The Effects of Nutrient Availability on Plant Growth and Development

Abstract

Plants are heavily reliant on nutrients present in the soil. In some cases, such as with nitrogen or phosphorus, the plant can send these nutrients from old tissue to new tissue in the event of a deficiency in the environment. This experiment sought to analyze the effects of certain nutrient deficiencies over a four week span of growth. It was discovered that nitrogen deficiency, phosphorus deficiency, and complete nutrient deficiency all led to significant differences in growth capacity over the span of the experiment. Standard chlorophyll content also showed significant differences when comparing the nitrogen-deficient and phosphorus-deficient treatments with the complete nutrient treatment. These results indicated that mobility of nutrients cannot completely offset a deficiency of said nutrient in the environment, it can only help the plant attempt to survive the deficiency.

Introduction

Plants are quite different from animals in many ways. Many animals are mobile, while plants are sessile and rooted to a certain place. One major difference between plants and the vast majority of animals is in the way that they intake products necessary for growth. This is not meant in terms of heterotrophism vs. autotrophism, but in terms of obtaining nutrients, monomers, and products necessary for producing energy. Most animals take in all necessary materials in the same place, via a type of mouth. Humans for example, take in air, water, and food through the mouth. Plants need to get certain materials from different places, but they take in these different materials through different methods. Carbon dioxide is obtained from the air through the plant leaves, where most photosynthesis takes place. Water and nutrients, though, are taken from the soil via the roots. This means that sugar is made through photosynthesis above ground, but the cells in the root also need it for cellular respiration. On the other hand, large amounts of nutrients can be taken into the roots, but cells above ground will need these nutrients for growth and other processes. This seems to indicate that only root cells will have nutrients and only cells above ground will be able to have sugar for respiration.

However, some nutrients are considered mobile nutrients, meaning that they can be transferred from older tissue to newer tissue. This means that should there be a shortage of the nutrient, it can be sent from the older tissue/foliage to new leaves. The two nutrient deficiencies examined in this experiment were nitrogen and phosphorus, which are both identified as mobile elements. One may think that nitrogen should not be an issue because of its abundance in the atmosphere, but plants lack the means for fixing gaseous nitrogen (N_2) into useable nitrogen (some exchange it with bacteria or fungi for sugars). It is the soil nutrient that most commonly limits plant growth. Nitrogen is a huge component in a plethora of macromolecules including proteins and nucleic acids. Based on this, the main observed effect of nitrogen deficiency in plants has been stunted growth. Nitrogen is employed in the formation of chlorophyll, so it is necessary to move nitrogen from the lower leaves to the higher leaves, which will have a better chance of catching more sunlight for photosynthesis. The resulting lack of chlorophyll in lower foliage results in discoloration of the lower leaves, known as chlorosis. Chlorosis results in a yellowish color in the leaves, which is more noticeable in areas further from the main leaf veins (Salisbury and Ross, 1992; Bennett, 1994).

The other nutrient in question, phosphorus (obtained and used in the form of phosphate), is the second most limiting soil nutrient and is a major component of phospholipids used in the production of cell membranes. While this is the only significant structural role of phosphorus, it also is used very much in nucleic acids and is vital for energy storage in ATP. This is the main reason that phosphorus deficient plants exhibit inhibited growth due to interference in typical metabolism and cell division (Salisbury and Ross, 1992; Bennett, 1994). Phosphorus, unlike nitrogen, can be recycled from old organic molecules, which can lead to decreased symptoms of phosphorus deficiency. One tree noted by Bergmann (1992) was able to survive in a medium without phosphorus for three years without growing. Degrading these organic molecules tends to lead to higher respiration rates in plants without phosphorus. Phosphorus does not have a role in chlorophyll synthesis, so leaves tend to retain the green color. Since the deficiency does stunt leaf growth, the leaves sometimes tend to exhibit a deeper green color than average leaves because they still produce a typical amount of chlorophyll, but in reduced leaf sizes leading to a higher concentration of chlorophyll. The deep green leaf color often associated with phosphorus deficiency makes them appear to be healthy. According to Bergmann (1992), it is nearly impossible to identify phosphorus deficiency in a plant without having a control plant for comparison. In some cases, the bottom sides of phosphorus-deficient plant leaves can display a purple pigment (anthocyanin). Bergmann also noted that in youth, the leaves can appear dark green but older leaves often exhibit chlorosis; perhaps a side effect of increased focus on phosphorus recycling rather than chlorophyll synthesis.

