Using Carbon Filtration in Soil to Reduce the Effects of Nitrate Pollution in Aquatic Ecosystems

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Abstract

Dead zones are areas in oceans and large lakes that do not have enough dissolved oxygen in the water to support life. In order for an area to be classified as a dead zone, it must have below 2-3 mg of oxygen per litre of water. The two biggest causes of dead zones are rising sea levels and fertilizer runoff. Our project aims to find a solution to the latter cause. Fertilizers contain nutrients that are designed to help plants grow faster and fuller, which is quite effective in agriculture. However, when runoff from farms or other areas where fertilizers are commonly used, this dissolved nutrients is flushed into aquatic ecosystems, where it helps algae to bloom extremely quickly. When the algae then dies, it uses vast amounts of dissolved oxygen to decompose, thus creating dead zones. Through our research, we discovered that activated carbon readily bonds to many things, including nitrates (NO_3), which are a major component in fertilizers. By bonding carbon to the nitrates, they are no longer able to cause extremely fast growth in plants, including algae.

Purpose

The purpose of this experiment is to test whether activated carbon filtration in soil can absorb nitrate compounds from captured fertilizer runoff efficiently and effectively in order to stop the increasing issue of dead zones.

Hypothesis

If activated carbon is added to soil then the concentration of highly-soluble compounds, specifically nitrate compounds, will be decreased as measured from captured runoff because activated carbon has a large surface area as well as a hydrophobic surface which allows it to absorb highly soluble compounds in water.

Research

Dead zones

Dead zones, also called hypoxia, are areas in large bodies of water where the amount of dissolved oxygen is under 2-3 mg of dissolved oxygen per litre of water. While these have existed for millions of years, hypoxic areas have become more common and more severe in recent years. Although there are areas that will naturally become dead zones due to high saline levels or thermal gradients, the most common cause is mostly a side effect of human activity. The majority of hypoxic areas are caused by the decomposition of algae in algal blooms, which are in turn caused by sea level rise or fertilizer pollution. Sea level rise can cause algal blooms by causing deposits of iron and other minerals found on continental shelves to be dissolved into the ocean, thus giving algae enough nutrients to quickly bloom. In areas where fertilizer is commonly used (mainly agricultural areas or golf courses), excess nutrients from fertilizers that are not absorbed by plants can be introduced to nearby aquatic ecosystems, also causing algal blooms due to excess nutrients.

Health effects of nitrates

Excess nitrates from fertilizer runoff in drinking water can have serious effects on human health and is described as *primary toxicity* (Fewtrell, 2004). For example, nitrates can lead to the formation of nitrosamines, mutagenic compounds, which may cause many types of cancer as well as other dangerous diseases (Science Direct, 2018). Furthermore, excess nitrates in groundwater can lead to eutrophication; the process of nutrient accumulation in water which leads to algal blooms.

Activated Carbon

One of the things that determines a filtration's success is its pose size distribution (PSD). The PSD refers to the number of particles a pore in a membrane can absorb (Science Direct, 2023). The PSD of activated carbon is one of the main factors that make activated carbon a good absorbent. This, with its high surface area, allows it to absorb highly-soluble compounds in water.

Slow-release Fertilizer

The fertilizer we used for this experiment was slow-release, meaning it has a coating that prevents it from giving the plant all the nutrients it needs at once. Slow-release fertilizers rely on either microbial activity to eat the coating and release nutrients, osmosis in which water dissolves the nutrients and forces them out, or diffusion through a concentration gradient. Slow-release fertilizer can also be affected by temperature. Every 10℃ change will cause a 2x fold effect in nutrient release.

Variables

Control Variables:

- Soil type
- Fertilizer type
- Fertilizer amount
- Water source

- Amount of water
- Lighting
- Temperature of growing area

Manipulated Variable:

- Amount of carbon in soil

Responding Variable:

- Concentration of NO_3 in captured water run-off

Procedure

Set up procedure:

1. Set up two containers (per sample). One container should have holes in the bottom, and the other should be able to collect the runoff from the first container.
2. In each container, we added two cups of soil, mixed with the appropriate amount of activated carbon to achieve the carbon to soil ratio for each sample.
3. Add three teaspoons of grass seed evenly over the top of each sample
4. For all samples except the control, add ~ 9.0g of fertilizer to each sample
5. Water samples (carefully to avoid disrupting the grass seed) with ~118 mL of water

Testing procedure:

1. Empty all remaining runoff water from collection container
2. Clean out container to remove any residue
3. Water sample, then wait 2-3 minutes for runoff to collect
4. Using a cloth as a filter, add water to test tube
5. Add 10 drops of test solution 1 to the test tube, then invert 10 times to mix

6. Add 10 drops of test solution 2 to the same test tube, then shake for approx. one minute
7. Wait five minutes for color to develop
8. Record data from test
9. Clean all supplies
10. Repeat steps 1-7 for all samples

Observations

Our first experiment was designed to test if our project was feasible. Throughout this experiment, we were able to observe many trends that were then used to design a more effective second phase. The grass sprouted on the eighth day of the experiment, and reached a height of over three inches within three weeks, whereupon the grass was trimmed to maintain a consistent height.

