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Failing Food Supply: Permaculture's Potential

An Undergraduate Thesis

By John Faltin

Presented to

The Environmental Studies Program at the University of Nebraska-Lincoln

In Partial Fulfillment of Requirements

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Major: Environmental Studies

Emphasis Area: Natural Resources

Thesis Advisor: Name: Sarah Osborn

Thesis Reader: Name: Christine Douglass

Lincoln, Nebraska

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Abstract:

Conventional agriculture is the currently leading production method to grow crops in the western hemisphere. Long-term sustainability of the system and all the components is secondary to producing high yields each growing season, which leads to issues such as erosion and reduced soil quality. Other agricultural production methods such as permaculture aim to build soil and improve quality every growing season. This experiment intends to look at the potential of permaculture to improve soil quality on small-scales at the end of each growing season. The parameters to gauge success are a larger concentration of macronutrients at the end of the growing season and a pH within the ideal 6.0-7.0 range. Replication of two experimental and control plots were implemented to test the potential of permaculture on small-scales, with control plot plants separated into rows to mimic conventional agriculture and experimental plot plants in the permaculture beds were placed by each other to enhance plant connections. Each bed received two applications of either organic or conventional fertilizer on the same date. Statistical analysis of the data showed that the only macronutrient successfully impacted by the permaculture methods was sulfur. The pH for both treatments was not improved and increased well above the ideal 6.0 – 7.0 range.

Introduction:

One of the most pressing environmental issues that has taken the forefront in recent decades is the food production system currently seen utilized most commonly in the western hemisphere. Short-term gains are being placed before long term sustainability of the system and with that comes an unprecedented amount of consequences to the natural world we live in.

This style of food production is termed conventional agriculture and focuses solely on either maintaining high yields or increasing the yields of the crops on a temporal scale of a year-to-year basis (Beus and Dunlap, 1990). Unfortunately, this yield-dependent focus puts important agriculture related goals such as soil conservation on the back burner, which leads to issues such as the loss of fertile topsoil due to high intensity pressures put on the soil (Pimentel et al. 1995). It also fails to recognize long-term sustainability of the agricultural system due to the high yields taking precedence over the conservation of the system in the long run (Ratta, 1998).

This conventional food production system is typically done on large scales and the crops grown are grown in a monoculture, which limits the type of diversity in the system down to one single plant that is then grown in a uniform manner across the entire field in production (Tilman, 1999). This oversimplification of a natural system allows the farmer to control variability in the system but at the cost of many tradeoffs that can be seen in systems containing a diverse amount of species. Typically the farmer will grow the single crop year-after-year or will still grow a single crop every year but will instead add in a rotation of another crop every other year which can assist in the breaking up of pest reproduction cycles (Altieri, 1998).

Monocultures are not something that one will find mimicked in the natural world because of the cyclical nature of natural ecosystems. When exploring the natural world and its many ecosystems, the common trend amongst all these ecosystems is their ability to function as multiple individual parts that come together to create a harmonious whole. Each individual component within the system not only has a place but also has purpose within the system. Nothing serves to diminish the system but instead actively works to create resilience and stability that allows all the individual components to coexist in a way that is mutually beneficial to all of

them. One style of agricultural production that aims to embrace the cyclical nature of ecosystems and the many benefits that ecosystems provide as well as move away from the negative impacts that are displayed in conventional agriculture is called permaculture.

Permaculture is an emergent field of agriculture that was first originated by an Australian researcher named Bill Mollison. Mollison originally designed a study of rainforest ecosystems as well as the processes of regeneration they experienced after a complete clear cutting in the forest of Australia. Mollison was able to identify that plants naturally group themselves in mutually beneficial communities. This led to the realization that if agricultural systems were made to mimic ecosystems, they could have the same self-sustaining properties we see displayed within ecosystems across the globe. For example some of the ecosystem services that Mollison noticed were the long-term stability and productivity of the system, substantially less labor and energy inputs, no inputs of pollutants, and the ability to not only conserve but also to build soil (Mollison, 1990). Since permaculture is something that is broadly defined and can be interpreted in multiple contexts, Mollison (1988) defined permaculture as the conscious design and maintenance of agriculturally productive ecosystems-which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter, and other material and non-material needs in a sustainable way. The whole concept of permaculture is something that is completely engrained in the idea of sustainability.

Sustainability is another concept that is broadly defined. In order to understand what is meant by sustainability in the context of this paper, the researcher will use the definition from the Environmental Protection Agency (EPA). The EPA states that “sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations” (EPA).

Since the emergence of the idea of permaculture there has been a slow building of research that shows clearly that it is possible to produce a balanced natural environment, quality yields that are sustained yearly, soil fertility as well as intact biodiversity, and natural pest control through simply conscious design of a diverse low-input system (Altieri, 1998). This style of agricultural production puts the phrase, “work smarter, not harder” directly into action. Significant research has been put into different cropping techniques, such as cover cropping and intercropping, which have shown direct benefits of such practices such as reduced runoff, increased soil stability, and atmospheric nitrogen fixation depending on the crop utilized (Gautreaux, 2016). Since permaculture integrates both of these principles as well as a whole slew of other natural processes it receives the added benefits we see displayed in those systems. Farmers have displayed multiple direct examples over the years that permaculture can indeed promote the optimal cycling of nutrients in the soil as well as organic matter turnover, closed energy flows, water and soil conservation and balanced pest-relationships that are born out of the relationships of various combinations of plants across different spatial and temporal arrangements (Altieri, 1998).

The overall functionality and behavior of the permaculture system largely depends on the interactions that are formed between different biological and non-biological components. By designing a system with functional biodiversity there ends up being different processes emerging that are highly beneficial to the system as a whole. These ecosystem services that impact the system and add to its stability and resilience are the activation of soil organisms and their

ecosystems, the active cycling of nutrients, and finally the enhancement of beneficial insects that can deal with troublesome pests (Altieri, 1998).

To break permaculture down into a more digestible form there has been a set of design principles and ethics that have been developed. As with any discipline there is a set of ethics involved within the permaculture process. There are only three ethics when discussing permaculture and they are as followed: care for the Earth, care of the people, and return of surplus to Earth and its people (also called “Fair Share”) (Mollison and Holmgren, 1978).

There is a series of 12 different design principles to keep in mind when designing a permaculture system. The permaculture design principles are as followed: observe and interact, catch and store energy, obtain a yield, apply self-regulation and accept feedback, use and value renewable resources and services, produce no waste, design from patterns to details, integrate and do not segregate, use small and slow solutions, use and value diversity, use edges and value the marginal, and finally creatively use and respond to changes in the system (Mollison and Holmgren, 1978). See Figure 1 below.

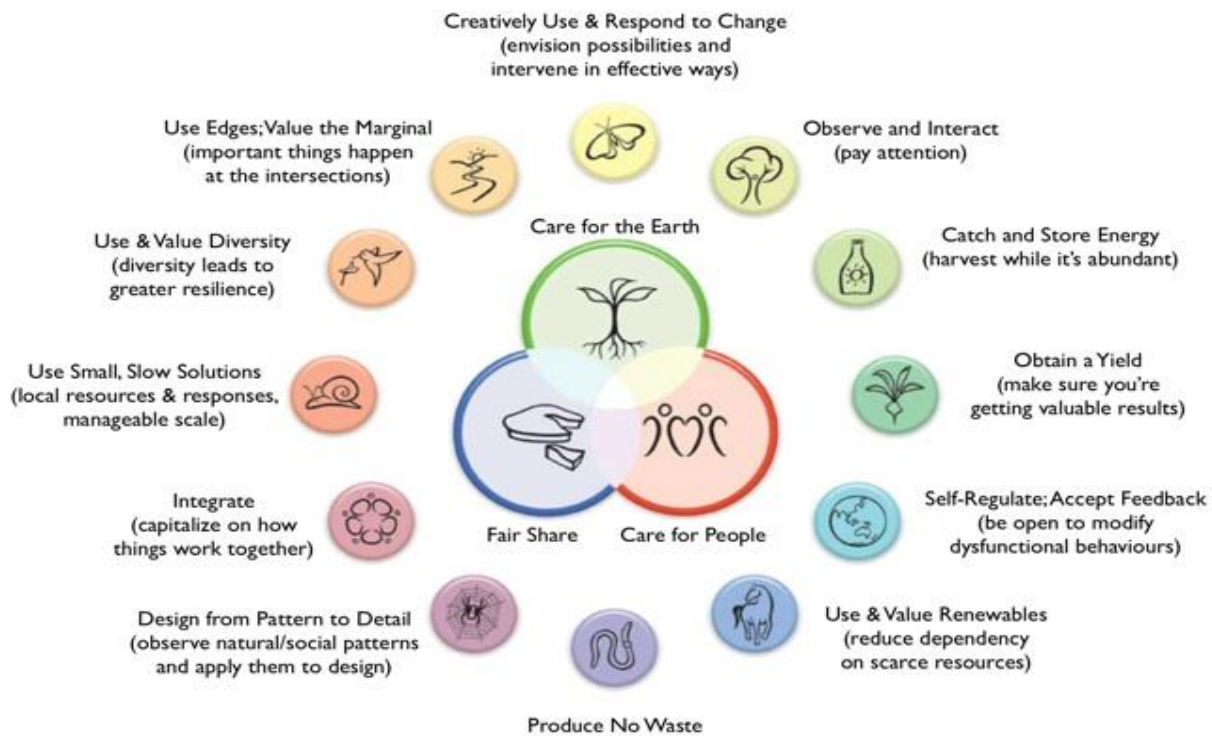


Figure 1: Permaculture Ethics & Design Principles (Holmgren’s 12 Permaculture Principles)

The design principles and ethics show that permaculture is something complex and interconnected. Permaculture does not follow the modern conventional style of agriculture production methods that are typically used in today’s age, which aim to increase stability and control over the system. In conventional agricultural systems farmers rely heavily on inputs into the system, which in most cases are not natural at all. Synthetic fertilizers, pesticides, and herbicides are common practice because of the continual issues with pest and weeds.

A lot of the issues that are found in conventional agricultural systems are formed by our desire to command and control these systems. Plants are typically grown in a monoculture,

which as stated earlier in no way shape or form mimics anything found in nature. This style of agriculture completely disregards biodiversity and focuses solely on the production of one crop in a heavily controlled environment. This style of agricultural production also leads to issues such as the erosion of the productive layer of topsoil on site. The inputs of synthetic fertilizers, pesticides, and irrigation only serve to minimize the erosion of the soil not stop it. Not only are there issues with soil erosion but these synthetic inputs have the potential to cause human health issues, pollution, destroy natural habitats, and contribute to high energy consumption and unsustainable agricultural systems (Pimental et al., 1995).

Permaculture not only aims to minimize the environmental and health issues associated with conventional agriculture but it completely eliminates them because of the way it mimics natural ecosystems. It's important to note that permaculture does not totally eradicate all farming practices associated with traditional farming but simply does not utilize the methods linked to the negative impacts currently seen (Whitefield, 2000). For example, instead of utilizing synthetic fertilizer other natural inputs such as compost are used. Pesticides are also something that can be used within a permaculture system but once again they cannot be something that are synthetic. Instead, natural pesticides are created out of things such as cayenne pepper that can be sprayed on the plants as a natural pest deterrent. One example of how traditional agricultural practices are still utilized in a permaculture system is the use of tilling to aerate the soil. Typically permaculture is done a smaller scale so you are not likely to see large-scale tractors or other farming equipment that is more common practice to use for large-scale agricultural production systems.

One very important thing that permaculture systems have more of an emphasis on than conventional agricultural systems is having high quality soil health and maintaining that high quality soil health. High quality soil is critical to food production and maintaining a sustainable system in the long term. When looking at soil that is in good health there are three separate characteristics and they are as followed: rich biological life, good soil structure, and readily available nutrients (Brown, 2015). Also, the soil's pH is very important and should be maintained between 6.0-7.0 because when it's in this range the nutrients are made readily available for the plant to uptake when needed (Cunningham, 2000).

High quality soil that is in good health will have a largely diverse biological population living within the soil. These organisms that are located in the soil have complex relationships and belong to their own ecosystems just like other organisms people are more familiar with. There should be billions of organisms in the soil that cannot be seen with the naked eye, but when examined closer through microscopes, they can be seen everywhere. Typically people are more familiar with earthworms and other larger organisms that can be seen in the soil relatively easy but there are other organisms such as bacteria and fungi that play just as important role. The biological life in the soil impacts the soil through its digestive activities and in turn ends up binding the soil and improving soil structure (Brown, 2015).

Soil type, such as sand, silt, or clay all benefit from the addition of biological life, which will greatly improve the soil quality. For example, in soils that are sandy the biological life will assist in the binding of the soil particles into larger aggregates, largely improve increase the amount of water the soil can hold, and lastly assist in the retention of soil nutrients (Brown, 2015). For soil types that are heavy in clay the addition of biological life will assist in the breaking up of clumps in the soil to allow any minerals that may have been trapped in the clay aggregates to be released for plant use.

Quality soil has a number of features that relate to its ability to hold structure and grow quality plants in the permaculture system. When the soil is wet it will allow for proper drainage so it does not get water logged and also retains water properly in periods when water is scarce. The soil should also have proper aggregates so plants do not get root compaction and have access to nutrients, which might be deeper in the soil. All of these characteristics add up to the soil's ability to resist erosion to natural forces such as wind or water.

Proper sized aggregates in the soil are crucial because of how connected they are to the stability and functionality of the soil. Water stable aggregates are important in the soil because the number of them in the soil shows its ability to maintain its structure and functionality during the most intense conditions. The water stable aggregates are measured by the extent that they can resist breaking apart when exposed to water or impacted by raindrops (Gugino 2007).

When a soil has minimal aggregate stability, it can be harmful to plants growing in it due to the plants getting constricted by the crust that forms on the surface as shown in Figure 3 below. This is an issue because both water infiltration and air exchange is severely limited which in turn largely impacts how easy the soil is to manage (DuPont, Beegle, White, 2017). When the soil is in poor health it cannot support an abundant population of biological activity-which creates a positive feedback loop that further damages the soil. The reason this happens is because the biological activity in the soil has a direct link to the formation of aggregates. Exudates from bacteria, entanglement of soil particles in fungal hyphae, and digestion of earthworms form aggregates (DuPont, Beegle, White, 2017), and the result of low biological activity in the soil is a reduced amount of mineral cycling and increased competition with pest organisms. Figure 2 below displays soil that is free from the issues associated with the poor quality soil shown in Figure 3.



Figure 2: High Quality Soil (Nolan, 2012)

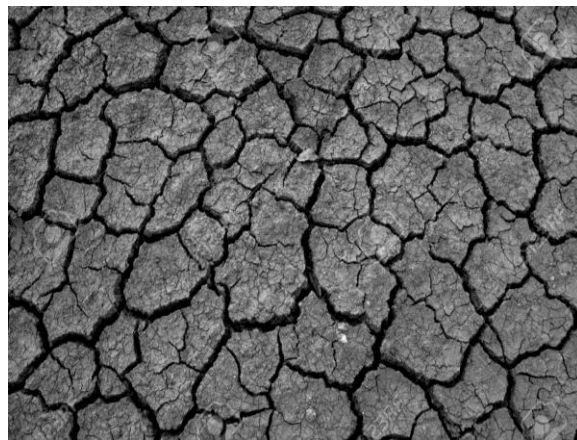


Figure 3: Poor Quality Soil

Permaculture has the potential to not only address the issues associated with conventional agriculture but it also has the potential to reverse them. Looking at all of the negative impacts conventional agriculture has on the environment, it is clear that there has to be a better way of going about food production. The incorporation of multiple disciplines such as ecology, landscape design, land management, energy and production, and community development allows for the integration of the knowledge from them all (Frank, 2015). This system's approach that mimics ecosystems creates beneficial relationships that increase the overall stability of the system.

Not only does permaculture offer a much-needed change in perspective but it also gives an individual a direct way of making a positive impact on their local environment as well as their health. It helps display a clear picture of the importance of diversity and the connections amongst the organisms in the system. Lastly, it ends up leading to an appreciation of soil, which is very important because all life is directly tied in with soil health (Hillel, 1992).

Methods:

The methods employed within the design of the research project adhere to the scientific method. Both control and experimental plots were utilized in the research to ensure results had an accurate comparison of the given hypothesis. The design consisted of four separate raised bed gardens that were 4 x 8 feet. Two of the raised beds were used as the control plots while the other two raised beds were used as experimental plots. Replication of plots was utilized in the experiment to ensure results are not biased. Figure 4 presents the four raised bed gardens that were utilized during the experiment.

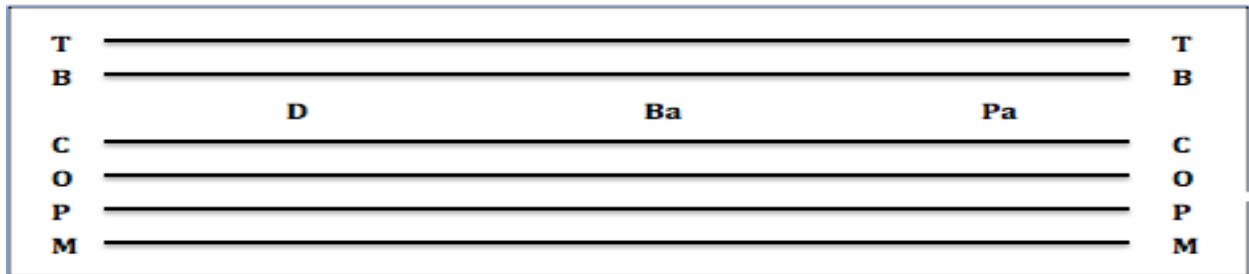
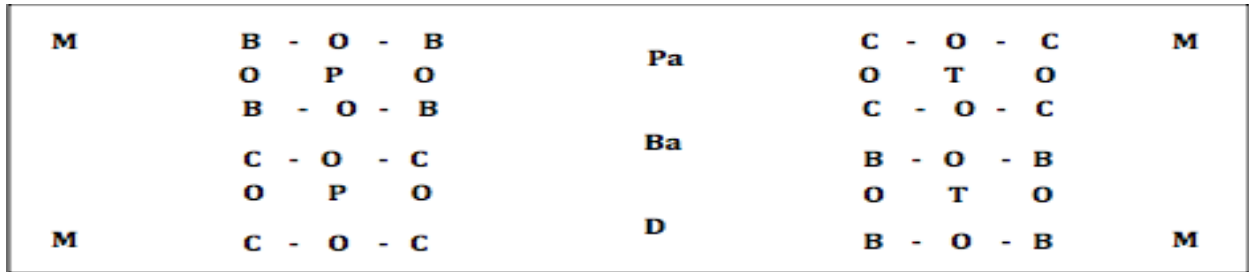


Figure 4: Control and Experimental Plots

All of the plots consisted of the identical type and number of plants that were planted on April 26. The type and amount of each plant per bed is as followed: four marigolds, two peppers, two tomatoes, fifteen onions, twenty carrots, one parsley, one dill, one basil, and twenty beets. The control plots had each of the plants separated in rows to mimic conventional agriculture. The rows mimicked conventional agriculture because they were placed in a manner that does not promote beneficial connections amongst them. The experimental permaculture raised beds were designed in a way that enhances natural connections as well as incorporates a systems approach that does not segregate plants into separate rows in the bed.

Both beds also experienced applications of either the conventional Miracle Grow All Purpose Plant Food or organic Ocean Solution Fertilizer. The applications of each fertilizer

happened on the same days and they took place on June 28 and July 28. Protocol for the applications came directly from the recommended guidelines of each fertilizer. A dilution rate of 1:100 was used on the experimental beds. Each bed received 5 gallons of water with five ounces of fertilizer dispersed evenly throughout each bed. Five gallons of water was applied evenly to each control plot with five tablespoons of fertilizer. Figure 5 displays the layout of the plants in both the experimental and control plots. The image on top is the experimental plot and the image below is the control plot.



Key:

Abbreviation	Plant Type
M	Marigold
P	Pepper
T	Tomatoes
O	Onion
C	Carrots
Pa	Parsley
D	Dill
Ba	Basil
B	Beets

Figure 5: Plant Layout of Control (Bottom) and Experimental (Top) Plots

Watering for each bed followed a strict schedule that allowed for each bed to receive an even distribution of water. The use of an irrigation box was implemented to allow for twenty-minute applications of water every other day starting after the initial planting of the garden on April 23. This style of watering continued until the completion of the final soil sample on October 3. The watering schedule was not altered even after a weather event such as a rainstorm.

In order to accurately gauge the success of the research project soil samples were

conducted on each of the raised beds. The style of soil sampling employed was grid sampling, which consisted of five separate test in each of the raised beds. Soil samples were taken from each of the corners as well as the center of each raised bed. This allows for nonbiased results that accurately show the distribution of soil quality amongst the entire raised bed.

