Problem

Can paper mill sludge be used as a fertilizer for plants and does it change the pH of the substrate it was used in? This problem was selected to learn if the chemical make-up of paper mill sludge produced results similar to or better than typical fertilizer for plants and how it affected the pH of the substrate.

Background Information

Soil is one of the basic building blocks of life as we know it. It provides the vital nutrients to plants that feed the human race. However, the nutrients in soil are not endless. As each new plant is planted and produces fruit over and over, the plant drains the soil of the nutrients that plant needs to live. These nutrients must be replaced so that soil can do its job.

Fertilizer adds nutrients back into the soil. A chemist named Justus Von Liebig and his colleague, Fredrich Wholer, invented modern day fertilizer in the mid 1800's. They researched the chemistry of plants, and how people might be able to improve plant growth through this chemistry. They discovered they could give plants more nutrients, and this would make them grow more. Even though fertilizer has been around since the world began in the form of feces, Von Liebig is one of the first people to try to create a chemical that people could use to increase plant growth.

Plants need many elements to grow tall and strong. For the plants to use these elements to make food, photosynthesis is necessary. Photosynthesis is a process that plants use to get energy from the sun so they can make food. In this process plant sugars are made by chemical reactions inside the plant leaves. The chemicals used in this reaction are carbon, hydrogen, oxygen, nitrogen, phosphorous and potassium. Nitrogen, phosphorous and potassium are the basic building blocks in the plant and are taken from the soil. Without these elements the plant would not grow. The plant must also get carbon dioxide from the air and water from the soil. To get these elements inside the plant, they must be dissolved in water. Then the water takes the minerals to the plant through the plants root system. This system gets the important elements to the plant leaves so that more energy for the plant can be made. Plant growth is very complicated and takes many working parts.

Fertilizer helps plants by restoring the elements in the soil they so vitally need. The elements supplied in most commercial fertilizers that plants need are nitrogen, phosphorous, and potassium. These are important because they develop the systems that the plant needs to grow and keep the plant healthy. First, nitrogen is important for the growth of stems and leaves. It also develops the green in the leaves called chlorophyll. These parts of the plant are important in photosynthesis. Next, phosphorous is important in developing the root system of the plant that takes in water and needed elements. Finally, potassium increases the amount of water the plant can absorb, and this water is needed for important chemical reactions. These elements added to the ground in fertilizer make sure the plant is healthy and strong enough to continue creating oxygen and food for people to live.

Fertilizer can come in many forms. Sometimes, by-products from industry contain the same nutrients added into soil by commercial fertilizer. This is true in the case of paper mill sludge (PMS). PMS is a generic term for residue left after wood has been used to make paper. It typically consists of cellulose (equivalent of dietary fiber), bacteria, water, nitrogen, oxygen, carbon, hydrogen, sulfur, and other organic matter. Wood is made up of cellulose fibers bonded with lignin, sugars, and other organic compounds. It is subjected to chemicals, heat, and pressure to dissolve lignin and free the cellulose fibers needed to make paper. Useable fibers go to make paper. Everything else goes into a tank. Solids settle to the bottom and liquids go to a water treatment process. The solids from the bottom of the tank are called sludge.

Approximately 10 billion tons of PMS are produced annually by the paper industry and pose a major disposal problem for paper mills. One possible solution to the industry's problem is the use of PMS as a fertilizer through land-spreading. Many studies have been conducted on how this organic material may improve the physical, chemical, and biological properties of soil.

When mixed with soil, PMS brings benefits to growing plants. For example, the elements in cellulose are not readily available to the plant, but are capable of holding water better than soil alone. The other benefit to plants comes from the nitrogen, oxygen, carbon, hydrogen, sulfur, and other organic compounds contained in the PMS. Many people use commercial fertilizers to put these nutrients in the soil, but PMS adds some of the same benefits.

Plants need these nutrients in the soil to use for its processes. Plants must go through photosynthesis to change the nutrients into fuel it can use. Photosynthesis is a process where plants change light energy from the sun into chemical energy for the plant. Photosynthesis requires chlorophyll, sunlight, carbon dioxide, and water. The plant gets carbon dioxide from air and water and needed nutrients from the soil. The sun's energy begins the process of turning carbon dioxide and water into oxygen and glucose. First, the light energy is stored in the chlorophyll. Then the chlorophyll releases its energy to create a chemical reaction the ends with the oxygen and glucose. The plant gives off oxygen that people breathe, and the plant uses the glucose it makes to grow more plant cells and power more photosynthesis. This basic process means that plants can take the light energy from the sun and create oxygen and food necessary for people to live.

