Plant Resonance *The effects of musical stimulation on plant well-being*

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Abstract

Inspired by a series of remarkable experiments summarized in the 1975 publication 'The Secret Life of the Plants', this project explores the effects of musical stimulation on plant-well being. In order to explore if audio frequency either stimulates cell growth or cause cell degradation in *Glyceria Maxima* plants, the performance of Plant-microbial-fuel-cells are analyzed under three conditions: (1) Indian Vedic music (2) Classic Rock music and (3) a control group. The experiments are evaluated in terms of difficulties, data are analyzed, results presented, and research obstacles are investigated and acknowledged. The combined results show that plants in the control group performed best. However, results also provide indications that the frequencies in Indian Vedic music positively influence plant growth, whereas classic rock causes atrophy - suggesting that plants respond not only to well known environmental patterns like sunlight, but also to structured patterns in audio frequency.

I Secret Plant Behaviour

Natural surroundings have a big impact on the energy and well-being of organisms. They respond to physical movements within their environment. For instance, known structured patterns like sunlight and humidity affect cell renewal in plants and directly stimulate growth. However, it turns out not only these well-known environmental patterns affect plant well-being. Ikea explored the effects of human communication on plant well-being[1], and found that plants receiving compliments thrived compared to those being bullied. How exactly these positive and negative affirmations influence the overall state of plants is still not clear, but the effects are undeniably real.

This kind of 'secret plant behaviour' has been researched before in the seventies. A remarkable collection of experiments is summarized in the 1975 publication 'The Secret Life of Plants' written by Peter Tompkins and Christopher Bird. The book casts light on the rich psychic universe of plants, and explores among many things their response to human care and nurturing, their reaction to music, ability to communicate with humans, curative powers and even lie-detector abilities. Although these experiments have on many occasions been dismissed as pseudoscience, they do suggest that plants have a richer way of interacting with the environment than is commonly believed.

Inspired by these curious experiments, this study explores the effects of musical stimulation on the well-being of plants. Of course it is impossible for us humans to know if our vegetative companions actually 'listen' to the music played to them, let alone whether they particularly like or despise certain genres or songs**.** Obviously, we as human beings do not have the same senses as plants and therefore will always be constricted to the basic five human senses in which we experience the world around us. However, what we can do is observe how the plants react to the music or, better yet, how plants react to audio vibrations we humans call music.

II Audio waves and Frequencies

When we strike a guitar, it produces sound. The vibrating strings make the adjacent air molecules vibrate. This vibration spreads in all direction, like water ripples. When it reaches our ear membranes, it makes them vibrate and we perceive a continuous of a definite pitch. The air vibrates in the same speed as the string, and the pitch of sound is determined by the speed of this vibration - called frequency. Frequency is measured in Hz, which is the number of vibrations per second.

These vibrations - also referred to as frequencies - can be physically felt, as one experiences standing very close to a loudspeaker at a concert. As audio waves travel through space these vibrations can penetrate the organic cells.

[1] Read more about these experiments at
https://www.ikeahackers.net/2018/05/ikea-bully-a-plant-experiment.html

Previous research on plants response to frequencies showed that dependent on the frequency level, playtime and repetition of the sound it can either stimulate cell renewal (growth) or cause cell degradation (shrinkage and atrophy) (Da Silva and Dobránszki 2014, Chivukula and Ramaswamy 2014). The right music can thus have a positive influence on the growth of plants. Unfortunately I am not a cell biologist and therefore my means of actually investigating the influence of frequency on cell level are limited. The process of photosynthesis provides a solution.

III Photosynthesis and energy production

Plant growth (cell renewal) can also be related to the process of photosynthesis - a form of biosynthesis in which light energy is used to convert carbon dioxide into among other things carbohydrates such as glucose. While most of the carbohydrates are used by the plant to feed itself, excess carbohydrates (called rhizodeposits) are eaten by bacteria naturally present in the soil. Interestingly, these bacteria produce protons and electrons when consuming the rhizodeposits, thus indicating and converting the plant's energy production. This implies these plants may be used as a natural source of renewable energy - commonly referred to as a Plant-Microbial-Fuel-Cell (PMFC) (please see figure X for the PMFC proces).

Logically we can state that when the plants grows, more leafy area is formed to receive sunlight, hence more photosynthesis can take place, more nutrients are produced for bacteria to consume, and subsequently more energy is produced. Measuring the voltage and current level is therefore a good indication of the amount of cell renewal or degradation (growth or shrinkage) of a plant. Naturally, we would like to know and keep under control the energy production's correlation with other possible changes in the plants' environment. To identify and closely monitor the latter, we measure on an hourly basis conditions of humidity, light intensity, temperature and soil-humidity.

