Soil Compaction and its Effects on Fertilizer Runoff in Soybean Crops

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Abstract

The purpose of conducting this experiment was to learn more information about the problem of fertilizer runoff and its relation to soil compaction as well as exploring possible solutions to both of these issues. A variety of research has been done over soil compaction and its effects on not only fertilizer runoff, but root growth and other problems caused because of compaction. A difference between compaction and other problems is that it is a visible one. It is easy to see soil compaction compared to nitrate levels in the soil. Other studies have been conducted on the effects of runoff nitrates on the water system and what causes this runoff. These studies conclude that the result of this extensive runoff has nothing to do with the water itself, but the soil it runs off of. The main issue with looking at fertilizer runoff is that many factors contribute to the problem. One of the main factors is soil compaction, which was independently tested in this study. This study specifically looks at the effects of soil compaction on runoff and the amount of nitrate in the runoff. Multiple rows of soybeans were planted in a greenhouse. Of these rows, half of the rows consisted of highly compacted soil, and the other half, loosened healthy soil. No other variables were changed in this study. Soybeans were planted every 2 inches in the rows which were spaced 7.5 inches apart. A collection system made up of gutters was made to collect the runoff after the soybeans were fertilized. The collected samples were then tested for nitrate. The results of this study supported previous studies as well as the hypothesis that the levels of nitrate were higher in the runoff from the compacted soil.

Introduction

This work was done to learn about the impact on soil compaction and fertilizer runoff and the relationship between the two. Research into other findings was conducted to form a hypothesis. Previous work had found that there is a correlation between compaction and runoff and they were both issues. This research was conducted to look for potential solutions in compaction and runoff by addressing the effect they have on each other. This research addresses two problems that are devastating to the agriculture industry. Soil compaction can cause root damage and other issues, while fertilizer runoff destroys the water system that leads to further damage. Other work has found that compaction and runoff are major issues and that they do relate to each other. This project was approached by looking at only the effects of compaction on nitrate levels. Only that specific area was targeted to look for a precise correlation between compaction and an aspect of runoff. An objective in this project was to learn about the process of not only compaction and runoff but look at soybean growth.

Literature Review

Environmentalists Worry about Fertilizer Runoff from Farms

In the fall, many farmers started to put fertilizer on their fields. These farmers applying fertilizer are worrying environmentalists because of where a lot of that fertilizer might end up. Runoff from farms is one of the key contributors to the growing dead area in the Gulf of Mexico, possibly over 8,000 square miles. The hypoxic, or oxygen-poor, zone is the cause of about 1.6 million metric tons of nitrogen dumped into the water, carried through rivers and streams in the United States. A large portion of the nitrogen comes from extra fertilizer in farm fields across the midwest. "Every reputable scientist is saying that Midwestern agriculture is a major source of nutrient-based pollution, too much nitrogen, and phosphorus," said a source by the name of Mr. Moore. Mr. Moore also said that fertilizer runoff could devastate the fishing industry of the gulf. People fear that the gulf could turn into the Baltic Sea and Long Island Sound, both turned hypoxic.

The Gulf is not the only water source to be affected by this, many towns in Illinois have invested millions of dollars to remove pollution that they are not responsible for. Illinois water pollution is 76 percent because of agriculture. The Illinois Pollution Control Board proposed fertilizer application regulations in 1971, but none were put in place and no state agency has revisited the matter since. To reduce nutrient concentrations after the draining of water from their fields, farmers can plant buffer or filter strips along streams and rivers. A well-positioned buffer can reduce nitrates, in field runoff, by as much as 70 percent.

To apply the perfect amount of fertilizer within a field, use of a variable rate applicator with global positioning satellite technology can reduce runoff. Applying fertilizer in the fall also is a contributor to farm runoff. Extension guidelines urge farmers to not apply in the fall unless certain temperatures are reached. The rising cost of fertilizer is a factor encouraging soil conservation, and a recent study showed that 33 percent of the farmers in the Illinois area overapply nitrates by 20 pounds per acre. Ninety percent of the time, reduced nitrate applications prove more cost effective for the farmer.

