What is composting?

A compost pile recycles household and garden wastes by allowing billions of decay organisms to feed, grow, reproduce, and die in a process that creates an excellent organic fertilizer and soil conditioner. While composting, microorganisms break down organic matter and give off carbon dioxide, heat, water, and eventually produce humus, the stable organic soil end-product. Composting can be a very simple process. The composter can create a bin and throw in equal amounts of "browns", or dry plant materials and "greens", fresh plant materials. With occasional stirring and water, compost will happen. In contrast, the study of finding an optimum soil additive that enhances a plant's fertility and rate of growth can be more exacting. The reason that compost improves soil for most plants is because its finished product supplies the three essential ingredients -- potassium, nitrogen, and phosphorus -- to the surrounding soil. Plants flourish in an environment that offers an abundance of these ingredients and also benefit from compost's abilities to prevent disease, add needed aeration, and prevent erosion by rainfall.

What do Potassium, Nitrogen, and Phosphorus do?

Potassium-

Potassium is integral for the life processes of a plant including the manufacture and movement of sugars and starch, and the normal growth by cell division. Potassium is taken from the surrounding soil by the roots.

Nitrogen-

Nitrogen in soil regulates a plant's ability to make proteins that are important for the formation of the protoplasm of new cells. It is most active in the young, tender parts of the plant's tissues, such as tips of shoots, buds, and newly opening leaves.

Phosphorus-

Phosphorus is necessary for photosynthesis and provides the mechanism by which energy is transferred within a plant. It is used in all living tissue of the plant. There is an ideal range to the amount of phosphorus in the soil surrounding a plant. I the level of phosphorus falls into this range, then the root system will flourish.

(Sunset Western Garden Book p. 50)

Two Types of Composting

"Hot" Composting

Under ideal conditions, there will be three stages to composting: the mesophilic stage, the thermophilic ("hot") stage, and the cooling period, which can take several months.

1. The mesophilic or moderate-temperature phase, lasts a few days and involves mesophilic organisms. These organisms break down the soluble, readily degradable compounds and give off energy in the form of heat. This heat leads to the steady increase of the pile's temperature.

2. Once the temperature reaches roughly 40 oC (104 oF), the thermophilic, or heat-loving microorganisms dominate. This heat speeds decomposition but it is necessary to aerate the pile consistently by stirring to prevent the temperature from exceeding 65 oC (145 oF). At this temperature, even thermophilic microorganisms break down, sterilizing the soil and defeating the purpose. During the thermophilic stage, fats, proteins, and complex carbohydrates (i.e. cellulose and hemicellulose) break down.

3. After the high-energy compounds are exhausted by the thermophilic organisms, the mesophilic microorganisms once again dominate. This marks the beginning of the curing stage of the compost. This curing stage lasts until all complex structures are broken down to their most basic forms. It is wise for a gardener to allow this process to continue as long as possible because mature compost is more stable and effective as an additive to soil. In mature compost, the food web becomes more complex, improving the local communities surrounding the young plant the compost fertilizes.

"Cold" Composting

In my experiment, I used a method known as cold composting. I used this slower, but equally effective method of composting for several reasons. The first reason was the small scale of my experiment, which required only a small amount of composted materials. The second reason was because I needed to be conservative with time. Surface area and volume are critical to the compost pile because there is a range of temperatures that the pile can reach without exceeding 65 oC. If the compost pile exceeds a certain volume (greater then roughly one cubic yard), there is not enough surface area to dissipate heat effectively. This leads to an overabundance of energy given off as heat and the sterilization of the compost. With cold composting I knew that overheating the pile would not be a concern and I could be sure to have a stable humus by the month of March.

In the process of cold composting, the pile is aerated by turning only once every week and only the mesophilic microorganisms break down the complex carbohydrates during the two to four month process. The temperature I measured in the piles ranged between 6oC (43 oF) and 19 oC (66 oF).

The Microorganisms- Chemical Decomposers of Compost

Most microorganisms "feed" by chemically decomposing organic materials such as compost. These organisms are present throughout the entire process of turning organic materials into humus and generally aid the formation of fertile soil.

