Oil in Soil: Acacia Trees on Mars

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Abstract

Martian regolith contains perchlorates (chlorine based compounds) and heavy metals toxic to plants and humans (amongst other obstacles preventing plant growth on Mars), (Henrique de Oliveira 2025). The Evrona Nature Reserve is a protected natural area in the Arava (southern Israel), (Gruner et al. 2015). The Evrona Nature Reserve has been affected by two oil spills from the same pipeline, with the first happening in July 1975 and the second happening in December 2014 (Nothers et al. 2017). Plants can suffer lethal or sublethal effects from oil spills, which can occur during contamination or shortly after. Oil pollution can also reduce germination, which affect plant communities long term (Ferrante et al. 2021). The most important plants in the Arava's ecological system are both the Acacia trees. They are defined as a key species and influence both the biotic and abiotic component of the habitat (Gruner et al. 2015). Oil pollution from these spills had a stronger effect on seedlings than on adult trees. The adult trees were mildly affected by oil pollution while the effects that the spills had on the younger trees could cause a long term reduction in the region acacia population (Ferrante et al. 2021). Phytoremediation is the usage of plants to clean up contaminated areas (*A Citizen's Guide to Phytoremediation* 2012). This experiment will observe Evrona's contaminated soil before and after attempting to germinate a seed in it. This theoretical paper is intended to be the seventh in a series connecting the Negev Desert's environment to Mars's with the eventual goal of the Negev Desert becoming an area for Martian simulation and experimentation in preparation for future missions.

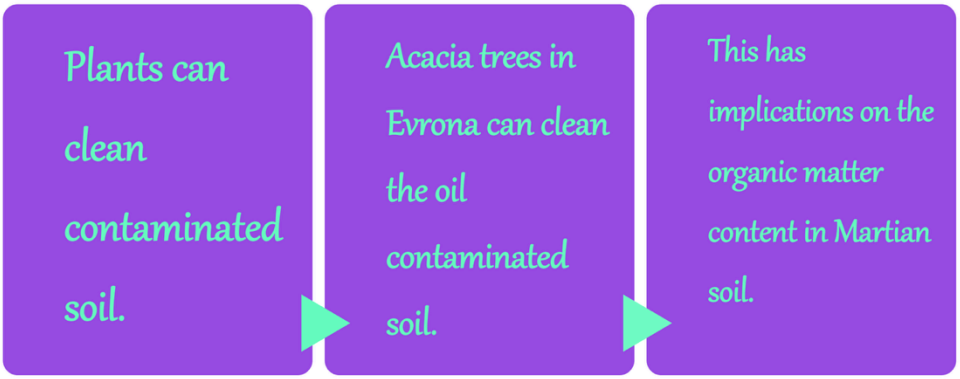
1. Introduction

Martian regolith contains perchlorates (chlorine based compounds) and heavy metals toxic to plants and humans (amongst other obstacles preventing plant growth on Mars), (Henrique de Oliveira 2025). Concentrations of perchlorate vary spatially and with depth, with some areas having soil containing 2%. Both Martian regolith simulant and high concentrations of perchlorate (2%) prevent plant growth. While plants can germinate in potting soil with low concentrations of perchlorate (1%), they cannot germinate in Martian regolith simulant containing perchlorate.

The Evrona Nature Reserve is a protected natural area in the Arava (southern Israel, around 15 km north of Eilat), (Gruner et al. 2015). The region is hyper arid with low precipitation (15-50 mm annually) and high temperatures. Deserts are the most prone region to terrestrial crude oil contaminations. The Evrona Nature Reserve has been affected by two oil spills from the same pipeline, with the first happening in July 1975 and the second happening in December 2014 (Nothers et al. 2017). “Oil can persist in terrestrial environments for decades, with dramatic effects on the vegetation”. Plants can suffer lethal or sublethal effects, which can occur during contamination or shortly after. Oil pollution can also reduce germination, which affect plant communities long term (Ferrante et al. 2021). Ecological effects are still present even 40 years after the spill, such as with the lack of Acacia germination in the areas with contaminated soil (Nothers et al. 2017). The most important plants in the Arava’s ecological system are both the Acacia trees. They are defined as a key species and influence both the biotic and abiotic component of the habitat (Gruner et al. 2015). Oil pollution from these spills had a stronger effect on seedlings than on adult trees. The adult trees were mildly affected by oil pollution while the effects that the spills had on the younger trees could cause a long term reduction in the region acacia population (Ferrante et al. 2021).