IV Materials and Methods

IV.I Context and experimental set-up

The experiments are taking place at Mediamatic[2], an institution for art and technology in the very heart of Amsterdam. Focussing on nature, biotechnology, art and science, Mediamatic provides the perfect environment for the experiments. Mediamatic is equipped with three greenhouses in which the plants will be tested against various conditions - more on these conditions a later. The greenhouses are 131 cm x 193 cm in size and made from 3mm thick gardener's glass and polycarbonate.

[2] For more information visit www.mediamatic.nl and view 'The Secret life of Plants' exposition.

Figure 1. Greenhouse setup @ Mediamatic

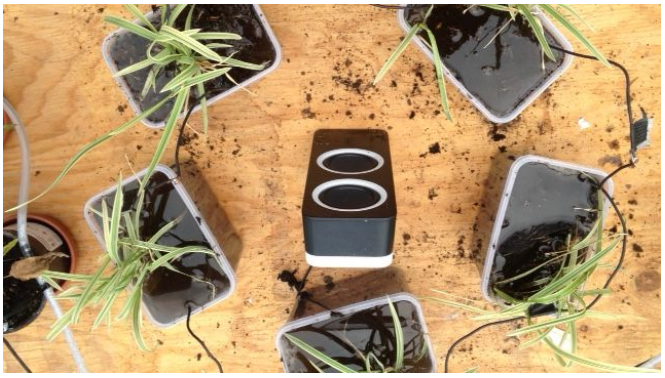


Figure 2. PMFC setup per greenhouse with audio source set in middle

Fifteen Plant-MFC's were constructed in total and divided over three greenhouses. Each greenhouse is housing five Plant-MFC's, switched in parallel (see figure 2) so the output shows an accumulation of the mV produced in all five cells. According to previous research done on electrodes optimization in Plant-MFC (Ter Heijne et. al., 2008), graphite felt is one of the most used materials for electrodes in Plant-MFC's. All Plant-MFC's were based on an anode compartment consisting of a graphite felt anode electrode (3mm thick). The cathode electrode consisted of a graphite felt (3mm thick), placed in a plastic container planter with a diameter of 15cm.

The electrical circuit was formed by copper wires, running through the graphite felt anode and cathode segments respectively. For each group of five Plant-MFC's, the anode and cathode electrodes were soldered together and connected to a voltage meter for accurate measuring. Each Plant-MFC's group was placed on a shelve system in the greenhouses, with the doors closed and a small window left open (for fresh air to come in). As the greenhouses are made of glass, natural light is able to come in - consequently natural light is subject to fluctuating according to the weather everyday. In order to normalize these fluctuations, artificial illumination was added to each greenhouse, positioned above the set-up resulting in an illumination period of 24 hours a day. The artificial light consisted of Philips GreenPower LED. At night the LEDs provide for 78% of light intensity while during the day natural light is added up, accumulating average light intensity to 87%.

The temperature too is subjected to fluctuations of the natural environment, as the greenhouses are situated outside. The experiments are taking place from April until the end of June, which means the maximal average temperature can range between 12 and 19 degrees celsius, whereas the minimum average temperature can range from 4 to 10 degrees celsius (KNMI)[3]. Greenhouses effects add to the average temperature, resulting in a range between 8 (night temperature) and 38 degrees celsius (daytime). According to previous research, the optimal ambient

[3] www.weerstatistieken.nl for climate related information about weather conditions.

temperature for microorganisms and plants are between the 23 and 27 degrees celsius, as they are expected to grow under these conditions.

IV.II Plants

Previous research into Plant-MFC optimization, showed that aquatic plants are the only choices for Plant-MFC's as they are sensitive to solution conductivity (Deng et. al., 2012). Building up on research conducted by Strik et al., (2008), *Glyceria Maxima* (also known as Reed Mannagrass of Liesgras, and very common at the Dutch shoreline) was selected to create fifteen Plant-MFC's, as this local species can grow in anaerobic sediments. These anaerobic conditions are necessary for a well-functioning anode compartment of a MFC (Strik et al., 2008).

The Plant-MFC is based upon two processes: rhizodeposition of organic compounds by living plants and electricity generation from organic compound in the MFC (Strik et al., 2008). Via photosynthesis, plants produce organic matter using energy from sunlight and carbon dioxide. Part of this organic matter is consumed by the plant itself for cell renewal and growth, whereas the surplus of this organic matter is being released into the soil, called rhizodeposits. These rhizodeposits consist of different types of organic compound, including (1) *Exudates*: sugars, organic acids, etc., (2) *secretions:* polymeric carbohydrates and enzymes; (3) *lysates:* dead cell materials; and (4) *gases*: ethylene and CO2 (Strik et. al., 2008, Bais, Harsh P., et al. 2006 and Pinton, Roberto, and Varanin, 2001). Electricity is generated by the anaerobic degradation of the root exudates by bacteria.