A factor in how well a plant grows is the pH of the soil. pH is the measure of how acidic or basic a substance is. This is measured on a 1-14 scale where 7 is neutral, 1-6.9 is acidic and 7.1-14 is basic, or alkaline. The pH is determined by how many hydrogen ions are in the substance. Different plants need different pH levels to survive and thrive. The pH level can affect the amount of available nutrients that are in the soil. So plants generally do well in a more neutral pH. PMS is believed to bring the pH of a soil closer to neutral therefore benefiting plants.

Soybeans, like most plants do best in a soil close to neutral. Soybeans are legumes native to East Asia and are rich in plant proteins. Soybeans are used for many things like food for humans and animals, biodiesel, and particle board. They do best in a pH range of 6.3 to 6.5, but the pH should not reach over 7.5. Not only does this increase nutrient availability, but also increases nitrogen fixation. Nitrogen fixation is the process in which unusable nitrogen is converted into usable nitrogen. This is caused through a symbiotic relationship with the Bacteria Rhizobia. Rhizobia lives in nodules in the soybean's roots. It fixes the nitrogen through the chemical reaction of $N_2 8H + 8e \longrightarrow 2NH_3 + H_2$.

Plants are critical for all living things on earth. Photosynthesis creates energy for the plant by making glucose and oxygen for living things to breathe. It takes specific elements to make this energy and oxygen. The plant gets the elements from fertilizer added to the ground and from the environment. Plants take the elements in through their roots and up to their leaves so that photosynthesis can occur. This process is very complicated and people have found ways to improve it. These improvements have benefited human kind by producing more food and more oxygen. In conclusion, without plants all life would end.

Hypothesis

Soybean plants grown in 50% paper mill sludge will grow larger and produce more beans than plants grown in 100% paper mill sludge, 75% paper mill sludge, 25% paper mill sludge, or the control. Also the substrate in the 100% paper mill sludge will have a higher nutrient concentration of nitrogen, phosphorus, and potassium, and a more neutral pH than the 25%, 50%, 75% mixtures, and the control group. The research supports the idea that the nutrients contained in PMS are important to soybean plant growth. It further supports the idea that PMS brings the substrate closer to a neutral pH, which increases the amount of available nutrients in the substrate. If the PMS is usable as a fertilizer, it will answer a need for by-product disposal in the paper mill industry and become a low cost fertilizer for farmers.