Phytoremediation is the usage of plants to clean up contaminated areas (*A Citizen’s Guide to Phytoremediation* 2012). This experiment will observe Evrona’s contaminated soil before and after attempting to germinate a seed in it.

My (Correlation) Predictions



2. Literature Review

2.1 Toxic Soil on Mars

"Scaling agricultural systems from experimental setups to large-scale production on Mars is essential to support a growing human presence." Soil based food systems that incorporate Martian regolith have the potential to support sustainable agriculture. They provide a circular use of resources by using the non-edible plant parts and food waste as compost to enrich the regolith with nutrients. Mars's thin atmosphere composed mostly of carbon dioxide (CO2, 93.5%), with nitrogen (N2) and frozen water subsurface and in polar ice caps, provide elements for an agricultural food system. However, Martian regolith contains perchlorates (chlorine based compounds) and heavy metals toxic to plants and humans (amongst other obstacles preventing plant growth on Mars), (Henrique de Oliveira 2025).

Mars's atmospheric composition	Earth's atmospheric composition
95.3% carbon dioxide (CO2)	78% nitrogen (N2)
2.7% nitrogen (N2)	21% oxygen (O2)
1.6% argon (Ar)	0.9% argon (Ar)
0.13% oxygen (O2)	0.04% carbon dioxide (CO2)

Table 1: Comparison of Mars's atmospheric conditions to Earth's (Henrique de Oliveira 2025), (Introduction to the Atmosphere, n.d.).

Mars's surface pressure is around 0.6% of Earth's atmospheric pressure. The lack of an ozone layer will also expose the crops to high levels of radiation. Mars experiences significant temperature fluctuations due to its thin atmosphere and distance from the sun. Surface temperatures can range from 20 degrees C during the day near the equator to -125 degrees C near the poles during winter nights. Mars also receives around 43% the amount of solar energy that reaches Earth's surface, which can limit photosynthesis. Greenhouses containing advanced control systems are essential to maintain stable temperatures, adequate humidity, and suitable light levels for photosynthesis in an environment where none of these factors occur naturally. They must also protect the plants from the high levels of cosmic and solar radiation that enter Mars's thin atmosphere (Henrique de Oliveira 2025).

The surface of Mars is covered in a layer of fine-textured soil compositionally similar to atmospheric dust. The soil contains silicon, iron, aluminum, magnesium, calcium, titanium, sulfur, and chlorine at unique elemental proportions (it's more rich in sulfur and chlorine compared to soils on Earth). It lacks organic matter and shows strong oxidizing activity, showing rapid chemical decomposition of organic matter. It's rich in amorphous weathered silicate and iron oxide grains but lacks grains of well-developed secondary silicates such as clays. It also lacks carbonates but contains high concentrations of chlorine and sulfur-salt minerals

(evaporites) and magnetically active minerals. The Mars rovers Spirit and Opportunity returned evidence showing that water-modified weathered rocks contain the minerals jarosite. Jarosite forms in aqueous environments of highly acidic sulfate solutions, which on Earth is typically near mine spills. Martian soil has characteristics that differentiate it from regolith, such as the chemical interactions with the atmosphere and hydrosphere, which alter the mineralogy and reactivity of the top layer of the Martian lithosphere, making it more chemically reactive and forming the global Martian soil layer (pedosphere), (Banin 2005).