IV.III Configuration

Two basic ways of creating Plant-MFC's exist: single-chamber or two-chamber Plant-MFC's. A two-chamber Plant-MFC could possibly function well for the current setup, as they both minimize inert resistance and oxygen diffusion. However, the membranes used in a two-chamber configuration are usually very costly. The principle of PMFC's with a single chamber is that oxygen concentration declines over the depth of water and sediment which makes a membrane (as used in an two-chamber PMFC) redundant.

The roots of the *Glyceria Maxima* are carefully placed in the flooded anode compartment of the Plant-MFC. Soil blocks the migration of H+ from the anode to the cathode and the diffusion of the root deposit to the anode surface, which increases mass-transfer resistance and ohmic resistance (Strik et. al., 2008). The cathode is placed in the water solution in order to use oxygen from air for oxidation-reduction reaction (redox) (please see figure 3).

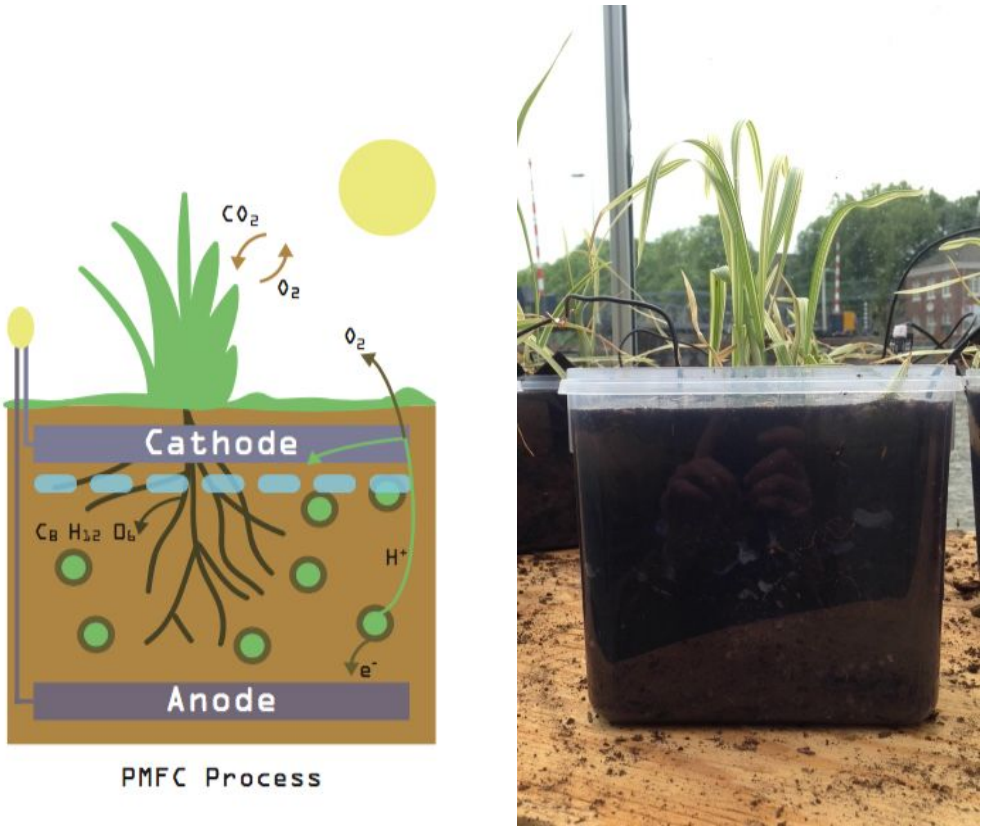


Figure 3. PMFC Process and one PMFC

As discussed above, the rhizodeposits consist of different types of compound and influence the electricity production of the PMFCs accordingly. Ideally, the soil in the support matrix (anode compartment) of the Plant-MFC would be analyzed for soil composition, as well as a analysis of the bacteria naturally present in the soil. However, this would require research efforts that are beyond the means and relevance of the current research. There is no reason to assume that these measurements will influence the experiments and research question proposed as such.

Due to lack of resources and the focus of the current research, the current experiments do not contain such an analysis.

Mixing normal potting soil - bought at the local gardening store - with the organic soil of the Reed Mannagrass, the anode compartment of the Plant-MFC's is filled up. The cathode is placed in the water solution as shown in figure 3.

