ISA STEAM Year 10-13: Design a system to capture rainwater to irrigate and regreen deserts.

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Aim:

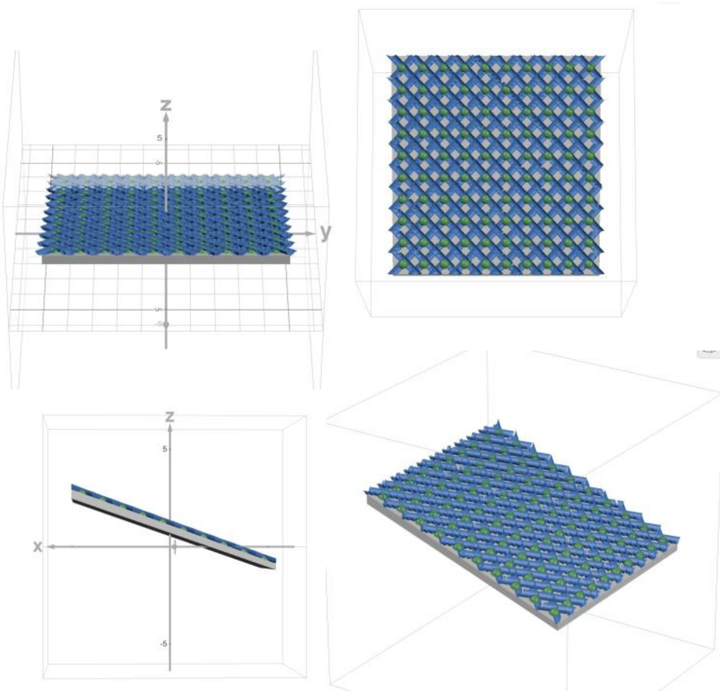
- To design a system to capture rainwater
- To use a reliable irrigation system with collected rainwater
- Assess the efficiency and effectiveness of the different irrigation systems
- Assess the success of the rainwater collection system

Introduction:

The desert is a vast arid land that makes up around 33% of the Earth's land surface. The desert is almost uninhabitable due to the lack of water which is essential for life. With the growing population of humanity much more space is needed to not only provide shelter but also food and one of the ways which this may be possible is through the regreening of the desert. This idea of transforming a wasteland such as the desert into an area fit to live and even grow food is what really drew me in. The Great Green Wall is an African lead initiative to combat desertification launched by the African Union in 2007 and with the ever-looming effects of global warming projects like this become more significant everyday. **Tarras F. and Benjelloun M.** said this in their paper ***'The effects of water shortages on health and human development'***: *"Shortages of water could become a major obstacle to public health and development. … The global health burden associated with these conditions is staggering, with an estimated 1.6 million deaths every year from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene."* Modelling and investigating the real world has always intrigued me and that is why I decided to take part in this competition; not only to create a potential solution to a growing problem but to also learn more about the world I live in.

Design of rainwater collection system:

The Namib Desert Beetle is an insect found in the Namib desert along the southeastern coast of Africa. It inspired the design of my rainwater collection system. The beetle has a back made of chitin that has textured hydrophilic bumps and waxy hydrophobic troughs which I mimicked in my design. The hydrophobic regions are coated in an epicuticular wax that creates a water repelling surface, opposing the hydrophilic regions which are due to the absence of the epicuticular wax, exposing the the chitin protein cuticle which acts as a nucleation site for the water.



