Turning Gravity Around – How do Roots react to pulling forces?

Kantonsschule Zug, Class 4E

1. Studying the literature

Roots, which may seem unspectacular at first sight, are actually very important for plants and their environment. They have several major functions for example the absorption of water and inorganic nutrients . Roots are even capable of absorbing these nutrients against the concentration gradient. The needed water is absorbed by tiny hair-like structures, which are called “root hairs”. Roots of plants are also able to enter into a symbiosis with certain fungi to form mycorrhizae. Roots are also important for reaching deeper ground layers where certain minerals can be found. Furthermore, some roots are able to perform photosynthesis like the roots of the mangrove.
“The roots of higher plants comprise a metabolically active and largely unexplored biological frontier. Some of their prime features include the ability to synthesize a remarkably diverse group of secondary metabolites, and to adjust their metabolic activities in response to different abiotic and biotic stresses.” [1]

While they may appear rather unnecessary, roots have a major impact on our lives, and an even bigger one in economy. Many roots are more important than the rest of the plant, which lay above the surface. For instance, there are many forms of roots which are edible and make up a big part of the human nutrition, e.g. carrots. Bigger roots even have the ability to stabilize the ground to prevent landslides and soil erosion. But there are also negative effects for humans. Plant Roots can break through sidewalks and may damage major ancient temples, such as the Mayan temples in Central America or the temple of Angkor Wat in the country of Cambodia.

To optimize farming, a lot of money is spent on the research of roots. Both, farmers and scientists try to fill the ground with more nitrogen without the use of fertilizers. A certain bacteria named Rhizobia helps them doing so. *“In order to express genes for nitrogen fixation, rhizobia require a plant host; they cannot independently fix nitrogen.”* [2] - *Rhizobia* live in a symbiosis with legumes and binds the nitrogen from the atmosphere and converts it into a more usable form for the plant. *“As a result of the nodulation process, after the harvest of the crop there are higher levels of soil nitrate, which can then be used by the next crop, and little to no nitrogen fertilizer is needed.”* [3] If they are integrated into a field, the following crop benefits from higher levels of nitrate in the soil, since bacteria remain inside the ground after the host dies, which leads to more nitrated fields, even without fertilizer. “*As biomass allocated to roots varies from 20% in tropical rainforests to 70% in temperate grasslands, root traits should be fully integrated into the resource economics spectrum.”* [4]

Regarding the physiology, roots have a simple structure, even though they take up most of the plant’s work.“ *When dissected, the arrangement of the cells in a root is root hair, epidermis, epiblem, cortex, endodermis, pericycle and lastly the vascular tissue in the centre of a root to transport the water absorbed by the root to other places of the plant.*“[5] The first growing root of a plant is called radicle. As every other root the radicle grows through cell division of the meristem which is protected by the root cap. These cells gradually mature into specialized cells, like the following. The root epidermis a boundary which protects the root of water loss and absorbs water and mineral nutrients. A further part of a root is the cortex, which is responsible for the transport of material into the central cylinder of the root, which happens with diffusion. The cortex of a root lies between the epidermis and the endodermis. The endodermis is another layer that allows the plant a certain control of the movement of water inside the organism. Next to the endodermis lies the pericycle. This cylinder surrounds and protects the vascular bundles (phloem and xylem), which are the main transport strands for water, minerals, glucose and other items.

Water transportation against gravity only works with the plants number one hidden trick. Guttation, which is the separation of water droplets at the tips and edges of leaves of plants caused by the root pressure. If the water potential of the root is lower than the high soil moisture level, water will enter the plant through the roots. Then, the water is pressed into the central cylinder of the root and forces the plant to exude some water. The root pressure can amount up to 6 Bar. It supports the water transpiration of the plant. This is especially necessary at night when the stomata of the plant are closed and the transpiration doesn’t work. If the transpiration stops working, the water stream, which transports the essential nutrients, breaks down. In this case guttation is needed to supply the plant with nutrients.

Guttation is often confused with dew, because they seem very similar. Dew is condensed water out of the air and arrives at night or in the morning; guttation is water which contains minerals and comes out of the plant.