For this experiment, a third treatment was also compared to the control. In one case, plants were grown in an environment where only distilled water was available to the roots. While one may expect all of the aforementioned symptoms to be present, nitrogen deficiency symptoms tend to be most prevalent. This is due to the fact that nitrogen is employed in many different ways throughout the plant while phosphorus has a role in fewer things. Without nitrogen, typical plant growth and development is stunted, thus there is less need for other nutrients and symptoms of other deficiencies could be reduced or absent. While most symptoms present are nitrogen deficiency symptoms such as chlorosis and reduced growth, a few phosphorus deficiency symptoms may occur as well, such as anthocyanin presence in and around leaf veins.

Another deficiency not examined in this experiment is iron deficiency. Iron plays a role in respiration, acting as both an electron donor and acceptor in electron transport, often in response to light (Salisbury and Ross, 1992). It is also needed for synthesizing proteins and chlorophyll. However, iron is an immobile element unlike nitrogen and phosphorus. This means that should an iron shortage occur, new tissue cannot receive recycled iron from older tissue. Because of this, iron must be constantly taken up by the plant in order for all iron needs to be satisfied. Because of its role in chlorophyll synthesis, iron deficient leaves also tend to display chlorosis, especially away from leaf veins. However, it is first seen in new foliage rather than old foliage because of its immobility. With nitrogen and phosphorus, deficiency symptoms would be seen in old foliage first because new, higher foliage would be in higher priority since they have the best chance of getting light. If phosphorus or nitrogen were unavailable at a certain time, deficiency symptoms could be seen. With these elements, though, a sudden influx of the element could reverse these symptoms because it could be mobilized to the deficient tissue.

Because of the symptoms seen in past experimentation, we expected the three deficient treatments to show differences in both weight and standard chlorophyll content (mg chlorophyll/g of leaves), a measure of chlorophyll density within a leaf. Our experimental hypotheses for each treatment (-N, -P, and distilled water) were that the weight and standard chlorophyll content would be different than those of the control experiment (complete nutrient availability). Our null hypotheses were that all weights and standard chlorophyll contents would be the same regardless of the treatment.

Materials and Methods

This experiment was carried out by following the procedure in the Plant Nutrient Deficiency OMP by Robert Kosinski (2015). Four different treatments were used, and all tomato plants were planted over a week's time in hydroponic recirculators. The four treatments were complete nutrients, minus nitrogen, minus phosphorus, and distilled water. Before planting, a different plant was used to determine the SCC (standard chlorophyll content) of the plant. This value was used to calculate the initial means, since there was no way to determine the SCC of the plants used in the experiment without severely hindering growth or killing them. The plants used were weighed initially and then planted into the recirculators. In these recirculators, the plant roots were submerged in water with a certain nutrient content based on the treatment. The liquid in the recirculators was constantly circulated from another tank to prevent nutrients from being used up. The plants were allowed to grow for four weeks, and were also harvested over a week's span, with groups harvesting the same plant that they initially planted. All plants of the same treatment were planted in the same recirculator with a light fixture above them. The plants were weighed again after harvesting, and random leaf samples from around the plant were used to determine the SCC of the plant. In some cases, dilutions had to be made because chlorophyll solutions were too dark for proper reading by the spectrophotometer, but these dilutions were accounted for. The unpaired chi-square median test was used to test the significance of the results.