Soil samples were conducted at the beginning of the project in order to show the state of the soil health prior to the research project as well as after the completion of the project. The first soil sample took place on April 6 and the final soil sample took place on October 2. Before and after samples are the methods that were used to display the effectiveness of the organic permaculture techniques. Each of the soil samples were processed through AgSource Laboratories in Lincoln, Nebraska to get a comprehensive soil health assessment, which includes an overall soil health rating, pH level, excess carbonate, soluble salts, sodium ppm, percent organic matter, analysis of nutrient elements (ppm), and actual and suggested percent of total CEC. For the purpose of this experiment the only elements from the soil test that are examined in detail are the major limiting factors to plant growth. The major limiting factors for plant growth are the macronutrients calcium, magnesium, nitrogen, phosphorus, potassium, and sulfur because they are needed in relatively large amounts (Maathuis, 2009). The overall pH of the soil will be looked as a well because soil pH is one of the most important measurements to determine soil health. It does a lot more than simply report whether the soil is basic or acidic. Because it impacts so much in the soil the availability of important nutrients and toxicity of other elements can be estimated because of their relationship with pH (Thomas, 1996).

Results:

The soils pH and macronutrient elements were analyzed separately in order to accurately gauge changes over time for the control and experimental plots. The average change of the soil's pH and macronutrients were calculated to determine if the organic raised bed permaculture system was successful in improving the soil quality at the end of the growing season. Below in Figures 6-11 are the graphs that display the changes in average concentration of macronutrients and pH over time in the experimental and control plots.

In order to compare the compiled data set to the original research statement statistical analyses were run to compare the average differences between the experimental and control plots. The pH and separate macronutrients were analyzed independently with the null hypothesis being $H_0: (\mu_{\text{Experiment}} - \mu_{\text{Control}} = 0)$ and the alternative hypothesis being $H_a: (\mu_{\text{Experiment}} - \mu_{\text{Control}} > 0)$. The null hypothesis represents the outcome one would expect if the experimental plot had a positive impact on soil quality at the end of the growing season. The alternative hypothesis represents the outcome one would expect if the experimental plot had no conclusive impact on soil quality then the control plot. In the case of the macronutrients a positive impact on soil quality would be a larger reserve of macronutrient elements available for the next growing season.

The p-value used to evaluate how well the data supports null hypothesis is $\leq .05$. The p-value represents whether the null hypothesis is rejected or not. Using the p-value of $\leq .05$ means that if the null hypothesis is true we would get our results 5 out of a 100 times (UC Davis). Therefore if the null hypothesis is rejected the outcome seen on the experimental plot is not conclusive to the organic permaculture treatment that was done to the raised beds.

Upon completion of all the statistical analysis of the pH and macronutrients elements for each experimental and control plot the data points in the direction of rejection of the null

hypothesis is every case besides the macronutrient sulfur. The p-values are as followed: nitrate – (.11390), phosphorus – (.29081), potassium – (.45200), magnesium – (.13579), calcium – (.21926), sulfur – (.02294), pH – (.5). So the overall conclusion for the statistical analysis is that sulfur is the only macronutrient that was impacted by the experimental treatment. No other statements can be made about the success of the treatment due to lack of evidence to support the organic permaculture techniques used in the experiment. Since the null hypothesis was rejected in just about every case the original purpose of the research is non-conclusive and the data does not support that statement.

There is not much difference visually between the experimental and control plots in figures 6-9. There is a large variation in dispersion of the data and this is likely due to left over soil elements from previous growing seasons. Another factor that could account for the variation would be previous applications of fertilizers and liming that has taken place over the years. The large concentration of calcium left over in both the control and experimental plots could have also been impacted by the fertilizer and liming treatments. Alkaline soils are greater associated with higher concentrations of calcium, and it can be in the form of precipitated CaCO_3 (lime) (Miller 2017).

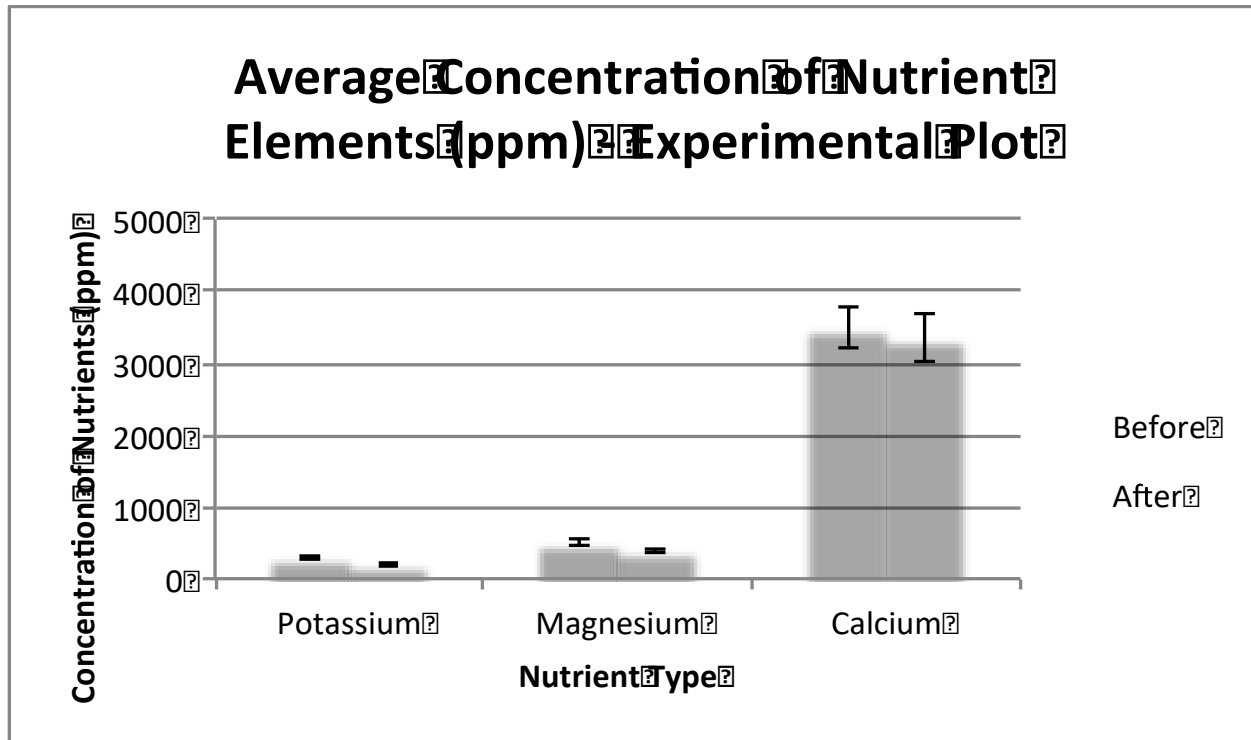


Figure 6: Experimental Plot – K, Mg, Ca

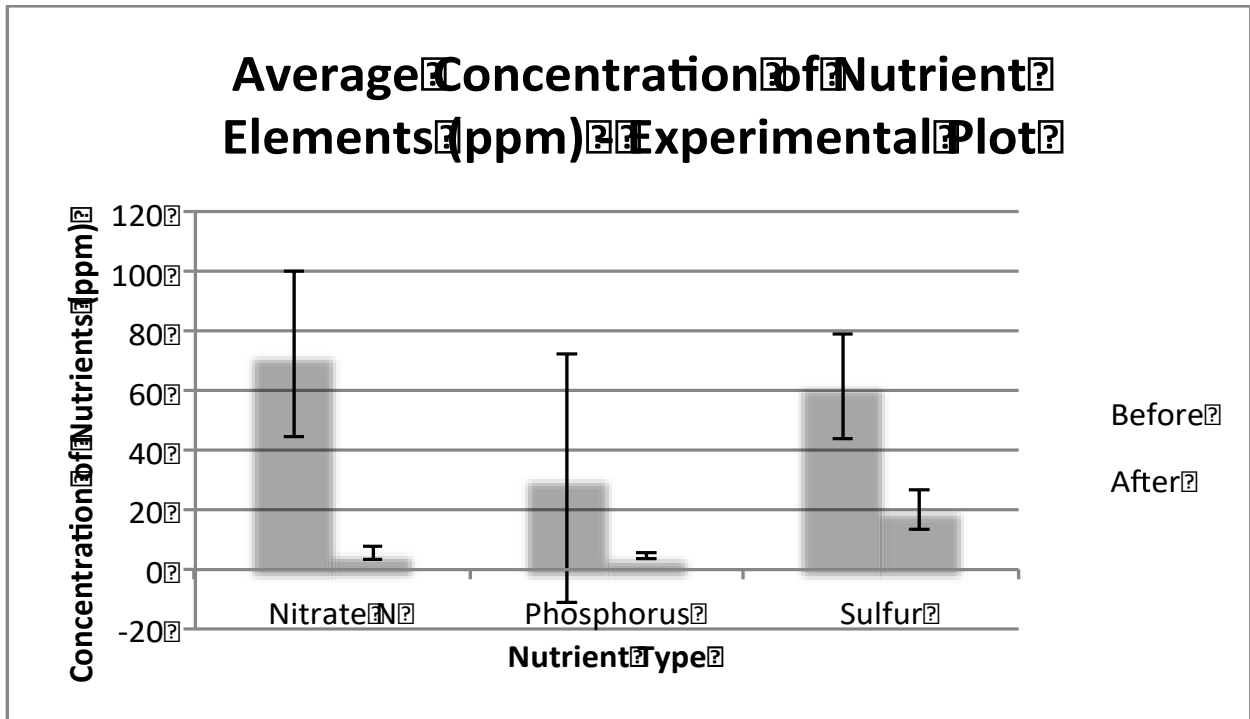


Figure 7: Experimental Plot – N, K, S

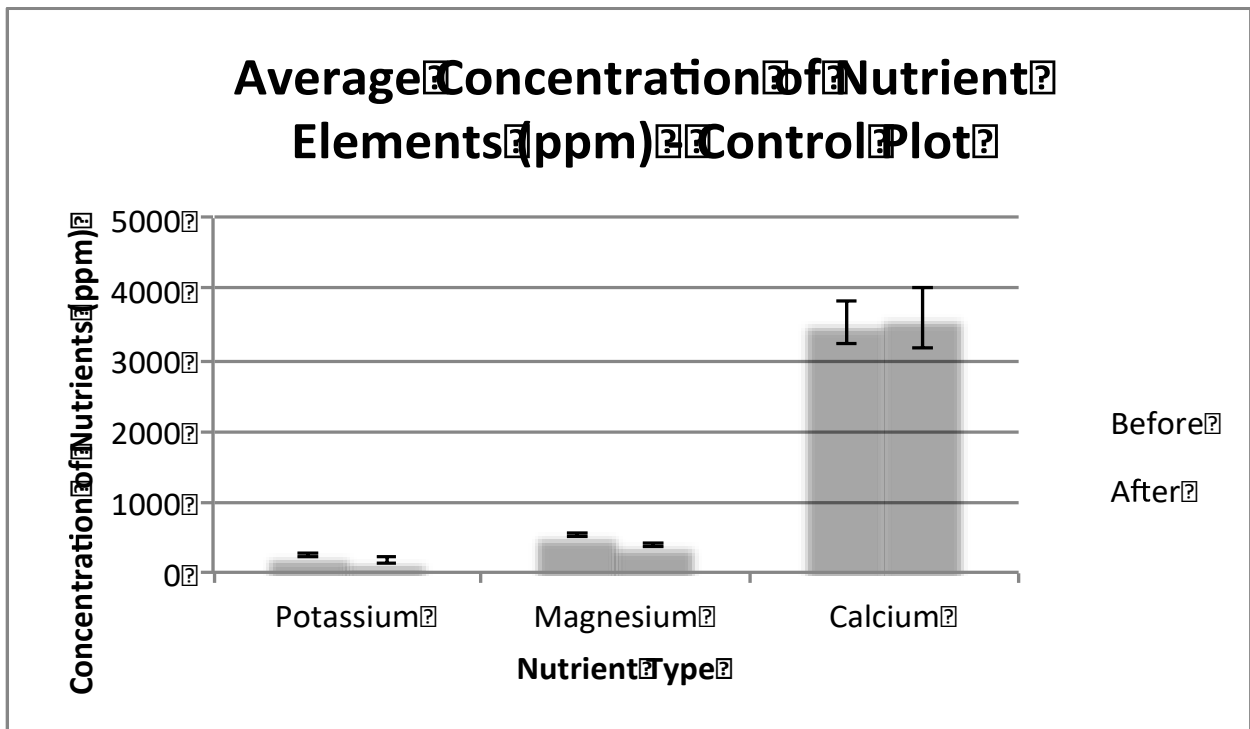


Figure 8: Control Plot – K, Mg, Ca

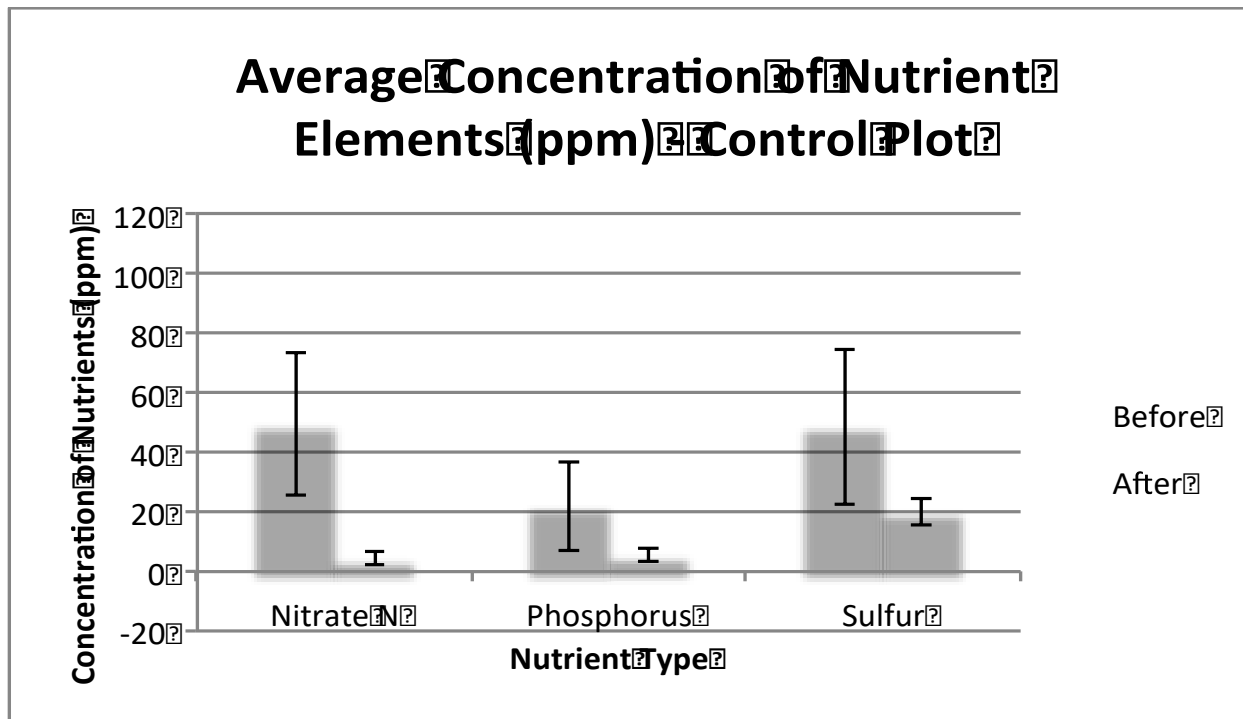


Figure 9: Control Plot – N, P, S

Below in Figures 10 and 11 it displays that the average of both the experimental and control plots was above the ideal 6.0 – 7.0 pH range before the experimental began. Both experimental and control methods failed to decrease the pH and in both cases the pH increased.

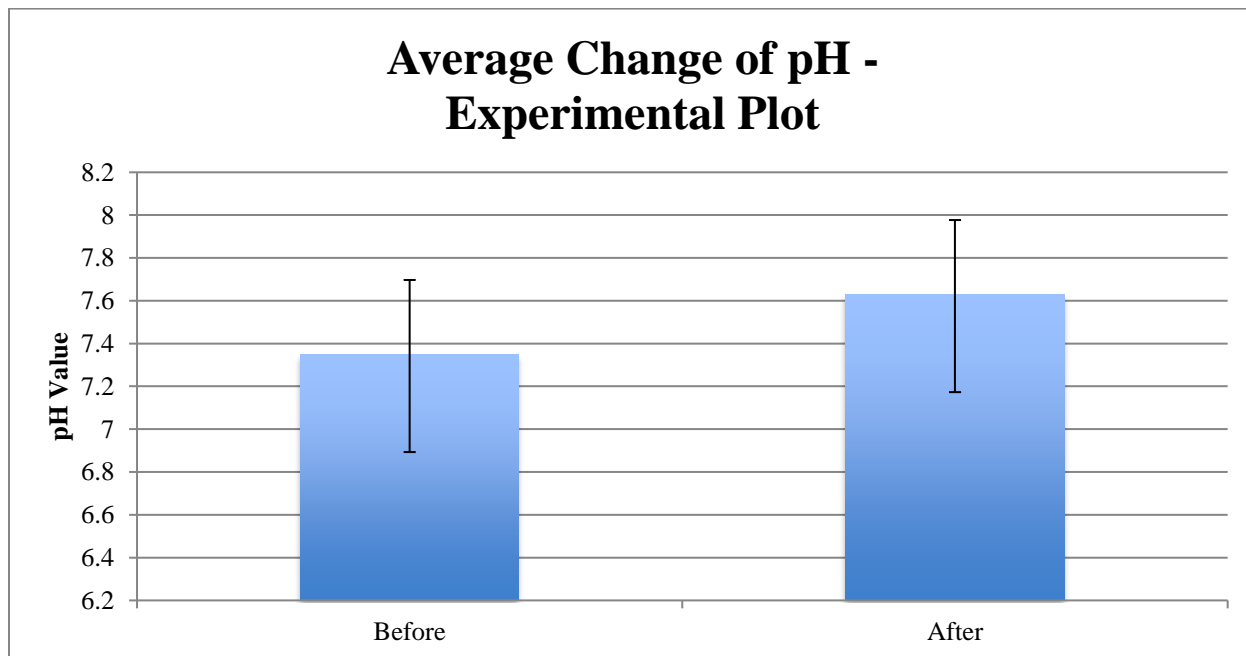


Figure 10: Average Change of pH – Experimental Plot

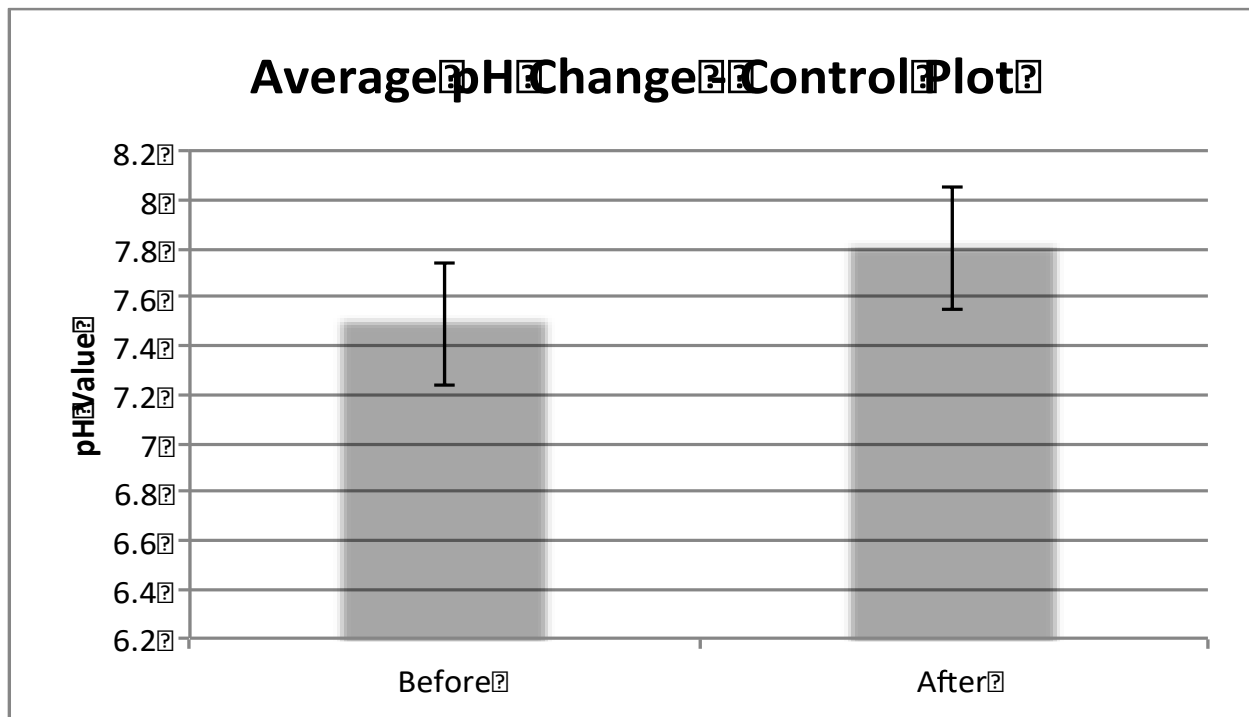


Figure 11: Average Change of pH – Control Plot

Discussion:

Upon completion of the project the data concludes that the methods utilized in the experimental plots were not successful in improving soil quality based on the parameters of macronutrients and soil pH. Sulfur ended up being the only macronutrient that the experimental methods had a beneficial impact on.