The nitrate levels in the runoff water in the two experimental samples both followed a common trend of starting at moderate levels of NO_3 in the runoff water, then decreased to low levels as the fertilizer began to be fully used, then increased after more fertilizer was added. Additionally, nitrate levels rose significantly towards the end of the experiment, which led us to believe that the carbon in the soil was also being used up. Throughout the experiment, while the nitrate levels varied quite a bit, the concentration of NO_3 in the runoff of the sample without carbon was higher than the sample with carbon consistently, usually 5-20 ppm higher.

For the second experiment, we experimented with four different carbon ratios in order to determine which one was the most efficient. There were some issues with the weather, and so it took longer for the grass to sprout. Furthermore, the added activated carbon resulted in more issues with growth, but more information on this can be found in the *Analysis* portion of this paper.

Nitrate levels were very low for the first two months due to weather conditions. The fertilizer did not receive enough Sunlight to dissolve quickly, and as it is a slow-release fertilizer, it took longer to give the grass the nutrients it needed to grow. However, the data from February shows a more accurate result that is closer to the data from our first experiment, when the samples received the needed amount of Sunlight.

Results

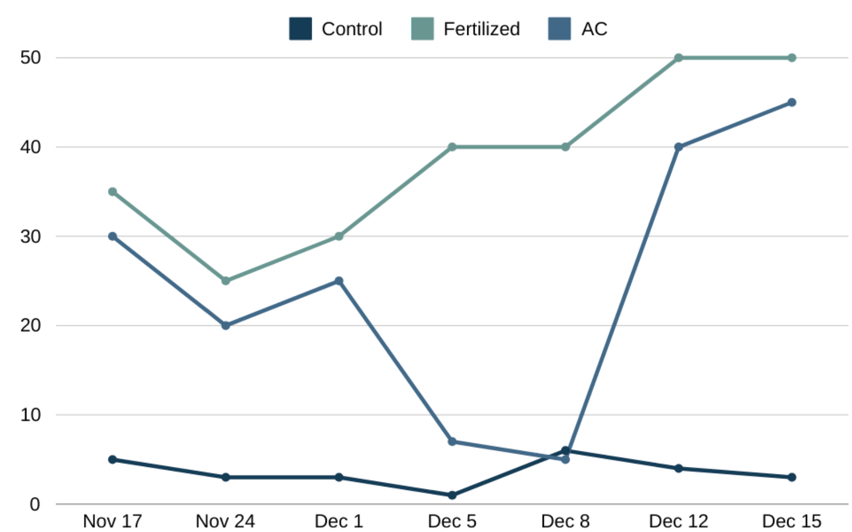

Table 1: PPM of nitrates (NO_3) in runoff water of experiment 1 (Nov 17 - Dec 15)

The first experiment was used to determine if the concept of adding activated carbon to soil would be effective at reducing the concentration of nitrates dissolved in the runoff water. We were able to successfully determine that adding the activated carbon to the soil did effectively decrease the amount of nitrates in the runoff water. Thus, through the results of this experiment, it was proven that this project does have merit, and a second phase to determine what the most effective concentration of carbon in soil would be run.

The second experiment involved experimentation with different ratios of activated carbon in soil. Due to unfavorable weather conditions, data from the last month of our experiment is the most useful. This data shows that out of the four activated carbon ratios, the 8:1 and 16:1 samples have the least nitrate concentration. Thus, these two are the ones with optimal activated carbon to soil ratios, but further experimentation under better growing conditions would have to be conducted to determine which of the two is better.

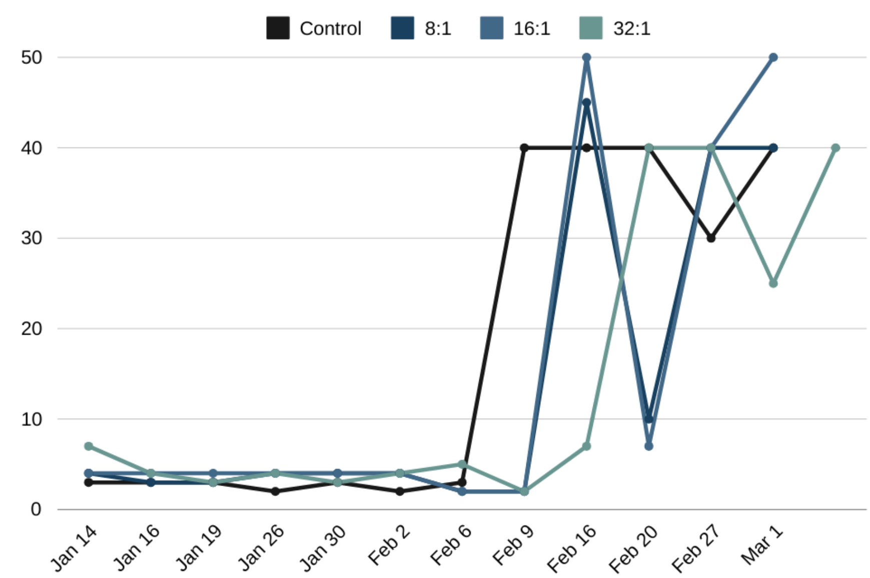

Table 2: PPM of nitrates (NO_3) in runoff water of experiment 2 (Dec 02 - Mar 01)