Perchlorate (ClO_4^-) is found in Martian regolith at levels toxic to plants, preventing the development of agriculture on Mars. Plants potted in soil are able to germinate in 1% perchlorate but had restricted growth and decreased leaf and biomass. Some plants are also able to germinate in regolith simulant without perchlorate, but with reduced growth. A way to develop Martian agriculture can be by using regolith, since it's derived from rocks and it would be impractical to transport soils from Earth. This would allow for agricultural expansion. Perchlorate on Mars may have originated from atmospheric chemical reactions of chlorine compounds with photochemically produced ozone or other non-gas phase processes. After its formation and deposition on Mars's surface, it formed Mg- and Na- perchlorate salts in a process that has been occurring for at least three billion years. Perchlorate salts probably cover Mars's entire surface due to atmospheric circulation and wind transport of sediments. Concentrations of perchlorate vary spatially and with depth, with some areas having soil containing 2%. Both Martian regolith simulant and high concentrations of perchlorate (2%) prevent plant growth. While plants can germinate in potting soil with low concentrations of perchlorate (1%), they cannot germinate in Martian regolith simulant containing perchlorate. The presence of perchlorate reduces plant productivity. However, perchlorate concentration of 1% does not have an increased effect compared to 0.5%. Perchlorate leads to smaller leaf area, but this is not concentration dependent. The pH values of soil solutions remain almost constant. The regolith on Mars needs to be introduced to organic matter because perchlorate also acts as a cementing agent to regolith when reacting with water. With the irradiation of Martian regolith over billions of years and the minerals and particle sizes of regolith, it would probably be equally as or even more reactive to water than analogous experiments done on Earth. Introducing a soil structure to Mars through organic matter would also provide the textural and water holding properties necessary for seed germination and plant growth (Oze et al. 2021).

2.2 Evrona Nature Reserve

The Evrona Nature Reserve is a protected natural area in the Arava (southern Israel, around 15 km north of Eilat), (Gruner et al. 2015). The region is hyper arid with low precipitation (15-50 mm annually) and high temperatures, and water is the main limiting factor of life there (Nothers et al. 2017). The Reserve contains the Evrona Salt Flat, which is a drainage basin for rivers flowing down the Eilat Mountains in the west and the Edom Mountains in the East. Evrona was once a typical salt flat, but after several large earthquakes (with one occurring in 1068), there was a displacement of fault lines which caused the salt flat to rise. The salt flats in the Arava (including the Evrona Salt Flat) have a rich and unique habitat compared to other areas in the Arava. The Salt Flat sustains a large number of species and tropic levels. The margins of the Evrona Salt Flat contain a flora belt (which contains Acacia trees). Other areas sustain reptiles and large mammals, and several species in the area are endangered and close to extinction (Gruner et al. 2015). There was a prolonged drought across the Arava Valley between 1995 and 2009 (Armoza-Zvuloni et al. 2021).

The Evrona Salt Flat's soil has alluvial characteristics (pebbles, gravel), and becomes more sandy and clayey downstream. The area which the oil stain has expanded into is made up of sand and pebble alluvium in the north-western part of the stain, and it's more sandy and silty downstream. The thickness of the soil downstream ranges from a few to tens of meters. The strata of the Southern Arava is lime and dolomite. The stain section of filling (oil filling in the rock cracks) in the southeast can be up to hundreds of meters deep. The Evrona Salt Flat area contains numerous faults in the southeast part of the contamination stain. There is a deep phreatic aquifer in the west and a connection between the surface and the groundwaters. In the east the aquifer is close to the surface (a few meters underground due to extractions and drilling in the area), (Gruner et al. 2015).