Bacteria-

Bacteria are single-celled organisms that make up nearly 90% of the microorganisms that are found in compost. They are responsible for most of the decomposition that occurs and also most of the heat produced in the pile. In the pile, most of the bacteria are motile and take one of three forms: rod-shaped bacilli, sphere-shaped cocci or spiral shaped spirilla. The bacteria that dominate during the thermophilic stage are generally of the genus Bacillus (which means rod shaped). These thermophilic organisms flourish in some of the world's hottest environments (the hot springs and the deep sea volcanic vents) and can survive the harshest conditions by forming endospores. These endospores preserve the nucleic information in an extremely thick-walled cell casing that can be shed when conditions become favorable. This allows new bacteria to form after an extended dormant period.

When a hot compost pile cools down, mesophilic bacteria regain dominant status in the pile. The longer the pile is allowed to remain unchanged in its cooling state, the more diverse the mesophilic population will become, benefiting the top soil's local community.

Actinomycetes-

Actinomycetes are a filimentous bacteria that lack nuclei yet grow multicellular filaments like fungi. The enzymes of these organisms allow them to break down cellulose, lignin, chitin, and proteins. They form long, thread-like branched filaments visible on the outer 10-15 cm of the pile.

Fungi-

Fungi include molds and yeasts and are responsible for the decomposition of complex plant polymers (i.e. cellulose) in soil and compost. They attack organisms that are too dry, too acidic, or too low in nitrogen for bacteria to decompose. Fungi need oxygen to survive and generally form molds toward the outside of the pile.

Rotifers-

Rotifers are small multicellular organisms that are found in films of water in the compost. They are secondary consumers that feed on bacteria, fungi, and organic matter.

Protozoa-

Protozoa are one-celled microscopic animals found in the water droplets of compost that play only a minor role in decomposition. They gain food from organic matter but can also act as secondary consumers that ingest bacteria and fungi.

The Invertebrates (Macroorganisms)- Physical Decomposers of compost

Macroorganisms are visible to the naked eye. Primarily, these organisms physically alter the compost by literally chewing, digesting, sucking, churning, and digging through the organic matter.

Nematodes-

Nematodes, or round worms, are the most prevalent of all invertebrates in the soil. Some live on decaying organic matter but others are the predators of algae, other nematodes, protozoa, and fungal spores. Some nematodes are pests that suck the juices of fruit plants while others contribute to the decomposition of the soil. They resemble a fine hair under a microscope.

Snails and Slugs-

Snails and slugs are mollusks that travel in a creeping motion. Snails have spiral-shaped shells mounted on their backs while slugs are shell-less. They both attack plant debris in the compost pile.

Earthworms-

Earthworms constantly tunnel and feed on dead plants and decaying insects during the daylight hours. As the earthworm digests organic matter, the matter is passed out in "casts" that have large amounts of calcium, bacterial diversity, available nitrogen, magnesium, phosphorus, and potassium. These casts highly improve the compost as the organic material decomposes. The most common earthworm in compost is the red wiggler (Eisenia foetida), which are about 5 cm long and have jointed bodies that range in color between buff and maroon.

Sow bugs-

Sow bugs are fat bodied crustaceans with dark protective plates mounted on their back and small plate-like gills on the underside of their bodies. They have ten legs and graze on organic vegetation. Sow bugs look similar to pill bugs (a.k.a. roly-poly) but do not roll into a ball when threatened.

Fermentation mites-

Fermentation mites are transparent bodied creatures that are able to withstand aerobic conditions in compost. They digest organic material and generally are a good indicator of anaerobic conditions.

Beetles-

Beetles are insects that are second and third level consumers in the compost pile. The most common beetles in compost are the rove beetle, ground beetle, and the feather-winged beetle. The feather-winged beetles feed on fungal spores while the rove and ground beetles feed on insects snails, slugs, and other small animals.

Springtails-

Springtails are small wingless insects that have the marked ability to jump large distances when threatened. They chew on decomposing plants, pollen, grains, and fungi.