Analysis

There were many challenges experienced during this experiment. Firstly, the activated carbon, much like fertilizer, wears off after 2-3 weeks, and so we decided to re-add activated carbon when we fertilize (every three weeks). However, the assumption that the amount of activated carbon added should be the same, much like fertilizer, resulted in too much activated carbon. According to our research, any addends to soil should not amount to more than 40% of the soil (LibreTexts Biology, 2023). Thus, only one of our samples was affected; the 4:1 carbon sample, as it amounted to 50% of added activated carbon after the second addition. After further research it was found that the amount of activated carbon added should amount to 10% of the amount of soil added. As such, one of our samples (8:1 ratio) was at its maximum, while the 16:1 and 32:1 ratios were lower than the maximum amount.

Secondly, the weather conditions were not ideal when the second experiment was run, especially with the cold spike, so the samples did not receive enough Sunlight to grow. Furthermore, the activated carbon needs to be left out in the Sun for at least one hour per month for it to remain activated, which is what makes it a good absorbent for highly soluble compounds. As such, the samples were moved to a different place in the house with a bigger window whenever there was Sunlight, which helped the process as seen in our data.

Thirdly, the cold spike also affected the release of nutrients to the plant, which is why the first two months of data show a low NO_3 concentration in all samples. This was fixed towards the end of the cold spike when the samples received more Sunlight and were in an overall warmer environment.

Overall, the experiment did have lots of challenges; however, the project does provide consistent results when run under optimal conditions for plant growth. Based on our experiment, a 16:1 and 32:1 activated carbon to soil (cups) ratios seem to be the best in both growth and nitrate absorption, but the 16:1 ratio may be better as it has consistent results of 3.0 ppm average when compared to the 32:1 ratio's 4.0 ppm average. The difference would be larger, around 5.0-6.0 ppm ratio average, if the samples had access to more Sunlight.

Conclusion

The issue that we are aiming to solve through this project is dead zones, which are aquatic areas with less than 2 mg of dissolved oxygen per liter of water. One of the biggest contributors to dead zones is nitrate pollution caused by fertilizer runoff. By reducing the amount of nitrates dissolved in aquatic ecosystems, the number and size of dead zones could be significantly decreased, as nitrates cause drastic algal growth which absorb large amounts of oxygen to live as well as decompose.

Our solution to this problem was to filter the dissolved nitrates out of the runoff water before they reach aquatic ecosystems. We did this by adding activated carbon directly into the soil. The carbon then bonded to the nitrates, effectively ensuring that they were no longer harmful to the environment by causing algal blooms, which lead to dead zones.

We ran two experiments to determine whether this concept would be effective at reducing nitrate runoff. The first experiment was solely to determine if adding activated carbon to soil would make a difference in the nitrate concentration of runoff. As the amount of nitrates in the sample with activated carbon in the soil was consistently lower than the sample without carbon, we were able to determine that the experiment does have merit. The second experiment demonstrated the effects different activated carbon ratios had on nitrate concentrations in captured runoff. According to data (specifically during the week in which samples had access to Sunlight), samples 8:1, 16:1 and 32:1 had better results when compared to the 4:1 sample, and within those 8:1 and 16:1 had better results when compared to the 32:1 sample. As such, our experiment proved the potential of activated carbon in reducing nitrate contamination due to fertilizer runoff.

Thus, our experiment suggests that using carbon filtration in soil to reduce nitrate contamination in drinking water is feasible and delivers desired results; however, the second round of experiments unfortunately did not show these results in the expected manner when compared to the first round of experiments due to the lack of Sunlight during the months in which the experiment was conducted.

Application

While our experiment was run on an extremely small scale, it would be possible to use in real world settings. Two main areas where carbon filtration in soil could make a big difference are in agriculture and golf courses. These are two of the largest producers of nitrate pollution caused by fertilizer runoff. By adding activated carbon into the soil of major producers of nitrate pollution, this could significantly decrease the harmful effects of fertilizer runoff, and thus decrease the amount of dead zones. However, adding activated carbon into agricultural practices would likely increase the cost of goods produced using it, as activated carbon is quite expensive. Additionally, the process to produce activated carbon can be harmful to the environment. While using activated carbon filtration in soil to reduce the amount of nitrate pollution in aquatic systems would certainly have positive impacts in reducing the impacts of dead zones, it may not be a viable solution in the near future. However, as methods of producing activated carbon become more effective, it could be a solution to a serious problem.

Sources of Error

Our experiment involved working with plants, which are a living organism, and thus can have issues that are out of our control, yet still affect the results of the experiment. If the number of grass seeds that were functional in one sample was much higher than another sample, this could lead to biased results. Additionally, some samples may have grass that reacts differently with the fertilizer, which could also lead to different results than expected. Another possible source of error in this experiment would be contamination. Despite taking measures to reduce the risk of contamination, keeping the samples close together (especially in experiment one) will always increase the risk of contamination.

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