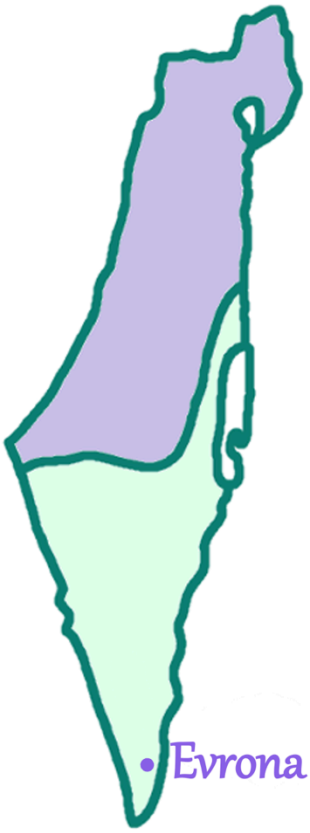


Figure 1: General location of Evrona within the Negev Desert (with the Negev in light green) on a simplified map of Israel (Porat, 2026).

Deserts are the most prone region to terrestrial crude oil contaminations. The Evrona Nature Reserve has been affected by two oil spills from the same pipeline, with the first happening in July 1975 and the second happening in December 2014. The soil in both the contaminated and non-contaminated areas is red brown sandy clay with alluvial pebbles and gravel. Soil moisture is below 2% except for when it (rarely) rains (Nothers et al. 2017).

In July 1975, a leak occurred in the Eilat-Ashkelon pipeline on the western side of the Evrona Salt Flat. Eight to ten million liters of crude oil leaked out and floated east into the Evrona Salt Flat. The oil flowed in streams around 0.5 to 5 m wide and penetrated into the soil to a depth of 10 to 40 cm. There was around 1.5 km of contamination area. The spill occurred in the summer, so some of the oil (the gas and liquid components) evaporated while the remainder formed a hard, asphalt-like crust on the surface of the soil (Nothers et al. 2017). On December 3rd of 2014, around five million liters of crude oil from the oil pipeline of the Eilat-Ashqelon Pipeline Company spilled from East of Be'er Ora to north of the Arava Evrona Nature Reserve. The oil spilled into several ravines and into the margins of the Evrona Salt Flat. The 2014 oil spill had lasted eight minutes until the valve was closed and around 5 million liters of oil continued to flow into the canyons for several more hours. The main toxic components in the oil

were polycyclic aromatic hydrocarbons (PAHs). There was immediately serious damage to the aquatic systems in the region after the spill, which was mainly caused by the toxicity of the chemicals in the oil (Gruner et al. 2015). The spill from 1975 was almost twice as large as the 2014 spill. Both spills were caused by damage to local underground pipelines (Hoai Tran et al. 2017).



Figure 2: Pools of leaked oil in Evrona (Gruner et al. 2015).

2.3 Oil Spill Effects on Wildlife

"Oil can persist in terrestrial environments for decades, with dramatic effects on the vegetation". Plants can suffer lethal or sublethal effects, which can occur during contamination or shortly after. Oil pollution can also reduce germination, which affect plant communities long term. Most terrestrial oil spills occur in deserts, because that's where wells are often located. Desert ecosystems are sensitive and take a long time to recover. Oil pollution changes the soil's physical and chemical characteristics, causes abiotic stress in plants. Oil pollution can reduce transpiration and photosynthesis, alter plant metabolism, and cause oxidative stress. The impact of oil pollution on plants depends on the oil type, soil characteristics, environmental conditions, plant species, and plant developmental stage (Ferrante et al. 2021).

This massive contamination (2014) possibly caused short to medium term extinction of local species in the aquatic systems. The potential implications of the spill on land still remain to be what happens during floods / heavy rain when the oil comes in contact with large quantities of water and the toxic oil being consumed by wildlife in the region. It's estimated that the area to which the oil flowed contained around 300 rodents, 1040 reptiles, 10,000 beetles, and 2,800 spiders as well as all their habitats. Large mammals and birds were affected as well. When crude oil penetrates deep into the ground, it contaminates the soil (and maybe even underground aquifers) with PAHs, which can cause physical, chemical, and microbiological changes. For example, oil contamination decreases the quantity of oxygen in the soil (hypoxia), which affects the microorganisms in the soil, therefore affecting the chemical composition of the soil. PAHs also release gases as they spread in the soil, contaminating the air as well. Sandy / desert soils are characterized by seeping great depths. In sandy desert soils when it rains 15-22 mm, the water can seep into the soil to a depth of around two meters. The oil from the leaks either evaporates, seeps into the land, or is naturally degraded by microorganisms. However, some of the oil crystallizes into solid tar lumps. The oil and its components remain in the environment and continue to influence it a long time after its leak (Gruner et al. 2015).