IV.III Music

The plants are tested against two conditions and a control group. *GreenhouseUnit1* functions as a control group, and is being measured under the same conditions as the musical conditions. In *GreenhouseUnit2,* the five PMFC's are exposed to three hours of 70's and 80's rock music - these songs are a compilation of artist among which Led Zeplin, The Rolling Stones, Guns and Roses and

Rage Against the Machine. Characterized by heavy drums and loud guitars, these songs are based upon an western tonal system. The western tonal system is based up on an fixed octave division into twelve equal intervals and is a limited scale. In 1975, Dorothy Retallack exposed plants to rock music and observed the plants during several weeks. Retallack noticed that the plants started to lean away from the audio source. Why this was happening could not be explained but Retallack assumed that it might have something to do with the percussions and amplified electric guitars present in rock music (Tompkins and Bird, p. 150).

The PMFC's in GreenhouseUnit3 are exposed to three hours of Indian Gandharva Veda music. These hymns are also referred to as 'The Eternal Music of Nature' and are traditionally played on several classic Indian instruments like the flute, violin harmonium and veena. Previous research conducted in 1973 by Dr. T.C. Singh at the University of Annamalai in India, showed that *raga's* have a frequency that stimulates organogenesis in *Hydrilla* plants (Tompkins and Bird, p. 146). The *raga* is a traditional form of South Indian devotional song and has a tonal system which can produce a deep religious feeling and specific emotions in a listener (Tompkins and Bird, p. 146). Dr. T.C. Singh found that plants listening to the *raga's* produced an average of 72 percent more leaves than the control plants, and had grown 20 percent higher. Furthermore, it is said these songs match the frequency of the day/night time as occurring naturally in the earth's atmosphere, listening to these Vedas at the right time therefore aligns the audio frequency with the natural environment in real-time.

In order to understand the differences in these two musical conditions, a frequency spectrum analysis is done using Audacity.

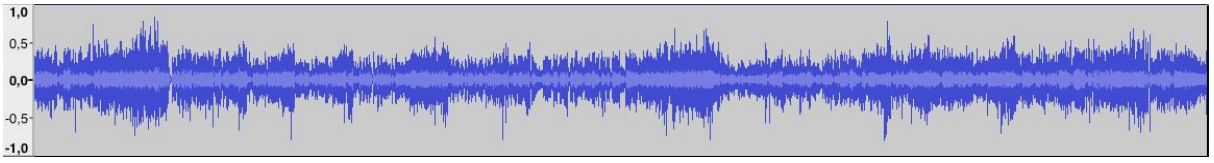


Figure 4. Vedic Music

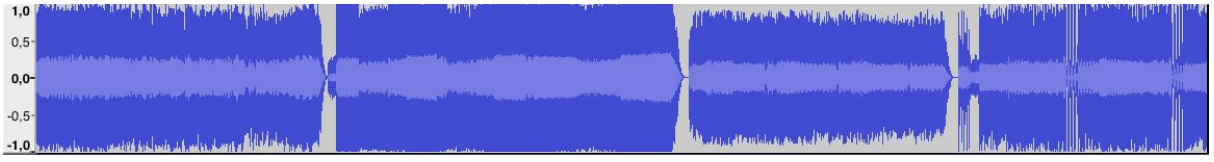


Figure 5. Rock Music

IV Hardware

In order to carefully monitor the plants, all of the measurements are automatized using an Arduino WIFI board and various sensors. Sensors used (and data measured) are light intensity, soil humidity, air humidity, temperature and voltage production (in mV). In order to measure current, the mV

production and the resistance of the sensor (30k Ohm) is used to calculate the current (A) production using the following formula:

$$I_{(A)} = V_{(V)} / R_{(\Omega)}$$

The Schematic for building the arduino board can be found in figures 6, 7 and 8 below. An arduino WIFI board is used as it connects directly to Mediamatic's WIFI and logs all data real-time in Google spreadsheets (see figure 9). for each greenhouse, one of these spreadsheet is formed (so Greenhouseunit1, Greenhouseunit2 and Greenhouseunit3).