[1] http://link.springer.com/article/10.1007%2Fs11627-001-0122-y

[2] http://en.wikipedia.org/wiki/Rhizobia

[3] http://en.wikipedia.org/wiki/Rhizobia

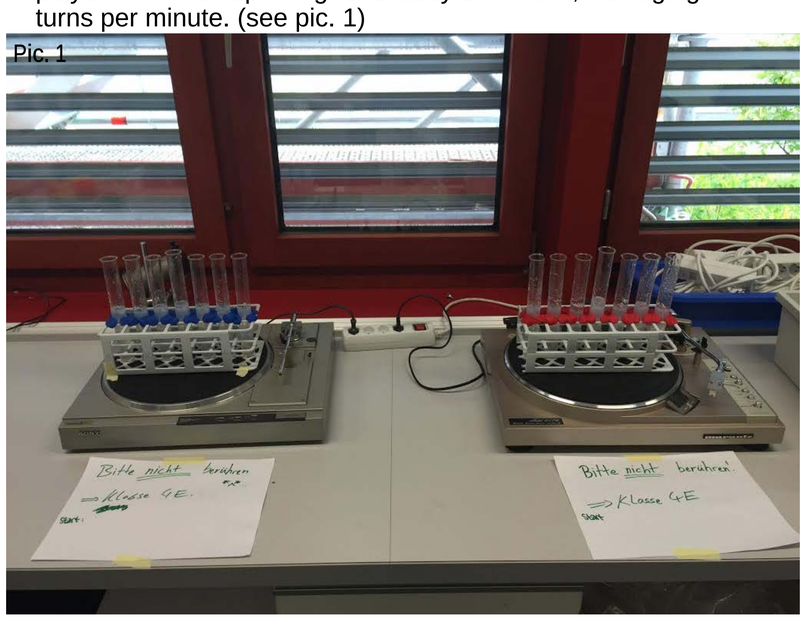
[4] http://onlinelibrary.wiley.com/doi/10.1111/j.1469-8137.2012.04247.x/full

[5] http://en.wikipedia.org/wiki/Root.

2. Material and Methods

A physiological approach seemed as the most reasonable one. The aim of the main experiment was to find out if the growth of roots aimed to the earth’s gravitational force. For this, two identical setups were built. Each one consisted of a Vinyl-Disc-Player player with a radius of 10.5 cm. A test tube holder was put on each one, holding a test tube with an opening of 3cm diameter. One test tube was placed in the middle and three others on either side to balance out the weight of the holder. The test tubes were placed 3.5 cm apart. Around 40 mL of Agar Agar (7 g/L) were filled into each test tube as a transparent soil for the roots to grow in. 7 identical cress seeds were placed into the Agar Agar, exactly in the center of the glass. The five seeds were placed in an even height distance of 1 cm. Both record players were left spinning for exactly one week, managing 45 turns per minute. (see pic. 1)

Pic. 1



3. The Forces

Pic. 2

Calculation of the centrifugal acceleration
Radius (r)=10,5cm/7 cm/3,5cm
Speed of rotation: 45 rpm
Circumference : 66cm/43,98cm/21,99cm
Speed (v): 0,495m/s , 0,33m/s, 0,165m/s
Formula for the circumference: ***U=2πr***
Formula for calculation of speed: v=Circumference/(Speed of rotation)
"Formula for calculation of the acceleration: " ***a =v^2/r***
Centrifugal acceleration on the tubes: 2,23m/s^2, 1,56m/s2, 0,78m/s^2

4. Choosing Variables

Independent variable: Gravity, Sound

Because of the spinning record player, we were able to add an extra force of 2.33m/s^2 to the gravity of earth, which should lead to a noticeable pattern in the directions the roots are growing. No kind of sound poisoning was seen and we couldn’t water the seeds since they were surrounded by Agar-agar.

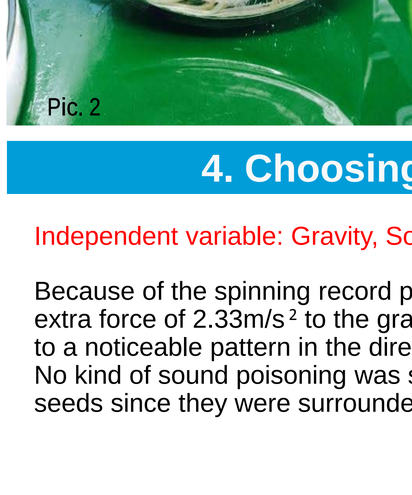
Dependant variable: Direction of root growth

Because of the added extra force, the roots should grow in a slight angle outwards instead of straight downwards.