Crude oil naturally degrades through the physical, chemical, and biological processes over time through plants and microorganisms. However, degradation in deserts occurs more slowly due to the low productivity of plants caused by unpredictable water supply and high temperatures. Ecological effects are still present even 40 years after the spill, such as with the lack of Acacia germination in the areas with contaminated soil (Nothers et al. 2017).

2.4 Acacia in the Arava

The most important plants in the Arava's ecological system are both the Acacia trees. They are defined as a key species and influence both the biotic and abiotic component of the habitat. The Acacias both directly and indirectly influence animals, other plants, and water balance in the region, and dominate the area with a density of up to 200 trees per km^2 (Gruner et al. 2015). They influence soil conditions and plant composition and provide food and shelter to several animals in the region. For example, gazelles primarily eat Acacia leaves in the summer due to the water in their leaves (Nothers et al. 2017). The fungus Mycorrhiza (also found in the Southern Arava and is a common species there), grows on the roots of Acacia trees (Gruner et al. 2015). However, they face aquifer depletion for agriculture, the conversion of natural land into agricultural land, seed infestation from beetles, and reduced precipitation. In the Evrona Reserve, an additional threat is the oil spills from an underground pipeline (Hoai Tran et al. 2017).



Figure 3: (https://minecraftbedrock-archive.fandom.com/wiki/Acacia_Trees)

Acacia trees are native to arid environments in Africa and the Arabian Peninsula, where they are a keystone species supporting the local animals and plants. Acacia Tortilis and Acacia Raddiana are the only tree species growing in the Evrona Nature Reserve. Acacia Tortilis is found across tropical and subtropical regions in Africa and the Arabian Peninsula. Acacia Raddiana is typically considered a subspecies of Acacia Tortilis, except in Israel where the two species are morphologically and genetically distinguishable and have different local distributions. Both species are found in the north of the Evrona Nature Reserve, but only Acacia Tortilis is found in the south of the reserve. Acacia trees are slow growing and long living, and

older Acacia trees can survive for around 600 years (Ferrante et al. 2021), (Armoza-Zvuloni et al. 2021).

Prior to the 2014 oil spill, there were around 100 Acacia Radiana in the Southern Arava and around 270 Acacia Tortilis, meaning that they are considered a common species in the region. The 2014 leak directly damaged 84 acacias directly (meaning the oil reached their trunk) and endangered another 205 acacias. Acacias have a deep root system which the oil can migrate to over time and a peripheral root system with a radius of up to three meters. The acacia roots are in symbiosis with fungi (mycorrhiza), which help the trees absorb nutrients and minerals, in processes of nitrogen fixation, and in coping with saline conditions. This means that the seeping oil can affect the tree's function by damaging the symbiotic fungi on its roots. As for the 1975 leak, the Acacias in the center of the flow appear to be vital and healthy and there does not seem to be a difference between the trees in contaminated and clean canyons. Several plants store PAHs in their tissues, with some storing them in their leaves and roots. PAHs can cause oxidative stress which can cause a decrease in the plant's function (Gruner et al. 2015).