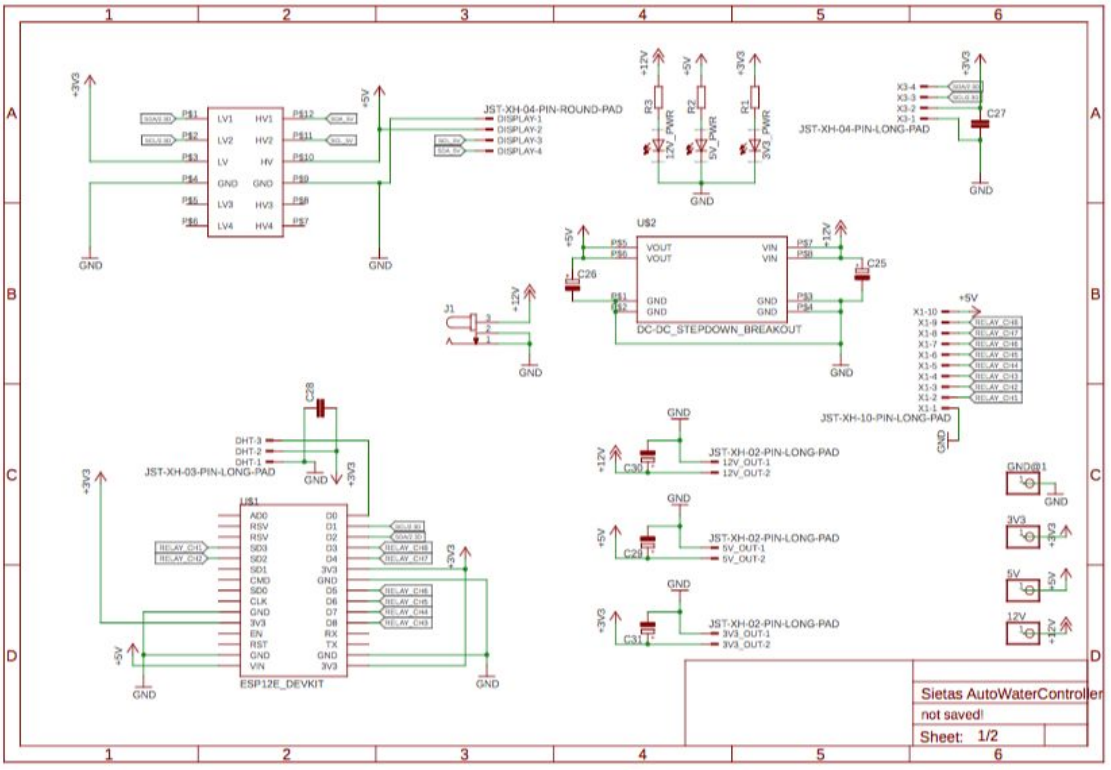


Figure 6. Schematic sensors

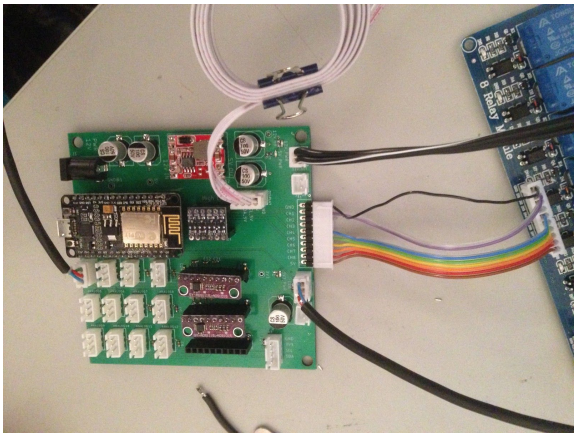


Figure 7. Picture of sensor board

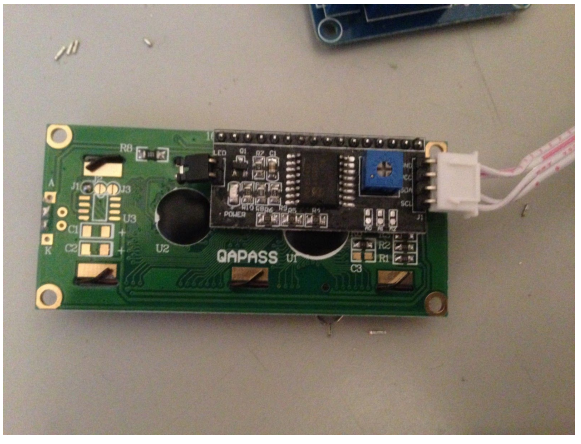
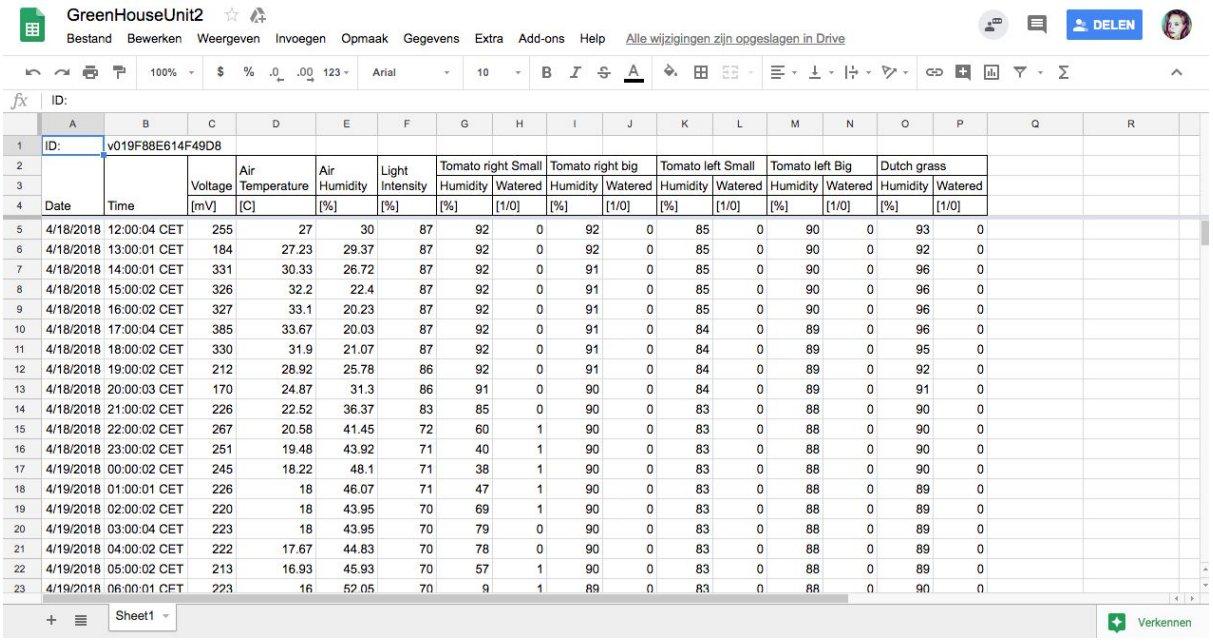