Ants-

Ants are insects with six legs, a head, a thorax, and an abdomen. Ants feed on many of the materials in compost but most importantly will bring materials such as potassium and phosphorus to the pile.

Much of the information of this section was found at Cornell University's compost homepage.

Planting

In order to test the compost that I created over a four month period (Nov. 1-March 1), I needed to design an experiment that would compare the two types of compost. I decided to use two types of plants, the early scarlet globe radish and the green leaf lettuce. I selected the radish because it would need a high amount of phosphorus and potassium for it's root system which forms the edible vegetable. I selected lettuce as my other plant, because it is a leafy plant that needs a high nitrogen content in it's surrounding soil. I hypothesized that the potato compost would benefit the radish more than the lettuce because the potato as a tuber plant and the radish as a root plant may share some immunities to disease and a need for similar nutrients. I further hypothesized that the lettuce compost would benefit the lettuce plants more then the radish plants because lettuce has a higher nitrogen content that would aid the above ground lettuce leaves.

I planted the lettuce and radish seeds to the specifications prescribed by the back of the seed package. The radish required a soil depth of 1/2 inch while the lettuce only needed 1/4 inch. The seeds were dispersed heavily along a soil line so I could later thin the sample size. I planted roughly forty seeds into each planter assuming that at least thirty should germinate (break the soil level).

In order to allow for maximum drainage (important for both lettuce and the radish) I purchased three plastic planters with two holes punched out of the bottom. The planters were 6 inches deep, 6 inches wide, and 18 inches long. I also used rocks underneath the soil to allow for aeration and drainage. I had to separate the lettuce samples into two of the planters (one type of compost per planter) and the other basin was used for the radish. I partitioned the radish planter because radish needs little space between each plant in order to fully mature.

After the plants matured, I used an Ohaus triple beam balance to find the masses of all of the samples left. Once I found the masses for every plant, I was able to find the average weight of every plant in each of the three planters. Once I found the four average weights, I was able to begin my analysis. Using a statistical procedure called a two sample T-test, I was able to judge whether the difference in the average weights happened by chance. By comparing the average weights of the plants rather than their above ground height, I was able to gauge the quality of the compost rather than the quality of the seeds or the nitrogen levels. I did not use planters with plain soil because I was testing if there was a relationship between the type of compost and the type of plant rather than weather the compost worked.

Compost Improves Soil

"Compost does several things to benefit the soil that synthetic fertilizers (and uncomposted soil) cannot do. First, it adds organic matter, which improves the way water interacts with the soil...Compost also inoculates the soil with vast numbers of beneficial microbes and the habitat that the microbes need to live. These microbes are able to extract nutrients from the mineral part of the soil and eventually pass the nutrients on to the plants" (Rot Web).

Procedure

Compost: For the first part of my research project, I created a lettuce based compost and a potato-based compost.

Step 1: The first step in creating two identical compost piles was choosing a spot that could be protected from the weather yet large enough for two piles could be built side-by-side. I chose an area adjacent to my house in the side yard. It was shady, protected from the wind, and was easily accessible.

Step 2: In order for me to determine how much lettuce, potato, and straw I would need to conduct the experiment, It was necessary to calculate what is known as the C/N ratio. The C/N ratio is defined as "the amount of bulky, dry high-carbon materials to dense, moist, high-nitrogen materials" (p.140 Basic gardening book). The ideal C/N ratio for compost organisms is between 25:1 and 30:1. Once I decided that lettuce, potato, and straw were going to be my organic materials, I needed to figure out how much of each I would need. In order for me to calculate the C/N ratios, I had to consult Appendix A of the On-Farm Composting Handbook. From the book I drew the values for: the amount of moisture that made up each ingredient (%moisture), the amount of nitrogen that made up each ingredient (%nitrogen), and the natural C/N ratios of the ingredients. Once I knew the %nitrogen and the C/N ratio, I was able to find the amount of carbon that made up each ingredient (%carbon). I now knew the four variables, so I could calculate how much straw I would need to go with 10 lb. of potatoes and 5 lb. of lettuce for a 30:1 C/N ratio. For the 30:1 C/N ratio, I needed to add .8 lb. of straw to the potato compost and 4.2 lb. of straw to the lettuce compost. (look at the Cornell homepage for equations and calculation instructions)