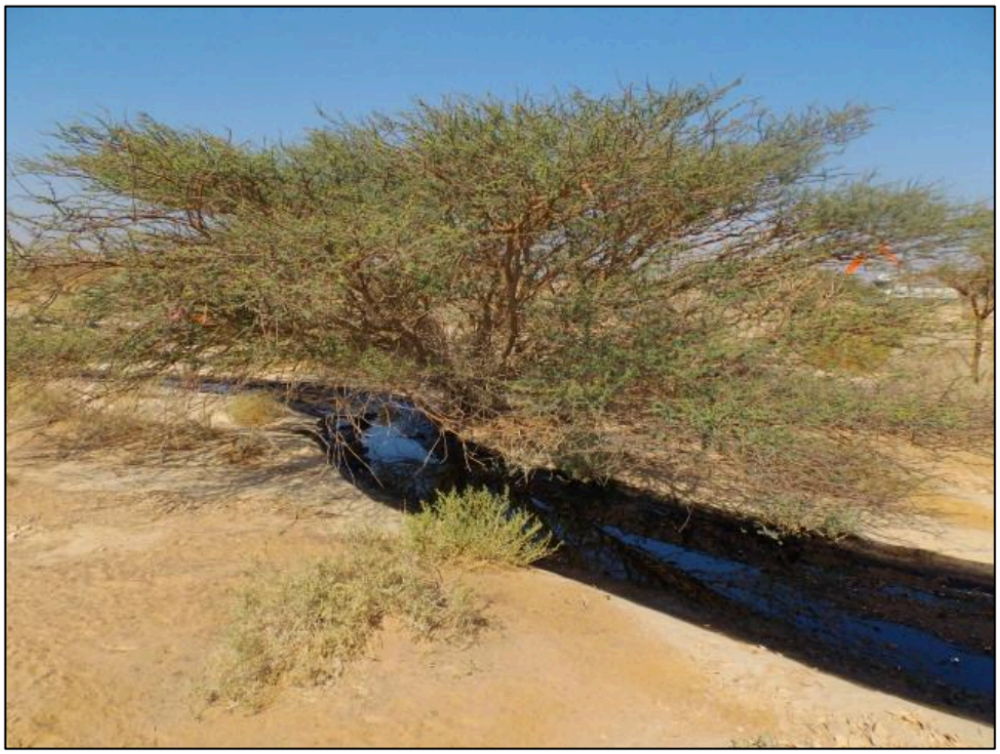


Figure 4: Oil flow in a canyon against an Acacia tree in Evrona (Gruner et al. 2015).

Oil pollution from these spills had a stronger effect on seedlings than on adult trees. The adult trees were mildly affected by oil pollution while the effects that the spills had on the younger trees could cause a long term reduction in the region acacia population. In A. Raddiana seedlings affected by the 1975 spill, the levels of several amino acids, amino acid derivatives, sugars, and organic acids were significantly reduced, while amino alcohols were increased. There were no major effects on the metabolic pathways of adult trees from both species exposed to oil. Oil pollution has a stronger effect of seedlings than on adult trees, and the affected processes mentioned above could be a result of osmotic stress (water shortage). Oil contamination to Acacia seedlings in general leads to both aboveground and belowground reduced growth. The metabolic impacts of seedlings grown in soils contaminated from the 1975 and 2014 spills were similar, meaning that the oil pollution has long lasting impacts on the region's soil. No seedling was able to germinate in the soil contaminated with oil from the most recent spill. The seedlings' sensitivity to the oil is possibly due to their short roots because they are more likely to be in contact with oil, which is usually distributed with the upper 30-45 of soil, while mature roots can extend deep into the soil (<10m), which reduces their direct contact with the oil. Using phenology to observe the Acacia in the contaminated areas every three months for four years after the 2014 spill, researchers found no differences between trees growing in oil polluted vs. unpolluted soils. This is consistent with research in the region after the 1975 spill showing that mature Acacia Raddiana trees were found consistently in all areas (1-7 m height), while young trees (<1 m tall) were absent in the contaminated soil even 42 years after the spill. There was no difference in metabolism between seedlings grown in 30% polluted soil and seedlings grown in unpolluted soil, which is the determined threshold for seedling germination in the region (Ferrante et al. 2021).