Figure 8. Picture of Arduino WIFI board



GreenHouseUnit2

Bestand Bewerken Weergeven Invoegen Opmaak Gegevens Extra Add-ons Help Alle wijzigingen zijn opgeslagen in Drive

DELEN

ID:

ID:	v019F88E614F49D8														
						Tomato right Small		Tomato right big		Tomato left Small		Tomato left Big		Dutch grass	
		Voltage	Air Temperature	Air Humidity	Light Intensity	Humidity	Watered	Humidity	Watered	Humidity	Watered	Humidity	Watered	Humidity	Watered
Date	Time	[mV]	[C]	[%]	[%]	[%]	[1/0]	[%]	[1/0]	[%]	[1/0]	[%]	[1/0]	[%]	[1/0]
4/18/2018	12:00:04 CET	255	27	30	87	92	0	92	0	85	0	90	0	93	0
4/18/2018	13:00:01 CET	184	27.23	29.37	87	92	0	92	0	85	0	90	0	92	0
4/18/2018	14:00:01 CET	331	30.33	26.72	87	92	0	91	0	85	0	90	0	96	0
4/18/2018	15:00:02 CET	326	32.2	22.4	87	92	0	91	0	85	0	90	0	96	0
4/18/2018	16:00:02 CET	327	33.1	20.23	87	92	0	91	0	85	0	90	0	96	0
4/18/2018	17:00:04 CET	385	33.67	20.03	87	92	0	91	0	84	0	89	0	96	0
4/18/2018	18:00:02 CET	330	31.9	21.07	87	92	0	91	0	84	0	89	0	95	0
4/18/2018	19:00:02 CET	212	28.92	25.78	86	92	0	91	0	84	0	89	0	92	0
4/18/2018	20:00:03 CET	170	24.87	31.3	86	91	0	90	0	84	0	89	0	91	0
4/18/2018	21:00:02 CET	226	22.52	36.37	83	85	0	90	0	83	0	88	0	90	0
4/18/2018	22:00:02 CET	267	20.58	41.45	72	60	1	90	0	83	0	88	0	90	0
4/18/2018	23:00:02 CET	251	19.48	43.92	71	40	1	90	0	83	0	88	0	90	0
4/19/2018	00:00:02 CET	245	18.22	48.1	71	38	1	90	0	83	0	88	0	90	0
4/19/2018	01:00:01 CET	226	18	46.07	71	47	1	90	0	83	0	88	0	89	0
4/19/2018	02:00:02 CET	220	18	43.95	70	69	1	90	0	83	0	88	0	89	0
4/19/2018	03:00:04 CET	223	18	43.95	70	79	0	90	0	83	0	88	0	89	0
4/19/2018	04:00:02 CET	222	17.67	44.83	70	78	0	90	0	83	0	88	0	89	0
4/19/2018	05:00:02 CET	213	16.93	45.93	70	57	1	90	0	83	0	88	0	89	0
4/19/2018	06:00:01 CET	223	16	52.05	70	9	1	89	0	83	0	88	0	90	0

Sheet1

Verkennen

Figure 9. Data logging in Google Sheets

V Experiments - Analytical Techniques

In analyzing all data - graphs are formed to create an understanding of the correlations between the fluctuating weather conditions are PMFC productivity (ADD ANOVA test results).

