**Forest Fire Management**

In 1972Yellowstone National Park began new �natural� fire management policies [1]. Natural fire policies are policies in which fire is allowed to burn �naturally� as it would without the influence of man. Fires that occur normally due to sources such as lightning are regular occurrences, so most species are adapted to deal with their effects. The idea of the new policy was to let natural fires occur rather than trying to completely prevent them and minimize their spread. In the 1950s and 1960s the National Park Service had experimented with fires as a tool in forestry in Everglades National Park and Sequoia National Park. The National Park Service actually said,

�The presence or absence of natural fire within a given habitat is recognized as one of the ecological factors contributing to the perpetuation of plants are recognized as natural phenomena and may be allowed to run their course when such burning will contribute to the accomplishment of approved vegetation and/or wildlife management objectives.�

Don G. Despain, a plant ecologist, is the focus of �Yellowstone fires and their legacy,� the source of the above information. During the early years of the natural fire policy, Despain served as spokesperson for the National Park Service.

At the time ecology was a new field and the policy received harsh criticism. Previous policy had actively tried to prevent any fires in the forest, but the new policies called for them to actually be allowed to burn! Many people saw fires as destructive and dangerous. They could kill people, wildlife, plant life, and destroy property. Fire historian Stephen J. Pyne of Arizona State University described some common worries even intellectuals have concerning fire [2]. Global warming and the destruction of biodiversity and soil fertility were some of the major concerns listed in an article �Fire Planet-- The Politics and Culture of Combustion� compiled from his articles and books which argue that fire is a vital and natural part of ecosystems around the world. He also points out that fire has been used as a tool for centuries to clear areas for farming and the amount of pollution caused by a limited amount of burning would be trivial compared to that caused by cars and factories.

In 1988 there was an enormous fire in Yellowstone. It was allowed to burn according to the policy, but soon grew out of control. In the end, over $120 million was spent to battle the blaze. The sight of a beloved national park in ruins revived the opposition to the natural burning policy. However, many scientists brought forth research that supported the natural burning policies. Life began to sprout from the ruins of the fire, and advocates such as Despain seemed to have been proven right. They concluded that the size of the fire had been due to the large amounts of dry material and high winds. Today the natural burning policies are still in place.

As stated earlier, ecosystems such as Yellowstone�s are adapted to fire. There are serotinous species such as the lodgepole pine that actually depend on fire to release their seeds [3]. The succession that takes places after fires is part of a natural cycle as well, and without fire, imbalances may occur in the ecosystem. In the Northern Rockies, for example, fires burned away young trees and shrubs that competed with the larger ponderosa pines [4]. The pines would survive fires because of their protective bark. The younger trees and shrubs were unable to establish themselves. When people began to suppress the fires they began to grow and compete with the other dominant species.

Fire is an important part of an ecosystem in many other ways. It destroys accumulated biomass that might not decompose fast enough and returns nutrients to the soil as well as affecting mineral flow and soil fertility. The Forest Ecosystem Management Plan for the city of Boulder includes controlled burning because of these reasons, but also because shorter and less intense burnings reduce the risk of a catastrophic fire and create a more natural environment [5]. It is generally believed that fires are inevitable, so if they are suppressed for some time and a large amount of flammable material builds up it will result in a larger fire that people will have less control over.

Less intense burnings, or surface fires, are more desirable because they reduce the amount of material available to burn and also because they do less damage to the plants. A fire that passes quickly over an area may destroy the grass and scorch the bark of trees there, but the grass can grow back easily if its roots are left unharmed and the trees are hardly affected if they are adapted to that environment. It is now commonly believed that by allowing such fires to burn out over forested areas people are actually creating a safer environment by reducing flammable materials, and helping the ecosystem by killing off exotic species and competitors.

Some species that have adapted well to fire :

Rabbit brush and aspen--They grow from roots that are protected from the fire, so if a fire ravages the surface they can still grow back.

Douglas fir--This tree has thick bark that resists fire and protects the living tree inside.

In short, there are two main strategies used by plants to further their species in the presence of fire [6]. They may grow quickly and die during a fire, but scatter their seeds to continue after the fire has passed. This is similar to the way some animal species reproduce. Spiders for example have relatively short lifespans but leave behind large amounts of eggs. The other strategy used by animals and plants is similar to that of the Douglas fir. An individual takes more time to mature, but it is protected. However, this strategy may not always work: if frequent fires are present the plant cannot establish itself and its protection.