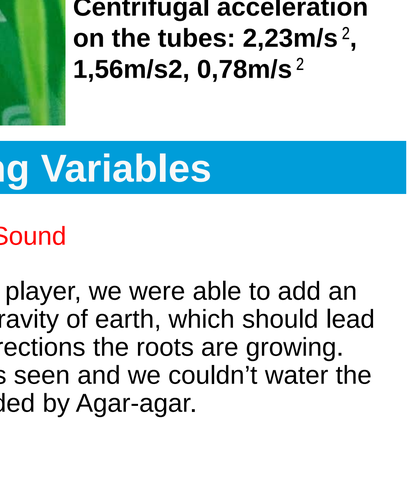
Controlled variables: Temperature, Light, Water concentration

We didn’t change any of the named variables significantly: The temperature was constant at room temperature (around 20 degree Celsius), the light was consisted of normal sunlight.

Pic. 3



Pic. 4



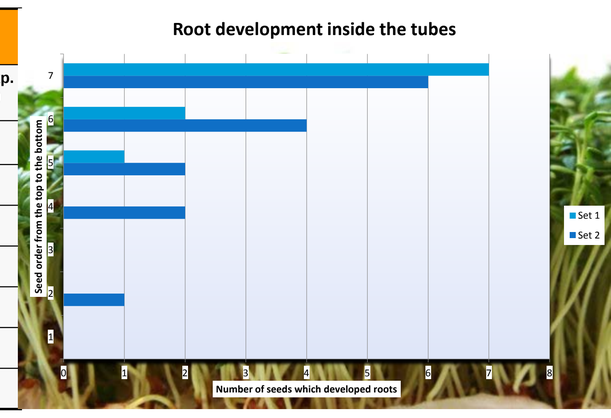
4. Data Collection and Processing

To collect the data the seeds were counted using a magnifying glass. The distances between each of the cress seeds were measured using a ruler, even though it was later noticed that this was rather irrelevant to our experiment. The same counted for the measuring of the length of the roots. This was also irrelevant to our experiment. The number of grown roots was the important aspect.

5. Data Presentation

As you can see, only the top two seeds sprout. If a seed sprouted, which was localized in a deeper region of the testing tube, it was because in some of the testing tubes there were bubbles filled with air inside the Agar-agar. In the top layer, only one seed didn’t sprout and in the second layer, not even fifty percent of the seeds sprouted. The vast majority of seeds below this layer didn’t sprout at all.

Depth Level	Number of grown seeds	
	Left Exp. (Dark)	Right Exp. (Light)
1)	6	7
2)	4	2
3)	2	1
4)	2	0
5)	0	0
6)	1	0
7)	0	0



6. Conclusion

It could be noticed that all of the highest laying seeds germinated except one. On the first of the record players two of the second highest seeds and one of the third highest seeds germinated while the bottom four seeds remained the same. The results on the second record player were similar as four of the second highest seeds, two of the third and fourth highest germinated showing a clear pattern. In addition to this also the second lowest seed germinated. On the first record player air bubbles were noticeable next to the fourth and sixth highest seeds.

7. Improving the Investigation

One very likely cause for the failure of the experiment may have been that the seeds, especially at the bottom of the test tubes, did not get enough oxygen to germinate. This is likely due to the weak diffusion of gases in Agar Agar. A possible take control of this factor could have been to create a hole for the oxygen to also spread to the lower seeds in the test tube. Although cress seeds were some of the best seeds available judging by their rate of growth, a seed which could have grown at a decent rate and would have needed less oxygen might have been the way to go. A very obvious method to perfect the experiment would have also been to let the record player spin longer and leave the seeds more time to germinate. As known roots grow best in their known habitats. These include the soil. With more time on the side the seeds could have been planted in normal soil. Even though it would have been very difficult to pull out the roots and to see the ear results, the results would have maybe been clearer.

8. Did you know?

- The oldest clonal tree is about 9’500 years old!
- The biggest living tree on earth has a height of 115.72 m and is called the “Hyperion”!
- There are over 23,000 different kinds of trees spread around the world.!
- The oldest organism has an age of 80’000 years! It’s called “The Trembling Giant” and can be found on the Colorado Plateau! It’s a forest of 47000 trees which have connected roots and are genetically identical: they are clones. It’s considered to be the largest living thing in terms of area and mass on earth. It has a genetic mutation, which allows it to grow a new tree whenever it’s roots hit the surface. The tree has conquered an area bigger than 100 acers with this technique. (404’685,65 square meters!)
- A White Cedahas grew less than 4 inches during its 155 years!
- Soap can be made out of Yucca Roots!
- Some desert plants live less than one month! They grow, bloom, and die within that short period of time.
- Fig trees can grow roots, which reach a depth of over 120 meters, although they just grow about 3 to 10 meters over the ground!

Pic. 1: The Main Experiment before starting

Pic. 2: The root system of beans

Pic. 3, 4: Th e testing tubes with the grown seeds