VI Results and discussion

Cumulative results of the PMFC show that the control group obviously did best. First month the Vedic music performed best, but then got caught up by the Rock music (see figure 10).

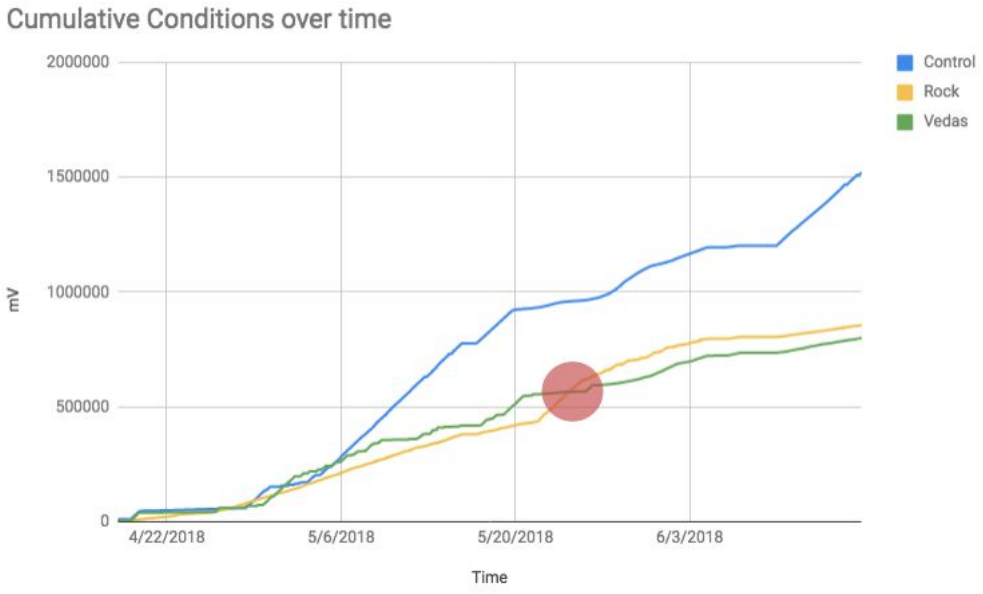


Figure 10. Cumulative data for each condition over time

However, the cumulative data does not allow us to see what actually happened during the two month, let alone have a greater understanding of the data. So let's zoom in a bit.

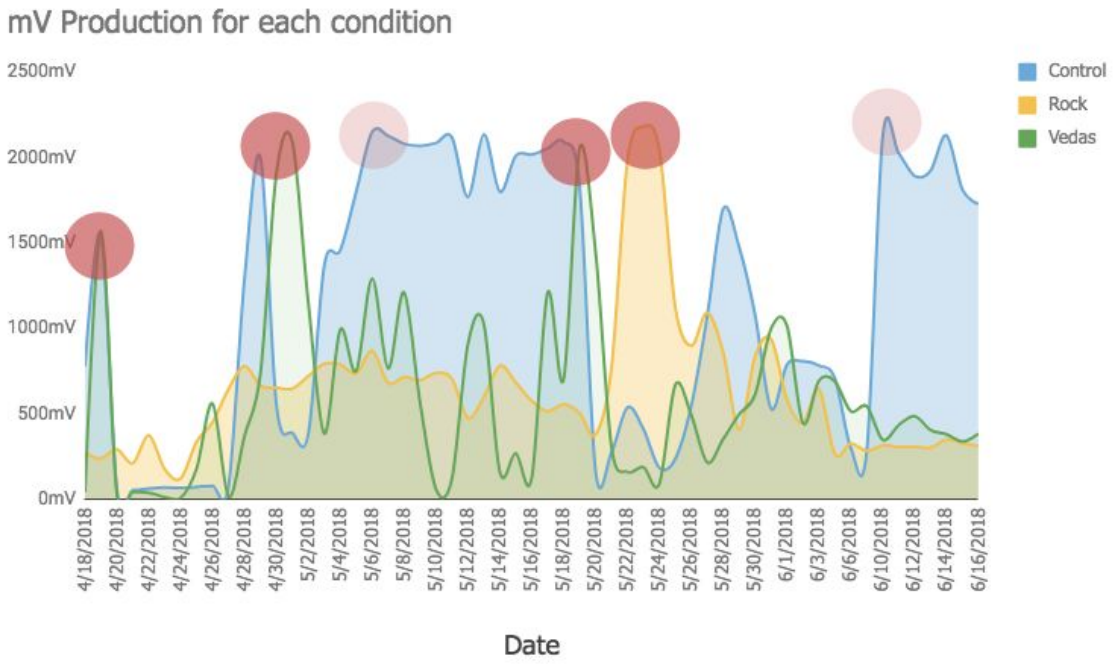


Figure 11. mV Production for each condition over time

VI.I First Month

Spike #1 We immediately see a up spike in the beginning of the experiments. the weather graph shows that It was 31 degrees in the greenhouses at night and air humidity was around 40%. Interestingly, this upspike in the Vedic group occurs when the music start playing at 00:00 at night. Curiously enough, the Rock condition shows the opposite, here we see a decrease in energy and current at the exact same time; when the rock music starts playing. Note however that we can also observe this up spike in the control group.