Acacia Tortilis is the dominant species and there is a lack of small / young trees (4-5 m tall, canopy size less than 2 m) were absent from the 1975 oil spill site even forty years later. Germination in Acacia seedlings was reduced significantly in 2014 oil contaminated soil and delayed in 1975 oil contaminated soil from the same sites. The higher germination rates in the 1975 spill are likely due to the evaporation of chemicals over time that would otherwise penetrate the seed (Hoai Tran et al. 2017). The germination rate of Acacia in the region affected by the 1975 oil spill was around 74% of a reference region (Nothers et al. 2017).

The layer of oil on the surface of the soil prevents water from penetrating the soil layers due to the hydrophobic properties of petroleum. Another factor affecting the seedling growth is the high temperatures both above and below ground due to the darker color of oil contaminated soils. The higher solar radiation absorption in the soils leads to air temperatures up to 46 degrees C. Petroleum contamination can also reduce the available of nitrogen and phosphate in the soil, which affects the plant's nutrients. The petroleum content of the soil at the 1975 spill site is at 25% the contents of the 2014 site soils, even though the 1975 oil was at least as hydrophobic as the 2014 oil (Hoai Tran et al. 2017).

3. Methodology

Phytoremediation is the usage of plants to clean up contaminated areas. Plants can clean soil containing metal, pesticides, explosives, and oil. A gap is that phytoremediation is most effective when contaminant levels are low because high contaminant levels can limit plant growth (as seen in the several experiments showing lack of Acacia seedling germination in Evrona's contaminated soil). Plants can also prevent the flow of contaminants away from the contaminated site or deeper underground. Phytoremediation can slow the movement of contaminated groundwater. Some plants can remove or break down contaminants by accumulating water and nutrients in their roots from the contaminated soil. Processes that plants use to clean up contaminants include (*A Citizen's Guide to Phytoremediation* 2012):

1. Storing the contaminants in their roots, stems, or leaves
2. Converting the contaminants to less harmful chemicals (mainly in their roots)
3. Converting the contaminants to vapors (released in the air)
4. Sticking contaminants onto their roots where microbes can break them down.

Research gaps surrounding phytoremediation are (*A Citizen's Guide to Phytoremediation* 2012):

1. The plants must be able to tolerate the contaminants.
2. Plants must be able to grow and survive in the local climate.
3. The plants' roots must be able to reach the depth of contamination (tree roots grow deeper).

The time of phytoremediation depends on (*A Citizen's Guide to Phytoremediation* 2012):