With pH all the averages were above 7.0-which is not an acceptable range for garden plants and it would be ideal to get the ranges back to where they are best for plant growth and nutrient availability. The ideal pH range for plant growth is between 6.0-7.0 (Cunningham, 2000). The pH value is critical for the availability of macro and micronutrients in the soil. Low pH reduces the macro and micronutrients, while the high pH reduces the availability of most micronutrients (Cornell University). This is important because if the macronutrient concentration had improved with the experimental methods it may have still not been available to plants due to a pH imbalance.

Variables such as the type of fertilizer that was utilized during the experiment could have had an impact on the results. There are multiple organic and conventional fertilizer brands to choose for raised bed gardens and usage of another brand may have led to completely different results.

The number of applications of fertilizer is another variable that could have impacted results. This experiment involved fertilizer application on two separate occasions but the product guidelines specified that up to four applications could have been utilized in amount of time the experiment was operating. More macronutrients might have followed the trend that sulfur followed after the statistical analysis.

Conclusion:

Food production and the impact it has on the planet will continue to be a major issue going forward into the future. While the creation of the organic permaculture raised bed gardens using the methods in this experiment was a failure for all the parameters looked at besides sulfur. It does not mean that permaculture might not have the potential at different spatial and temporal scales.

Looking towards future experiments the temporal scale of a year-to-year basis severely limited the result of the experiment. If time was not a limiting factor before the experiment was created it would have been much better to extend the temporal scale to multiple years to see changes over the years and see if there is any information that is missed by simply looking at the impact of one short growing season. It also would have been useful to include more sampling per bed to get a larger distribution of data points to represent each bed. While five samples per bed allowed for an even distribution of data from each raised bed it could have been better represented by 10 samples or more per bed.

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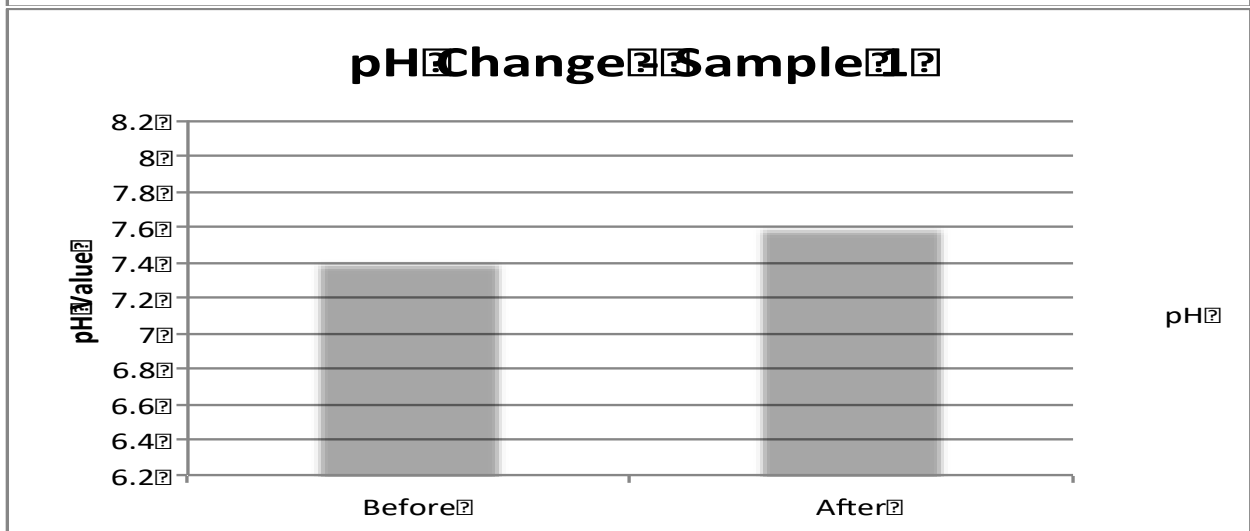
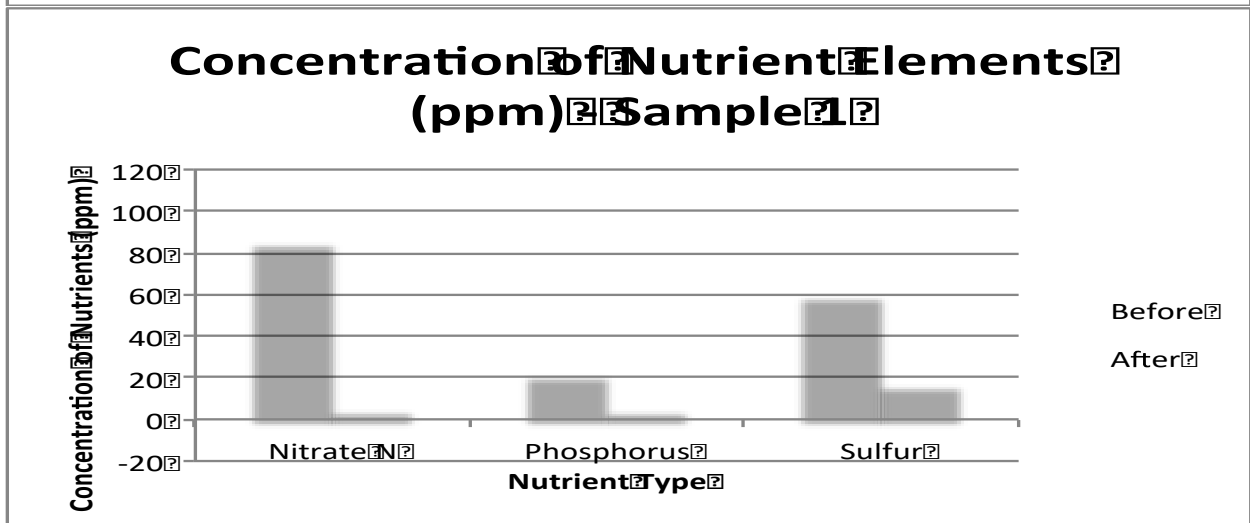
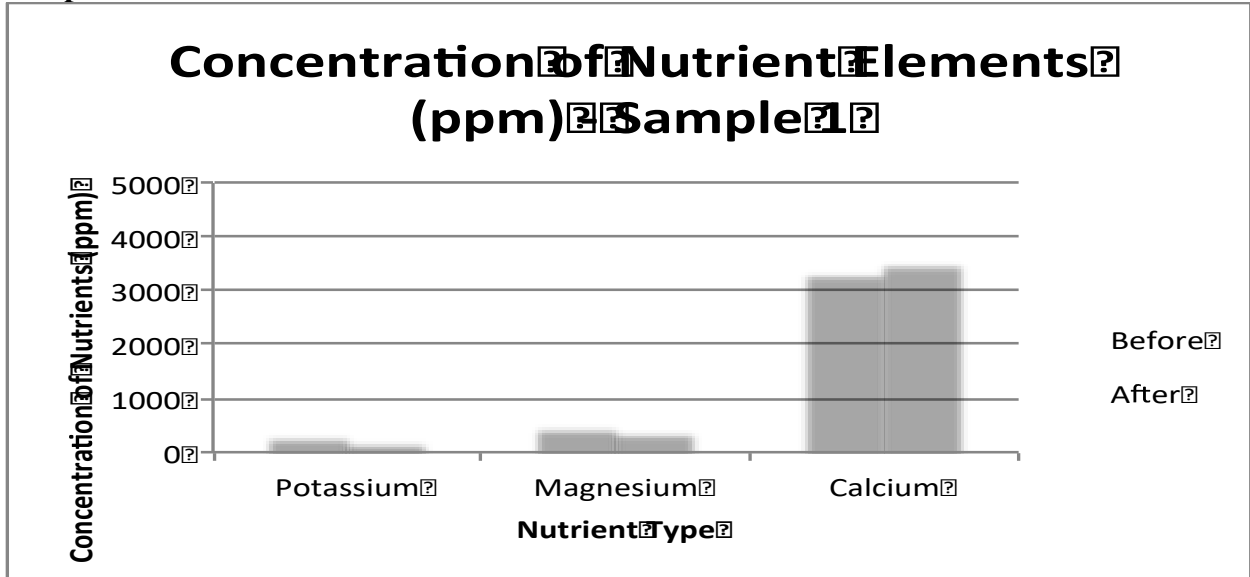
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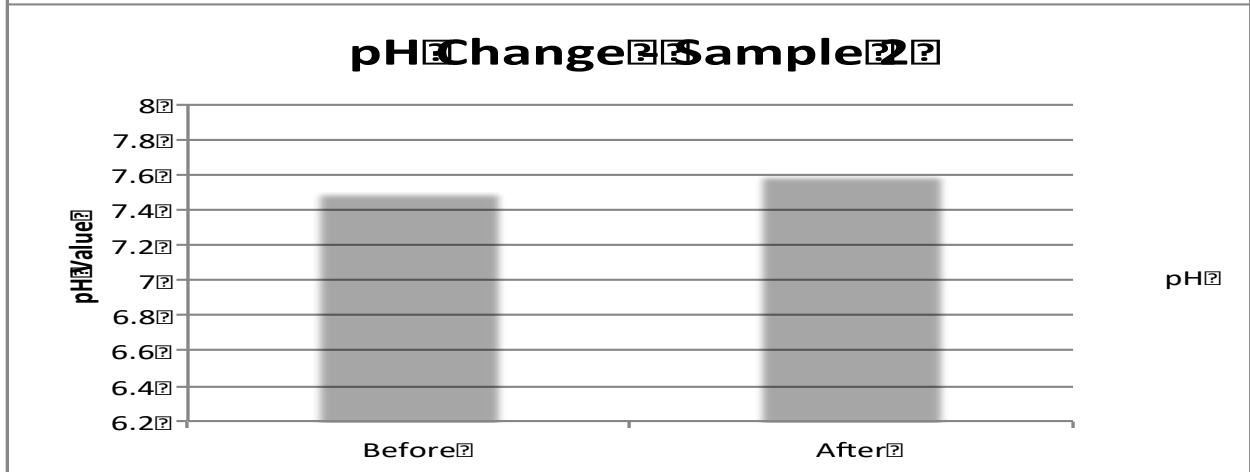
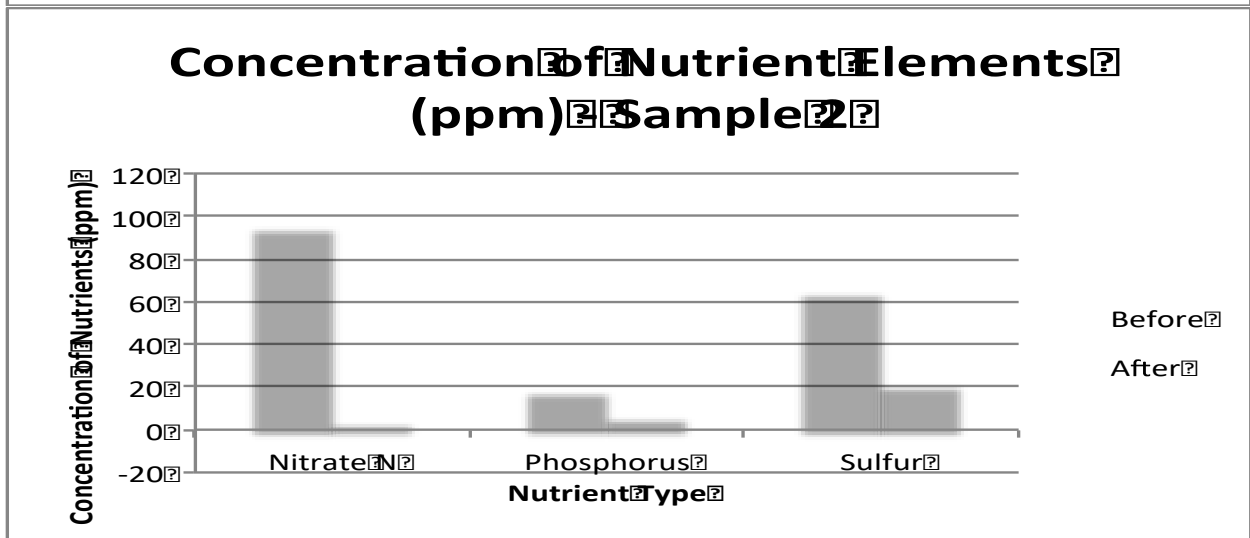
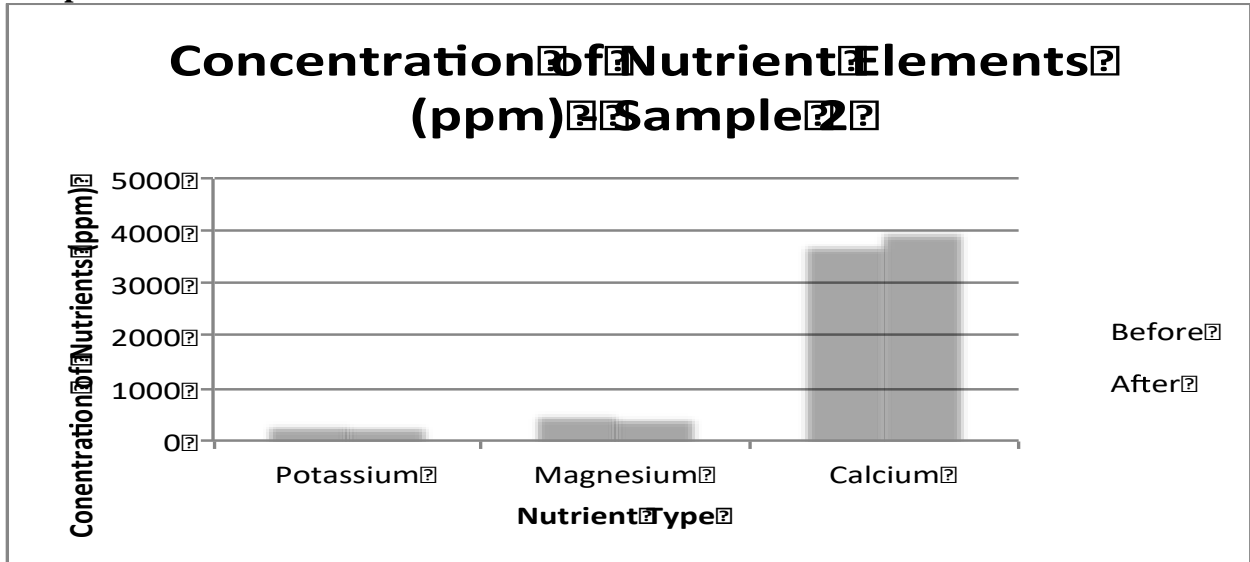
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Appendix A