Step 3: Once I chose the area and calculated the amount of straw that I needed, I collected the materials that I would need for the experiment. These included:

1. 40 lb. of backyard sand

2. 10 yd. of black plastic compost bin material

3. Thermometer (oF)

4. pitch fork (for aerating compost by turning)

5. 5 lb. straw (a large garbage bag full)

6. 10 lb. russet potatoes (sliced for easier decomposition)

7. 5 lb. lettuce clippings

8. plastic bags (rain cover)

9. 10 lb. soil from yard

Step 4: After collecting my materials, I used the black plastic material to form two bins that were 28 inches tall and had a diameter of 19 inches. After securing the bins, I added 20 lb. of sand to each bin as a bottom layer. I then added the 10 lb. of potatoes and .8 lb. straw to one pile and 5 lb. lettuce and 4.2 lb. straw to the other. My last step was to disperse 2.5 lb. top soil into each container and then add water until the consistency of a "wet sponge" was reached. I then took the temperature and stirred (aerated) the compost once a week.

Planting: To test the effectiveness of the compost, I planted a leafy vegetable (lettuce) and a root vegetable (radish) using the compost as soil. In order to control the variables that existed in this experiment, I treated each sample as similarly as possible.

Step1: I purchased three identical plastic bins that were 6 inches deep, 6 inches wide, and 18 inches long with two drainage holes in the bottom. I then partitioned the radish bin with a piece of wood covered in duct tape. The next step was to choose granite river rocks from my front yard and place them in the bottom of the bins. These rocks were used to give maximum drainage underneath the soil and to not allow soil to clog the drainage holes at the bottom of the bins.

Step 2: I placed four inches of my compost-soil mixture on top of the rock layer. The first bin was filled with only lettuce-based compost, the second bin was filled with only potato-based compost. The third, partitioned bin, had lettuce-based compost on one side and potato-based compost on the other.

Step 3: I now used a piece of wood that would furrow the soil in a straight line so I could get a consistent distance between the rows of seeds and a consistent depth of seed planting. I planted the radishes 1/2 inch below ground level and the lettuce 1/4 inch below ground level. I then covered up the seeds with soil and then watered the seeds.

Step 4: In order to protect my plants from a number of organisms, I mounted them on top of empty paint cans so all three stood nearly a foot off of the ground. I watered the plants as needed and thinned the sample size when the plants germinated.

Measurements- Plant Mass and T-testing

Well known statistical principles offer a way to decide if differences measured in an experiment are due to the conditions controlled by the experimental design or due only to chance. In the case of my experiment, I took a small sample of the early scarlet globe radish and a small sample of green leaf lettuce plants. To measure the effectiveness of a particular compost on a particular plant, I took the mass of all of the plants in each sample planter.

In order to weigh the plants, I first had to harvest the plants from the compost soil with great care. This care was taken so I could accurately weigh not only the visible leaves, but the root system as well. I used a process in which I placed the unbroken soil into a large bucket of water to dissolve the surrounding dirt. After submerging several plants that were attached in a piece of soil, I was able to separate each plant individually and place them into the next bucket of water. In the second and third bucket along the row, I cleaned out the root structures which were filled with organic matter and clumps of soil. I cleaned these to attempt to have as close to the true mass of the plant as possible. After cleaning, the plants dried for ten minutes and then were weighed. I used the same process to harvest and clean every single plant.

To weigh each plant, I used an Ohaus triple beam balance. I then broke the plants into four different categories so I could compare like samples. These categories were: radish plants in lettuce compost, radish plants in potato compost, lettuce plants in lettuce compost, and lettuce plants in potato compost. After categorizing and then weighing every plant, I was able to find the average mass of each of the four categories. The average weight of each category is also known as the mean mass. After calculating the mean masses, I calculated the standard deviations for every sample. The standard deviation is the distance from the mean. The sum of the standard deviations in a category, divided by the number of samples in that single category, is also known as the standard deviation. I now have a mean mass and a standard deviation for each of the four categories.