Results

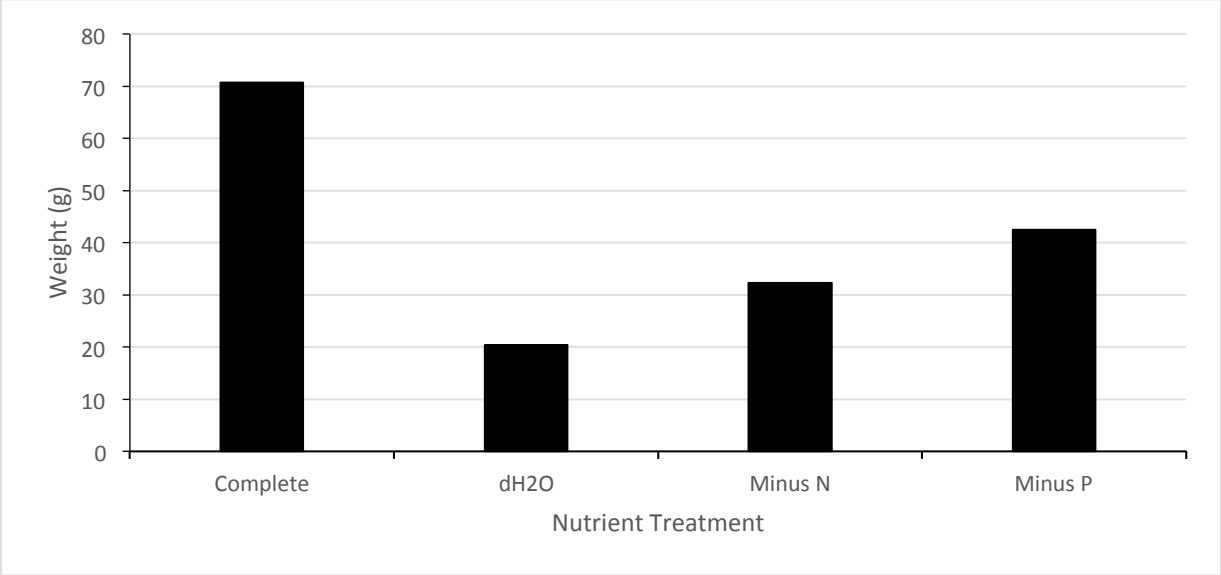

Figure 1: Average weights of tomato plants after four weeks of growth in hydroponic recirculators under the stated nutrient conditions. Minus N indicates a complete nutrient supplement minus nitrogen, and Minus P indicated a complete supplement minus phosphorus. Chi-square values are shown in Table 1.

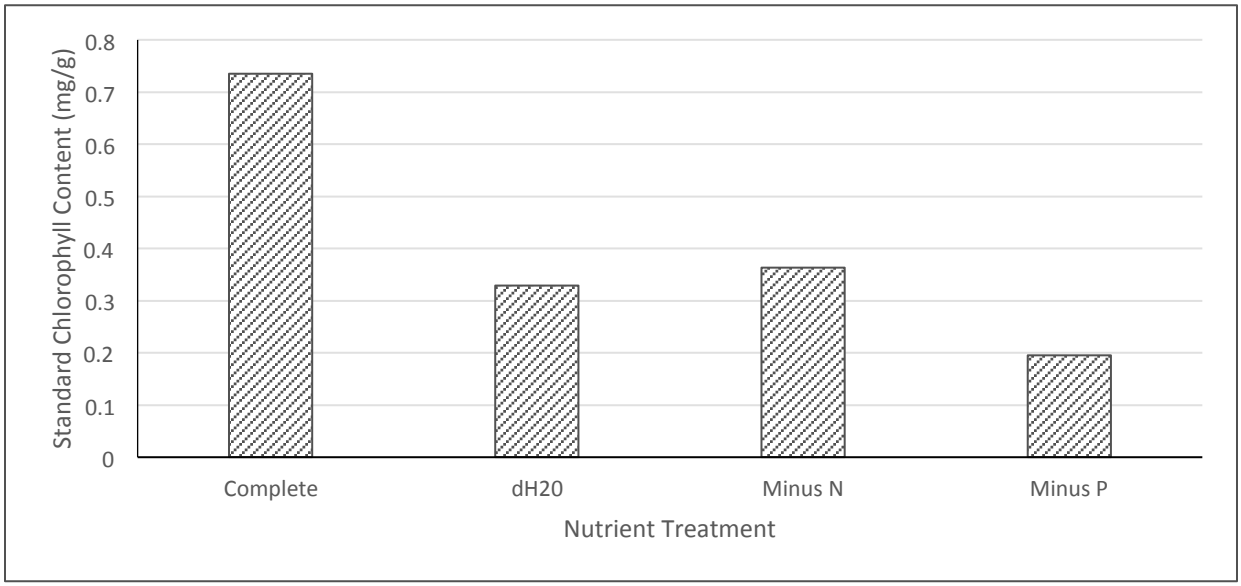

Figure 2: Standard Chlorophyll Contents of tomato plants after four weeks of growth in hydroponic recirculators with the stated nutrient conditions. Minus N indicates a complete nutrient supplement minus nitrogen, and Minus P indicated a complete supplement minus phosphorus. Chi-square values are shown in Table 2.

Table 1: Initial weights, final weights, and results of the chi-squared median test for data presented in Figure 1.

Nutrient Treatment	Initial Mean Weight	Final Mean Weight	Chi-Square Value	P-Value
Complete	13.81 g	70.73 g	N/A	N/A
Distilled H_2O	15.03 g	20.38 g	16.71	4.36E-5
Minus Nitrogen	16.83 g	32.31 g	15.63	7.71E-5
Minus Phosphorus	10.13 g	42.45 g	7.82	0.0052

Table 2: Initial SCCs, final SCCs, and results of chi squared median test for data presented in Figure 2.