Overall, the article was very informative and gave a lot of helpful information. The author of the article is a very qualified reporter and had a lot of knowledge about fertilizer runoff and its effects from the many people he interviewed, as well as having his contact information online meaning he stands behind his article. One of the people interviewed, Mr. Robert Moore, was a credible source because of his connection to environmentalism and his passion for keeping the Illinois water system clean. Two other people who were either interviewed or gave facts are Del Christensen of Trees Forever, an Iowa-based organization that promotes tree and grass plantings as well as Shannon Allen, the Illinois district's watershed specialist. The article was published on September 4th of 2001, yet the information in the article still stands relevant. The article was retrieved off of a scholarly website, INFOhio, a trusted organization for educational sources. The fertilizer runoff article was very professional in the design of the site as well as the author's writing style, it was a very informative article.

Our Fertilized World

If it is difficult for someone to break up the soil in the ground, then it is very difficult for the roots of the plants to grow through it, this is called soil compaction, compressed soil in a reduced volume. The soil has 3 components, air, water, and solid material. For healthy soils, the volume should only consist of half solid materials, the rest should be air or water. Space is needed for the gas exchange between oxygen and carbon dioxide. The gases that travel to and from the plant from the atmosphere, as well as the water needs to get to the root system. Soil compaction occurs when there is less air space and a higher density. The solid materials are made up of minerals and organic matter. The mineral part is composed of broken down rock, while the organic matter can be composed of any living or once living things, such as roots, leaves, and microorganisms.

Soil can be compared to a pile of bricks, in a perfect world someone would like the bricks to be organized to allow water flow, instead of random placed empty spaces of all shapes and sizes. Organic matter is also a key factor, still comparing soil to a pile of bricks, the organic matter is the smaller factor in the soil, but it is like the mortar to hold the bricks in the perfect position. Organic matter is like a healthy adhesive for the soil.

Compaction in the soil is a problem for a multitude of reasons. There will not be proper space for the roots to penetrate the soil properly. Improper root penetration could cause for the plant to not be able to take in nutrients and water. Another potential problem is that if the soil to compact, rainwater and snowmelt can run over the surface of the soil and into stormwater systems can potentially cause erosion or other issues. Soil can become eroded and compacted by vehicles driving over the top of it, as well as soil is left untouched, as loose soil can blow away, leaving only the dense compacted soil. How to reduce compaction?: To reduce soil compaction, there are two important things to manage, the soil structure, and the amount of organic matter. To reduce soil compaction by improving soil structure, tilling and turning the soil over are viable options. However, tilling soil can greatly reduce organic matter in the soil. To increase the level of organic materials in the soil, compost is a good option. By adding anything from leaves and mulch, manure can increase the nutrients in the soil as well as the airspace in the soil for root and water penetration. Cover crops are another great way to reduce soil compaction. The plants turn sunlight into a carbon based material. The roots of the cover crop also leave pores and room for air and water in the soil. Soil is compacted when wet, the wet soft soil is easily compacted.

This article was very informative on the properties of soil and soil compaction. The author, Andrea Basche, has a Bachelor of Science in Biological Sciences as well as a Masters in Applied Climate Science and a Ph.D. in Crop Production & Physiology and Sustainable Agriculture. The article was published in May/June of 2019. The article was retrieved off of a scholarly website, INFOhio, a trusted organization for educational sources. The authors writing style along with the style of the article is very professional and trustworthy.

Loosening Up. Horticulture

If we don't watch out, our planet could be destroyed by agriculture. Nitrogen is the engine of agriculture and the key to feeding a hungry world. Without this important element, photosynthesis can not happen, protein cannot form, and plants cannot grow. The fastest growing crops that humanity depends upon, corn, wheat, and rice are the most nitrogen hungry plants. They demand more than is naturally available. Factories capture inert nitrogen gas from our atmosphere and force it into union with hydrogen in natural gas, creating the compounds plants love. Nitrogen fertilizer has been applied to fields all over the world, totaling more than a hundred million tons.

Without that fertilizer human life wouldn't be where it is today, the soil of our earth just could not handle that amount of depletion from growth by itself. Almost half of the nitrogen in our body's muscle and organ tissue came from factories. There is still a price to pay for this modern miracle. Runaway nitrogen is suffocating life in lakes and estuaries as well as groundwater contamination and climate warming. As our starving world looks to feed billions of mouths nitrogen high proteins, but at the cost of our air and water. China has the most visible nitrogen dilemma. When China's population grew by an astonishing 300 million people, traditional agriculture couldn't keep up.