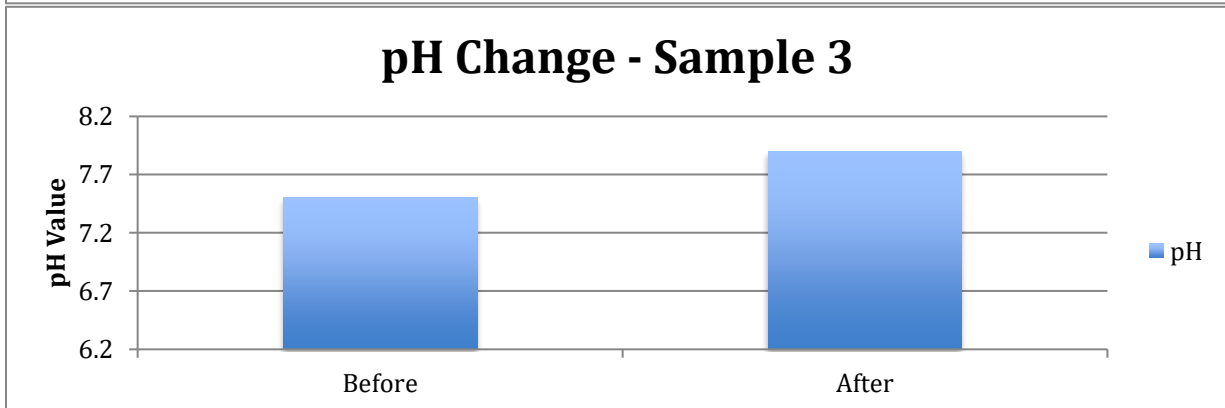
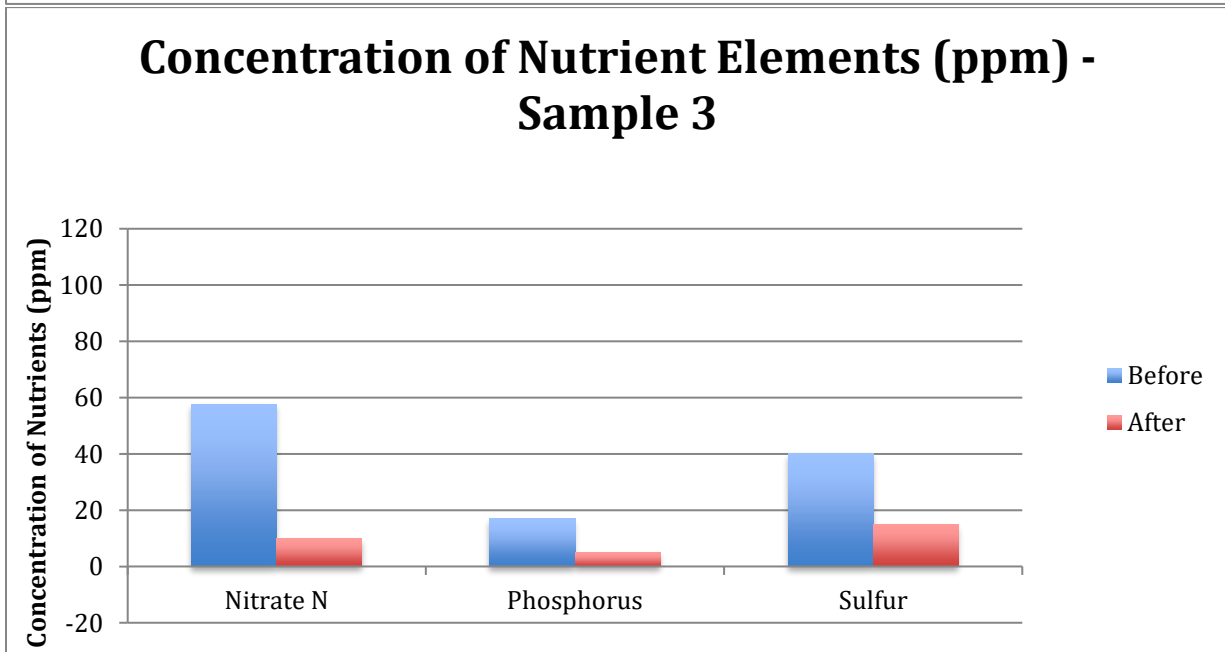
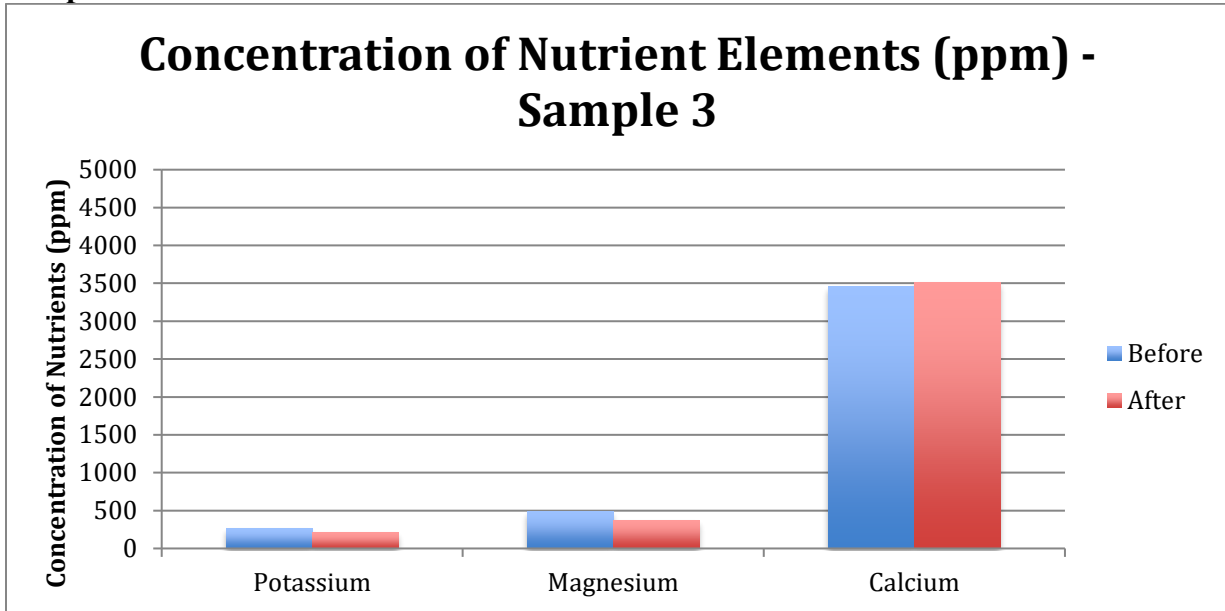
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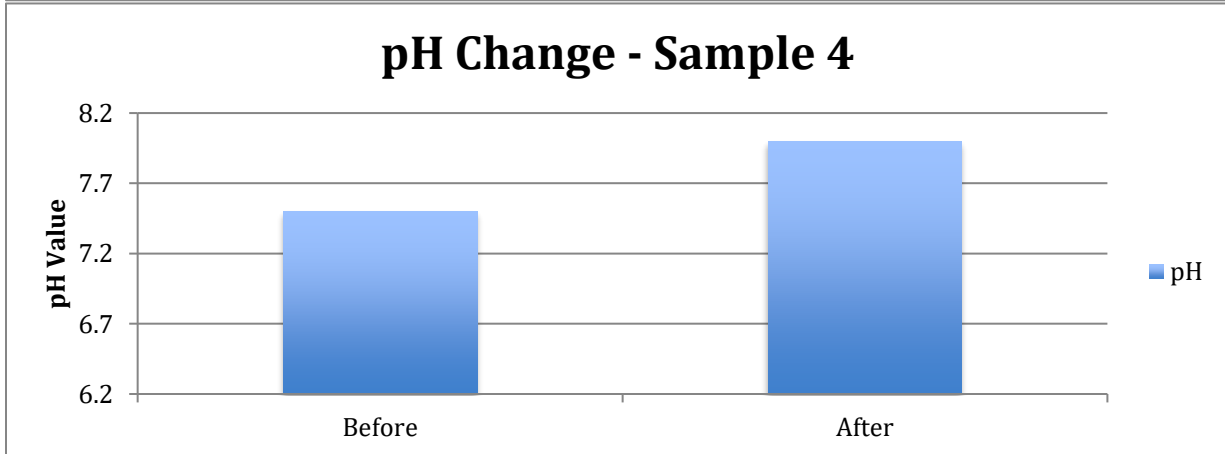
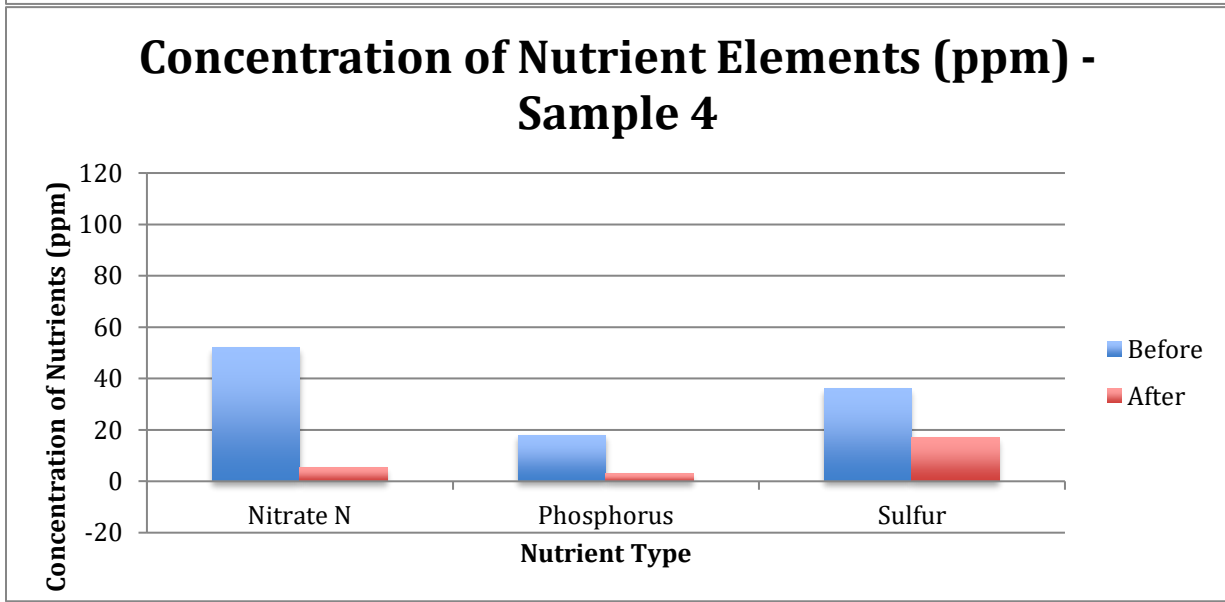
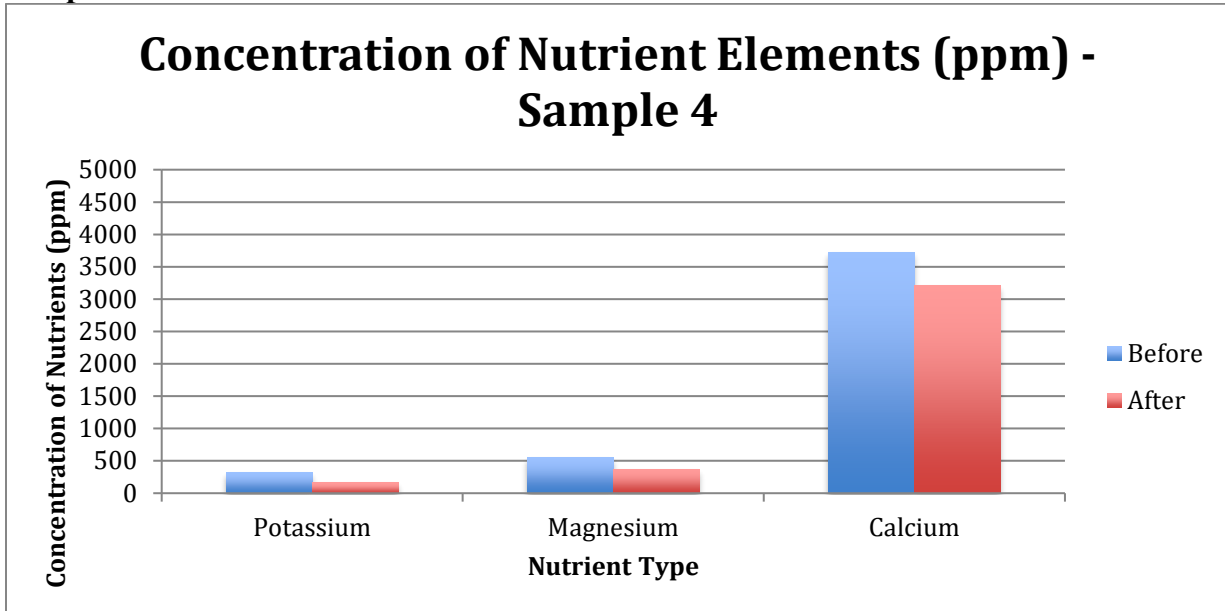
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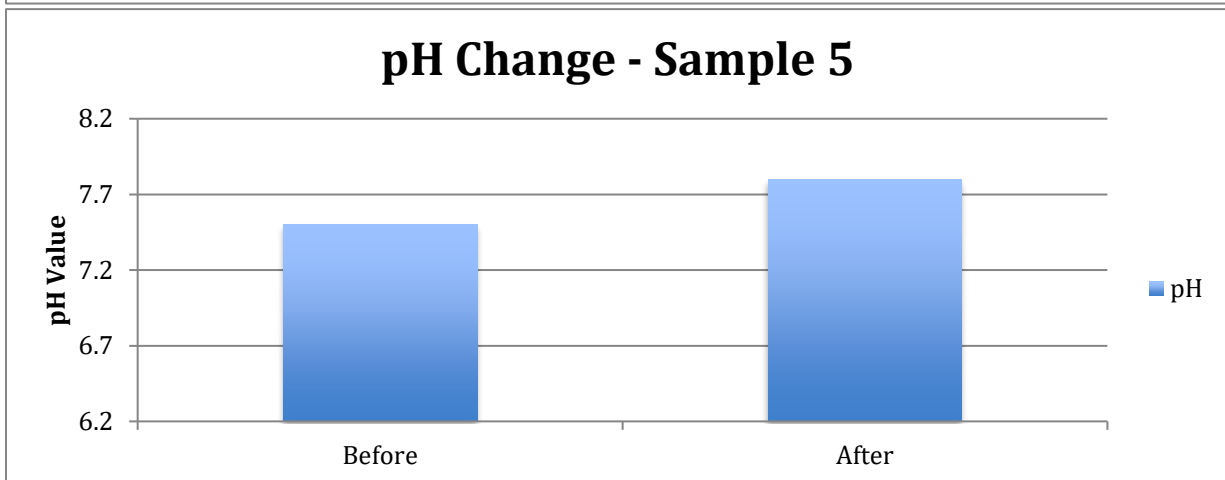
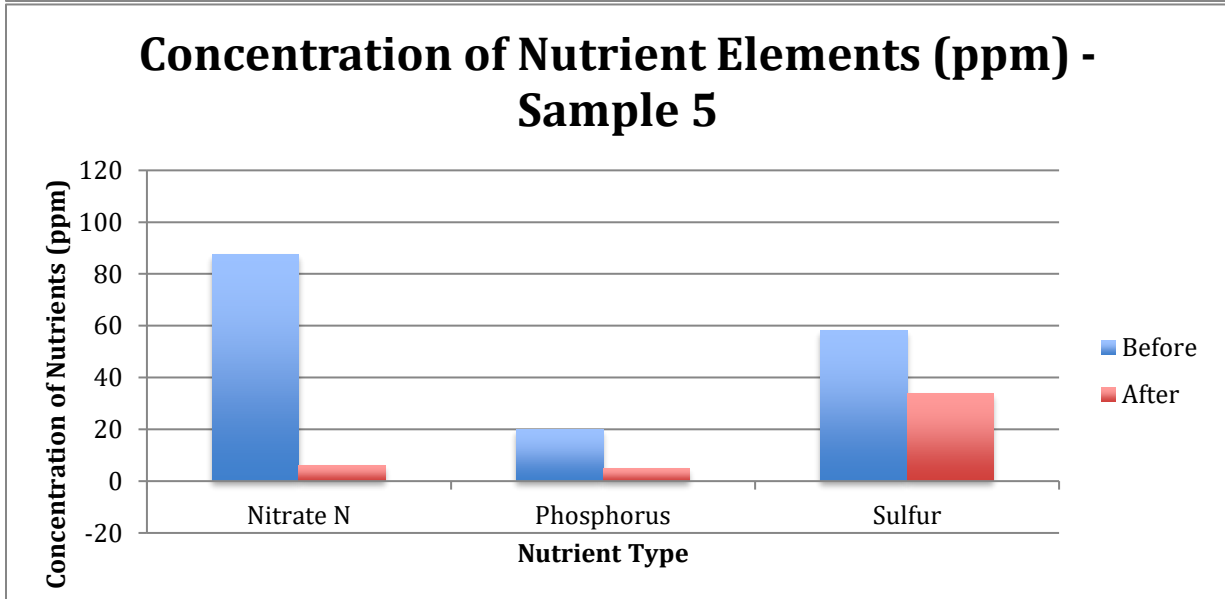
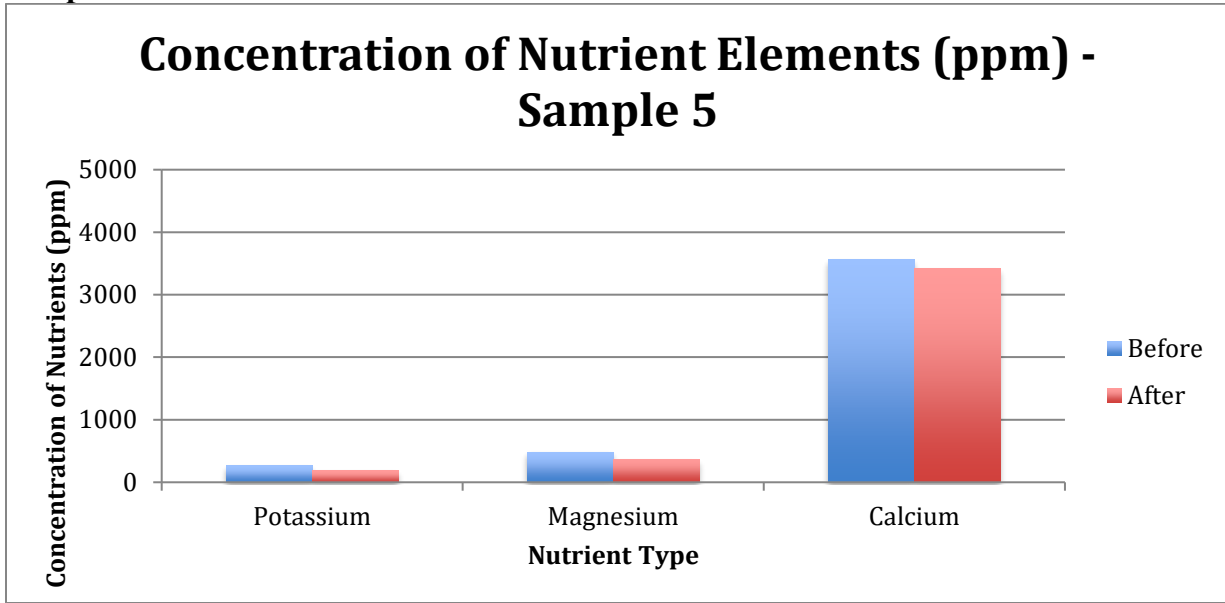
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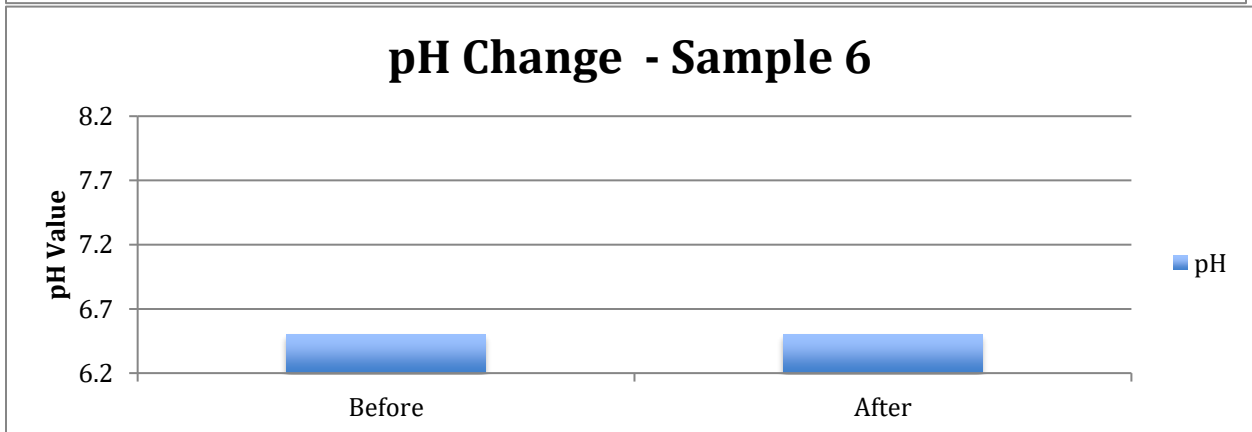
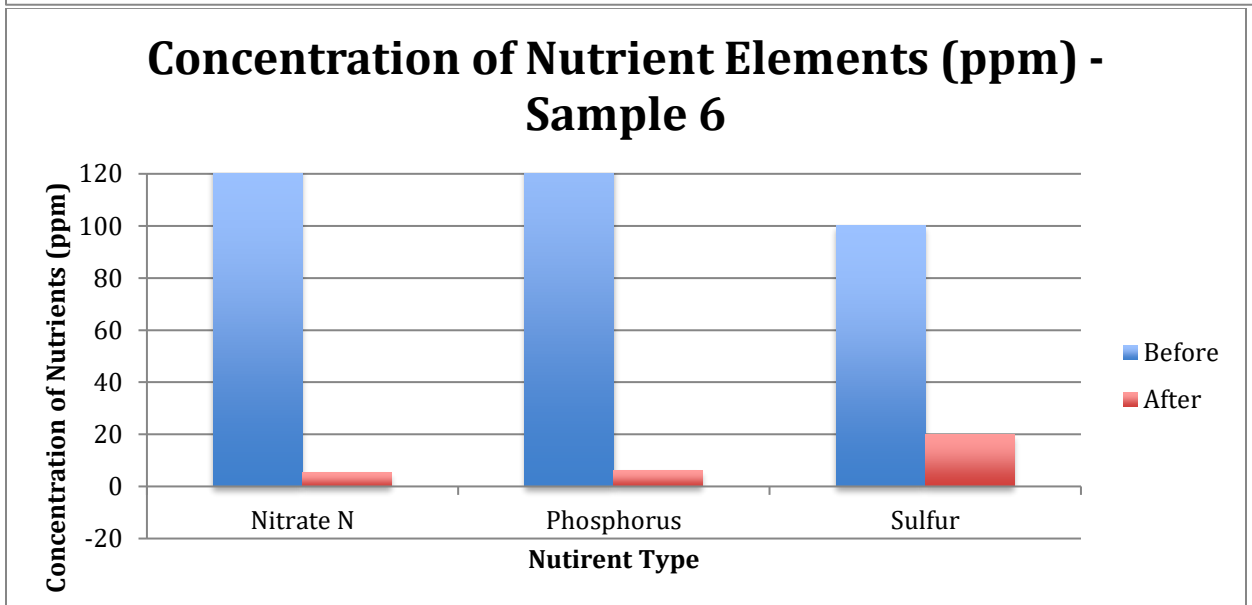