Once I computed the standard deviation and the mean from each set, I again separated the four categorized samples. I compared the radish plant in lettuce compost to the radish plant in potato compost (T-test 1). I also compared the lettuce plants in the lettuce compost and the lettuce plants in the potato compost (T-test 2). To test whether there was a statistically significant difference between the two radish samples and the two lettuce samples, I conducted a study called the two sample T-test. The two sample T-test tells the statistician whether a difference between the two radish means or the two lettuce means happened by chance. It can also tell the statistician that there is another reason for the difference (a statistically significant difference).

I did this test at the 95% confidence level. The 95% confidence level literally means that the T-test that I ran would occur the same way 95 times out of 100. In an example, 5 out of 100 could reject the hypothesis, while the other 95 samples taken would support the hypothesis. This type of error is associated with all statistical analyses as they are not foolproof.

If you would like to learn more about this process or would like to see why I chose the T-test instead of another type of test, please read chapter 6 of The Basic Practice of Statistics.

I will have to do the two-sample T-test twice. This is because I want to compare the means of the radish plant in the potato compost to the radish plant in the lettuce compost (test 1) and I also want to compare the means of the lettuce plant in the lettuce compost to the lettuce plant in the potato compost (test 2).

Other Tests:

In order to gain perspective on my experiment, I tested the phosphorus levels, nitrate levels and the pH on the four respective soils.

pH: pH is the amount of hydrogen ions present in a sample. It is measured on a negative logarithmic scale that generally runs between 1 and 14. 1 is the most acidic compound and 14 is the most alkaline or basic compound. To take the pH of the soils, I used a small piece of pH paper and let it rest in the soil for a short time. I then compared the sample paper to the side of the pH paper dispenser. I took the pH of the two piles of finished compost, and then I took the pH of the soil in each planter.

Nitrate: The nitrate test that was available to me was a water-based test. In order to attain a measurable sample of nitrate, it was necessary for me to filter the soil sample several times.

Step 1: As the first step, I measured out 11/4 cups of tap water and poured it into a beaker. I then measured out one ounce of soil, and stirred the water until the soil was suspended. I used a pieces that I cut from a Hanes undershirt to use as a filter.

Step 2: To filter the water and soil mixture I held the T-shirt piece across the top of the beaker and then poured the mixture through it into another beaker. I then discarded the "filter". I repeated this process twice more for a total of three filtrations for each water sample.

Step 3: Once the sample was filtered, I poured the sample into the given test container. I then added two drops of nitrate activator and inverted the bottle several times while allowing one minute to pass. I then used a glass ampule to take the sample. After two minutes passed, I compared the ampule to the given color code and was able to gauge the relative amount of nitrates in parts per million of each of the four soils.

Phosphate: Like the nitrate test, the phosphate test was water-based. It was necessary for me to filter the samples so I decided to use the same process of filtration.

Step 1: As the first step, I measured out 11/4 cups of tap water and poured it into a beaker. The second step was for me to measure out one ounce of soil. I then stirred in the soil and cut out a piece from a Hanes undershirt to use as a filter.

Step 2: To filter the water and soil mixture I held the T-shirt piece across the top of the beaker and then poured the mixture into another beaker. I then discarded the "filter". I repeated this process twice more for a total of three filtrations for each water sample.

Step 3: Once the sample was filtered, I poured the sample into the given test container. I then added a packet of phosphate test activator, shook for one minute, and then used a glass ampule to take the sample. After ten minutes passed, I compared the ampule to the given color code and was able to gauge the relative amount of phosphates in parts per million for each of the four soils.

Hypothesis

The materials that make up a compost pile have an affect on the levels of phosphorus, potassium, and nitrogen that are in the finished humus. Ingredients that are high in nitrogen, high in phosphorus, and high in phosphates make a complete fertilizer, the ideal soil additive that contributes to the growth of plants in that soil. Potato plants and radish plants require high levels of phosphorus and potassium to stimulate below ground growth while lettuce requires high nitrogen levels to stimulate above ground leaf growth. Because of these facts, I reasoned that a potato-based compost would most benefit the radish plants and a lettuce-based compost would benefit the lettuce plants.