Many plants who live in areas subject to periodic fires grow from their roots up instead of from the tip. This way if a fire destroys the upper portion of the plant the meristematic tissue below can generate new growth. Think of grass in a lawn as an example. If the lawn is cut, the grass will continue to grow. In a plant such as a tomato plant, if the tips of the plant are all cut off then growth would not occur from the ground up.

**Biological Factors of Soil Fertility**

N.A. Krasilnikov from the Institute of Microbiology at the Academy of Sciences in Russia wrote Soil Microorganisms and Higher Plants, a book reviewing research on the relationship between soil fertility and biotic factors such as fungi, algae, and bacteria as well as larger creatures such as worms and insects [7]. Krasilnikov claims that �microorganisms constitute the most important and indispensable link in the nutrition of plants.� Bacteria and fungi are important most obviously as decomposers in the soil. They make nutrients from humus (defined by Encyclopedia Britannica online as �nonliving, finely divided organic matter in soil, derived from microbial decomposition of plant and animal substances�) available for plants� use while eliminating unwanted waste [8]. Fungi are also useful in symbiotic relationships as myccorhizae which provide plants with more nutrients than they would be able to access otherwise by providing them with a larger surface area. Nitrogen fixing bacteria are known to be vital in the nitrogen cycle, converting it into a useable form for other organisms. This was discovered as early as 1889 when scientists Hellriegel and Voronin (1886) found that microorganisms were responsible for the nitrogen fixation in leguminous plants.

Worms and insects contribute to the soil after their death by adding organic material, but also in life. Worms affect the structure of soil by their excrements as well. Other organisms mentioned in the book were actinomycetes, ultramicrobes, and protozoa. There may be thousands or even tens of thousands of these in one gram of soil. The following descriptions come from information obtained from Encyclopedia Britannica [8]:

actinomycete-- a member of a heterogeneous group of gram positive, often anaerobic bacteria. It often forms mycelium and may form spores. The motile forms move by flagella and the common actinomycetes in soil are harmless to plants and higher organisms.

protozoa- Members of the subkingdom protozoa. They are simple but eukaryotic organisms and often exist as symbionts or parasites. Most protozoa are microscopic.

bacteriophage- any virus that infects bacteria.

nematode-also called roundworm. They may be found free living in soil or water, or as parasites in plants or animals. Nematodes are bilaterally symmetric, elongated, and often tapered at the ends. The ones in soil are generally microscopic.

The interactions between organisms in soil as well as the physical makeup of the soil itself all affect its fertility. The way water is held by the soil and the was nutrients are cycled in and out are important as well. If the makeup of soil is too porous or not porous enough then a plant cannot access the nutrients it needs. The relationship between plants and some specific types of bacteria (the ones responsible for nitrogen fixation) or fungi (such as those that are vital in orchids as myccorhizae) is an interesting one. If plants can utilize the nutrients produced or absorbed by their symbionts, then can they also utilize the metabolic products of free living organisms similar to such symbionts? Either way the plant benefits, assuming the nutrients are somehow absorbed. Thus the free living microorganisms in soil surrounding a plant can be as important to that plant as symbiotic bacteria in alfalfa or soybeans.

**Experimental Design**

My experiment is a combination of these two ideas. True, forest fires seem to be acceptable, even beneficial in most cases. The plant species have adapted to grow alongside fires and they benefit from the nutrients released after a burning. But what about the biotic factors in the soil? Organisms that are beneficial in the soil, possibly ones that are harmful to plants as well, are unable to protect themselves from fire as plants are. Wouldn�t their destruction affect soil fertility and consequently plant growth? If so, will any visible changes be due to the destruction of organisms that were detrimental to growth (competitors, mold, etc.), the nutrients released from organisms such as worms, or the lack of the beneficial microorganisms? And what organisms survive the heat? Some bacteria, for example, can live in such extreme temperatures that they could not have been killed by fire.