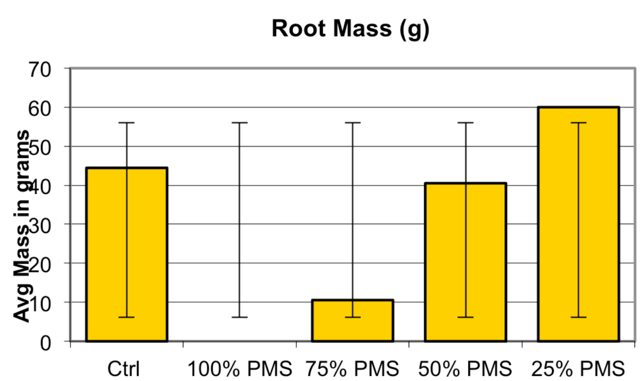
Testing the Hypothesis

In order to test the hypothesis, 50 Janon pots were used to plant 50 soybean seeds in various mixtures of PMS and Farfard Professional Formula. The bags of PMS were all mixed prior to mixing with Farfard Professional Formula to ensure an even distribution of nutrients. Ten pots marked “control” were each filled with 1350 ml Farfard Professional Formula to be used as a control. In a garden wheelbarrow 3,375 ml (25%) of PMS and 10,125 ml (75%) of Farfard Professional Formula were mixed together by hand for two minutes. Then, ten pots marked “25%” were each filled with 337.5 ml (25%) of PMS and 1012.5 ml (75%) of Farfard Professional Formula. In a garden wheelbarrow 6750 ml (50%) of PMS and 6750 ml (50%) of Farfard Professional Formula were mixed together by hand for two minutes. Ten pots marked “50%” were each filled with 675 ml (50%) of PMS and 675 ml (50%) of Farfard Professional Formula. In a garden wheelbarrow 10,125 ml (75%) of PMS and 3,375 ml (25%) of Farfard Professional Formula were mixed together by hand for two minutes. Ten pots marked “75%” were each filled with 1012.5 ml (75%) of PMS and 337.5 ml (25%) of Farfard Professional Formula. Ten pots marked “100%” were each filled with 1350 ml (100%) PMS. One soybean seed was planted one half inch below the surface of the growing medium in each pot. The pots were placed outside in an area covered with clear plastic and in full sun. The clear plastic was five feet above the containers and was to prevent excessive rain from damaging the plants. The pots were monitored daily to look for germination. After day 20, any seed that had not germinated was recorded as a “did not germinate.” Every third day the plants that germinated were watered with one half cup of tap water. This was repeated for 63 days from August fourth until October fifth. On October fifth the number of bean pods per plant was counted and the plants were weighed. All bean pods longer than five (5) millimeters were counted on each plant and recorded. The weighing process involved separating the root system from the foliage by cutting the point on the plant where the two areas met. The root system of each plant was shaken for five minutes and then rinsed to remove growing medium from the roots. A mid-sized plastic bowl was placed on the scale and the scale reset at zero. The root system was placed in the bowl and the mass was recorded in ml. The foliage of the plant was placed the clean plastic bowl and the mass was also recorded in ml. This step was repeated for each of the 50 pots. Growth was measured on average number of bean pods per plant in each group, average mass of roots per plant in each group, and average mass of foliage per plant in each group. The number of seeds germinating per group was also evaluated.

Results

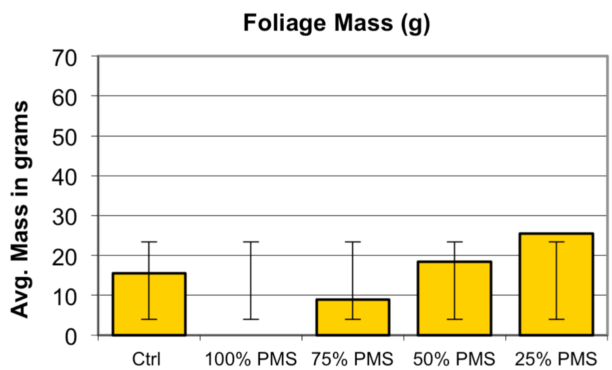
Plants depend on the nutrient content and pH of their growing mediums to grow. Five groups were used to test if PMS added to the growing medium affected plant growth. Areas observed as growth indicators were average root mass, foliage mass, and average number of bean pods per plant.

Root mass was affected by different percentages of growing mediums. Between the greatest and least average mass of groups was a difference of over 49 grams. The greatest average mass was 60 grams for the 25% PMS



group. This is greater than one standard deviation with a standard deviation of about 58 grams. The least average mass was 10.56 grams for the 75% PMS group. However, the control group averaged 33.88 grams more mass per plant.

Average foliage mass has similar results to that of average root mass of plants. The 25% PMS group had the greatest average foliage mass at 25.5 grams. This group again exceeded one standard deviation. 50 % PMS was the next greatest at 18.5 grams. The control group had a mass of 15.56 grams. 75% PMS group had a foliage mass of only 8.89 grams. The total difference between the 25% PMS and 75% PMS groups was 16.61.



Like the average root mass per plant and average foliage mass per plant, the 25% PMS group has the highest average number of bean pods per plant. Similar to the average foliage mass per plant, the 50% PMS group produced the second highest number of bean pods on average per plant The 25% PMS group produced the greatest number of bean pods with an average of 9.1 bean pods per plant. The 50% PMS, 75% PMS and control groups had 8.6, 4.0, and 6.22 bean pods on average respectively. None of the groups exceeded one standard deviation in this measurement.

While not one of the initial areas targeted for measurement, the number of seeds germinating in each group generated a surprising result. While most groups only had one plant not germinate, none of the seeds in the 100% PMS group germinated.

