0.8 | 1.1 | 1.3 | 1.7 | 2 | 2.5 |

GERMINATION

Experiment 1 Trial 2

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 5.0-5.4 | 0 | 3 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 10 |
| 5.5-5.9 | 0 | 4 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 |
| 6.0-6.4 | 0 | 6 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 6.5-6.9 | 0 | 6 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7.0-7.4 | 0 | 4 | 7 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7.5-7.9 | 0 | 3 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 |

STEM

Experiment 1 Trial 2

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 5.0-5.4 | 12 | 21 | 19 | 15 | 4 | 17 | 8 | 16 | 14 | 14 |
| 5.5-5.9 | 22 | 26 | 16 | 27 | 16 | 12 | 14 | 9 | 18 | 12 |
| 6.0-6.4 | 21 | 25 | 14 | 18 | 17 | 17 | 17 | 15 | 18 | 23 |
| 6.5-6.9 | 6 | 22 | 14 | 19 | 32 | 23 | 17 | 14 | 21 | 15 |
| 7.0-7.4 | 21 | 30 | 39 | 27 | 31 | 30 | 15 | 12 | 14 | 23 |
| 7.5-7.9 | 40 | 15 | 6 | 26 | 41 | 42 | 15 | 21 | 17 | 61 |

Mean Stem Length

|  |  |
| --- | --- |
| 5.0-5.4 | 14 |
| 5.5-5.9 | 17.2 |
| 6.0-6.4 | 18.5 |
| 6.5-6.9 | 18.3 |
| 7.0-7.4 | 24.2 |
| 7.5-7.9 | 28.4 |

PRIMARY ROOT

Experiment 1 Trial 2

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 5.0-5.4 | 3 | 3 | 3 | 3 | 6 | 4 | 8 | 5 |  |  |
| 5.5-5.9 | 5 | 4 | 3 | 3 | 2 | 3 | 5 | 2 | 4 | 2 |
| 6.0-6.4 | 5 | 4 | 3 | 3 | 4 | 9 | 3 | 5 | 3 | 4 |
| 6.5-6.9 | 44 | 5 | 5 | 10 | 32 | 11 | 7 | 4 | 6 |  |
| 7.0-7.4 | 6 | 5 | 8 | 4 | 12 | 4 | 5 | 8 | 4 | 3 |
| 7.5-7.9 | 40 | 17 | 5 | 8 | 24 | 6 | 5 | 9 | 53 |  |

Primary Root Mean

|  |  |
| --- | --- |
| 5.0-5.4 | 3.5 |
| 5.5-5.9 | 3.3 |
| 6.0-6.4 | 4.3 |
| 6.5-6.9 | 12.4 |
| 7.0-7.4 | 5.9 |
| 7.5-7.9 | 16.7 |

KNOTS

Experiment 1 Trial 2

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 5.0-5.4 | 4 | 4 | 6 | 4 | 2 | 3 | 3 | 6 |  |  |
| 5.5-5.9 | 4 | 5 | 3 | 3 | 3 | 2 | 6 | 1 | 3 | 1 |
| 6.0-6.4 | 5 | 4 | 3 | 2 | 5 | 7 | 3 | 5 | 3 | 3 |
| 6.5-6.9 | 3 | 3 | 8 | 4 | 6 | 3 | 4 | 8 | 6 |  |
| 7.0-7.4 | 1 | 3 | 7 | 4 | 5 | 5 | 2 | 8 | 8 | 5 |
| 7.5-7.9 | 9 | 7 | 5 | 4 | 6 | 4 | 3 | 5 | 2 |  |

KNOT (mean)

|  |  |
| --- | --- |
| 5.0-5.4 | 3.2 |
| 5.5-5.9 | 3.1 |
| 6.0-6.4 | 4 |
| 6.5-6.9 | 4.5 |
| 7.0-7.4 | 4.8 |
| 7.5-7.9 | 4.5 |

Conclusion

Our hypothesis was the bigger the seed, the faster the germination and the better the growth performance. Our results support our hypothesis. In our experiment on the effects of seed size on a pea plant’s height, on the final day in the soil condition, the 6mm seeds grew on an average of 6.6 cm more than the 5mm seeds. The 7mm seeds grew on an average of 0.5 cm more than the 6 mm seeds, which is 7.1 cm more than the 5mm seeds (Refer to Seed Size and Height in Soil graph). In the vermiculite condition, which we used as a control to see how the plants would grow without added nutrients, the 6mm seeds grew on an average of 5.2 cm more than the 5mm seeds. However, the 7mm seeds grew on an average of 1cm shorter than the 6mm seed. Still, the 7mm grew 4.2 cm more than the 5mm seeds (Refer to Seed Size and Height in Vermiculite graph). So, it still shows that bigger seeds produce bigger plants than smaller seeds.

In our experiment with germination, during the first trial, the only the 6mm and 7mm seeds started germinating during the first day. By the end of the first week, only the 6.5 mm and larger seeds had at least 80 percent of its seeds germinated. In the end of the first trial, however, only the 5.5-5.9 mm seeds did not have all of its seeds germinated. After twenty days, it only had 70 percent of its seeds germinated (Refer to Germination Trial 1 graph). We did the experiment again for repetition, and in the end, all the seeds germinated. This supports our hypothesis that bigger seeds germinate faster than smaller seeds.

In our experiment to test if bigger seeds have bigger stems, radicles, which help a plant transfer nutrients from the soil, and knots, which contain bacteria that break down soil nutrients. In the end of the first trial of the first experiment, the 6.5-6.9mm seeds had the longest stem length at an average of 14.4mm. However, both the 6mm and the 7mm seeds produced stems bigger than the 5mm seeds. In the second trial, the 7.5-7.9mm seeds produced the longest stems averaging at 28.4mm, which is over 14mm longer than the 5.0-5.4mm seeds, which was the shortest. Furthermore, in the first trial, the radicles of the 6.5-6.9mm seeds were the longest, with an average of 8.3mm by the last day. In the second trial, the 7.5-7.9mm seeds had the longest radicle averaging at 16.7mm. Moreover, in the first trial, the 6.5-6.9mm seeds grew the most knots. However, in the second trial, the 7.0-7.4mm seeds had the most knots at an average of 4.8. However, the 7.5-7.9mm seeds came in a close second with an average of 4.5 knots, which is only an average of 0.3 knots difference. The data still shows that bigger seeds produce longer stems and radicles and more knots than the smaller seeds, which will help it survive by producing more nutrients.

Even though the 7mm seeds did not always have the best growth performance, it always performed better than the 5mm seeds. In conclusion, we do believe that bigger seeds produce bigger plants, parts, and a faster germination rate than smaller seeds.

Recommendations

If we were to conduct this project again, we would recommend using bigger sample sizes, such as more seeds. Also, we believe that it would be interesting to conduct the experiment again using different types of seeds, such as avocado seeds or wheat seeds, to see if seed size affects growth performance in different seed types.

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