The soil is affected differently by the large fires that occur less frequently with fire suppression policies and the more frequent, smaller fires that occur with the natural policy. The larger fires reach much higher temperatures for a longer time. This heats the soil to higher temperatures in the layers near the surface. If higher temperatures degrade soil fertility this would be another argument for the natural burn policy.

To simulate the effects of forest fires on soil fertility I took soil that I hoped would contain large amounts of organisms and heated it for varying amounts of time. I used plant growth as an indicator of soil fertility. The soil I used came from my yard. The soil was rather high in clay and so to compensate I mixed it with lighter redwood compost. In my garden I have seen a variety of insects and many, many worms. Because stores only sold sterile potting soil and there were no nearby forests to steal dirt from I decided this was the next best thing.

For plants I wanted to grow something with a taproot. Because after a forest fire the ground is exposed to air potentially containing all kinds of spores and mold, I felt it was not necessary to enclose my plants, but I wanted to grow a plant with roots that would be deep enough to reach soil that would remain sterile even though the surface would be in contact with non-sterile air. I began with radishes (*Raphanus sativus*) because they had a reasonably short growing time, but then used rye grass on my second trial because it was fast and could give me a larger sample size in less space than radishes which proved to have immense leaves.

I decided to research this topic because a project pertaining to plants could be used for my botany requirement as well as statistics if enough data could be gathered on plants to test. My father was the one who suggested forest fires as a topic and explained in the beginning about controlled burning and other practices. The experimental design appealed to me because it was simple, as you will see in the description of the procedure. Another reason why I chose this topic was the new greenhouse. I wanted to be able to take advantage of the new facility as this is my last year at the school.

**Question:**

Is it possible that a fire that heats the soil significantly has a negative effect on the complicated web of interactions between biotic factors soil and soil fertility?

**Hypothesis:**

Intense forest fires kill many beneficial organisms in soil, thereby degrading soil fertility.

**Prediction:**

If intense forest fires decrease the fertility of soil by killing organisms beneficial to plants, then radishes or rye grass grown in soil heated to high temperatures should have inferior growth rates to those grown in normal soil.

**Experimental Procedure:**

Materials used:

1) 144 radish seeds (*Raphanus sativus)*, scarlet white tip, Lilly Miller brand.

2) 4 level tablespoons of rye grass seeds.

3) Four 3 Liter plastic boxes measuring 10.5�X15�X5.5�.

4) A (metric with inches as well) ruler to take measurements.

5) Power drill

6) Thermometer

7) A barbecue was used to heat the soil

8) Redwood compost

9) Garden soil

10) 4 Garbage bags

11) Large metal baking dish the same size as the plastic boxes in number 3.

12) Microscope

13) Camera

14) Small shovel

15) Sharpie

16) Masking tape

17) Potholders

18) Knife

19) Paper towels

20) Scale

21) Sandwich bags

22) Pipette

23) Slides and cover slips

**Trial One:**

10/8/00:

1) Use a power drill to drill 6 evenly spaced holes for drainage in the bottom of each of the plastic boxes. Set aside.

2) Mix a large amount of soil and redwood compost so that it is one part garden soil to two parts redwood compost using the small shovel.

3) Pour enough of this mixture into a plastic bin to fill it two inches from the top. Pour this soil into the metal baking dish.

4) Turn the barbecue on to 400 degrees Farenheit. Put the metal baking dish of soil into the barbecue after it has warmed up for about 10 minutes. Let the soil sit for 10 minutes, then remove carefully from the barbecue using potholders. Measure and record the temperature of the soil by inserting the thermometer in the middle of the dish.

5) After letting the soil cool to approximately room temperature, I poured it into a garbage bag and labeled it, tying the top in a knot.

6) Repeat steps 3 through 5 letting the soil remain in the 400 degree oven for 20 and 30 minutes, respectively. These batches of soil heated for different lengths of time will be used to show any pattern that may exist in plant growth due to the heat.

7) Create a control sample in the same way but with no heating. This control will show what would occur if no changes occurred. If the control was not present, any growth shown in the other boxes could not be compared accurately.

If the prediction is correct, then I would expect to see the most growth in the control box, then slightly less growth in the 10 minute box, even less in the 20 minute box, and the least amount of growth in the 30 minute box.