In order to test this hypothesis, I did a side-by-side comparison of the two types of compost. I compared the average mass of radish samples in each compost to find out if the whether the difference of the means was explained by chance or a superior compost. I then compared the average mass of the lettuce samples in each compost to decide if there was a superior compost or not. By design, I was be able to determine whether my hypothesis was supported or debunked by my data.

Results:

pH test:

potato-based compost- 7.0

lettuce-based compost- 7.0

lettuce/ potato-based compost- 8.0

lettuce/ lettuce-based compost- 7.5

radish/ potato-based compost-7.5

radish/ lettuce-based compost- 7.0

Nitrate Test:

lettuce/ potato-based compost- 1.0 ppm

lettuce/ lettuce-based compost- .8 ppm

radish/ potato-based compost- 1.0 ppm

radish/ lettuce-based compost-.8 ppm

Phosphate Test:

lettuce/ potato-based compost- .8 ppm

lettuce/ lettuce-based compost- 1.0 ppm

radish/ potato-based compost- .6 ppm

radish/ lettuce-based compost-.8 ppm

Two Sample T-test- the Radish Samples

After comparing the sample means, I found that the radish samples had no statistically significant difference at the 95% confidence level. The average mass of the radish plants in the potato compost of 2.52 grams was not significantly greater then the average mass of the radish plants in the lettuce compost which was 3.15 grams.

Two Sample T-test- the lettuce samples

After comparing the sample means of the two lettuce samples, I found that the average mass of lettuce grown in the potato compost was statistically significantly higher than the average mass of the lettuce grown in the lettuce compost. The lettuce grown in the lettuce compost had a mean mass of 1.18 grams that was smaller than the lettuce grown in the potato compost that had a mean mass of 2.66 grams.

Conclusions and Discussion

After taking the statistical analysis, I found that it did not matter for the radish, a root plant, which of the two kinds of compost made up its soil. The type of compost in the lettuce's soil did matter significantly however. The lettuce that was grown in the potato compost had a mean mass that was significantly higher than the lettuce grown in the lettuce compost.

The first test with the radishes, which found no difference between the type of compost and the plant eventually grown, did not support my hypothesis, because the mean mass of the radish grown in the potato compost would have needed to have been statistically greater then the mean mass of the radish grown in the lettuce compost. Surprisingly, the lettuce compost had a higher (although not significantly higher) mass, which refuted my hypothesis.

The second T-test also refuted my hypothesis. The lettuce in the potato compost of grew significantly larger than the lettuce in the lettuce compost. This was also a surprising result that can be explained by unknown factors.

I believe that several factors could help explain the unexpected results of my experiment. The first is that it is reasonable to speculate that the potato compost was more fit for the lettuce compost because of it's higher nitrate concentration. By the same logic, the lettuce compost was more fit for the radish plants with it's higher phosphate levels. A second factor could be that I used too much compost as a soil for the radish plants in the potato compost and for the lettuce plants in the lettuce compost. A way to test this hypothesis would be to use an incrementally smaller ratio of compost to regular soil. If a range of ratios for compost were found that would benefit plant growth at minimal levels, farmers could know exactly how much compost they would need for the acreage of their farms. An outside factor that is certainly related to my project was the bizarre weather patterns that we have experienced thanks to El Niño. This cold weather front slowed the growth of my plants which could have prevented them from reaching several stages of maturity that would have brought along with increased size, a need for different nutrients.

The hypothesis for this set of experiments was that soil enhanced by nutrients provided by vegetable leaves would benefit the growth of leafy vegetables such as lettuce ad that similarly, soil enhanced by a plant reliant on root structure would enhance the growth of root vegetables such as radishes. Careful scientific method was used to test this hypothesis. The results were mixed and unexpected, and my hypothesis was not supported. The experiment is useful in at least two ways, however. First, valuable information was obtained regarding soil preparation for lettuce growing as well as radish growing. Second, the procedure and results suggest that many other research projects could be done in this field, to find the optimum soil enhancement for root and leafy vegetables.