The Namib Beetle has an uncanny ability to collect water from fog which is abundant in the desert and transform it into liquid water that it uses to survive. This mechanism was the basis for my water collection system design. The Namib beetle uses the bumps and grooves on its back to condense fogs into water droplets. It does this through the use of hydrophobic and hydrophilic regions this is the idea that I used for my design. I created a surface that can be laid across desert land and collect rainwater which then leads to an underground irrigation system. The whole surface is sloped 20° toward prevailing rain direction to collect the maximum volume of rainwater. The hydrophilic regions are rounded hemispheres coloured in green in the diagram with a diameter of 6mm spaced 6mm apart. The hydrophilic regions would be made of concrete coated in styrene-acrylic copolymer emulsion which I chose because once it has dried on concrete it becomes water insoluble. Furthermore, the acrylic ester side chains provide hydrogen bonding sites for water and concrete making it suitable. It is also stabilised by polar groups from ions when in water. There are also hydrophobic regions that will be used to direct the water collected to the channels (in blue on the diagram) that will transport it to the irrigation system. The hydrophobic region is arranged in channels that in chevron pattern to reduce lateral speed and increase the speed of gravity driven flow. The channels are 6mm width and 6mm depth**.** The hydrophobic region would be made out of concrete coated in silane. The silane coating is crucial because it is what gives the concrete the hydrophobic property. Silane is a small molecule that has one end that attaches well to concrete and the other that is hydrophobic coating the pores of concrete in a water repelling layer. This is because of the polarity difference between the silane coating and water since water is polar and silane is non-polar allowing the water to bead up and run off the surface of the concrete. The entire system would be comprised of 4 square surfaces tilted toward a central drainage system with a collection system. Water would be stored vertically to decrease space needed to store the water. The system can then be replicated over a large area to maximise rainwater collection. I used the Desmos 3D graphing calculator and mathematical equations to create the 3D models of my water collection system.

<u>Cost:</u>

Making a water collection system on a scale large enough to regreen a desert requires the consideration of cost effectiveness as the profit from the result of the irrigation must be higher than the cost of the system itself. This is why for the hydrophilic regions I chose to use concrete coated in styrene-acrylic copolymer emulsion. I chose to use concrete as the base because it is cheap in bulk amounts and silane coated concrete is easily accessible. I chose styrene-acrylic copolymer emulsion because the acrylic part introduces polar groups that make it hydrophilic and once dried is water insoluble so replacement would not have to be regular. Concrete is also the material I chose for the hydrophilic regions. This would be cost effective as the surfaces would be poured into shape in one singe sheet of concrete filling a mould and then the styrene-acrylic copolymer emulsion could be applied to the designated hydrophilic regions: reducing labour costs and in turn overall cost.

Irrigation Methods:

I investigated 3 different irrigation methods to decide which would be most effective alongside my water collection system. The 3 methods I explored were: Subsurface Drip Irrigation (SDI), Olla Irrigation and Drip Irrigation. I chose these 3 methods because they are easily accessible and relatively inexpensive to execute.

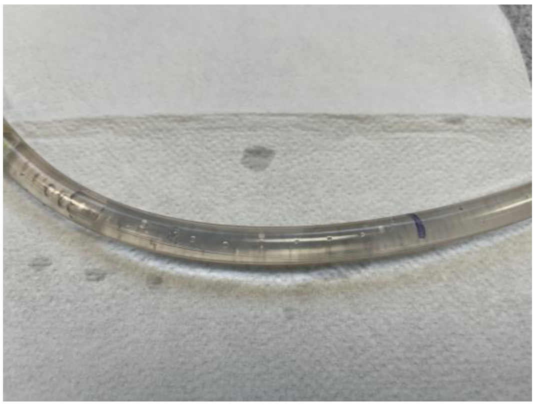


Figure 1

Figure 2

In each method I used soil mixed with water to make it damp in a beaker and administered a known volume of additional water to each pot. In total I had 9 pots; 3 of each method and in each I planted 25 mustard seeds. For the Olla irrigation method, I planted a terracotta pot under the surface of the soil and filled it with the total 30ml of additional water at the start of the experiment. The terracotta pot slowly secreted the water into the soil over the 8 days which the mustard seeds grew. For the subsurface drip irrigation poked holes in pipes (as shown in Figure 1) and buried the under the soil. I filled each pipe with 10ml of water on days 1, 3 and 6 to give enough time for the water to fully seep from the pipe into the soil. Finally, for the drip irrigation method I used a large cotton pad on which I applied 15ml of water to on days 1 and 4. I tested the use of cotton, nylon and muslin mesh (see Figures 3, 4 and 5) alongside the cotton pads however I chose the cotton pads as the water dripped the slowest from these.

Figure 3

Figure 4

Figure 5

Method:

Olla irrigation:

- Mix 120g of soil with 75ml of water
- Put 90g of soil into beaker and reserve 30g
- Use terracotta pot to push down the soil and create a cavity for it to sit in
- Place terracotta pot into soil
- Measure 30ml of water in a measuring cylinder and add to terracotta pot
- Cover with cotton pad
- Put reserved 30g of soil on top of cotton pad and pack down
- Plant 25 soaked mustard seed into the top of the beaker
- Allow to grow for 7 or more days

SDI irrigation:

- Measure out 15cm of tubing
- Use a needle to poke 25 evenly disturbed holes into it. Measure with a ruler
- Put blue tack at one end of the pipe and make sure it is suctioned and secure
- Mix 120g of soil with 75ml of water
- Put pipe into beaker and make sure it is twisted round as evenly as possible with one end sticking out of the beaker
- Put prepared soil into beaker with pipe and pack down as tightly as possible but ensure no soil enters the end of the pipe sticking out
- Plant 25 soaked mustard seeds into soil
- Fill the pipe with 10ml of water using a syringe
- Leave mustard seeds to grow for 7 days and ensure to add 2 more doses of 10ml of water at even intervals during the 7 days

Drip irrigation:

- Mix 120g of soil with 75ml of water in a beaker
- Plant 25 soaked mustard seeds into prepared soil
- Cover with a large cotton pad
- Measure 15ml of water with a syringe
- Add water to cotton pad
- Leave seeds to grow and uncover cotton pad when growth has started
- Use cotton pad to administer water on day 3 or 4 and the remove once done

Apparatus:

Materials and Apparatus used	Uncertainty	Quantity	Justification
Beaker	N/A	x9	Used to hold soil and mustard seeds as they grew
Pipe	N/A	x3	Used in the SDI irrigation system to provide water to the plants
Needle	N/A	x1	To poke holes in the pipe used for the SDI irrigation system
Terracotta Pot	N/A	x3	To hold water in the Olla irrigation system
Syringe	$\pm 0.01ml$	x1	To measure the volume of water administered to pipes and cotton pads
Measuring Cylinder	$\pm 0.1ml$	x1	To measure water to initially dampen soil and put in terracotta pots
Cotton Pads	N/A	x6	To cover terracotta pots under soil and used as irrigation method in drip irrigation system
Soil Moisture Meter	$\pm 0.5m^3m^{-3}$	x1	To measure soil moisture in each pot
LED Lamp	N/A	x1	To provide light to the plants
Filament Lamp	N/A	x3	To provide light and warmth to the plants
Incubator	N/A	x1	To provide warmth to the plants
Scissors	N/A	x1	To cut pipes to desired length

Risk assessment

Apparatus / Material	Hazard(s)	Risk Level	Control Measures
Beakers (x9)	Breakable glass → cuts if broken	Low	Handle with care; place on stable surfaces; clear up breakages using dustpan & brush only
Plastic Pipes (x3)	Sharp edges after cutting; tripping hazard if left on floor	Low	Cut carefully using scissors; ensure ends are smooth; store safely
Needle (x1)	Sharp object → risk of puncture injury	Medium	Only the teacher or trained student to use; keep capped when not in use; store in labelled container
Terracotta Pots (x3)	Breakable → shards cause cuts; heavy if dropped	Low–Medium	Handle with care; do not place near edges of benches; inspect for cracks before use
Syringe (x1)	Potential misuse; small parts; contamination risk	Low	Use only for water; supervise use; store clean and dry
Measuring Cylinder (x1)	Breakable glass → cuts if dropped	Low	Use on a flat surface; avoid force; place away from edges
Cotton Pads (x6)	Minimal hazard	Low	Keep dry before use; ensure clean pads
Soil Moisture Meter (x1)	Sharp probe can cause skin puncture if misused	Low	Insert probe gently; avoid contact with skin; supervise use
LED Lamp (x1)	Electrical hazard; overheating if poorly ventilated	Low	PAT-tested; keep away from water; ensure cables are not trip hazards
Filament Lamps (x3)	Can become very hot → burn risk; electrical hazard	Medium	Do not touch when on; allow to cool before handling; keep away from flammable materials; use heat-proof mats if needed
Incubator (x1)	High heat → burn risk; electrical hazard	Medium	Only staff operate temperature controls; avoid touching heating elements; PAT-tested
Scissors (x1)	Sharp edges → cuts; risk when cutting pipe	Low	Use with care; cut away from body; store securely
Soil and Water	Slipping hazard if spilled; contamination risk	Low	Clean spills immediately; wash hands after handling

Results:

Pots A, B and G were the Olla irrigation method, pots C, D and H were the drip irrigation method and E, F and I were the SDI irrigation method.

Pots	Height of Seedlings Grown (cm)																Average Height of seedlings (cm)
A	10.0	5.0	2.9	6.2	6.0	6.1	7.0	4.2									**5.925**
B	4.9	4.0	3.5	7.2	5.0	4.1											**4.783**
C	7.3	8.6	7.2	7.4	7.4	7.4	7.5	9.4	9.6								**7.978**
D	7.6	7.9	7.8	8.2	6.7	4.5	10.0	10.8	8.2	9.0	7.5	4.4					**7.717**
E	8.3	6.6	8.0	8.6	8.1	8.8	8.4	8.0	8.3	8.2	8.0	9.0	9.0	6.9	5.8	3.9	**8.260**
F	8.7	6.5	7.3	6.0	4.0	3.9	3.7	6.5									**5.825**
G	6.5	3.5	6.7	6.0	3.9	5.2	3.2	3.5									**4.813**
H	7.0	8.9	9.6	9.0	9.6	6.5	6.2	8.9	9.1								**8.311**
I	6.3	7.8	8.4	8.9	8.0	7.8	5.9	8.1	6.9								**7.567**

Table 1 Heights of seedlings grown in different irrigation types

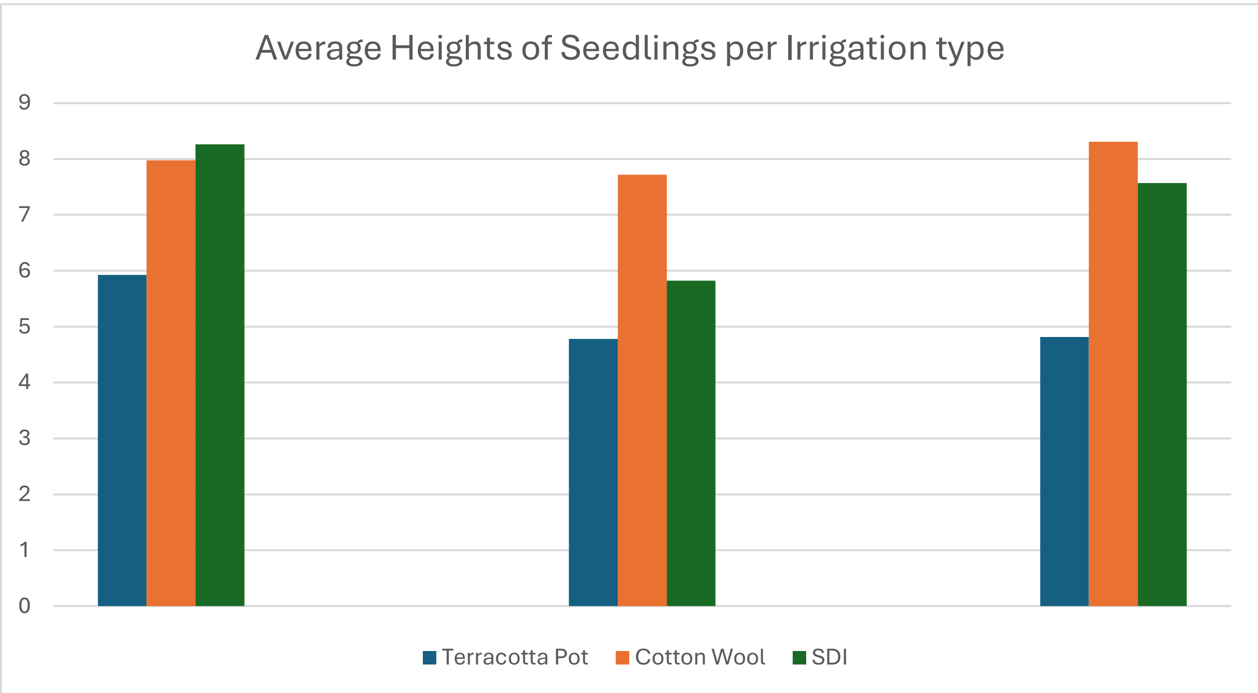


Chart 1 Average heights of seedlings grown in different irrigation types

Pots	Percentage Germination (%)	Change in soil moisture (m^3m^{-3})
A	32	-4
B	24	-2
C	36	-1
D	48	-1
E	60	+1
F	32	-2
G	32	-2
H	36	+2
I	36	-1

Table 2 Percentage germination and change in soil moisture of seedling grown in different irrigation types

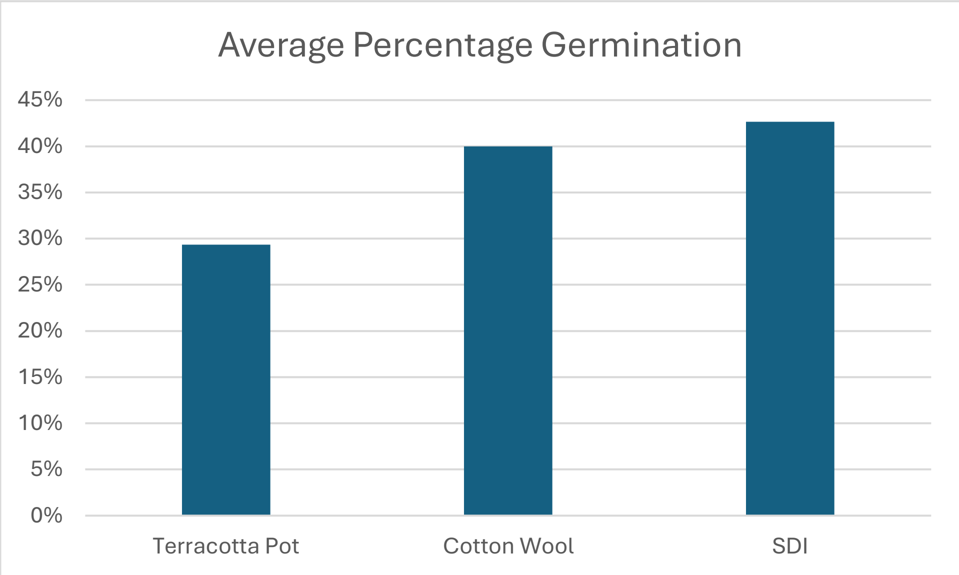


Chart 2 Average percentage germination of seedlings grown in different irrigation types

Evaluation:

Figure 6

Figure 7

While checking upon the growth of the mustard seeds, I realised that over the weekend the heating would be turned off in the school and the drop in temperature especially during the winter would drastically affect the growth of the seeds. During the nights of the school week the pots were kept in an incubator but from there would be a lack of light which also affected the growth of the seeds. So, on day 3 I made the decision to switch the LED lamp I was originally using to provide light to to seedlings to filament lamps so that both light and warmth could be provided and the temperature would stay constant (shown in Figures 6 and 7).

Conclusion:

Overall, I was extremely pleased with the results of my experiment. The results showed a reliability of the irrigation systems meaning that they would be very useful in the prospect of regreening the desert. I was able to observe the benefits of each method and that has led me to conclude that the Subsurface Drip Irrigation method is the best. While it did not have the highest seedling height or soil moisture it did have the highest seed germination percentage and when looking to regreen an area I think this is the most important variable as there may have been other factors affecting the rate of growth that I ay not have recognised or been able to control.

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