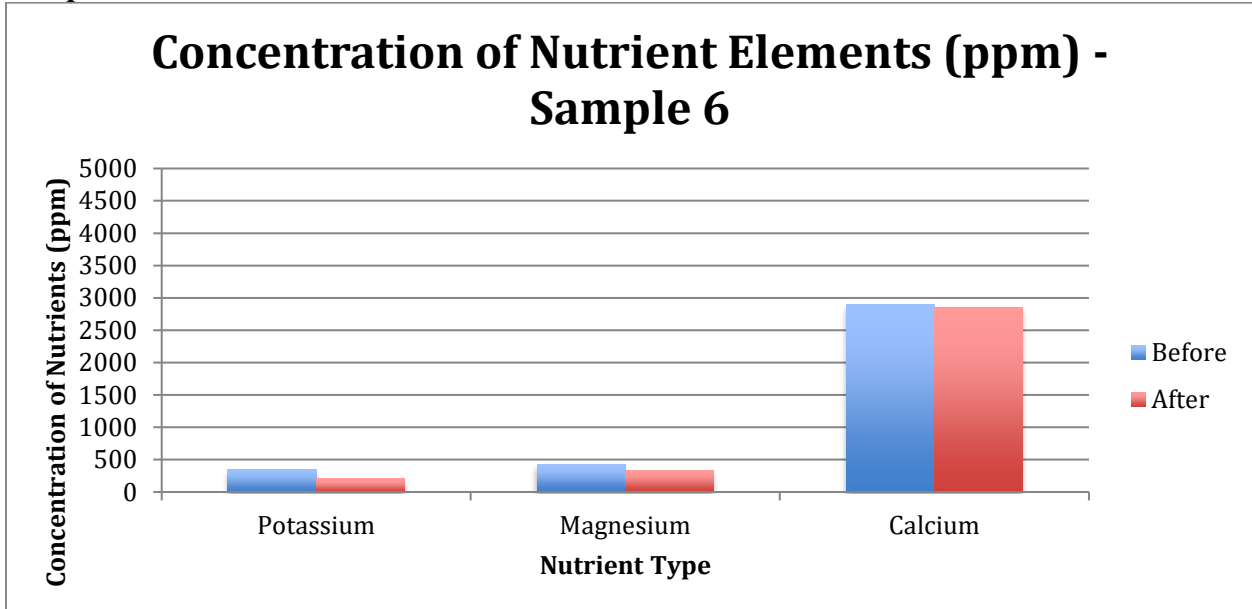
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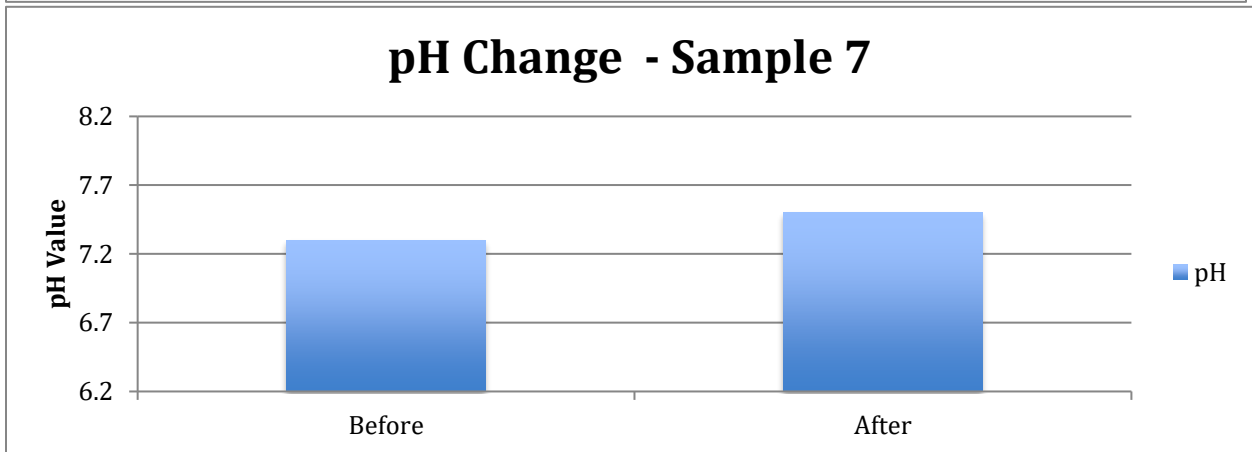
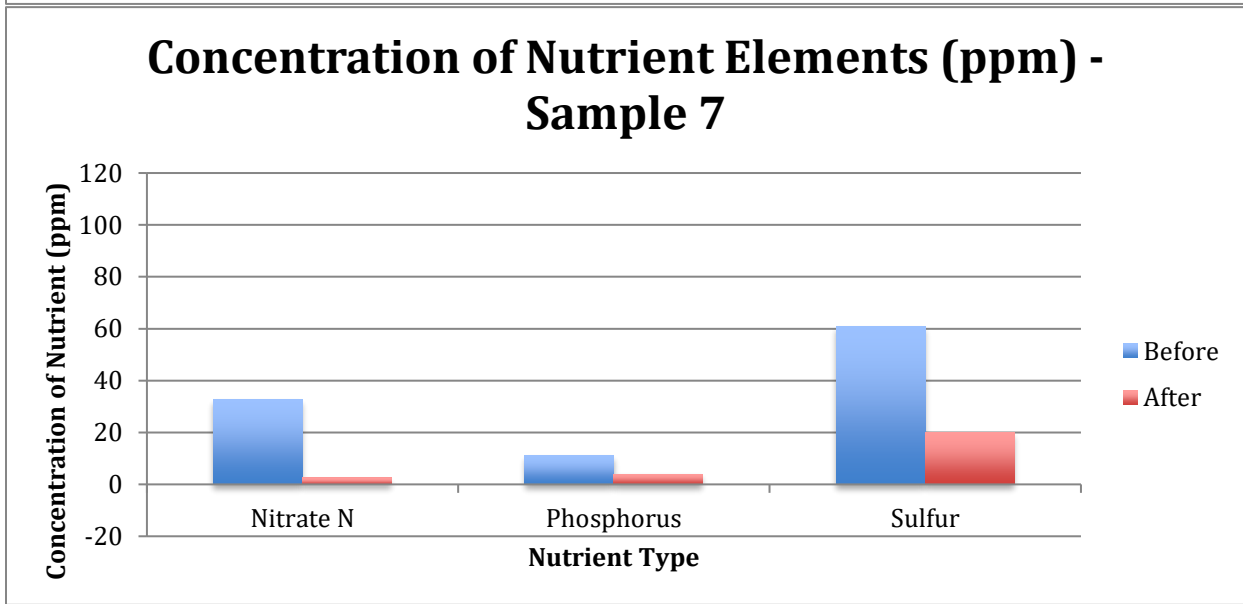
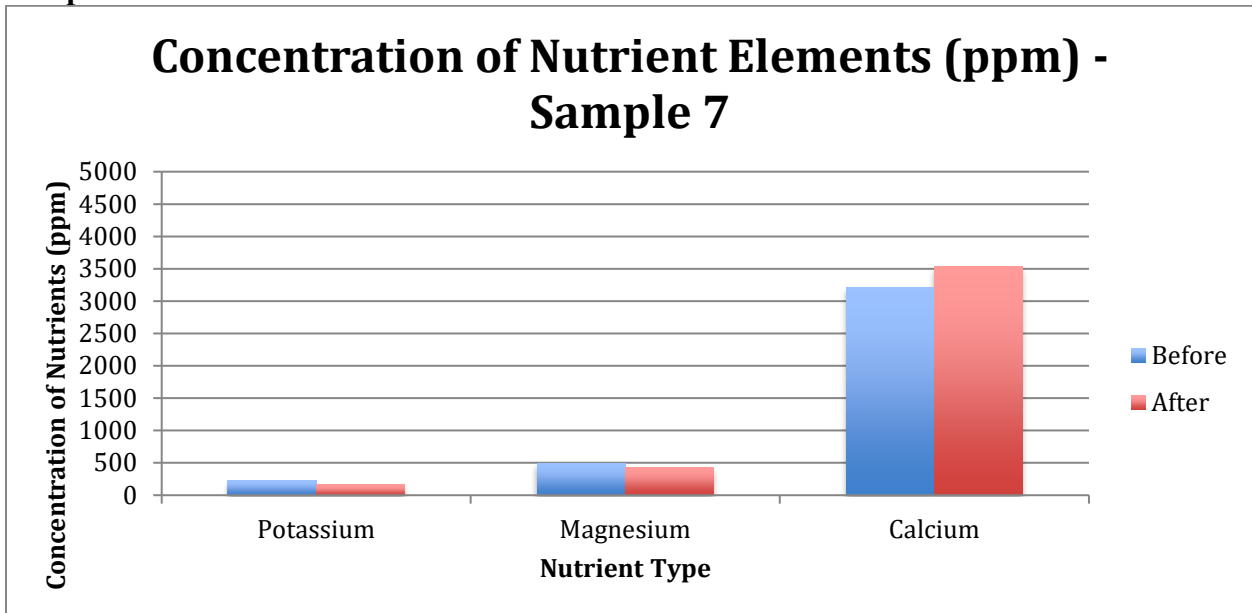
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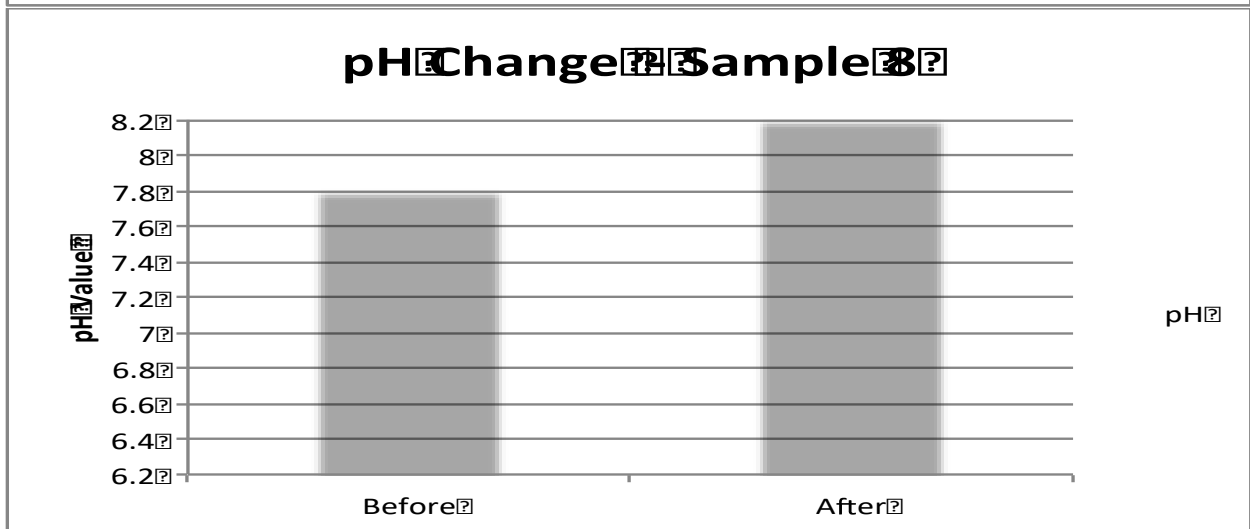
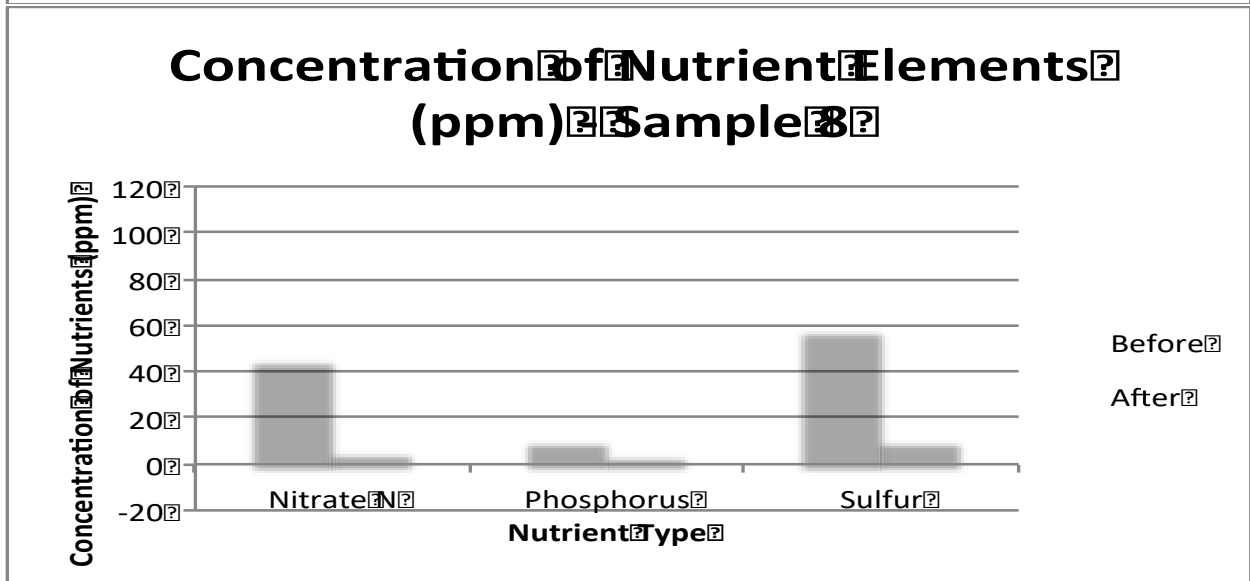
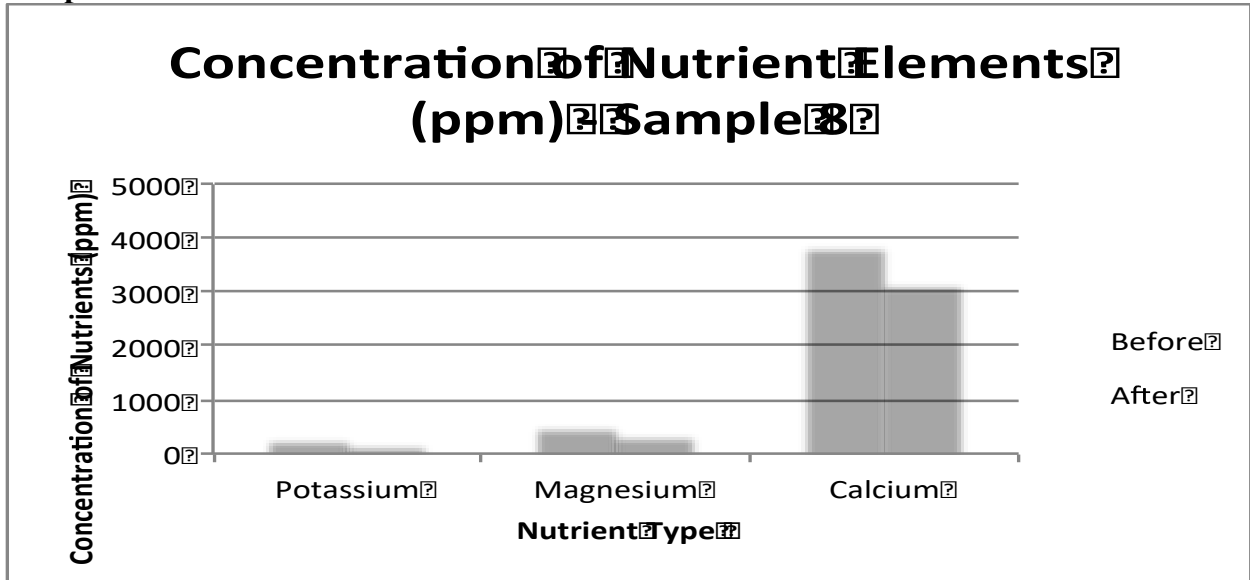
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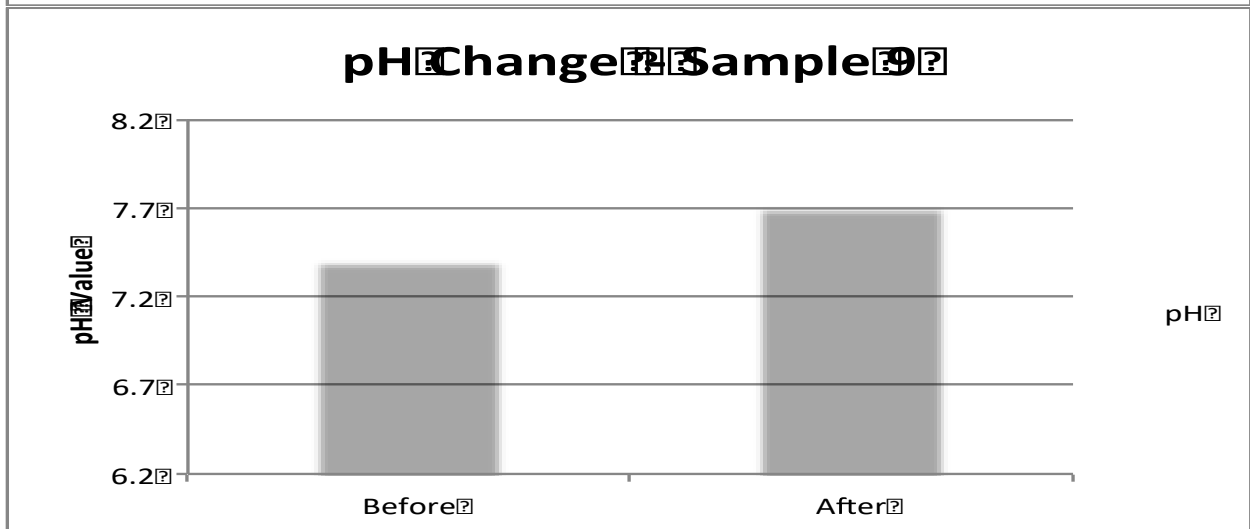
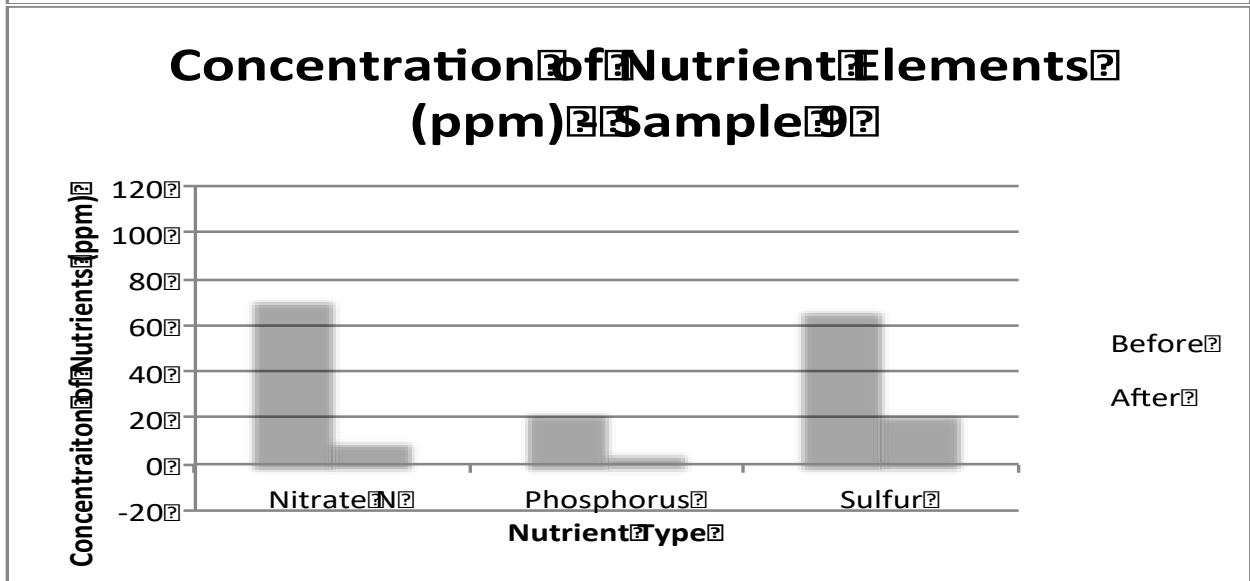
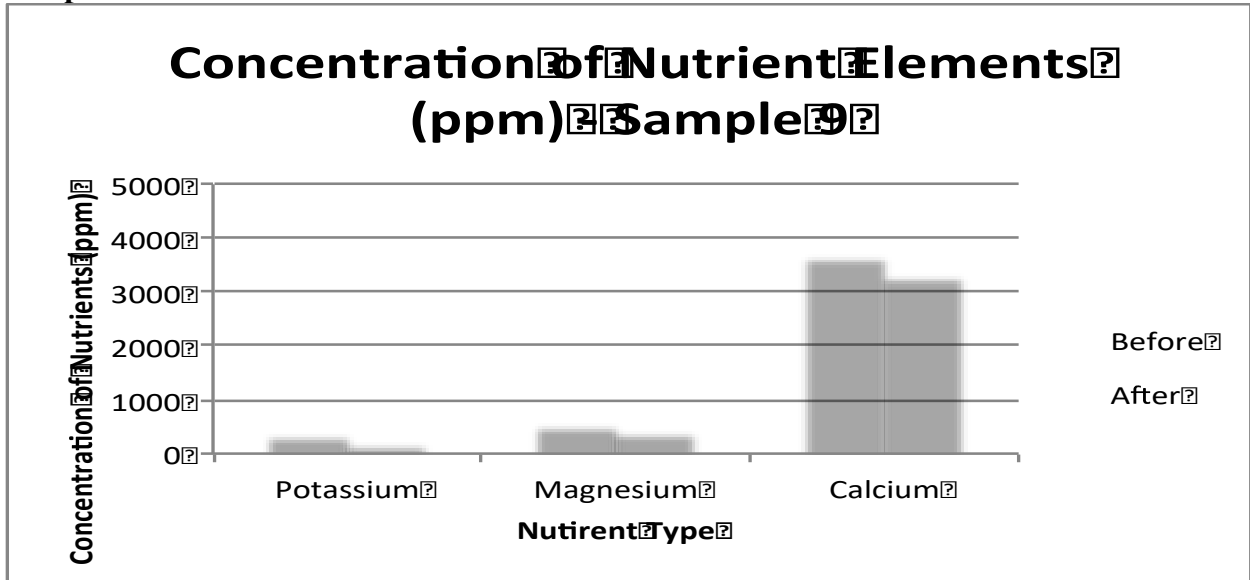