Note: Because I was using the greenhouse at school I carried all the supplies need for planting to school. This is why the garbage bags were needed. Due to certain circumstances I was unable to plant until the 14th. Also, while I was heating the soil our barbecue ran out of propane and the batch of soil had to be rushed into the house. The oven may not have had the same affect. Another worry was that the soil did not actually reach temperatures high enough to kill certain bacteria and organisms. This was a major concern in my experiment. People that I asked for advice at Orchard Supply in Livermore and a local nursery in Pleasanton had said that if soil is heated too high certain elements may change and actually become poisonous. They also said that I should not use any soil I do not know the history of. If it had been sprayed with pesticides or had fertilizers in it, harmful fumes could result from heating. Because of this I did not want to heat the soil to too high a temperature, but it is unlikely a barbecue could reach that high a temperature anyway.

10/14/00:

8) Open the bags and pour the contents into separate boxes, labeling each with the time heated on tape with sharpie.

9) Make 12 holes evenly spaced, 6 holes by 2. Make them a half inch in depth and plant 3 seeds in each hole. Cover the seeds, pat gently.

10) Water each box with a liter of water.

I had wanted to have a regular watering schedule, but it was difficult because some days the boxes seemed to need more or less water. I made a list of how much I watered and when after the 14th:

10/16/00--1 liter per box

10/17/00--1 liter per box

10/24/00--1 liter per box

10/25/00--.5 liter per box

10/26/00--1 liter per box

10/27/00--.5 liter per box

10/31/00--.5 liter per box

11/2/00--1 liter per box

11/9/00--1 liter per box

11/14/00--.5 liter per box

11/16/00--.5 liter per box

11/19/00--1 liter per box

11/25/00-1 liter per box

11/28/00--1 liter per box

10/21/00:

11) On this day I began to thin out the radishes. I consistently pulled up the smaller looking of the extra radishes in each space, leaving a total of 12 in each box.

10/23/00

12) I finished thinning out the radishes.

Note--In one box, two of the radishes that had been left after thinning were mysteriously dead. This was probably due to another student using the greenhouse. The significance is merely that the sample size was minimized.

Due to winter break (11/20--11/28) I had to take the experiment home. During the move of the radishes, one plant was damaged slightly and due to the different environment the plants suffered slightly. They fell victim to aphids and were sprayed with insecticide on 11/26/00. Because they all received the same treatment I hoped that the data would not be significantly altered.

12/1/00:

13) I took measurements on the radishes.

For each box: Pull up the radishes and rinse clean under water. Pat dry with paper towels. Save some soil collected from each corner of the box to examine later by sealing it in a labeled sandwich bag.

For each radish: place the radish on the scale, using a beaker if necessary. Record mass. Take the next measurements in centimeters. Measure the length of each leaf; record. Measure the length of the root from the tip to the base of the leaves; record. Cut the radish root on its circumference at the widest point so that the diameter may be recorded. Use a camera to take any pictures that may be helpful.

12/8/00:

14) I used a school microscope to examine the soil for microorganisms. It was difficult to find a way to sample the soil in a legitimate way. This is a major flaw in the experiment. To make slides, I added water to the bag of soil, moving it around the entire bag. I extracted a few drops of the water with a pipette and examined it for living organisms and sketched any that I saw. I made several slides for each box�s dirt, but, as I said, it was difficult to do this in a structured way. If I did not find any life after 5 slides I would move onto the next box. When I did find something living I would sometimes return to other boxes to look again, but this was a tedious way to look for microorganisms.

**Trial Two:**

For the second trial I decided to use rye grass because the results from the first trial convinced me I needed a larger sample size. Rye grass also grows fast and does not have leaves as large as radishes which were difficult to measure. The soil mixture I used for this trial was also different. This time there was a higher percentage of garden soil. I hoped that this way I would be able to see more microorganisms and that their effects, if any, would be more obvious.

2/4/01:

1) Clean the boxes from the previous trial and set aside.

2) Make a mixture that is 25% redwood compost and 75% garden soil.

3) Follow the same steps 3 and 4 from Trial One.

4) Instead of transporting the soil in garbage bags I transferred it directly into the plastic boxes.

2/5/01:

I carried the boxes to school and stored them in the greenhouse.

2/9/01:

5) Remove a half in of soil from each box.

6) Scatter a tablespoon of rye grass seeds evenly in each box, replace the soil and pat gently.

7) Water each box with a liter of water.

Here is the watering log for the second trial:

2/14/01--.5 liter per box

2/16/01--1 liter per box

2/21/01--.5 liter per box

2/23/01--.5 liter per box

2/27/01--.5 liter per box

3/1/01--.5 liter per box

3/2/01--1 liter per box

3/5/01--1 liter per box

3/7/01--1 liter per box

(After this point I was sick and the boxes were neglected. When I returned they were in poor shape, so the next few weeks I spent reviving them. It was also much warmer in the greenhouse and they dried out more than the first trial had in the winter. Most excess water simply drained out.)

3/12/01--2 liters per box

3/13/01--2 liters per box

3/14/01--1 liter per box

3/15/01--1 liter per box

3/16/01--2 liters per box

3/19/01--2 liters per box

3/20/01--1 liter per box

3/21/01--1 liter per box

3/22/01--1 liter per box

3/23/01--2 liters per box

3/26/01--2 liters per box

3/28/01--2 liters per box

3/29/01--1 liter per box

3/30/01--2 liters per box

4/2/01:

I took measurements. The roots of the rye grass were very fibrous and I could not pull them up without damaging them, so the only measurements I could take were on the blades of the grass. I took 20 from different areas of the box, for each box. I would pull up the grass, then rip off any roots below the green portion of the stem. It was difficult to tell where the ground level was on the plant because some of the white grew above the ground and there was no other reference point on the plant, so I just ripped off the white portion by the roots. I massed each plant and recorded the values. I measured the length of the plant as well. I saved some of the soil from each box in sandwich bags to examine later. I used a camera to take pictures of the grass and roots as I took my measurements.

4/7/01:

On this day I examined the soil from the second trial in the same manner that I did for the first trial. I found the same number of organisms (about 2 in all boxes after over 20 samples).

**Data:**

After the soil was heated, these temperatures were recorded from the middle of the baking dish:

Table 1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Trial 1:** | box: | degrees F | **Trial 2:** | box: | degrees F |
|  | 0 minutes | 60 |  | 0  minutes | 70 |
|  | 10 minutes | 110 |  | 10 minutes | 94 |
|  | 20 minutes | 140 |  | 20 minutes | 130 |
|  | 30 minutes | 170 |  | 30 minutes | 140 |

This is the rough data from Trial One:

Table 2--CONTROL:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Radish: | Mass (g) | Diameter (cm) | Average leaf length (cm) | Total radish length (cm) |
| 1 | 9.85 | 0.2 | 18.8 | 10.6 |
| 2 | 17 | 0.9 | 26.3 | 13.5 |
| 3 | 4.8 | 0.65 | 14.7 | 7.5 |
| 4 | 10.8 | 0.8 | 22.45 | 9 |
| 5 | 11.85 | 1.9 | 18.375 | 13 |
| 6 | 19 | 1.6 | 21.47143 | 19.5 |
| 7 | 37 | 2.2 | 34.5 | 14.3 |
| 8 | 10.7 | 0.8 | 20.45 | 18 |
| 9 | 14.35 | 0.6 | 24.5 | 15.7 |
| 10 | 4.9 | 1.5 | 13.93333 | 13 |
| 11 | 8.2 | 0.2 | 21.83333 | 13 |
| averages | 13.49545 | 1.031818 | 21.57392 | 13.37273 |
| standard deviation | 8.96876 | 0.6709 | 5.689 | 3.56317 |

Table 3--10 MINUTE BOX:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Radish: | Mass (g) | Diameter (cm) | Average leaf length (cm) | Total radish length (cm) |
| 1 | 10.7 | 1.7 | 15.875 | 10.3 |
| 2 | 10.9 | 1.5 | 15.9 | 18 |
| 3 | 16.75 | 2.3 | 18 | 12.5 |
| 4 | 18.85 | 2.8 | 18.9 | 11.5 |
| 5 | 14.9 | 2.5 | 16.65 | 9 |
| 6 | 10.55 | 1 | 17.375 | 12 |
| 7 | 4.5 | 0.5 | 14.76667 | 7.5 |
| 8 | 9.6 | 0.3 | 22.9 | 12 |
| 9 | 9.3 | 0.7 | 17.18 | 9.6 |
| 10 | 8.8 | 0.7 | 17.18 | 11 |
| averages | 11.485 | 1.4 | 17.47267 | 11.34 |
| standard deviation | 4.21354 | 0.8969 | 2.23546 | 2.80958 |