Spike #2 Again a spike in the Control group at night, when it is 12 degrees combined with a very high air humidity (50%). A little later, there an up spike occurs in the Vedic condition at night, at 00:00 when the music starts playing, however it is quite cold (10 degrees) and the air humidity is very low (26% degrees). This forms a pattern for 3 nights in a row - whereas we can observe a downspike in the Rock condition during these days. This seems to suggest that the Vedic music helps the plants in time that the weather is very cold.

Spike #3 A up spike which lasts for several days i the Control group: weather shows that it it is very warm these days (around 35 degrees in the greenhouse combined with a high air humidity at night). These effects are not observed in both musical conditions however.

VI.II Second Month

Spike #4 Again an up spike in the Vedic condition when the music start playing at 00:00 at night, 25 degrees. At the same time we observe a down spike in the Rock condition for several days.

Spike #5 A up spike in the energy and current production of the Rock condition. Average temperature around 25 degrees during daytime, around 12 at night. Interestingly, a one PMFC plant died in this period. Important to understand that when a plant dies, the nutrient of the plant get absorbed by the ground and therefore we might see a spike in energy production as these nutrients are consumed by the microbes in the cell. This lasts a few days, after which we see a steep decrease of energy production for the time lasting.

Spike #6 The final days of the experiments the weather is very warm - sometimes temperature in the greenhouses goes above 40 degrees with a very high air humidity at night. The only group that seems to profit from this is the control group - whereas both musical conditions shows a decrease.

Overall we observed that more energy is produced at nighttime as photosynthesis takes place during light hours. This process takes time ofcourse, and therefore often a spike in voltage production takes place at night, when the rhizodeposits have infused the soil for the microbes to consume.

Vedic Music seems to aid the plants when they endure bad weather conditions, whereas Rock music makes matters worse. The most energy efficient group however is to be the control group as this groups appears to be more stable in in energy production over time than any of the musical conditions.

Interestingly, when comparing these experiments with the experiments conducted by Dr. T.C. Singh and Dorothy Retallack - we can visually observe the difference between the greenhouses.

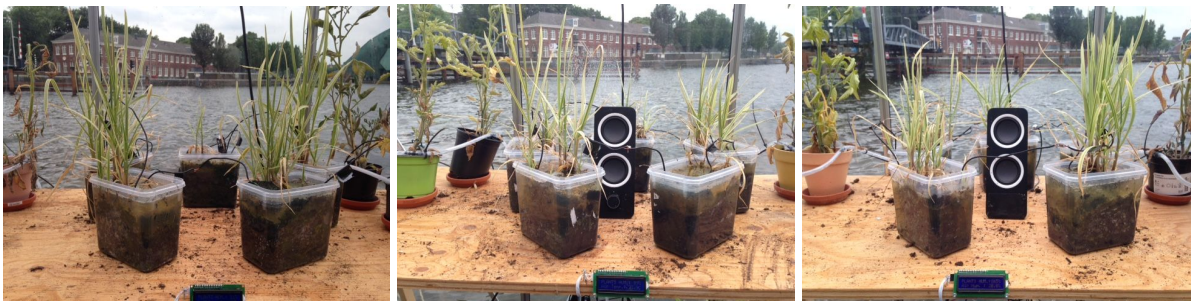


Figure 12. Control group, rock condition, vedic condition

The control group plants are growing stable, whereas the Rock condition shows frail (and one plant even died) leaves that slightly move away from the audiosource. The Vedic condition plant show more leave surface and appear to grow straight and lush. Just looking at the data obviously shows

some discrepancies with the plant appearance within the experiments.

VII Discussion and Further Research

The results seem to suggest that frequencies in music, can affect cell growth or cell degradation in plants. However, a lot of questions are yet unanswered. In order to answer these, further research should be done. As these experiments were very small scale - they form a first exploration into this subject. New experiments could have a bigger setup with more plants, in a an controlled environment where also the climate conditions would be kept the same. Furthermore, I would like to test with various playing times for the music, as the vedic theories show that playing music continuously could possibly benefit the plants.

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