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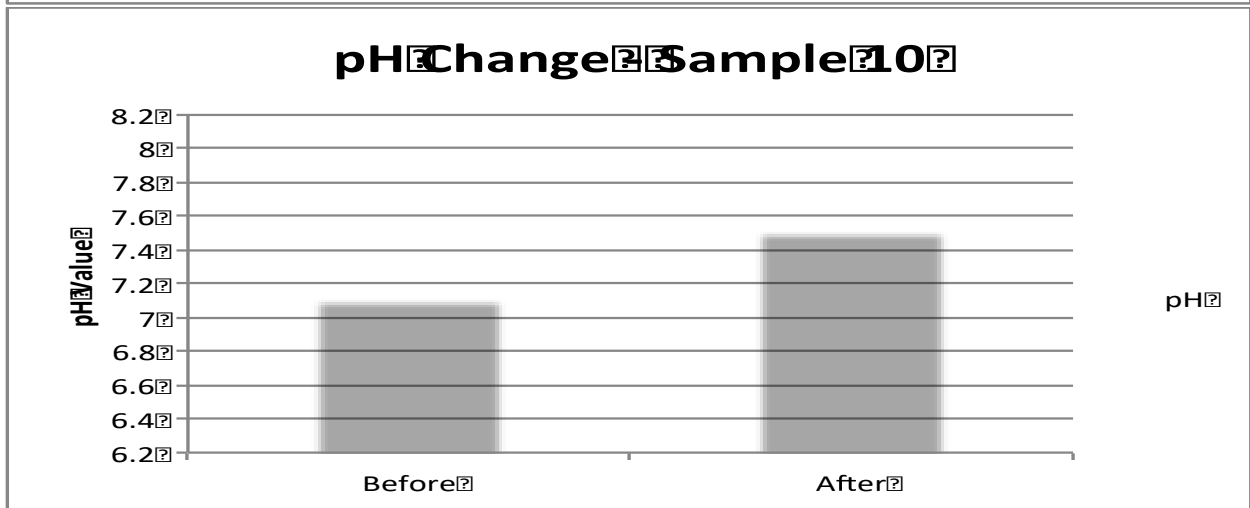
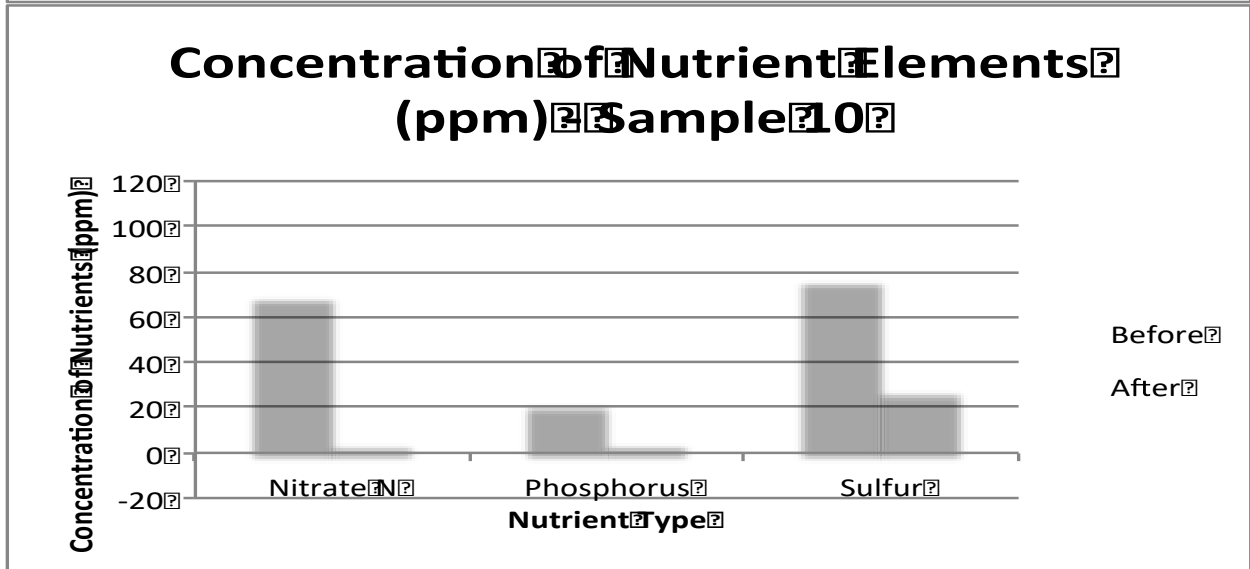
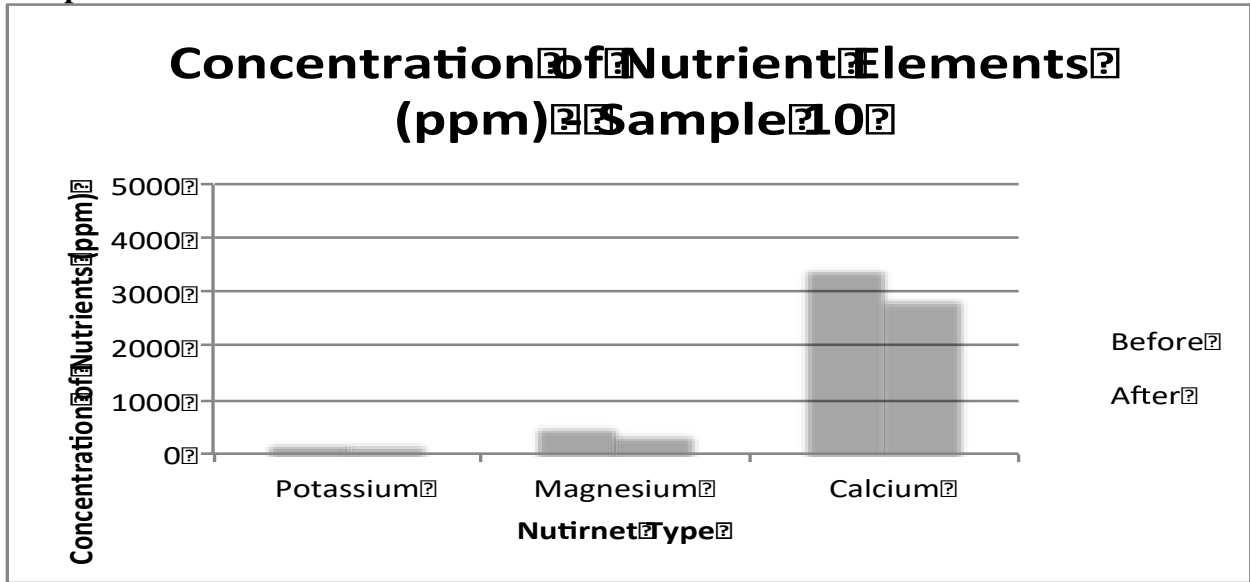
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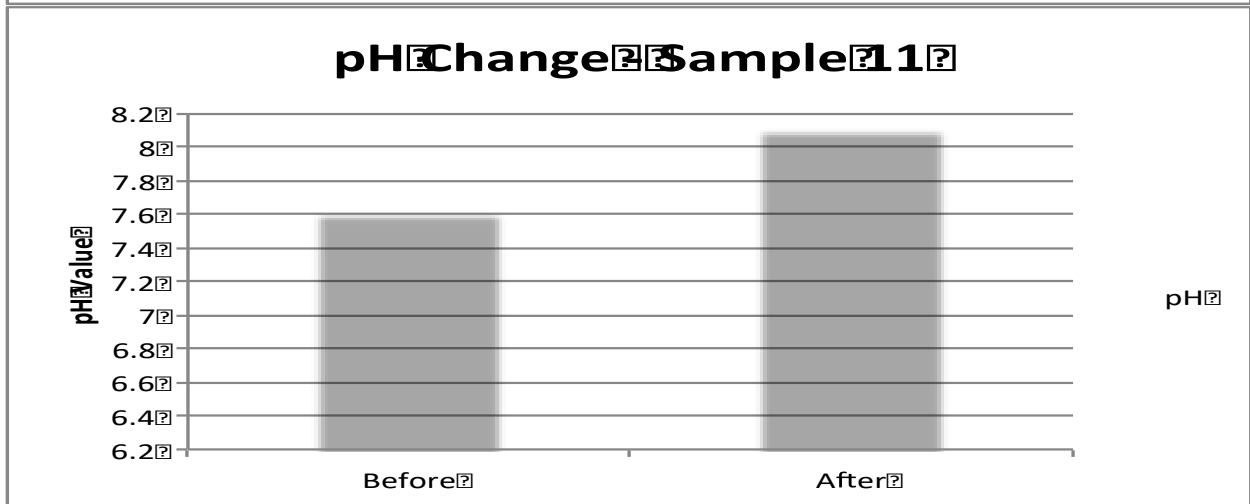
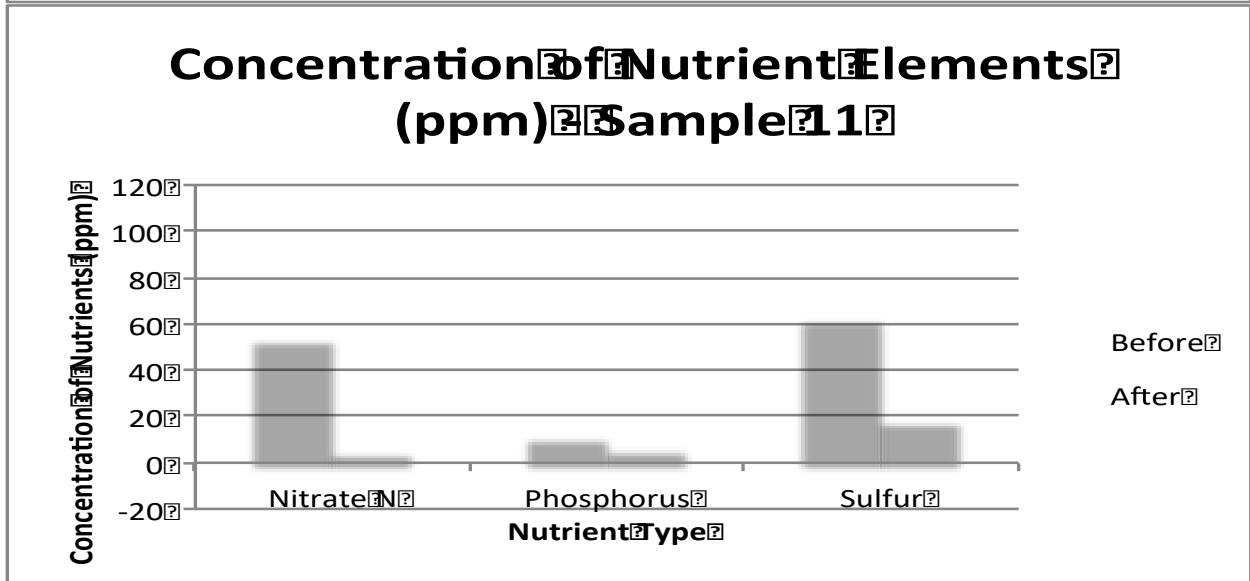
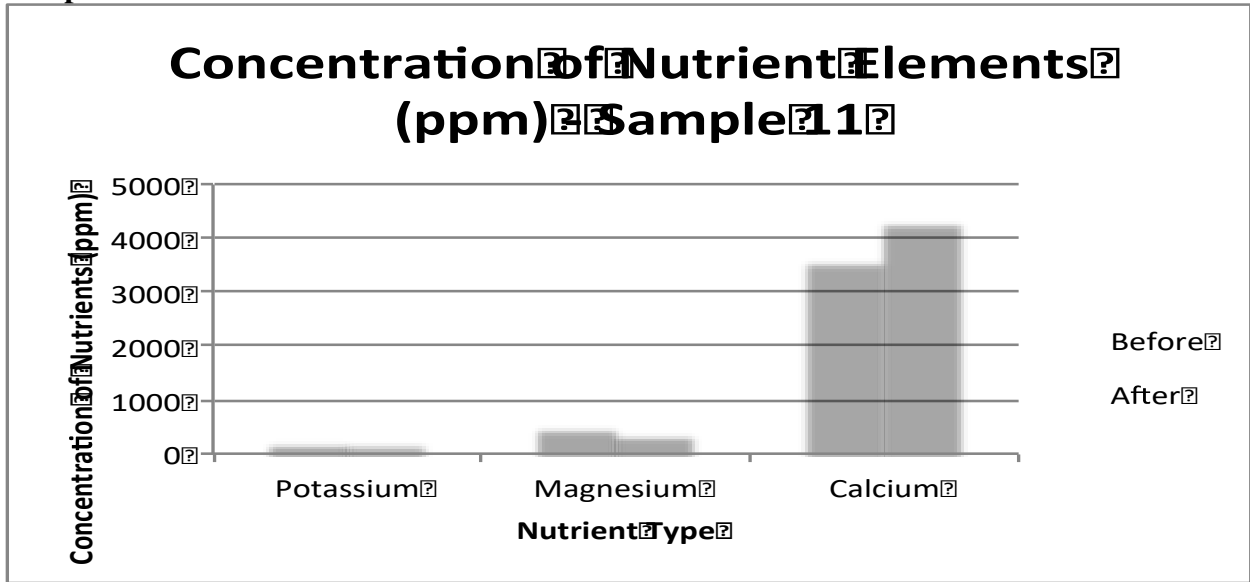
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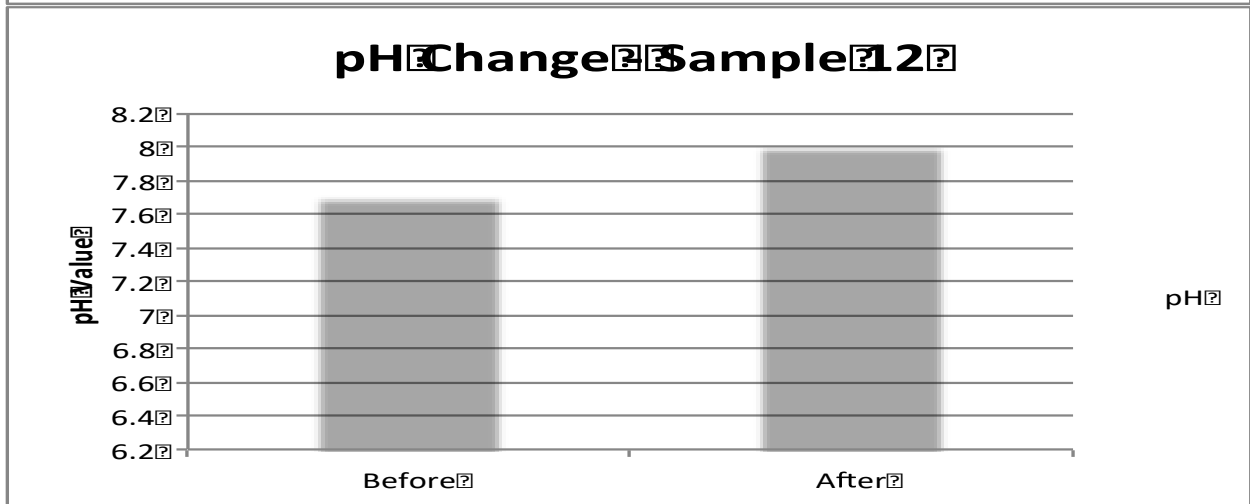
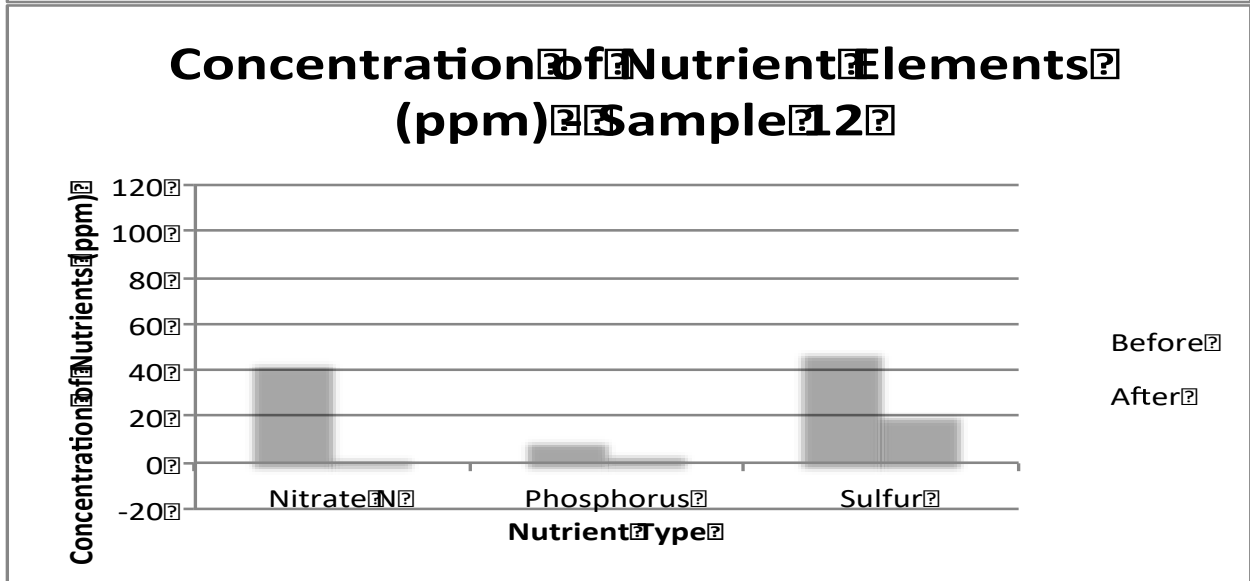
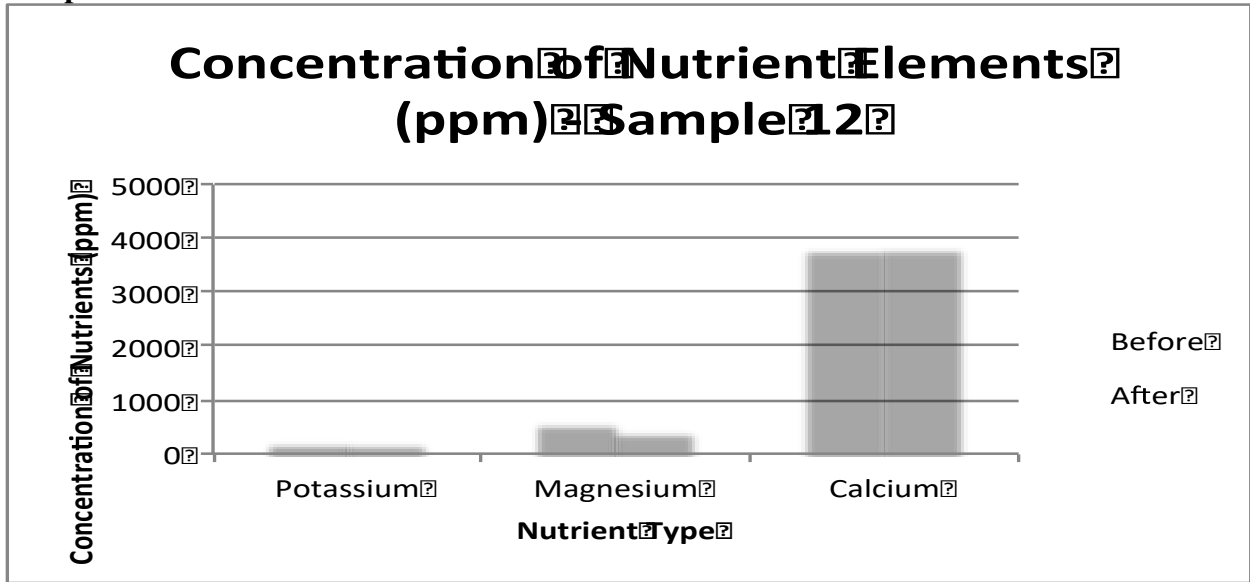
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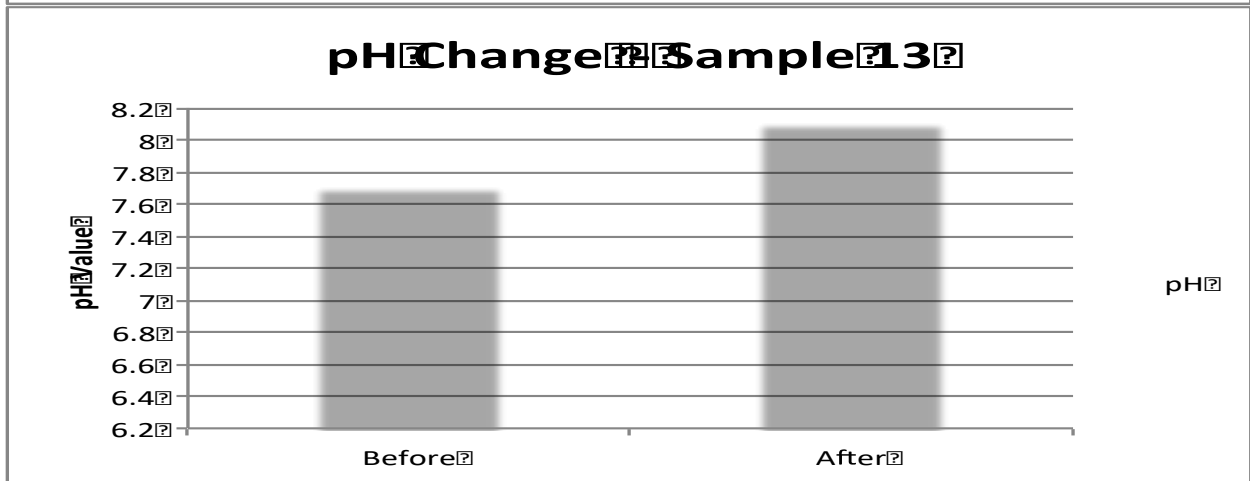