Table 4--20 MINUTE BOX:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Radish: | Mass (g) | Diameter (cm) | Average leaf length (cm) | Total radish length (cm) |
| 1 | 31 | 2.3 | 21.03333 | 10.4 |
| 2 | 22.2 | 2 | 22.1 | 9 |
| 3 | 13.2 | 0.9 | 18.28571 | 14 |
| 4 | 14.7 | 2 | 18.2 | 10.5 |
| 5 | 15.35 | 2.2 | 15.25714 | 11 |
| 6 | 24.15 | 2.1 | 19.7 | 12.5 |
| 7 | 6 | 0.7 | 14.83333 | 11.5 |
| 8 | 7.6 | 0.7 | 14.78 | 13 |
| 9 | 20 | 2.4 | 20.125 | 11 |
| 10 | 7.9 | 0.4 | 17.475 | 15 |
| 11 | 9.5 | 1.2 | 17 | 11 |
| 12 | 9.85 | 0.6 | 18.6 | 12.3 |
| averages | 15.12083 | 1.458333 | 18.11579 | 11.76667 |
| standard deviation | 7.7623 | 0.77043 | 2.3919 | 1.67187 |

Table 5--30 MINUTE BOX:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Radish: | Mass (g) | Diameter (cm) | Average leaf length (cm) | Total radish length (cm) |
| 1 | 13.45 | 0.8 | 20.8 | 11.5 |
| 2 | 10.95 | 0.7 | 15.7 | 14 |
| 3 | 37.5 | 2.4 | 26.66 | 15 |
| 4 | 6.6 | 0.2 | 15.3 | 13.4 |
| 5 | 12.7 | 1.5 | 16.44 | 12.6 |
| 6 | 19.3 | 1.6 | 23.625 | 9 |
| 7 | 32.55 | 2.5 | 21.25 | 17 |
| 8 | 32.05 | 2.4 | 21.74286 | 20 |
| 9 | 23 | 1.1 | 20.04 | 12 |
| 10 | 22.4 | 2 | 19.84 | 15 |
| 11 | 12.3 | 0.4 | 20.75 | 11 |
| 12 | 20.1 | 0.7 | 22.35714 | 11 |
| averages | 20.24167 | 1.358333 | 20.37542 | 13.45833 |
| standard deviation | 9.7256 | 0.824 | 3.309 | 3.0007 |

The measurements are difficult to interpret if viewed only in charts such as Tables 2 through 5; the graphical representations of the averages calculated in these charts are more accessible. Figure 1 (below) compares the amount of time soil was heated and the weights of radishes grown in the different boxes in trial one. Figure 2 compares the amount of time the soil was heated to the diameter of the radishes grown in the different boxes in trial one. Figure 3 shows the amount of time the soil was heated vs. the average radish leaf length in trial one. Figure 4 shows the amount of time the soil was heated vs. the total radish root length in trial one. Figure 5 shows the amount of time the soil was heated vs. the average mass of a blade of rye grass from trial two. Figure 6 shows the amount of time the soil was heated vs. the average length of a rye grass blade from trial two.

To determine whether or not any differences observed were statistically significant or merely due to chance I used a two variable T-test. In each case I compared a box to its control and tested a null hypothesis of no difference against its two-sided alternative. The null test for each case is that both samples (the control and a variable) are representative of populations showing the same amount of growth. This means that there is no difference in growth due to the amount of heating the soil received. The alternative hypothesis is that there is a difference in growth. For each case I will use a rejection level of .1. I am using such a high rejection level because my sample sizes were smaller than I would have liked and any differences will be difficult to see. The t-test is valid in that each box is independent of the other, though it is difficult to tell if the distributions of growth for each individual box are normal. Many of the distributions, which I checked on my TI-83 while finding the standard deviations, were slightly skewed right. Because the sample sizes were so small this is not surprising. There was also a great deal of variability within the samples.

Here are the results of the T-tests:

**Control Vs. 10 Minute Box--Trial One**

--To compare mass:

t=.6669, degrees of freedom=9, P-value=over .25

--Fail to reject the null hypothesis--It appears that there is no significant difference between the average mass of radishes in the control box and the radishes of the box that contained soil heated for 10 minutes.

--To compare diameter:

t= -1.05687, degrees of freedom=10, P-value=between .15 and .2

--Fail to reject the null hypothesis--The test indicates that there is no significant difference between the average diameter of radishes in the control box and the radishes of the 10-minute box.

--To compare average leaf length:

t=2.2106, degrees of freedom=10, P-value=between .025 and .05.

--Reject the null hypothesis--This test indicates that there is a significant difference between the average leaf lengths of radishes in the control box versus those in the 10-minute box. The average leaf length for the control box is greater than that of the 10-minute box.

--To compare average root length:

t=1.45807, degrees of freedom=10, P-value=between .05 and .1.

--Reject the null hypothesis--This test indicates that there is a significant difference between the average root lengths of radishes in the control box versus those in the 10-minute box. The average root length for the control box is greater than that of the 10-minute box.

**Control Vs. 20 Minute Box--Trial One**

--To compare mass:

t= -0.46282 , degrees of freedom=9, P-value=over .25

--Fail to reject the null hypothesis--It appears that there is no significant difference between the average mass of radishes in the control box and the radishes of the box that contained soil heated for 20 minutes.

--To compare diameter:

t= -1.4187, degrees of freedom=10, P-value=between .05 and .1

--Reject the null hypothesis--The test indicates that there is a significant difference between the average diameter of radishes in the control box and the radishes of the 20-minute box. The average diameter measurement for the control box is less than that of the 20-minute box.

--To compare average leaf length:

t= 1.8702, degrees of freedom=10, P-value=between .025 and .05.

--Reject the null hypothesis--This test indicates that there is a significant difference between the average leaf lengths of radishes in the control box versus those in the 20-minute box. The average leaf length for radishes in the control box is greater than that of the 20-minute box.

--To compare average root length:

t= 1.36365, degrees of freedom=10, P-value=between .1 and .15.

--Fail to reject the null hypothesis--This test indicates that there is no significant difference between the average root lengths of radishes in the control box versus those in the 20-minute box.

**Control Vs. 30 Minute Box--Trial One**

--To compare mass:

t= -1.7306, degrees of freedom=9, P-value=between .05 and .1

--Reject the null hypothesis--It appears that there is a significant difference between the average mass of radishes in the control box and the radishes of the box that contained soil heated for 30 minutes. The average mass of radishes in the control box is less than that for the 30-minute box.

--To compare diameter:

t= -1.04568, degrees of freedom=10, P-value=between .15 and .2

--Fail to reject the null hypothesis--The test indicates that there is no significant difference between the average diameter of radishes in the control box and the radishes of the 30-minute box.

--To compare average leaf length:

t= 0.610439, degrees of freedom=10, P-value=over .25.

--Fail to reject the null hypothesis--This test indicates that there is no significant difference between the average leaf lengths of radishes in the control box versus those in the 30-minute box.

--To compare average root length:

t= -0.06203, degrees of freedom=10, P-value=over .25.

--Fail to reject the null hypothesis--This test indicates that there is no significant difference between the average root lengths of radishes in the control box versus those in the 30-minute box.

**Control Vs. 10 Minute Box--Trial Two**

--To compare mass:

t= 1.648, degrees of freedom=19, P-value=between .05 and .1

--Reject the null hypothesis--It appears that there is a significant difference between the average mass of grass in the control box and the grass of the box that contained soil heated for 10 minutes. The average mass of grass in the control box is greater than that for the 10-minute box.

--To compare average length:

t= 3.8901, degrees of freedom=19, P-value=less than .0005.

--Reject the null hypothesis--This test indicates that there is a significant difference between the average length of grass in the control box versus that of the grass in the 10-minute box.

**Control Vs. 20 Minute Box--Trial Two**

--To compare mass:

t= -1.54123, degrees of freedom=19, P-value=between .05 and .1

--Reject the null hypothesis--It appears that there is a significant difference between the average mass of grass in the control box and the grass of the box that contained soil heated for 20 minutes. The average mass of grass in the control box is less than that for the 20-minute box.

--To compare average length:

t= 1.27789, degrees of freedom=19, P-value=between .1 and .15.

--Fail to reject the null hypothesis--This test indicates that there is no significant difference between the average length of grass in the control box versus that of the grass in the 20-minute box.

**Control Vs. 30 Minute Box--Trial Two**

--To compare mass:

t= -2.56222, degrees of freedom=19, P-value=between .005 and .01

--Reject the null hypothesis--It appears that there is a significant difference between the average mass of grass in the control box and the grass of the box that contained soil heated for 30 minutes. The average mass of grass in the control box is less than that for the 30-minute box.

--To compare average length:

t= -0.60442, degrees of freedom=19, P-value=over .25.

--Fail to reject the null hypothesis--It appears that there is no significant difference between the average length of grass in the control box and that of the grass of the box that contained soil heated for 30 minutes.

**Additional observations:**

In the soil of the control box on the first trial I observed a nematode and a clear, spherical organism. On the second trial I saw another nematode in the control box, but in none of the other boxes did I observe anything alive. There were many organisms living in the control box soil at the beginning of the experiment, so the experimental environment must not have been conducive to their survival.

In the control box I noticed there were more weeds than in the variable boxes. On the inner sides of all boxes I saw some green growth, presumably algae resulting from the excess moisture. This lurking variable could have provided competition with the plants.

**Conclusions:**

When all the data is examined together it proves inconclusive. My prediction, �If intense forest fires decrease the fertility of soil by killing organisms beneficial to plants, then radishes or rye grass grown in soil heated to high temperatures should have inferior growth rates to those grown in normal soil,� would have been supported by clear linear trends in graphed data, but none of the graphs were perfectly linear. Most were like Figure 4--curved, showing no trend. Several of measurements were contradictory. Figure 2 shows radish diameter to be greater in the 10-minute box than the control box and the 30-minute box while Figure 4 shows a greater average root length in the control box and 30-minute box than in the 10-minute box. Because I was attempting to compare growth and the averages were reciprocal with different types of measurements (root length versus radish diameter for example), I cannot make any conclusions.

Another disturbing incongruity occurred in my t-tests. For the t-tests on the data for the second trial both the 20-minute and 30-minute boxes showed �significant� differences from the control in average grass mass, however, the 30-minute box showed a greater mass than the control while the 20-minute box showed a lesser mass. Because one would expect the 30-minute box to have an average mass closer to the 20-minute box than to that of the control, I am suspicious of the data.

Due to the many errors in my experimental design (such as the small sample size) and other unexpected problems, such as the aphids and sudden death/maiming of certain radishes, my data has proven inconclusive. Some of the data (Figures 1, 5, and 6) seems to suggest that fires may be beneficial to plant growth. This could be because the heat releases nutrients that are directly available to plants, providing immediate benefits. Perhaps any changes due to the deaths of the microorganisms in the soil would take longer to observe. The temperature I used to heat the soil may have been too low to cause a significant change. It is very possible that in natural burning, small fires that make organic material available to plants may not damage the microorganisms in the soils.

**Recommendations:**

If anyone wishes to repeat this experiment or attempt something like it I have many suggestions.

Use a biodome of some kind to isolate the specimens from insects, spores, and other possibly disruptive variables.

Try using other taproots such as carrots, if time allows. Do not use fibrous roots!

Try using soil taken from a forest, if possible. Ask someone for help to be sure there are no dangerous chemicals that could be inhaled after heated.

Heat the soil itself to specific temperatures that differ significantly. In this experiment the soil itself reached temperatures much lower than the barbecue, this could have been a reason why the data was so confusing. --Use a different means to evaluate the quantity and variety of microorganisms in the soil.

Try to find a way to water regularly without over watering or drying out the plants.

Use something other than a barbecue to heat the soil, but make sure it will not heat the soil so much that the composition of elements within the soil could become a lurking variable and poison the plants. The temperature to use to simulate a forest fire is unknown, and it is difficult to emulate the top-down application of heat without industrial equipment.

Ideally, this experiment would be performed using samples of soil from areas following real forest fires.

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