Conclusion

The hypothesis being tested was soybean plants grown in 50% paper mill sludge will grow larger and produce more beans than plants grown in 100% paper mill sludge, 75% paper mill sludge, 25% paper mill sludge, or the control. Also the substrate in the 100% paper mill sludge will have a higher nutrient concentration of nitrogen, phosphorus, and potassium, and a more neutral pH than the 25%, 50%, 75% mixtures, and the control group. In both cases the hypothesis was incorrect. Different combinations of the growing medium produced interesting results. First of which is that four of the groups germinated more than 90% of the seeds planted while the seeds in the 100% PMS group did not germinate. 25% PMS and 50% PMS groups had the most plants germinate while 75% PMS and control groups had the second most plants germinate. This might be because of the PMS in the growing medium. PMS holds a lot of water. It holds 50 grams of water for every 50 grams of PMS. Water is important for germination because it activates enzymes in the seed which starts the growth of the plant. PMS in the growing medium would hold more water around the seed to activate the enzymes for germination. An unexpected result was that 100% PMS did not germinate any seeds. This might have happened because of the large amount of water that can be held in PMS it could have drowned the seed. Also, the seed may have sat in between the large pieces of sludge and there was not enough seed-water contact for it to germinate.

All of the growth indicator categories were dominated by the 25% PMS group, but none more so than the average root mass. The 25% PMS group had the heaviest roots and the control had the second heaviest. This may have been caused by larger amounts of calcium than the other groups. However, this can not be confirmed as the calcium content in the mediums was not tested. Calcium helps to grow the root system of the plant, along with phosphorus. The extra calcium most likely came from the Farfard Professional Formula as the two groups containing the largest amount of this medium had the greatest root mass.

The number of bean pods per plant on average was also investigated as a growth indicator. Between the 25% and 50% PMS groups there was not a great difference. This result would suggest that each group had the same amount of phosphorus available, but that explanation does not match the identical phosphorus readings when the nutrients were tested. One reasonable explanation for the similar number of bean pods, but an identical reading is that the testing equipment was not very accurate and gave a general idea of the concentration of the nutrients contained in the growing mediums. Therefore there could have been different numerical levels in the growing medium. This could also explain the large differences between the other mediums, which also had identical readings to those mentioned above.

A final area was observed for growth. The average foliage mass per plant was recorded. The 25% PMS group weighed 16.61 grams more on average than the 75%PMS group. The most likely cause of this difference is the 25% PMS group had more nitrogen than the 75% PMS group. This is unsupported by the nitrogen testing, as the two groups produced identical results. The same theory explained above also applies here. This theory is further supported by the fact that the control group had a higher nitrogen test result than the other groups which all had identical results. The 25% PMS group has the largest amount of Farfard Professional Formula outside of the control group. This theory however does not explain why the control group had the highest nitrogen test result but the 25% group still had a higher foliage mass than the control group. After further research, it is likely that the Farfard Professional Formula contained a "spark" of nutrients to boost initial plant growth. This spark would have been quickly depleted by the growing plant. This effect was most notable in the leaves of the plants in the control group. The leaves were yellower than in all groups containing sludge except the 100% PMS group. The nutrients contained in the sludge last much longer and continue to deliver nitrogen to the foliage increasing the mass of the foliage in this group. This lead to bright green, healthy looking leaves in the three PMS groups producing plants.

At the beginning of the experiments all of the groups were tested for their nutrient levels and pH. The hypothesis predicted that the 100% PMS group would have the highest nutrient levels and most neutral pH. This hypothesis was proved incorrect. This may be because the testing equipment was not very accurate and gave more of a general idea of the nutrient levels than an exact numerical value. Also, the pH testing did not have a higher alkaline level than 7.5. This hypothesis was proved wrong beyond doubt in the nitrogen test as the control had a higher nitrogen test result than all of the other mediums, so even with a more accurate test it would have still proven the hypothesis incorrect.

Future research around this topic should include a larger sample size and more research into the chemical make-up of PMS and how it would affect crops. The pH level of the growing medium should be measured more accurately to look at its affect on the release of nutrients in the soil. Also the macronutrient content should be measured more accurately and the micronutrient content should be measured as well. Finally, different amounts of PMS should be tested with different bases to determine the optimum combination for maximum growth.