With the combination of nitrogen fertilizer and improved seeds, the soil quality and capabilities have soared. Scientist have a different side of the story. "Nitrogen fertilizer is u=overused by 30 to 60 percent," says a scientist of the Agriculture University in Beijing. Once spread on the field, the compounds make their way into the water sources and into the air, as well as makes its way through food to people. Someone also recalls the river being clean back when he was a kid, but now he cannot see the fish anymore because of cloudiness from the phytoplankton, the plankton reacts to the water that is eutrophic, or on nutrient overload. "A recent national survey of 40 lakes in China found that more than half of them suffered from too much nitrogen or phosphorus. (Fertilizer containing phosphorus is often to blame for algal growth in lakes.)" There is a glimpse of a solution on a farm in western Iowa. The Rossmann family uses nitrogen, but not from a commercial factory. They use nitrogen-fixing bacteria from the root nodules of legumes such as soybeans. This produces less runoff at the cost of less nitrogen being added to the soil. There are many ways to prevent runoff and help soil quality.

The author of this article is very well informed on the subject of fertilizer runoff. Dan Charles is the Food and Agriculture Correspondent for a journalist company, NPR. The author gets his information from a variety of sources interviewed including scientists Xiaotang Ju, and Zhu Zhaoliang who are skilled in the field of nitrogen, as well as its effects on the environment. The article was published in May of 2013 and is still relevant. The article was retrieved off of a scholarly website, INFOhio, a trusted organization for educational sources. The article was retrieved off of a trusted organization website and is very informative. The writing style of the author is very professional as well as the design of the website.

Senate passes Farm Bill including water quality, funding provisions

The United States Senate had passed the 2018 Agriculture Improvement Act on an 86-11 vote. Commonly referred to as the Farm Bill, the measure extends programs that protect drinking water from farm runoff and help rural communities improve their water infrastructure. The program offers assistance to farmers in the form of grants for farmers who partner with water quality utilities and achieve other matters. The NACWA, National Association of Clean Water Agencies, has engaged with Congress in a bipartisan manner on the Farm Bill to advocate for more expansions on ways to protect clean water. Many of the key conservation and elements of water quality in the sent are also in the House Farm Bill which passed on a much more close, 213-211.

Both Bills would contain similar items in the bill and recognize the importance of protecting clean water. Many house Democrats voted against this Bill as it would interfere with food stamp recipients. What the Senate did not recognize was the harm on the water from non-farm areas. The Bill is mainly directed at farmers and ignores the repercussions from urban fertilizers from gardens. The Bill is focused on farmers because of the larger use of fertilizer but is not directed at all users and causes of the problem of fertilizer runoff in water sources.

This article was very informative, the author of this article, WFM STAFF had a lot of knowledge on the subject and was informed. The article was published on July 2, 2018, and has very present and relevant. The article was found on a .com site that seemed proud of their information and seemed knowledgeable. There was a slight bias towards the side of the Congress and not the farmers but it was not too strong. The spelling and writing style of the page was very professional and advanced.

Soybean Nutrient Needs

Soybeans have a good response to fertility in soils. In Iowa (and other states) it is common practice to fertilize crops. High yielding soybeans require large amounts of nitrogen (N), phosphorus (P), and potassium (K), as well as small amounts of sulfur (S). Soybeans respond well to all of these nutrients, especially N and K. Soybeans can achieve their nitrogen needs through a process known as nitrogen fixation. The soybean plant symbiotic relationship with the helpful bacteria (*Bradyrhizobium japonicum*) to convert atmospheric N gas to ammonium nitrate, a form of N usable by the plant. The bacteria attaches to the roots of the plant and are a factor in the nodules of the soybean plant. The nodules have a key part in the nitrogen in the plant and protect the bacteria from oxygen.

The nodules then begin supplying oxygen during early vegetable growth. Plant health can be affected by plant nutrient levels. Soybeans grown in high nitrogen levels are more susceptible to disease attacks and plants suffering from low levels of K are more susceptible to infection. In conclusion, nutrients have an important role in soybean growth, such as the protein rich soybeans that are rich in nitrogen to the phosphorus needed in the forming and growth of seeds and roots.

This was a very informative research paper, the authors were very knowledgeable and qualified. The research paper was published in 2013 and is very formal and relevant. The paper was found on an edu site and was very scholarly and credible. The paper was published on Iowa State University's website and was backed professionally. The writing style and site design were both correct and professional. All adding up to a great research source.

Soil and Soil Water Relationships

Soil is made up of four different things, organic matter solids, mineral solids, and water and air. The mineral matter is form broken down rocks and the organic matter, dead plants, and animals. The empty holes in between the solid matter is filled with water or air. The mineral portion is made up of silt, sand, and clay. The makeup determines the soil texture. Most soil texture can be explained using the soil triangle. Soil texture is important for water draining.

erosion, and other properties. Most soil is 45-65 percent solids and 35-55 pores. The most solid material is 2-5 percent organic matter. Organic matter can include living organisms. Agriculture soils have less organic matter and organisms compared to an untouched forest.

Air and water occupy the pore space, the amount of water or air changes depending on whether it has recently rained or if it is dry. Tillage from farming can change the soil structure and texture, mostly in a negative way while change form organic organisms is usually positive. Soil structure is determined by how the soil particles are shaped and arranged. Soil structure affects how water and air can move through it. There are 6 main soil structures, platy, prismatic, columnar, granular, blocky, and single grained. Single grained and massive soils are referred to as structureless. In massive soils, the soil moves slowly, while in single grained like sand the water runs through.

These are just a few examples of how soil structure affects water and air movement. Soil bulk density describes the mass ratio of dry soil to the total volume. Total volume includes solids and pores. Soil bulk density related to the soil's porosity, or the number of pores in the soil. With soils of the same soil structure, compacted soils have less porosity and greater bulk density. With soils of the same soil structure, loose soils have more porosity and less bulk density. Bulk density also gives information on the potential for runoff of chemicals used in agriculture as well as erosion. Two things that remove nutrients are runoff and erosion both occur in soil with higher bulk density. Soil with low bulk density can cause vertical leaching of nutrients and keep them away from crops. The same way soil structure can be changed, bulk density can also be affected by physical practices, like tilling. Complete soil porosity can be affected by using the equation, total porosity= 1- (bulk density/particle density) Soil samples can be obtained with a core, or a device used to take undisturbed samples in multiple depths. Bulk density can be measured with these samples. Well structured soils typically have greater particle density and bulk density. Soil porosity is fluctuated by soil texture and aggression, as well as other natural processes from organic organisms.

Course soil tends to have less porosity than fine soil. Even though the average pore size in course soil is larger, there are more pores in smaller sizes in finer soil. How a pore functions is determined by the size of it. Macropores are larger than.08mm and usually the pores between aggregates, used for water drainage. Macropores can also give nutrients to the roots, but also cause agricultural chemical runoff. Macropores help in free drainage in soil, free drainage is also called preferential flow as the water can take the preferred path away from the bulk density soil. Preferential flow can cause rapid leaching, having nutrients and agrochemicals flow right past the roots and not being taken into the soil. Macropores can be compacted into micropores. Micropores are .08 mm or less and occur inside soil aggregates, hold water, and agrochemicals, as well as are part of capillary water distribution. They hold water, but most of the water doesn't make it to the plants.

The amount of water held by the soil at any given time is the soil water content. Not all water in soil is available to plants. The water accessible to the plant is called plant availability water. The way the water flows is important to the relation to the soil structure, for example downward flowing water can be used easily by plants. Water, however, can flow past the root system of a pant. Gravitational water is water that flows freely under gravity. Gravitational may or may not get used by the plant depending on environmental conditions. Sandy soil has a low amount of plant available water, and a large amount of gravitational water flowing through the macropores. Because of this crops grown in sandy soil will be affected by droughts more easily. On the other hand, clay soil has a higher plant availability because of the enhanced aggression but has a higher unavailability due to how tightly the micropores. Also, loamy soils have the largest plant available water, they also have the same gravitational and unavailable water content, because of this they loam is prized for agriculture.

The energy status of water is referred to as soil water potential, or soil water tension. Soil water potential is the amount of energy required to extract water from the soil. Differences in water potential energies are responsible for the way water flows in the ground. Water moves from higher to lower potential energy status. Adhesion, surface tension, and cohesion in the air and water in dry soil pores cause the water to be held tightly inside through suction. Water is held the most tight in clay soil in present micropores. Gravitational potential is caused by the pull of gravity on the water. Gravitational potential is determined by vertical distance between water and reference elevation. Characteristics of water drainage or important soil properties that help agricultural production.

The authors of this paper, Mr. Zachary M. Eaton and Ms. Emily Bock are well informed and qualified as they are both educated in Biological Systems Engineering from Virginia Tech. The article is relative as it was published in 2016. The paper was published by Virginia Tech as vt.edu. The style of the research paper was very professional as the writing style and format was professional as well. The research paper was on a variety of topics and was helpful in all of these said topics.

Materials and Methods

Problem: What is the relationship between soil compaction affecting fertilizer runoff?

Hypothesis: If compacted and loose soil were fertilized with nitrate and tested for runoff, then compacted soil will have the highest amount of nitrate in the runoff collected.

Independent: Compaction

Dependent: Nitrate in parts per million

Constants: Water, Amount of Water, Location, Temperature, Sunlight, Seeds, Soil Type, Amount of Soil, Container Type, Nitrate Fertilizer, Amount of Nitrate Fertilizer, Fertilizer Test

Materials:

- Calking
- Calking Gun
- Drill
- Drill Bit (5 mm)
- Greenhouse
- Kite String
- LaMotte 5891 Water Test Education Kit,Nitrate (12 tests)
- 5 ft. Metal Gutters (6)
- Nitrate Fertilizer
- Pencils (12)
- 5 ft. Plastic Gutters (6)
- Pliers
- Serological Pipette
- Soil
- Soybean Seeds (72)
- 10 ml. Test Tubes (12)
- Water

Methods/Procedure:

1. The listed materials were gathered.
2. The six metal gutters were placed outside. The gutters were placed upside down and next to each other.
3. A drill and drill bit was used to drill holes two inches apart across all six metal gutters.
4. The gutters were then placed in a greenhouse right side up. The center of the rows were placed seven and a half inches apart.
5. The plastic gutters were tied underneath the metal gutters using kite string for water collection
6. A calking gun was used to patch holes anywhere water can escape through the plastic gutters.
7. Pencils were placed in between the bottom of the plastic gutters and the kite string
8. The pencils were spun to tighten the string to the plastic gutters
9. The metal gutters were filled with the same amount of soil
10. The soil was compacted in 3 of the 6 gutters
11. Soybean seeds were planted every 2 inches in each of the metal gutters
12. Soybeans were equally watered daily
13. When the soybeans reached V3 stage, the liquid nitrate fertilizer was equally applied
14. Samples of fertilizer runoff were collected in 10 ml. test tubes using a serological pipette
15. 2 Nitrate tests were performed on each sample collected
16. The results were analyzed

Results and Data

The results of this experiment showed that there were higher nitrate levels in the runoff from the compacted soil then there were from the loosened soil. The average difference in nitrate ppm was about 7 between the loose and compact soil. There were multiple trends as there was only one test in the loosened soil with a higher nitrate level than one of the compacted samples. So 5/6 of the tests completed in the loose soil had lesser nitrate levels that the compact tests. The one outlier would be L3 test 1 having a higher nitrate level than C3 test 2.

	Control	Test 1	Test 2	Average per Row	Overall Average of Rows
L1	6	29	26	27.5	27
L2	6	21	27	24	
L3	6	30	29	29.5	
C1	6	39	33	36	34.33333333
C2	6	36	34	35	
C3	6	35	29	32	

Table 1: This table shows the rows, with L being loose soil and C being compacted soil, and their nitrate levels.

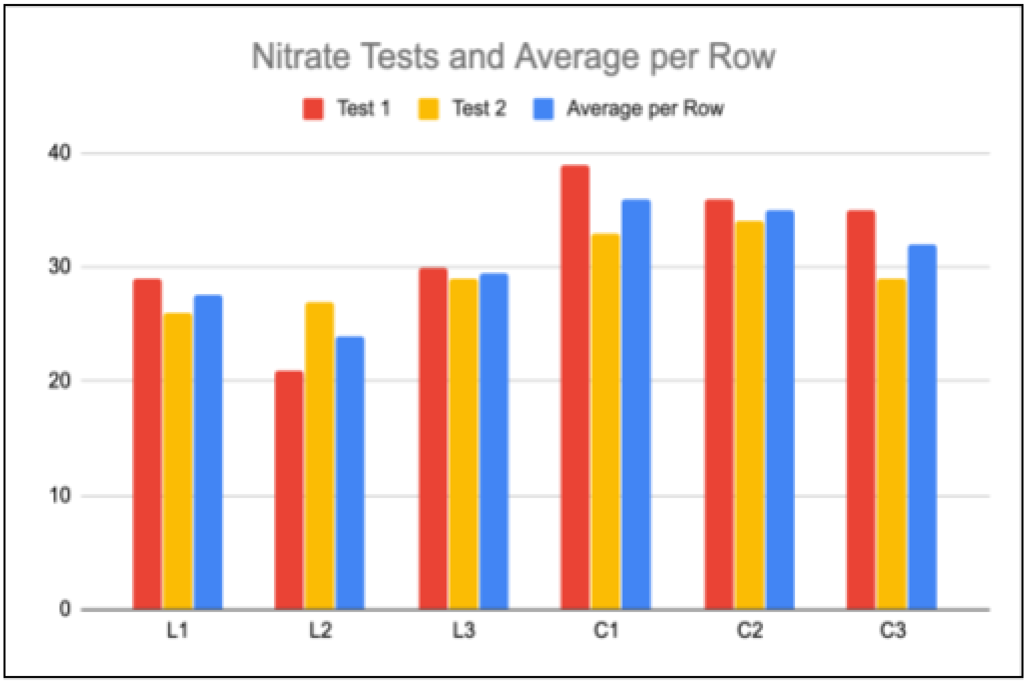

Figure 1: Graph used to show data in above table.

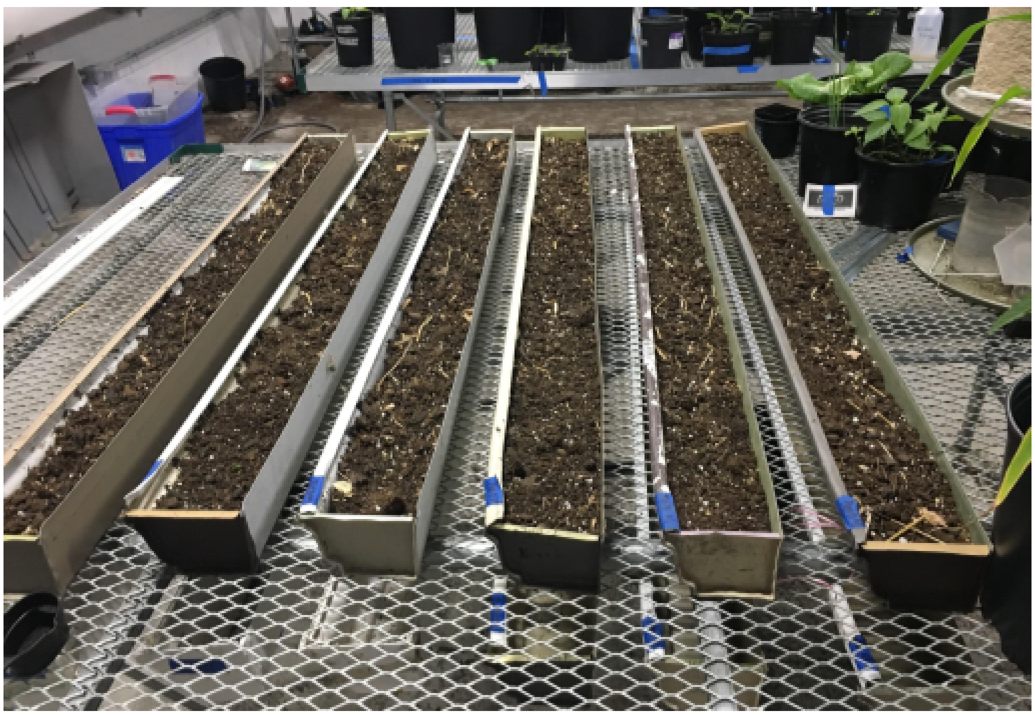

Figure 2: A picture of the row set up before the seeds were planted.

Figure 3: Picture taken after fertilization of plants and collection of runoff.

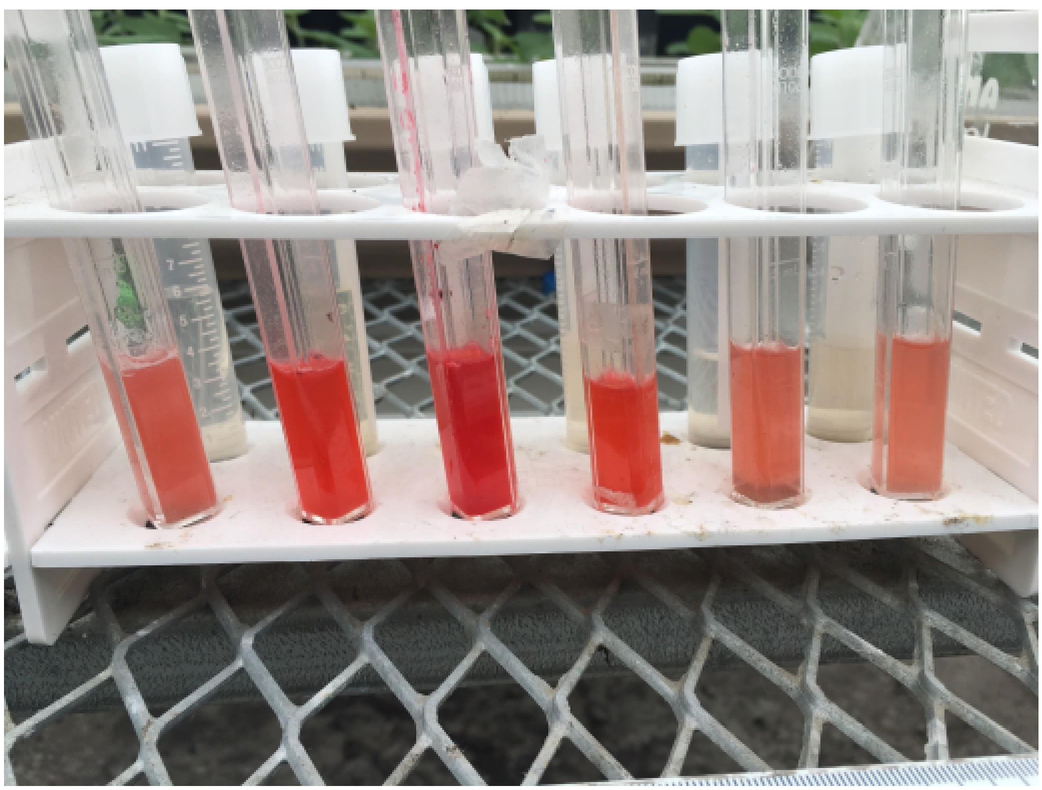

Figure 4: The results of nitrate test 1.

Discussion and Conclusions

In this experiment, multiple rows of compacted and loosened soybean plots were used. The rows were equally cared for and then fertilized with nitrate at the V3 phase. The data collected shows that the nitrate levels in the collected runoff from the compacted rows are higher than the loosened rows. This can be seen in the comparison between the first and second tests in the rows L1, L2, L3, and C1, C2, C3. The average difference in nitrate ppm was about 7 between the loose and compact soil, the loose having the lesser nitrate ppm, or parts per million.

The hypothesis previous to this experiment stated, "If compacted and loose soil were fertilized with nitrate and tested for runoff, then compacted soil will have the highest amount of nitrate in the runoff collected." The results of this experiment supported the hypothesis in that the nitrate ppm is clearly higher in the compacted soil. This data could be expected as the loosened soil has more macropores and micropores to hold the nitrate and fertilizer. This process along with the results from the experiment support this hypothesis. The results show that in loose soil trials higher nitrate levels occur in runoff compared to compacted soil trials, this was also supported by the statement "Thus, soil texture and structure, biological activity, and the level of compaction are the main factors that influence the amount and type of pore space in the soil." (Easton, 2016)

Potential Errors	Improvements
As the soil was compacted before seeding, the compact soil could have prevented the germination of soybeans in the compact rows. This was not a consistent variable.	Compact the soil right before fertilization of the rows to keep everything constant.
The same amount of fertilizer was applied but not in a specific way. The potential change of fertilization procedure could have caused flaws.	Fertilize in a more precise way than just pouring around the plant to ensure consistency.

Multiple people can find this information useful, farmers and agriculturalists, as well as those in the water industry, could benefit from knowledge from compaction and especially. fertilizer runoff. This can be useful to the public as the public is affected by both compaction and runoff and providing solutions to compaction could also provide solutions for lowering nitrates in runoff. Science can benefit from this as it could lead to possible solutions in compaction and runoff, major issues to the agriculture and other industries.

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