1. The contamination levels.
2. The contaminated area's size.
3. The plants' growing time.

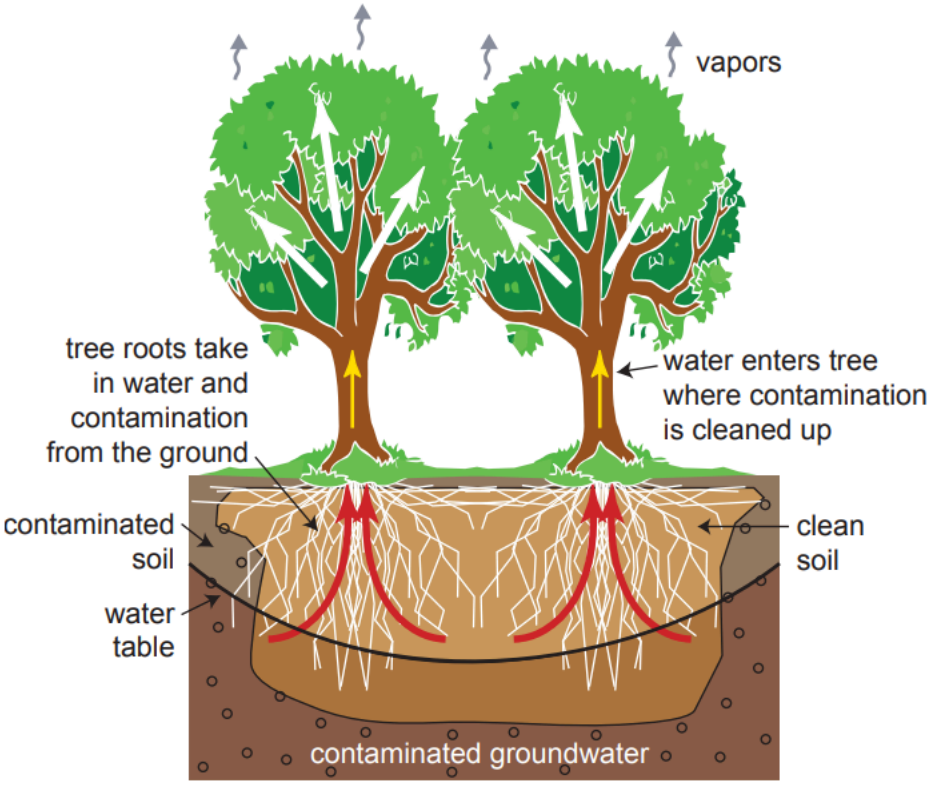


Figure 5: Diagram of phytoremediation (*A Citizen's Guide to Phytoremediation* 2012).

Acacia Mangium is considered one of the best candidates for phytoremediation due to its fast growth, high biomass, and its ability to adapt to nutrient poor and metal contaminated soils (Al-Samman et al. 2025). A challenge with counting the number of Acacia trees in a given region is that they are often standing dead for decades (Armoza-Zvuloni et al. 2021). If we observe the accumulation of toxins in the root of a dead Acacia tree in Evrona compared to the root of a healthy Acacia tree from somewhere else in the region, we can understand the positive impact of Acacia roots on Evrona's contaminated soil.

Martian soil contains no organic matter (*Martian Soil* 1989). There are several studies showing the seedlings of both kinds of Acacia tree are unable to germinate in soil contaminated from the Evrona spills. However, there is a lack of data on how the seed affects the soil rather than how the soil affects the seed after potential phytoremediation. This experiment will observe the soil before and after attempting to germinate a seed in it. We can assume that the first seed won't germinate, but attempt planting another seed in that same soil after the original and

observe the impact again. Unlike previous experiments done on Acacia in Evrona, this experiment should focus on the organic matter content in the soil rather than on the plant growth response. Acacia Raddiana and Acacia Tortilis seedlings should be planted in both a sample of Evrona's contaminated soil and a sample of soil from somewhere else in the Negev with a low organic matter content.

4. Conclusion

Acacia trees are a keystone species throughout the Negev (Gruner et al. 2015). Several studies have been done on the effects of the Evrona oil spills on both Acacia seedlings and have found that they are unable to germinate in the contaminated soil. However, a research gap is the effect of oil on adult Acacia trees. Specifically, what makes the trees able to grow in the contaminated soil on top of the environment already being considered hyper arid. By comparing the adult trees affected by oil to other Acacia trees throughout the Negev not influenced by the spills, we may be able to understand what it is that makes plants able to continue growing despite extremely harsh conditions. Although this experiment wouldn't address the Martian agricultural research gaps such as Mars's atmospheric pressure and composition and Mars's gravity (Davies et al. 2004), it would address the toxic soil on Mars, which is a major barrier to agriculture there.

4.1 Potential Implications

1. Proving that phytoremediation can occur between Acacia seedlings and Evrona's soil can indicate a method to introduce organic matter to Martian soil and progressing Mars agriculture to sustain human life long term.
2. However, I believe that even proving Evrona's soil as impossible to germinate Acacia seedlings would make the region analogous to Mars in terms of toxic soil preventing agriculture.

5. Acknowledgements and Disclaimers

I would like to disclaim that all uncited information in this paper is theoretical.

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