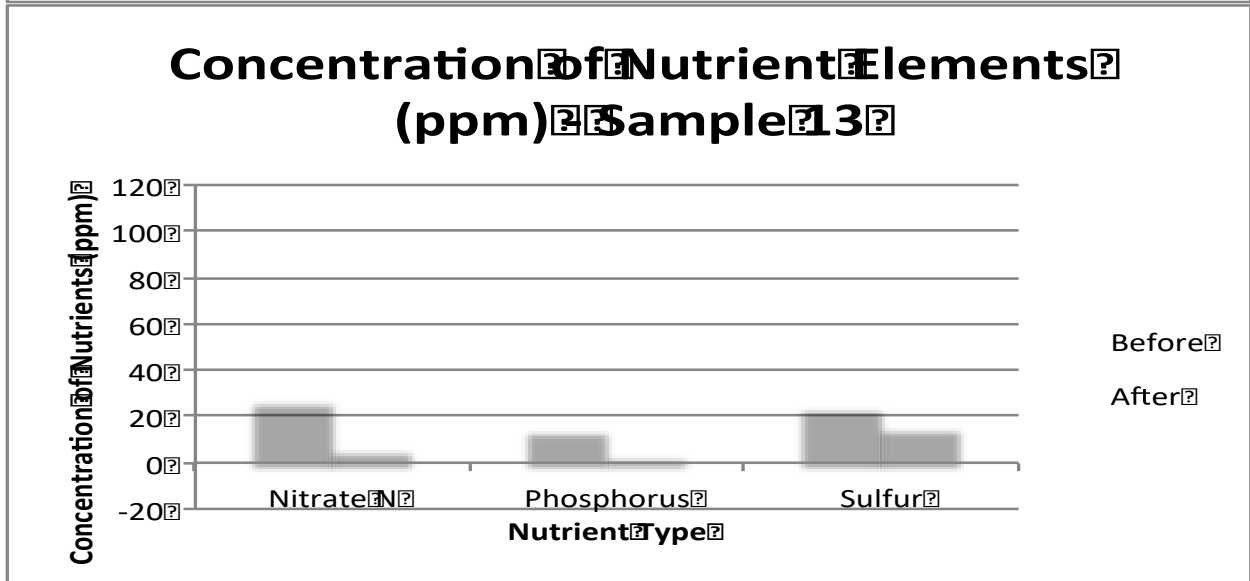
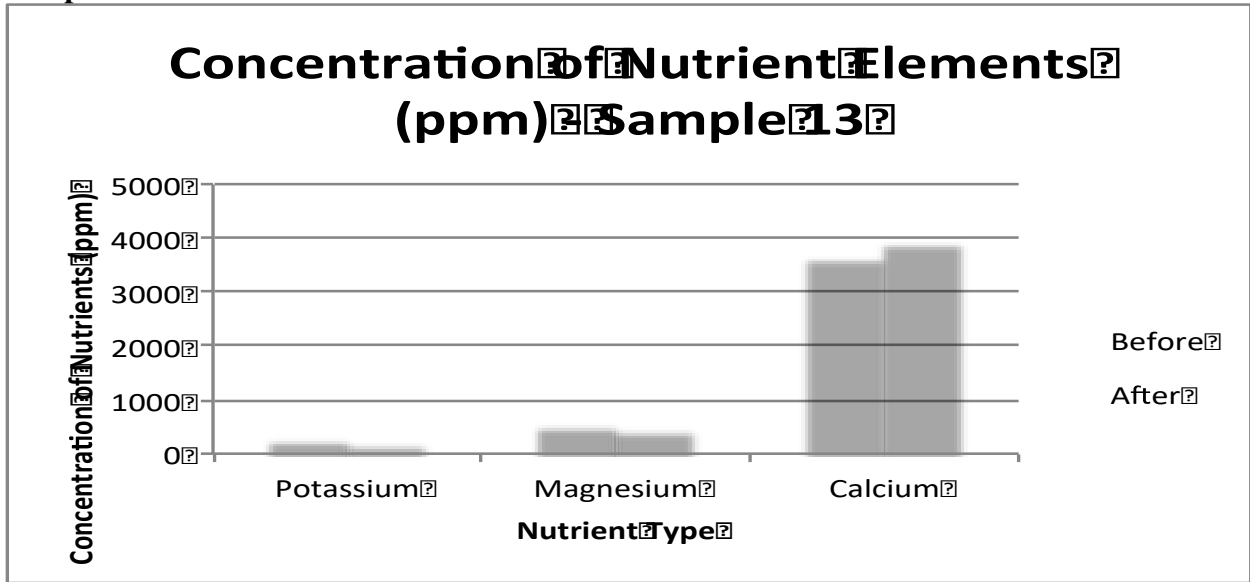
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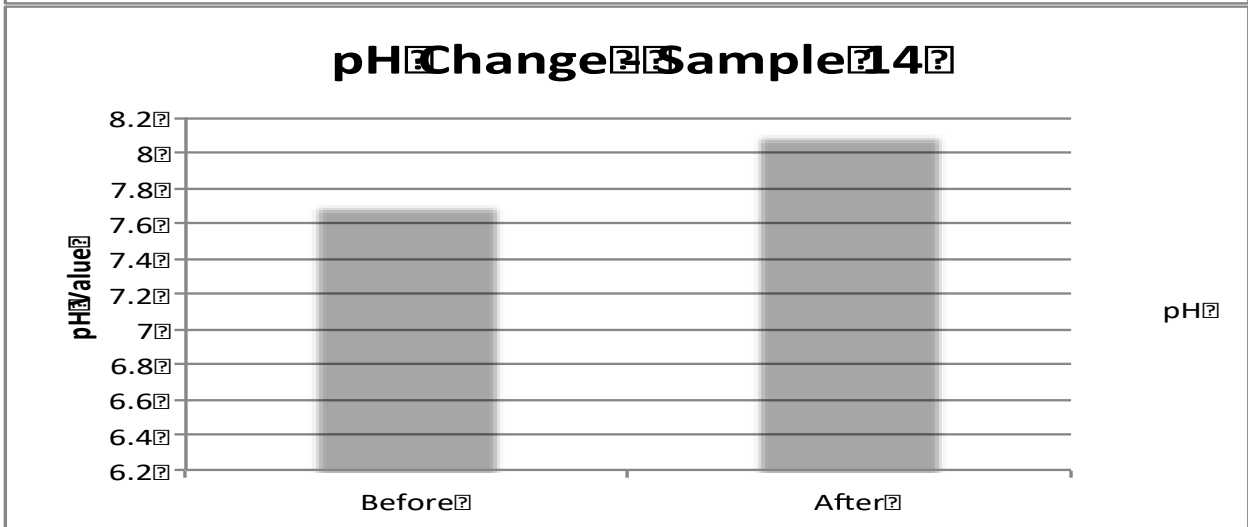
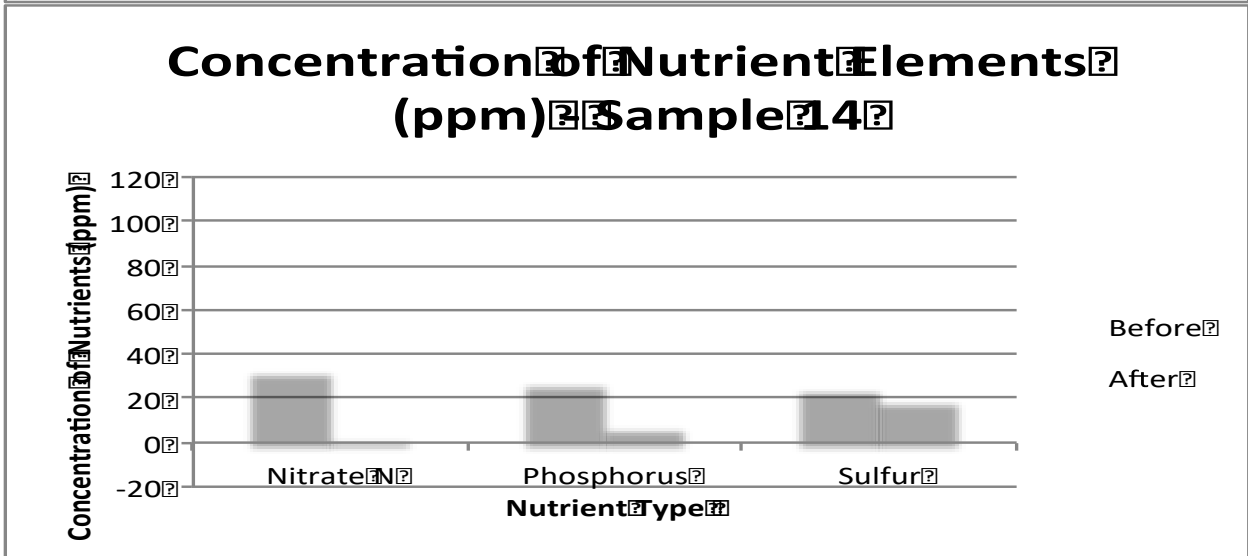
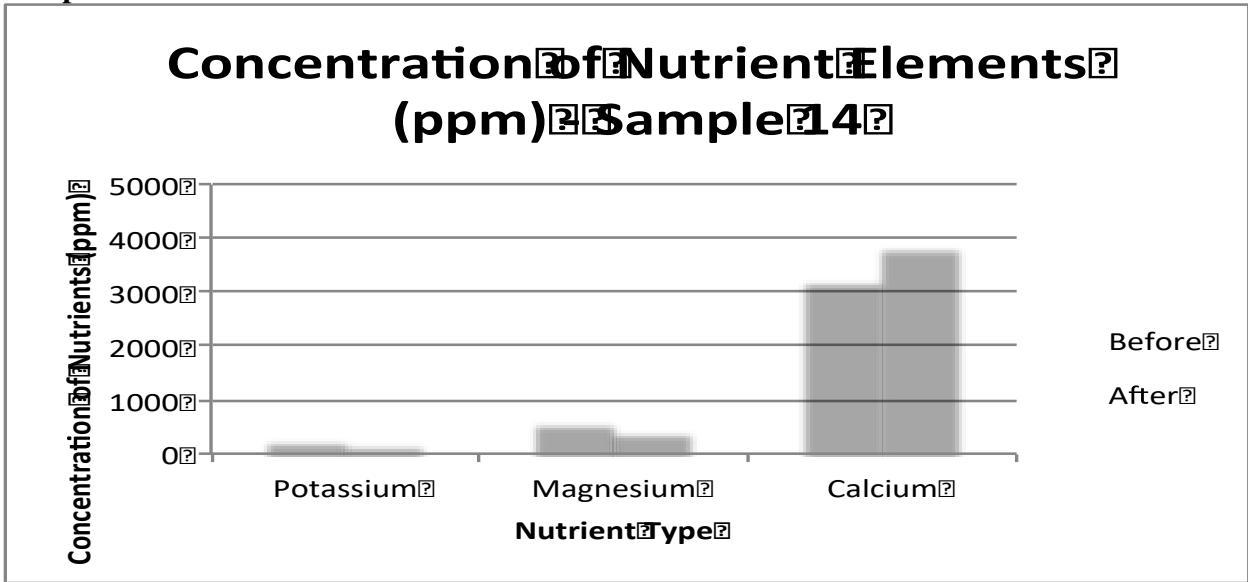
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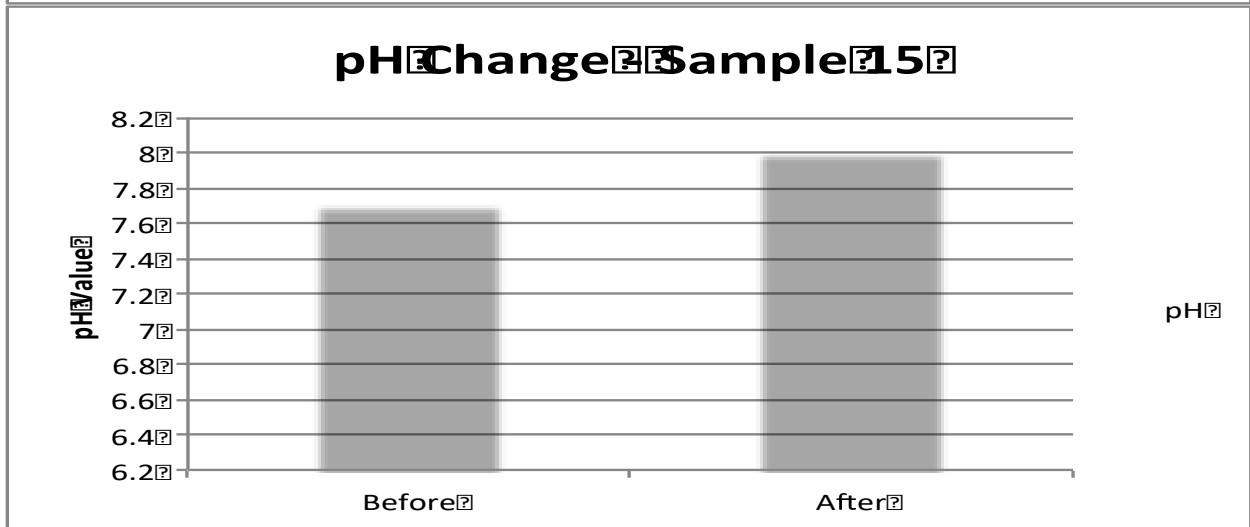
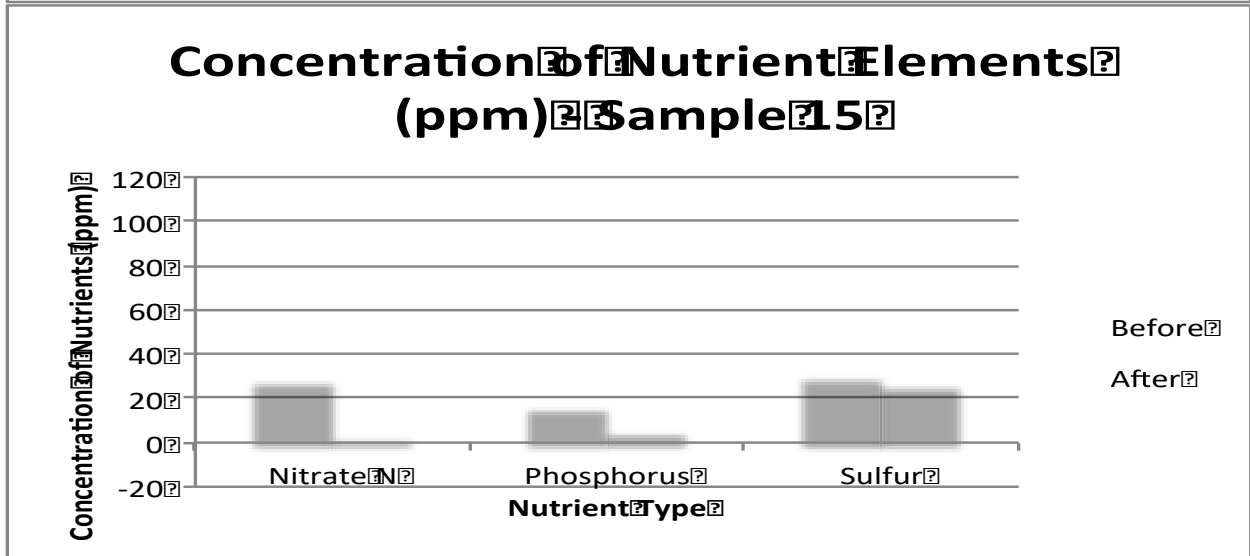
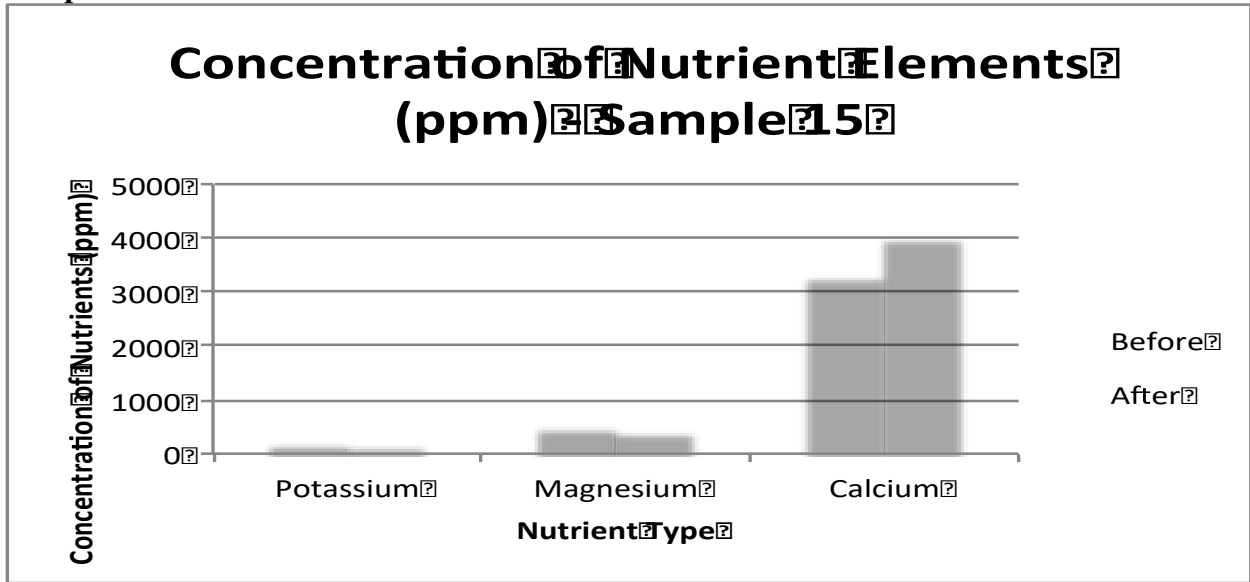
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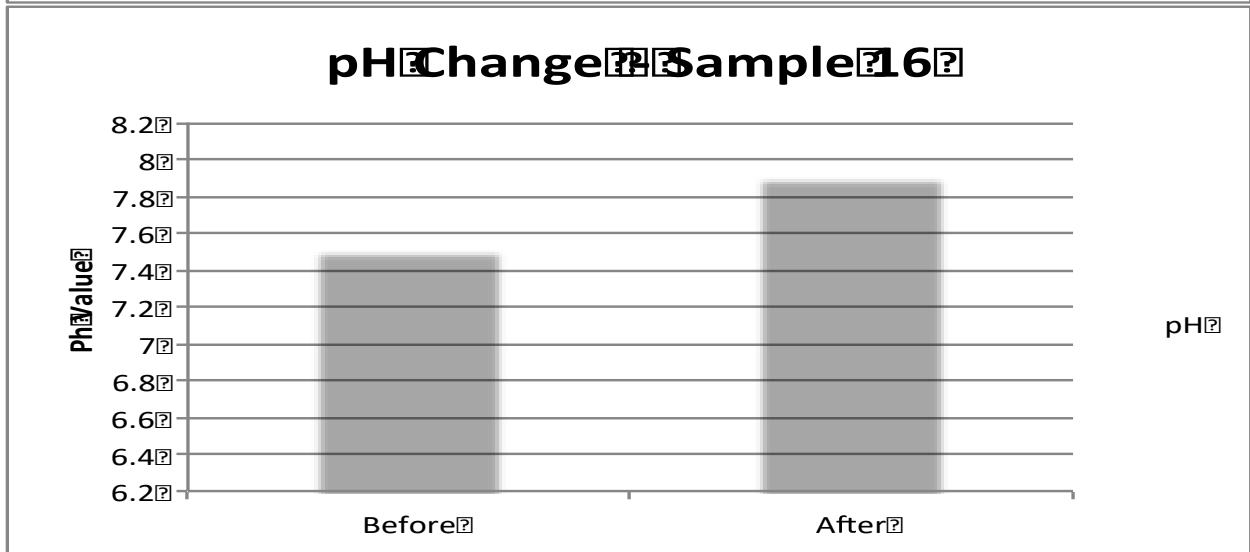
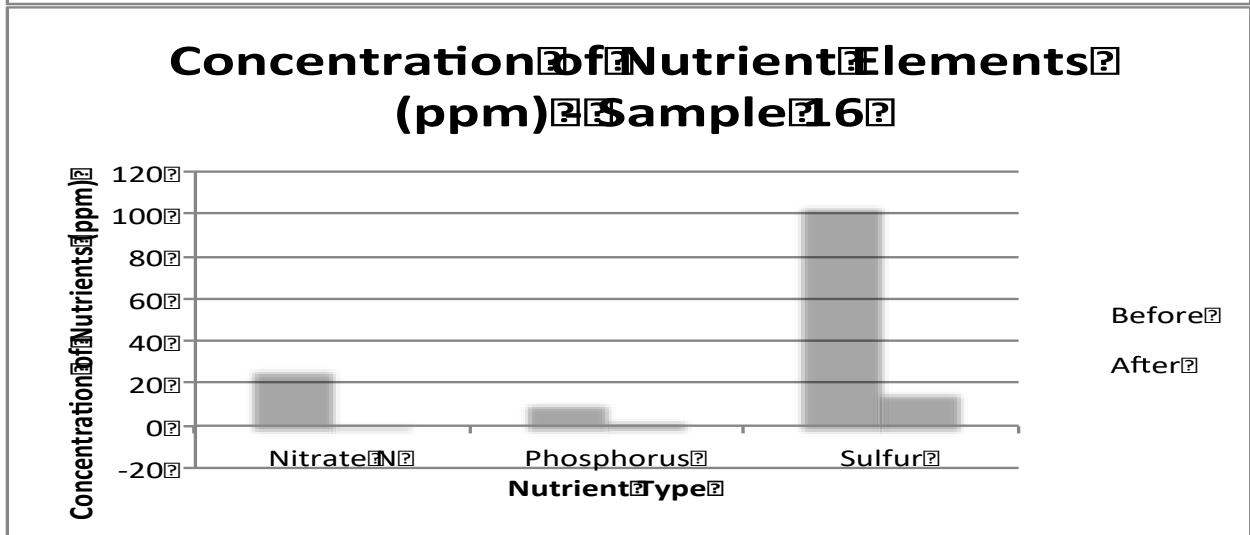
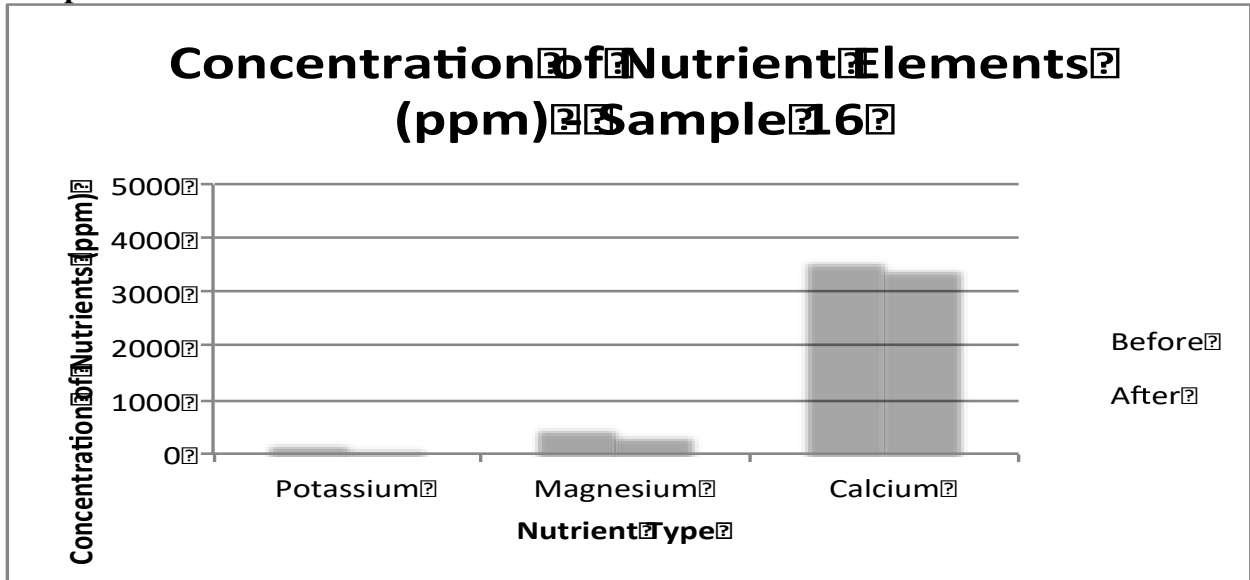