Nutrient Treatment	Initial Mean SCC	Final Mean SCC	Chi-Square Value	P-Value
Complete	0.244 mg/g	0.735 mg/g	N/A	N/A
Distilled H_2O	0.211 mg/g	0.33 mg/g	1.24	0.265
Minus Nitrogen	0.19 mg/g	0.364 mg/g	6.33	0.0119
Minus Phosphorus	0.22 mg/g	0.195 mg/g	9.9	0.00165

The complete nutrient treatment displayed both the highest weight and SCC out of all the treatments. As seen in Figure 1, the weights of all treatments other than the complete displayed severely reduced weight after four weeks of growth. The SCC for all other treatments were also relatively low compared to that of the complete nutrient treatment. Only the minus phosphorus treatment averaged half of the complete treatment weight, and only the minus nitrogen treatment managed half of the average SCC of the complete. Chi Square values for the comparisons indicated that all differences except for the SCC of the distilled water treatment were significant.

Discussion of Results

The results of the chi squared median test indicate that all of these differences were significant except for the difference between the SCCs of the complete and distilled water treatments. Therefore, we failed to reject the null hypothesis that a plant with complete nutrients and a plant with no nutrients available would display the same SCC. All other null hypotheses related to weight and standard chlorophyll content were rejected, although not necessarily in the way expected.

As seen in Figure 1, the nitrogen treatment displayed the highest average weight out of the three nutrient deficient treatments. We expected the weight to be significantly lower than the complete treatment, but actually expected the phosphorus plants to be smaller because of its important role in respiration. This did not occur as expected, but could possibly be attributed to the fact that the initial weights of all plants were higher than typically used in this experiment. As mentioned before, plants can recycle phosphorus for use in new tissue, so the more biomass the plant had initially, the better equipped it would be to combat a phosphorus deficiency.

There were a few more surprises in the standard chlorophyll content analysis. While the distilled water treatment was expected to display the most significant effects of nutrient

deficiency, the chi-square median test indicated that there was no significant difference between the SCC of the two treatments. The only possible explanation is that the decreased chlorophyll synthesis was offset by the significant reduced growth displayed by the distilled water treatment (only about 5 g of new biomass over 4 weeks). Perhaps the biggest surprise was that the nitrogen deficient treatment displayed the highest SCC out of all three deficiency treatments. Because of nitrogen's large role in chlorophyll synthesis, the nitrogen deficient treatment was expected to at least display an SCC lower than that of the phosphorus treatment. As a matter of fact, the minus nitrogen treatment displayed a relatively large increase in SCC over the four week span while the minus phosphorus treatment's SCC decreased slightly.

A few sources of error in this experiment were possible, and did occur. Firstly, a number of the plants in the complete treatment had collapsed. After roughly a 500 percent increase in weight, the small cups that were used for planting could not support the weight of the plants and fell over. This resulted in death of many of the complete treatment plants near the end of the experiment, which could have allowed for an increase in photosynthetic activity in the other treatments due to increased light availability. Another possible issue involves the treatments all being placed together under a single light fixture. All treatments were together in the sense that they were on the same table, but each recirculator had its own light fixture over it. This could have led to error if one of the light fixtures had an issue because that bias would affect only one treatment, or at least had a far more significant effect on that treatment. One other issue with the complete treatment is that one of the recirculators ran out of water because the pump was removed from the water source. These plants died, but not due to nutrient deficiency, so their data was included in the means.

The majority of data from this experiment agrees with the results from past experimentation, but the major difference was the SCC of the distilled water treatment. Occasionally the setup of the chi square median test led to the declaration of insignificant differences between treatments due to a high level of variability, but this was not as much of an issue this year. In the future, experimentation may trend to analysis of a sort of threshold point where symptoms of nutrient deficiency appear. We simply took away all phosphorus and/or nitrogen from the treatments, but would chlorosis still occur if a plant simply had half of the typical amount of nitrogen? Another interesting experiment would be an analysis of plant/fungus or plant/bacteria mutualism. Would plants be able to completely offset the effects of nitrogen deficiency if they had other organisms to fix atmospheric nitrogen and exchange it with them? If not entirely, what is the extent to which these organisms could help limit symptoms of nutrient deficiency?

Literature Cited

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