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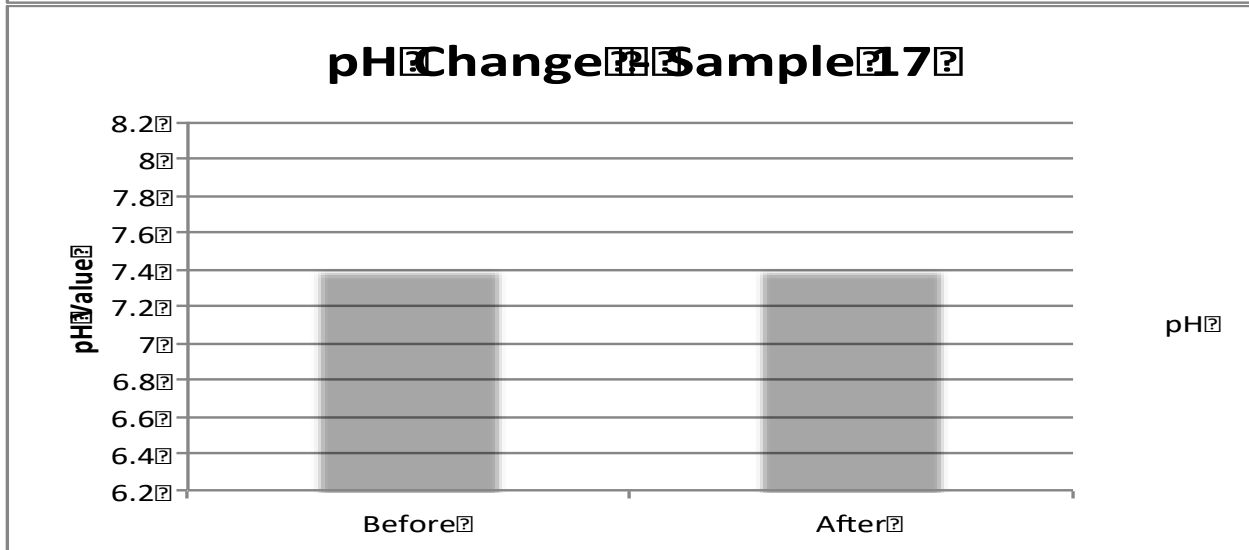
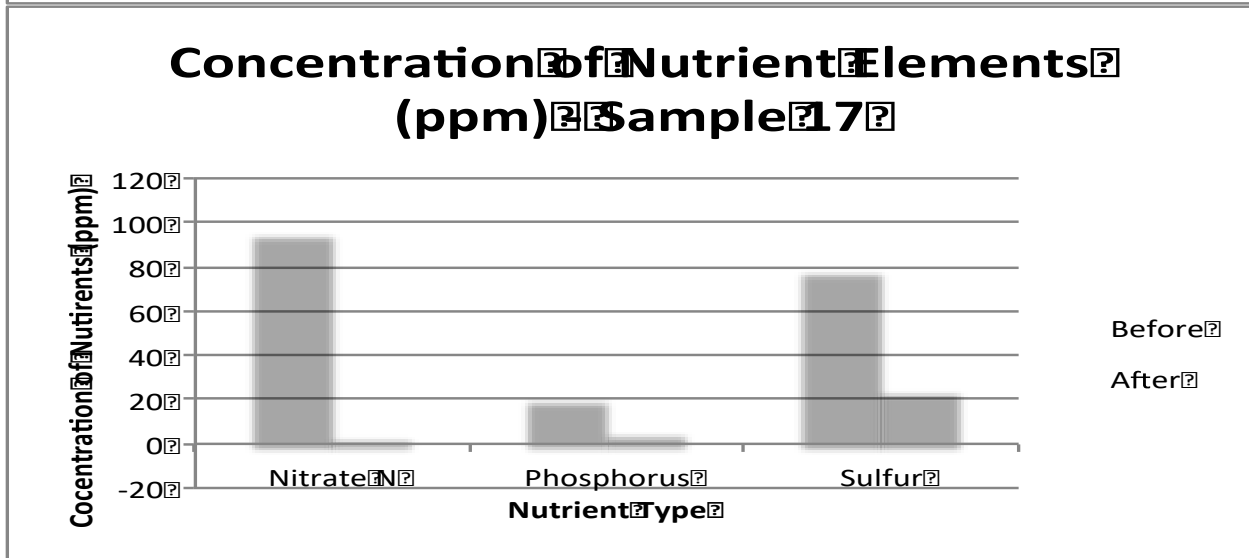
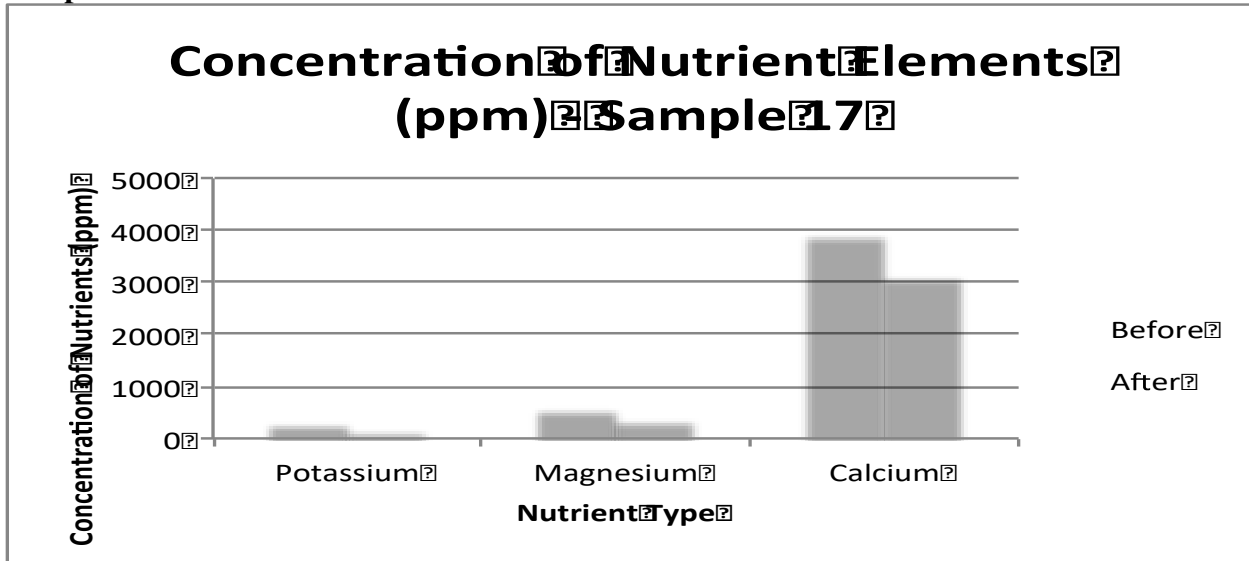
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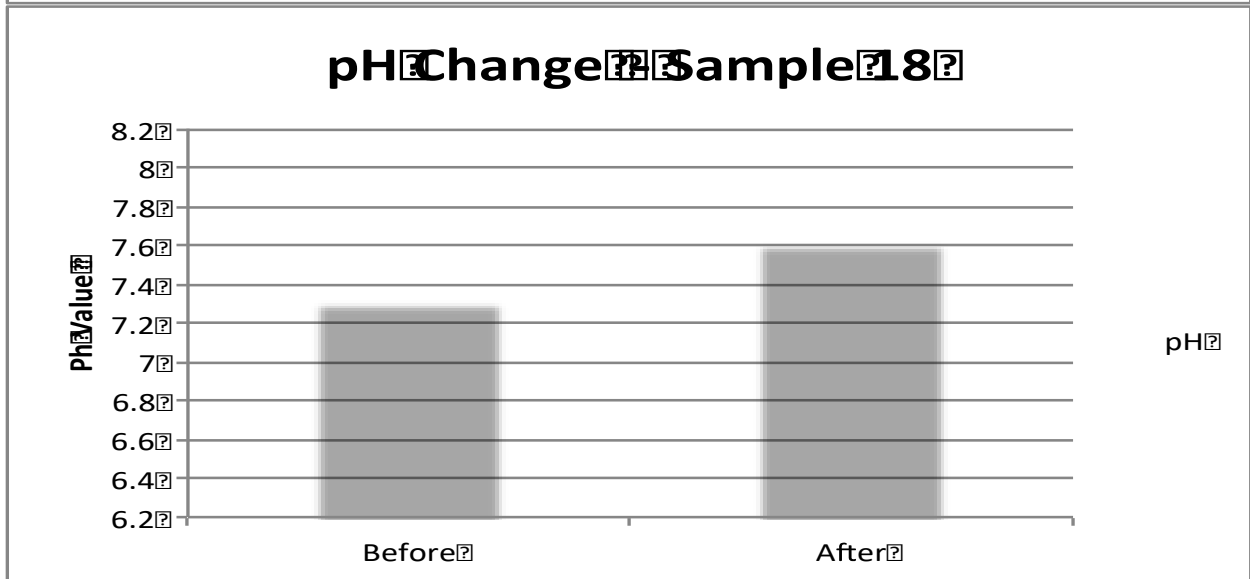
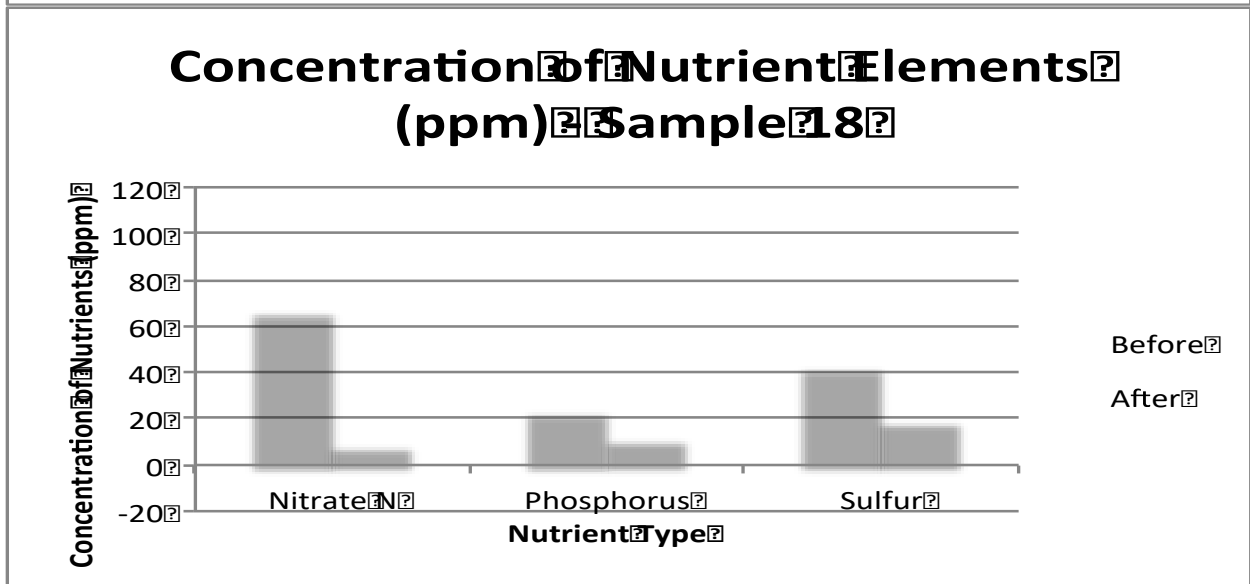
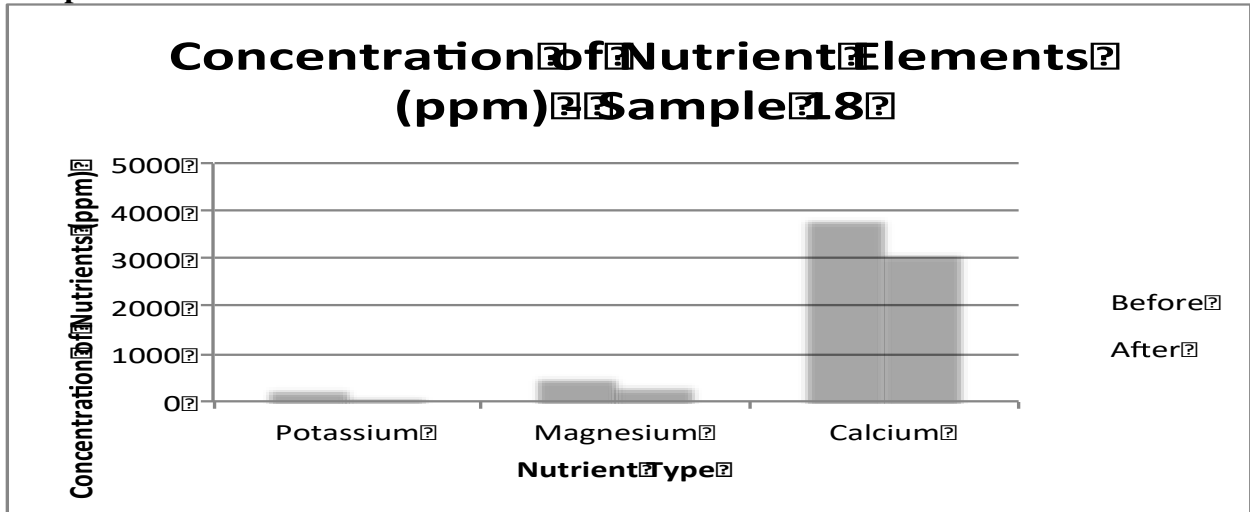
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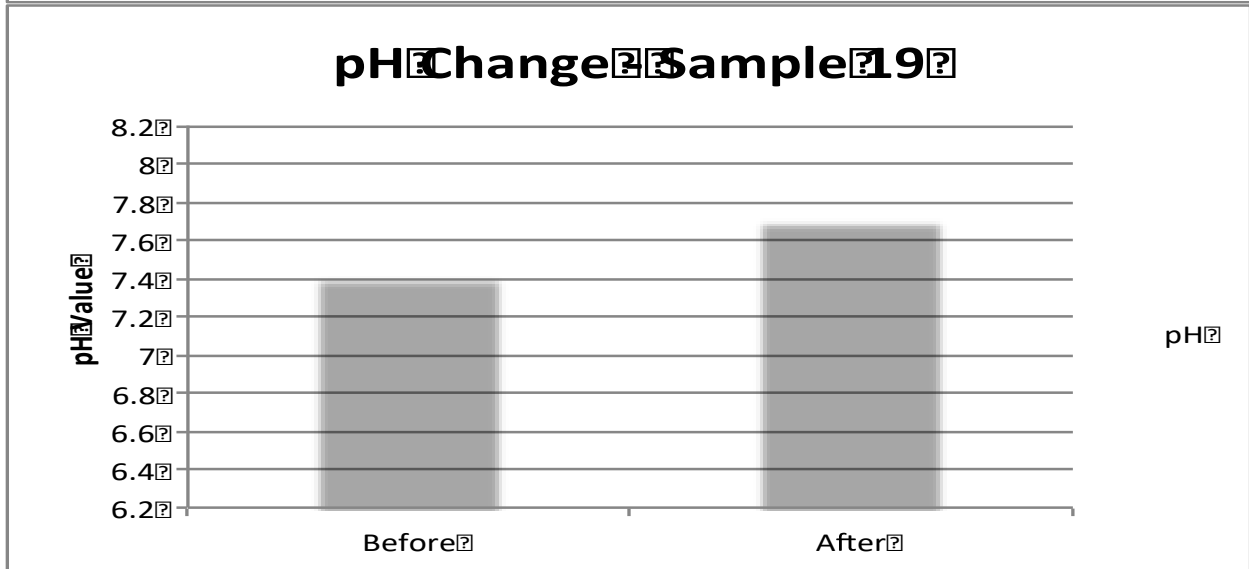
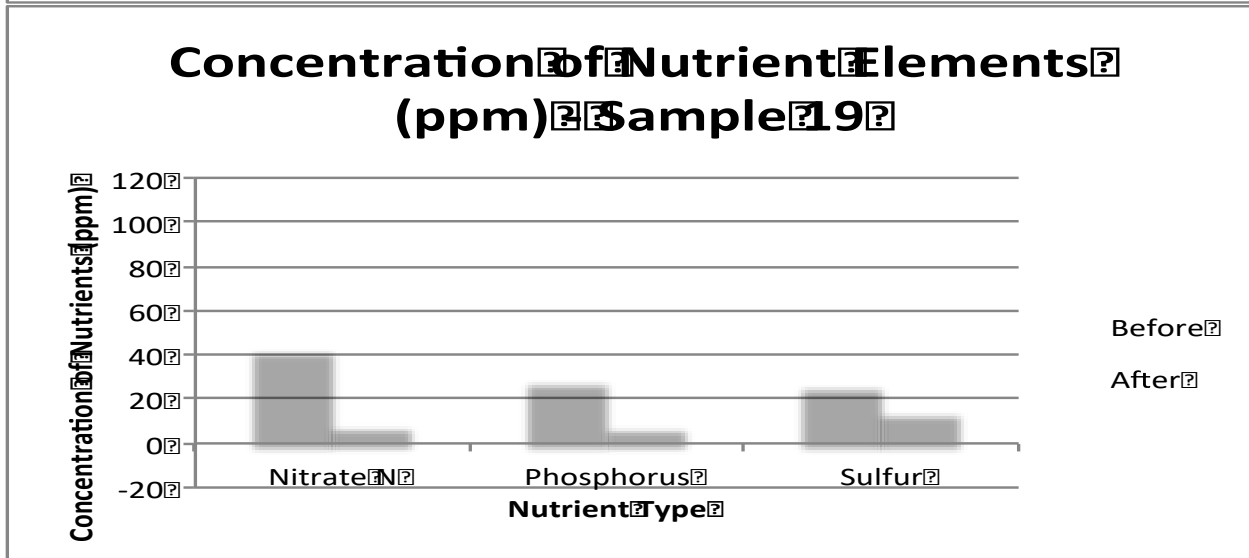
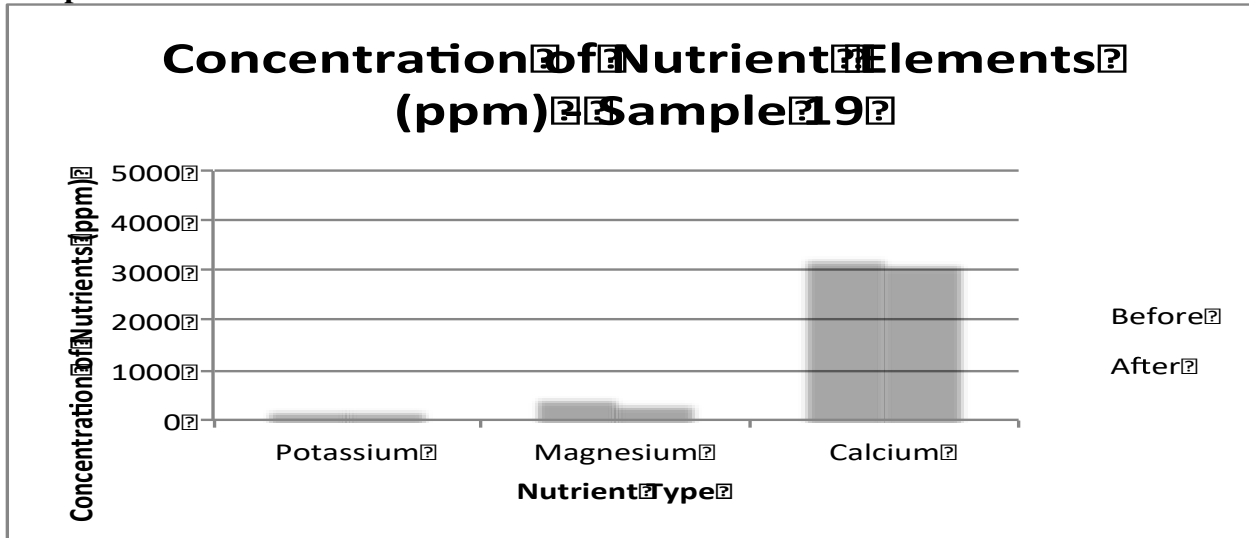
Sample 17:



Sample 18:



Sample 19:



Sample 20:

