Nutrients in *Glycine max* amidst Temperature Increase

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Abstract

This study was completed in order to evaluate the relationship between temperature and content of elements such as potassium, iron, and zinc. Soybean (*Glycine max*) seeds were grown at two temperatures, 25 and 32 degrees Celsius, and all other variables were kept constant. Plants were monitored for 30 days under constant temperatures before being tested for levels of a variety of elements by Spectrum Analytic laboratory. Notable elements which increased in content when grown in higher temperatures were nitrogen, phosphorus, and potassium. The most notable elements which decreased were iron, calcium, and manganese, along with almost all other micronutrients tested. Micronutrients are smaller quantity nutrients required for growth, as opposed to the three main macronutrients, being N, P, and K. An increase in nitrogen levels in higher temperatures was associated with a shift in almost all other elements to trend downward, especially micronutrients, a relationship affirmed by background research. As a result of this study, increased temperature was correlated to a decrease in micronutrient content. The research conducted is a testament to the need to accelerate climate change mitigation and advancements in climate and plant science in order to accommodate the needs of human biology as Earth changes. Decreases in element content of rice for example are significant considering “an estimated 600 million people would be heavily affected by these decreases” (Chen, 2018). Simultaneous decreases in multiple elements in the future, as this study supports, including iron, calcium, magnesium, boron and others, will clearly have a devastating effect on the food industry and thereby humans.

Category: Botany

Introduction

Global climate change is creating challenges with food production. Some estimate cereal crops may be decreased by 20% to 40% by 2100 due to increased surface temperatures alone (Zhu, 2018). In areas of the Earth in which crops are mass produced, an increase in temperature by only a few degrees Celsius could dramatically decrease crop yield and therefore endanger much of the food supply (Thuzar, 2010). Coupled with climate issues comes the significant issue of plant nutrition. For over 2 billion people (over a quarter of the world's population), rice is the primary food source, and supplies 25% of global calories. Recent studies link an increase in CO_2 levels to decreases in vitamins B1, B2, B5, B9, zinc, iron, and protein in rice grains. These statistics most heavily impact countries with a lower gross domestic product per capita, and are associated with protein and mineral deficiency (Zhu, 2018). Different crop types and environmental conditions should be examined in relation to plant nutrients, which will in turn impact the entire population of the world.

Iron has been the most prevalent nutritional deficiency in the United States since anemia was able to be diagnosed. Iron deficiency has become so problematic that baby and child friendly foods, such as cereal, rice, and other grains are now fortified by iron. Oxygen in the human body relies on iron-binding proteins to transport it throughout the body. Iron is stored in proteins in order to be released when necessary, an amount that directly aligns with the amount of iron taken in. Iron deficiency can result in, according to Brody, "fatigue and weakness, poor work performance, increased risk of infections, difficulty keeping warm, lightheadedness, rapid heartbeat, and shortness of breath with exercise." There are two types of iron, heme and non-heme. Heme is found in meat, poultry, and fish, and is far more easily absorbed. Non-heme iron, is found in vegetables and fortified foods. As much as 25% less non-heme iron is absorbed compared to heme iron (Brody, 2012). Decreasing iron levels poses a significant health risk, especially to countries who rely on non-heme iron to avoid iron deficiency (Brody, 2012).

Vitamin B has an important role in the human diet and a deficiency yields unwanted side effects. While anemia (an insufficient number of red blood cells) is commonly caused by vitamin B9 deficiency, there are many other factors. According to Christopher (2015), “malnutrition, malabsorption, complication or undernourishment in pregnancy, alcoholism, and medical conditions that impair vitamin retention” are some common symptoms of vitamin B9 deficiency. He also notes that those with autoimmune diseases are more often subject to vitamin retention issues. The deficiency can be corrected by increasing folic acid levels. B9 deficiency has many health effects such as megaloblastic anemia, in which red blood cells are underdeveloped but appear larger than normal, an insufficient number of white blood cells, and defects of the brain and spinal cord in developing fetuses (Christopher, 2015). According to Christopher (2015), signs and symptoms of B9 deficiency include “tiredness, premature greying, mouth ulcers, inflammation around the sides of the tongue, and stunted growth.” Anemia, the most common B9 deficiency inspired disease, is recognized by symptoms such as fatigue, a sensitive tongue, and diarrhea. All of the effects foreshadow the issues of decreasing nutrient content in rice and other foods such as soybeans (Christopher, 2015).

Zinc is considered an important element for all living organisms due to its ability to assure molecular stability in biological matters such as DNA, membranes, and ribosomes. Zinc was proven to be necessary for normal growth of animals in 1934. Production of zinc increased globally from 0.5 million metric tons to 6.1 million tons from 1900 to 1978 and continued to increase afterwards (Eisler, 2007). However, according to Eisler (2007), “Marginal deficiency of zinc in man is probably widespread and common throughout the world, including the United States.” Zinc deficiency in soil is curbed by zinc sulfate, which is also used in fungicides. In Japan, 250 tons of zinc sulfide are sprayed each year (Eisler, 2007). Zinc deficiency is a much greater issue for mammals than zinc toxicity. Zinc is used in all cell cycle stages and significantly impacts biological elements of the human body. Zinc deficiency leads to appetite loss, slow healing, incapacitated brain development, disabled immune systems, and other considerable effects. It also is linked to low birth weights and birth malformations, as well as poor survival rates in other mammals. Zinc deficiency in humans is usually related to malabsorption issues or lack of zinc fed to children. Eisler (2007) also says that, “simple nutritional deficiency due to marginal zinc intake may be common, even in the United States.” This article illustrates that a global reduction in zinc levels in food would have a substantial negative impact.

Protein is a macronutrient that works throughout the human body. Humans need it to regulate organs and tissue as well as muscle development. Legitimate protein deficiency is almost non-existent in the United States and most developed countries. However, it is a problem in countries such as Africa and Asia which are not as heavily developed as the United States. Not getting enough protein over an extended amount of time can lead to serious health effects. There are 20 total amino acids, but only 9 are considered essential (meaning your body cannot produce them). Leal (2018) states that about a billion people have an inadequate protein intake. Protein deficiency can lead to muscle wasting (after the body takes protein from muscle tissue), poor wound healing along with reduced collagen formation, and infections due to a weak immune system. In all countries, especially underdeveloped, protein deficiency would pose an enormous problem (Leal, 2018).

As identified, having a balanced diet that incorporates the required nutrients for optimal health, such as iron, zinc, and protein, is critical for our world. However, climate change and soil imbalances may make food production with the needed nutrients challenging in the near future. Further research must be conducted to understand the extent of the effects of climate change, including the way levels of elements react to environmental changes.

The demand for potassium is expected to greatly increase, particularly in emerging areas of the world where it will be used for crop growth. However, much of the potassium fertilizer placed in soil is not accessible by the plant and so high amounts of potassium must be placed in the soil. Therefore, breeding for plants that have an increased ability to gain access to this potassium with better root systems, for example, will be beneficial, especially in countries where potassium is not as readily available or not available in large quantities. Cereal crops, which include corn, rice, and wheat, require the highest amounts of potassium fertilizer. Potassium plays a key role on a crop’s ability to withstand drought, pests, and pathogens. However, current methods of analyzing potassium content in soil are inadequate and pose a risk to disparity in fertilization (Zörb, 2014). Zörb (2014) urges further research to halt diminishing soil fertility and increase the sustainability of the world’s food sources.

As Sardans & Penuelas (2015) writes, potassium has become as important as many other key elements to plant productivity. As aridity rises around the globe, potassium is becoming a staple due to its water utilization abilities. Contrary to nitrogen deposition, other issues, such as changes in land use and increasing CO_2 in the atmosphere, must be further explored. Potassium has been established as being directly linked to water economy in ecosystems. The wetter an environment is, the greater the plant's ability to absorb potassium. Therefore, the plant's ability to absorb potassium will slowly diminish as temperatures increase. Furthermore, potassium is involved in many crop functions that reduce drought stress. Potassium has become associated with many other functions such as protein synthesis, transport of amino acids, root expansion, photosynthetic activity, and defending crops against drought as well as diseases, pests, waterlogging, and other issues. Potassium, although it is required in large amounts for crop growth, is less available to farmers in poor countries which leads to potassium deficiencies is large farmlands (Africa, in particular). Socio-economic factors also lead to decreased crop productivity, for example in China and Egypt. As climate models project an increase in drought complications, the world must find sustainable solutions (Sardans, J., & Penuelas, J, 2015).

Rice farming is the largest land use for producing food, accounting for about 90% of all food produced in Asia. Rice production is one of the most important economic activities on Earth. Rice is the most important food in the diet for the largest number of people on Earth, being eaten by about half the world's population. Rice is also the largest food source for the poor and provides a quarter of global energy per capita. Rice is produced in a large variety of climates, both in precipitation and temperature. In 2009, 78% of rice was eaten by humans, a number compared to 14% for corn (Global Rice Science Partnership, 2013). There are approximately 144 million rice farms around the world, land or which 94% of (in rice area) was found in low and lower-middle income families in 2008, compared to 41% for wheat (Global Rice Science Partnership, 2013). Rice has the capability to provide vitamins, minerals, and fiber, and is often the basic ingredient of every meal, especially in low and lower-middle income families. People generally struggle with protein, vitamin, or mineral deficiency when they engage in heavy labor that demands high calorie intake. This is typically met by an increase in consumption of rice instead of a variety of nutrient dense foods. Considering the fact that rice production tripled between 1961 and 2010, a decrease in the nutritional value of rice could devastate many hard working families around the globe (Global Rice Science Partnership, 2013).

Temperature is also one of the primary factors which affects plant growth. Warmer temperatures have been shown to speed up phenological development, but not to simultaneously increase biomass or leaf area (Hatfield, 2015). Grain yield in corn was reduced by up to 80-90% in all increased temperature cases (Hatfield, 2015). These instances were antagonized by unequal distribution of water within plants. A greater understanding of the relationships between temperature and water is needed. Temperatures in the next 30-50 years are expected to increase by 2-3 degrees Celsius (Hatfield, 2015). Temperature extremes during the summer would have a large effect on plant productivity. Crops that are photosensitive, such as soybeans, would have their phenological development interrupted by temperatures. Temperature extremes also affect pollen viability and the plants ability to be fruitful. When air temperatures rise beyond a certain threshold, instead of crop yield falling at the same rate of previous temperature increase, crop yield loss significantly accelerates. Crop yield loss estimations greatly vary, but most studies do not include adaptations such as improved irrigation. Plant response to temperature is variable by species (Hatfield, 2015). Therefore, detailed research must be performed for each specific plant.

After rice, corn and soybeans are two of the most widespread crops in the world. The United States produces 38% of the global soybean supply along with 41% of the world’s corn supply (Schlenker, 2009). Schlenker (2009) portrays the effects of drastic climate change on crop growth. It was found that soybean crop yield increased with temperature up to 30 degrees Celsius but that temperatures exceeding 30 degrees greatly harmed the crops (Schlenker, 2009). Schlenker also highlights the fact that the decline of crop yield after the critical temperature threshold is a much steeper one than the incline to the critical temperature threshold leading up to the threshold. Crop yields will be dramatically decreased by the end of the century, if growing regions are kept the same. Greater heat tolerance may be possible for plants in the future since, as climate change occurs, new seed varieties, irrigation systems, and other technological adaptations will be introduced. These advancements will be necessary in order to avoid the issues discussed (Schlenker, 2009).

The soybean has become an important piece of each person's everyday life, and have been since they were grown 1,000 years ago in Asia. People typically consume soybeans without realizing it. Soybeans are high in protein and flexible in terms of their usefulness in foods. Most soybeans produced today are fed to animals, which in turn has an impact on all people who eat meat. Soy has other uses such as oil and margarine for frying and cooking, soaps, and soy is growing in usefulness for biofuel. Soy may supply about 10% of EU biofuel by 2020 according to some estimates (Thuzar, 2010). Although soy is used in much greater amounts for animal food, soy oil has a much greater economic value. Products of soy are also used in processed foods such as chocolate and baked goods. An increase in meat consumption is the main piece which fuels the rise of soybean use. For example, poultry production grew by 711% between 1967 and 2007 (Thuzar, 2010). However, soybeans are also eaten directly, mostly in countries such as Japan, where they are incorporated into products such as tofu (Soy and Its Uses, 2017). Dependence on soybeans for food has greatly increased in many countries specifically within the past 30 years. In the areas where many of these crops are currently grown, the prospect of a few degrees temperature increase would considerably decrease crop yield and therefore endanger much of the food supply. The acceptable temperature for soybean growth is 15-22 degrees Celsius at emergence, 20-25 degrees at flowering, and 15-22 degrees at maturity (Thuzar, 2010). Thuzar (2010) spotlights the need to use "policy, politic, and global cooperation" (p.177) to reduce the effects of global warming and protect our crops to sustain human life in the long term. However, concentrations of methane have increased by 150% since the industrial revolution. Global warming will put heavy restraints on crop yields in the tropics and across the world. Temperature limits a plant's ability to pollinate and therefore create food. If these issues cannot resolved, food production and availability throughout the world will dramatically decrease (Thuzar, 2010).

Corn, wheat, and rice provide the world with 60% of its food (Chen, 2018). Grains feed people iron, important B vitamins, zinc, and protein, along with carbohydrates. However, billions of metric tons of carbon are being discharged, an issue which may diminish the nutritional value of rice. In an experiment in which carbon dioxide was pumped through tubes to increase thickness, essential elements were lost. Chen (2018) says, "Iron, zinc, and protein losses ranged from 5 to 20 percent. Vitamins B1 and B5 dropped up to 30 percent, depending on variety. Folate (vitamin B9) declines across the nine rice varieties ranged from 10 percent to 45 percent." These nutritional declines have disastrous health effects on the many people who depend on rice for their diet. Chen (2018) uses Bangladesh, a poor country, as an example, citing the fact that 3 quarters of their calories come from rice. An estimated 600 million people are heavily affected by this issue. Common problems caused by a deficiency in these nutrients are established.

Although increased CO2 levels make plants grow faster, the nutrient levels do not rise at the same rate. Although some varieties of plants are better at handling new levels and maintaining nutrients, Chen says that convincing people to change to a new type of crop is not always easy. Another contributor points out that humanity could always work together to mitigate climate change as whole (Chen, 2018). One of the most concerning aspects it the fact that citizens who are limited to nutritionally deficient foods are put at risk for stunting, malaria, and diarrheal disease (Zhu, 2018).

Climate change has impacts beyond agriculture itself. Less research has been performed in terms of opportunities across the food system to mitigate climate change than in agricultural systems specifically. Climate change is set to cause issues with sea-level rise, food distribution around the world, and hazards in all of the food cycle. Climate change is expected to add 600 million more hungry people to the world by 2080, along with 24 million undernourished children. About half of these children live in sub-Saharan Africa, as poor countries are often more heavily impacted by climate change. Each category of food production has ways in which emissions could be improved. A large quantity of research has already been performed on staple crops in terms of increasing crop yield while decreasing nitrous oxide emissions. Other categories of food production are less recognized for their emissions and must be reformed. For example, food processing, refrigeration, and transportation are major contributors to greenhouse gas emissions. Public policy will be a primary factor in the attempt to reduce emissions. Currently, only a small portion of the global climate finance goes to agriculture. Changing this would go a long way to aiding the future of the food industry, which will be heavily impacted by climate change.

Problem

Climate change already is causing changes in weather and temperature which will only escalate in the future. Nutrients in crops will be impacted by increasing temperatures and decreasing water supply.

Rationale

Rice provides approximately 25% of global calories, and alongside increasing CO2 levels, is subjected to decreases in vitamins B1, B2, B5, B9, zinc, iron, and protein levels. An estimated 600 million people would be heavily impacted by these decreases (Chen, 2018). Increasing surface temperatures, which may decrease cereal crop production by up to 40% by 2100, affect plants such as *Glycine max* in a similar manner (Zhu, 2018). Given the broad impacts of food production on society, nutritional deficiency, in *Glycine max* for example, would have serious effects and a compulsory response.

Question

How does a temperature increase from 25 to 32 degrees affect levels of potassium, iron, and zinc in *Glycine max*?

Hypothesis

If temperature of the growth environment is increased from 25°C to 32°C, quantities of essential minerals in *Glycine max* including potassium, iron, and zinc will decrease.

List of Materials

I.) For plant growth:

Soybean seeds

Topsoil

Water

II.) For equipment:

70 x 50 x 13 cm plastic tub for growth

Electric LED plant grow light

Extension cord

Pitcher to measure water

Refrigerator (insulated box for controlled temperature)

Space heater with temperature control

Digital thermometer to visually check temperature

Hygrometer to check soil water content

Tape if needed to close gap between fridge door and body to help maintain temperature if necessary.

Centimeter ruler

Electric timer to turn the plant grow light on and off in 12 hour cycles

Method

1) Fill plastic tub with top soil
2) Plant 20 soybean seeds (per directions on the seed package) in tub
3) Water until the hygrometer indicates the soil is wet
4) Place tub in test environment (unplugged refrigerator) and maintain temperature to 25 degrees constantly using temperature automated space heater. The heater automatically activates and deactivated as necessary to regulate to the given temperature.
5) Keep grow light active for 12 hours a day about .3 meters away from the plants.

6) Check and record temperatures in the morning and evening of every other day -- adjusting climate using the space heater gauges as necessary to ensure consistency.
7) Water each group with 0.5 liters of water every 5 days or as needed to keep soil damp.
8) Record qualitative observations such as greenness of leaves and root complexity.
9) After 30 days, send plants to Spectrum Analytic Inc. (Spectrum) to test for levels of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, zinc, and sodium.
10) Repeats steps 1-13 in 32 degrees Celsius, after setting the new space heater temperature.
11) Compile and illustrate data

Safety

Operate space heater with care

Watch for mold growth in high-humidity environment

Data Analysis

1. Temperature data (in Celsius) will be checked on the morning and evening of every other day to ensure consistency.
2. Quantitative observations about the health of plants and roots will be made where appropriate.
3. Using the test results from Spectrum Analytics, statistics will be computed for analysis, including average, average deviation, maximum, minimum, mean, and median. Conclusions can then be drawn about the effects of temperature on such elements.
4. Create charts and graphs using Google Sheets and other tools as needed.

Results

Table 1

Temperatures-Independent	**°C**	**°C**
Growth 2 (25°C)	Morning	Evening
11/4/18	23.3	23.9
11/6/18	27.8	26.7
11/8/18	24.4	26.1
11/10/18	23.9	25.6
11/12/18	23.9	26.1
11/14/18	25.0	25.6
11/16/18	25.0	25.0
11/18/18	23.9	25.0
11/20/18	24.4	25.0
11/22/18	23.9	25.6
11/24/18	25.0	26.7
11/26/18	24.4	26.1
11/28/18	24.4	26.7
11/30/18	25.0	25.6
12/2/18	23.9	26.1
12/4/18	25.6	25.0
	393.9	410.6
	804.4	Average= 25.1

Temperatures-Independent	**°C**	**°C**
Growth 1 (32°C)	**Morning**	Evening
10/4/18	28.3	32.2
10/6/18	30.6	32.8
10/8/18	31.7	33.9
10/10/18	30.6	32.2
10/12/18	30.0	32.8
10/14/18	32.2	32.8
10/16/18	32.8	33.3
10/18/18	31.7	31.7
10/20/18	33.3	33.3
10/22/18	31.7	33.3
10/24/18	31.1	32.2
10/26/18	31.7	32.8
10/28/18	31.1	33.3
10/30/18	31.1	33.3
11/1/18	31.7	33.3
11/3/18	32.2	32.8
	501.7	526.1
	1027.8	Average= 32.1

Table 2

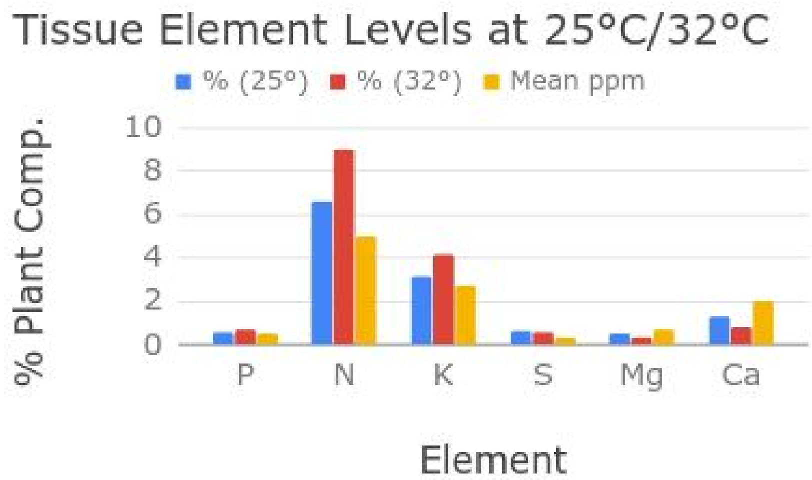
25°C

Plant Test	Plant Nutrient Level	Normal Range
Nitrogen	6.64 %	4.50 - 5.50
Phosphorus	0.61 %	0.35 - 0.75
Potassium	3.13 %	2.00 - 3.50
Calcium	1.28 %	1.50 - 2.50
Magnesium	0.55 %	0.40 - 1.00
Sulfur	0.62 %	0.20 - 0.50
Boron	64.2 ppm	20 - 50
Copper	16.2 ppm	8 - 20
Iron	4350 ppm	50 - 400
Manganese	114 ppm	20 - 100
Zinc	79 ppm	20 - 60
Sodium	1020 ppm	0 - 200

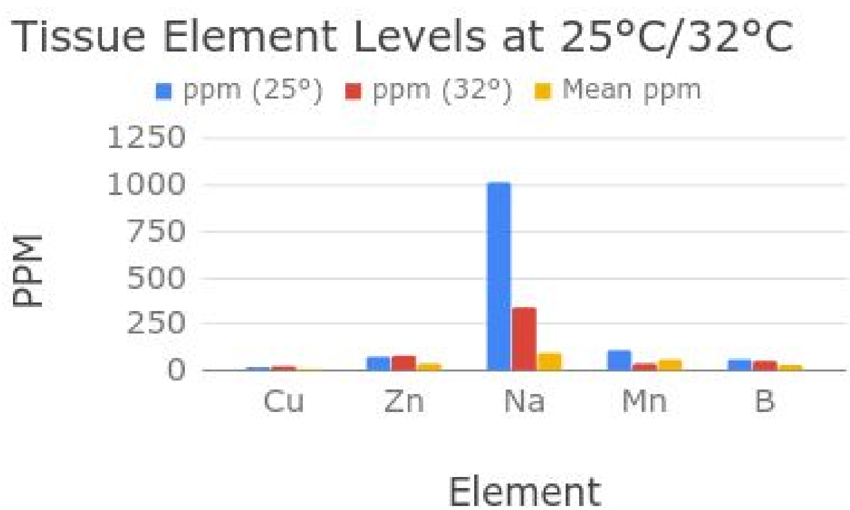
32°C

Plant Test	Plant Nutrient Level	Normal Range
Nitrogen	8.97 %	4.50 - 5.50
Phosphorus	0.69 %	0.35 - 0.75
Potassium	4.14 %	2.00 - 3.50
Calcium	0.81 %	1.50 - 2.50
Magnesium	0.35 %	0.40 - 1.00
Sulfur	0.57 %	0.20 - 0.50
Boron	54.6 ppm	20 - 50
Copper	22.9 ppm	8 - 20
Iron	499 ppm	50 - 400
Manganese	41 ppm	20 - 100
Zinc	80 ppm	20 - 60
Sodium	345 ppm	0 - 200

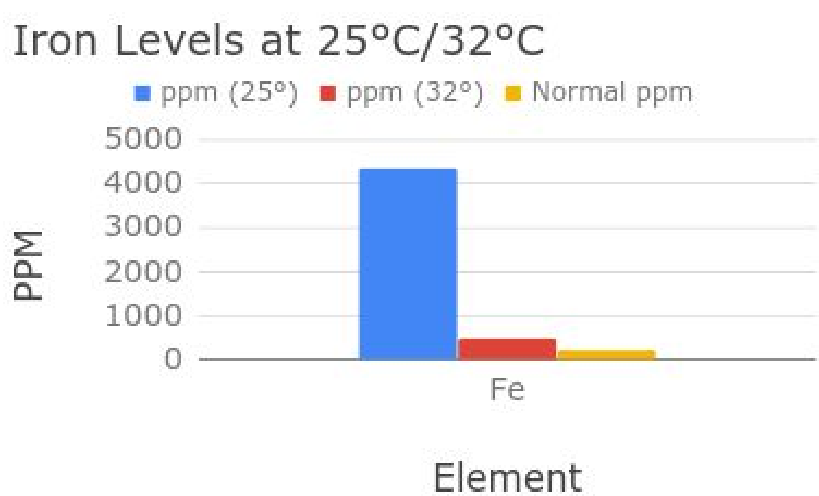
Graph 1



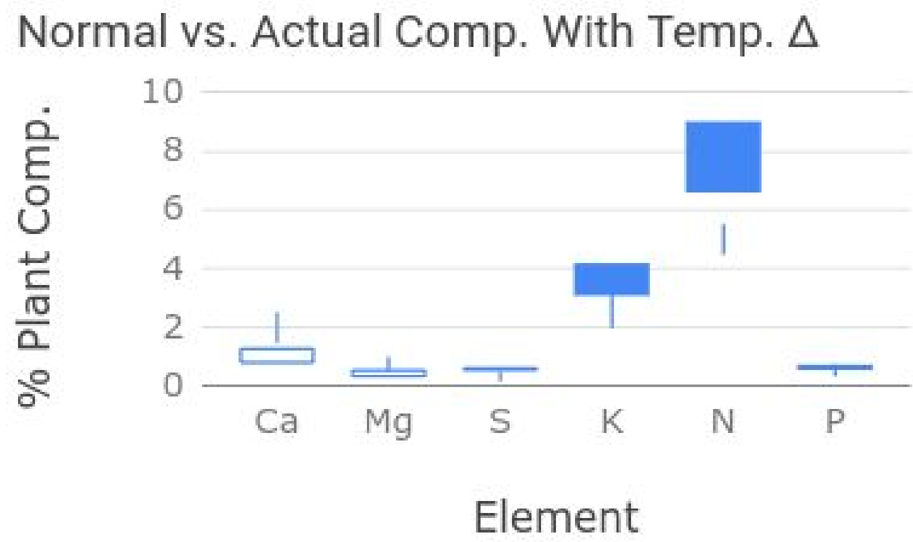
Graph 2



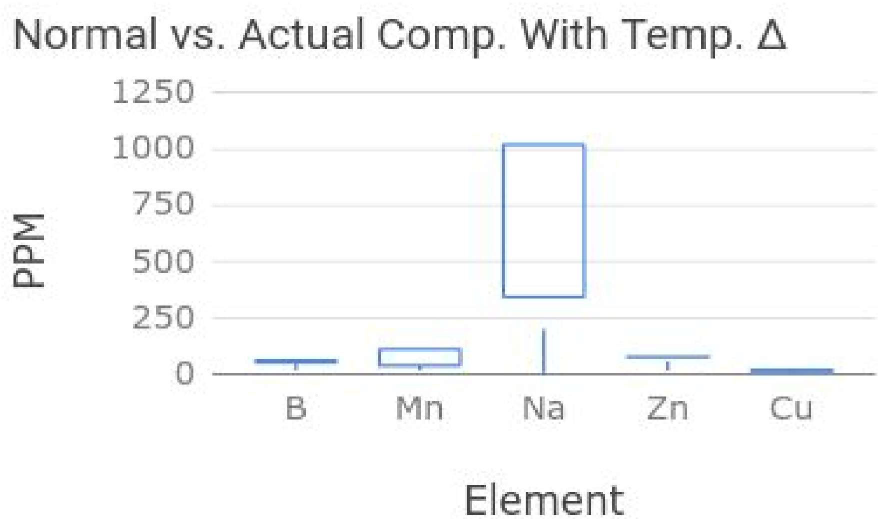
Graph 3



Graph 4



Graph 5



Graph 6

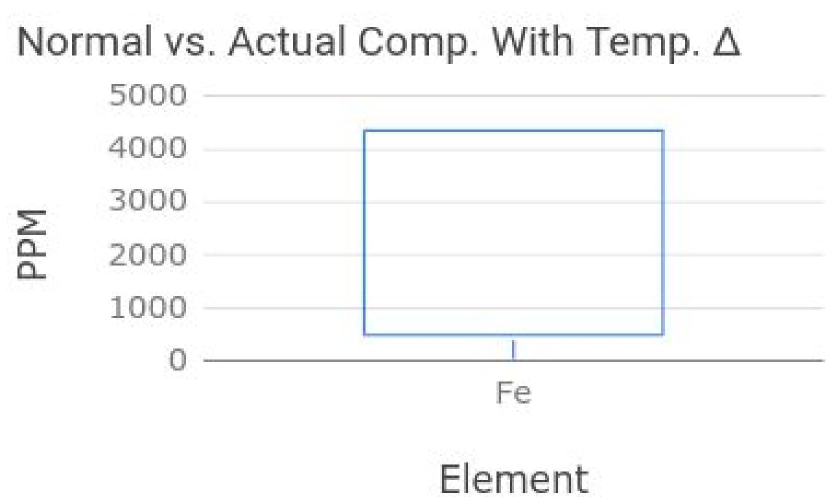
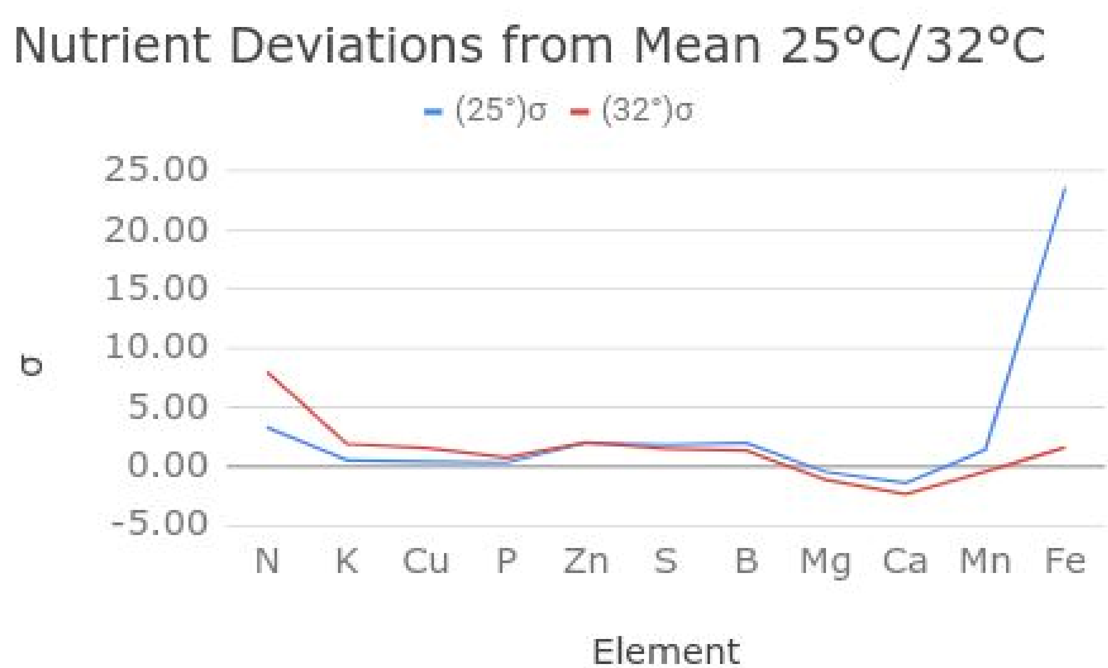


Table 3

Deviations from Mean by Element

	(25°)σ	(32°)σ
N	3.28	7.94
K	0.51	1.85
Cu	0.37	1.48
P	0.30	0.70
Zn	1.95	2.00
S	1.80	1.47
B	1.95	1.31
Mg	-0.50	-1.17
Ca	-1.44	-2.38
Mn	1.35	-0.48
Fe	23.57	1.57

Graph 7




CARROLL
25°
3 weeks
25°
3 weeks

Discussion of Results

To begin with, table 1, the figures being in chronological order, shown in the results section above, includes temperatures recorded on the morning and evening of every other day, averaged in order to compare to goal temperature for each growth. Goal temperature for each growth and achieved temperatures using the set environment were very similar. Qualitative observations during these measurements included higher levels of green at 25°C and higher yellow at 32°C. Root systems were similar in each, and full size plants were an estimated 46 cm in 25°C and 61 cm in 32°C.

Table 2 shows the initial reports from Spectrum Analytic regarding content and normal content of the listed elements. These numbers allowed for detailed analysis and graphing and are the most important initial data.

Graph 1, 2, and 3 illustrate element content in the form of bar graphs and allow for direct comparison between 25°C and 30°C growths, along with comparison to the mean content for each respective element according to extensive Spectrum Analytic database. While N,P, and K clearly increased as shown in graph 1, most other elements remained constant or showed mild to heavy decreases in content when exposed to higher temperatures as seen in graphs 1, 2, and 3.

Relationship to the mean seems to vary by element, while iron varies most heavily from the mean. Highlights of graphs 1,2, and 3, which show nutrient content at 25°C and 32°C, include the fact that a significant rise occurred in nitrogen and potassium levels in the 32°C while key elements such as iron, magnesium, manganese, calcium, and boron decreased in the higher temperatures.

Graphs 4, 5, and 6, traditionally used for stocks, overlay the normal expected values for the tested elements with the actual results. The top and bottom of the thin line represent a normal range for each respective element based on Spectrum Analytic data, while the candle (box itself) represents element content at 25°C and 32°C. 25°C is the "opening" (as in real life as temperatures increase) and 32°C is the "closing." A hollow box shows element content loss and vice versa from opening to close. The open and close values are the top and bottom of each box. For example, we see that Iron, Fe, opened above 4,000 ppm and closed below 1,000 ppm, hence the hollow box, a loss in content. Its normal range is seen below the opening and closing values.

Graphs 4, 5, and 6 illustrate a similar point to graphs 1, 2, and 3 in a different manner, while pointing out that some elements were above or below their normal range in both growths. Lab observations from the agronomist noted, however, that some elements with high levels of some elements in early growth could be expected to even out as the plants matured.

Table 3 shows centralized deviations, calculated by subtracting the mean from the actual result and dividing by one deviation of each element ($(x-\mu)/\sigma$), based on the normal range provided by Spectrum Analytic. Graph 7, which tracks deviations from 0, the mean, is based on table 3, sorted to track the greatest increase in element content with increased temperature, to the greatest decrease. These visuals allow a comparison between elements free of offset resulting from higher and lower ranges, which otherwise only allow comparison of content between a single element.

Table 3 allows for all element content in both growths to be compared on the same scale by showing their variation from the normal mean. The graph of these values, graph 7, shows the major findings of the project, including the elements that decreased and increased in content in the higher temperature in relation to the normal range for each element. The most notable elements that increased in content in higher temperatures were nitrogen and potassium. The most notable elements that decreased were iron, along with almost all micronutrients (instead of the three main macronutrients, being N, P, and K). The increase in nitrogen levels in higher temperatures, as shown in all graphs, caused the other elements to trend downward, affirming a relationship between nitrogen and the other elements tested through this report.

One anomaly in the data is that of sodium. Sodium content appears to have gone down dramatically in higher temperatures, however, on the lab report, sodium is shown as hardly decreasing in comparison to the 2nd report. For that reason, sodium was ejected from the graphs and tables, being ruled as containing error.

Conclusion

This experiment partially supports the hypothesis that if temperature of the growth environment is increased from 25°C to 32°C, quantities of essential minerals in *Glycine max* including potassium, iron, and zinc will decrease. Relationships between elements led to inverse correlations among certain element content levels. Notably, essential elements nitrogen and potassium increased in higher temperatures. While this may seem contradictory to the given hypothesis, Ujwala explains that nitrogen is known to reduce uptake of "almost all secondary and

micronutrients like calcium and magnesium iron, manganese, zinc and copper" (La Ranade-Malvi, 2011). This is especially important to the conclusion of this experiment, which shows that nitrogen content increased by the greatest amount, about 4.66 deviations, in the higher temperature growth. From that growth, almost all other related secondary element content either remained the same, or dropped significantly at 32°C. Although nitrogen may appear to increase and be a beneficial aspect of hotter temperatures, background research shows this is the cause of the decrease in other element levels.

Another factor, discussed by Hatfield & Prueger, which may contribute to lower element content in 32°C compared to 25°C is faster plant growth. This study notes that, "warm temperatures increased the rate of phenological development; however, there was no effect on leaf area or vegetative biomass compared to normal temperatures" (Hatfield & Prueger, 2015). While plants are stimulated to grow at a faster rate in the higher given temperature, nutrient content cannot keep up with this growth, meaning more biomass is not produced during phenological development (plant growth cycle) to compensate for increased growth when plants encounter raised temperatures. Ultimately there is less nourishing content in the plant when compared to a cooler growth environment. Lower content of key elements in many types of plants such as rice, soybeans, wheat, and more, has serious side effects. One study estimates "600 million people would be heavily affected by these decreases" (Zhu, 2018). Background research for this project illustrates the devastating effects deficiency in vitamins, iron, zinc, and other elements can have.

One decrease resulting from higher temperatures was manganese. This is key since "Manganese is a very important component of photosynthesis, nitrogen metabolism and nitrogen assimilation; it activates decarboxylase, dehydrogenase and oxidase enzymes" (La Ranade-Malvi, 2011). Decreases in iron levels alone can cause weakness, increased risk of infections, rapid heartbeat, and many other long term effects (Brody, 2012). When coupled with decreases in calcium, magnesium, boron and other elements, increasing temperatures will clearly have a devastating effect on the food industry and thereby humans.

Although sodium was not included in results due to inconsistencies in measurement, and the amount of decrease is not definite, it can be assumed that sodium levels decreased in the higher temperature growth. Both measurements from Spectrum Analytic show a significant drop in this element, however how great a drop is unsure and therefore no definite conclusion can be reached relating to sodium in this experiment.

Nutrients in crops will be impacted by increasing temperatures and decreasing water supply as the effects of climate change continue to escalate. Increasing temperatures alone, as represented by this project, have a significant negative impact on essential elements for plant, and thereby human, growth. Climate change action and advancements in plant science must accelerate quickly in order to accommodate the needs of human biology as climate, and thereby Earth, changes.

Recommendations

One area for which requires additional research and testing is that of sodium. Sodium requires a greater number of trials to be re-run in order to attain an accurate and consistent measurement. Although sodium was ejected from the graphs and tables for this project, being ruled as containing error, this element is key to human biology. Quantifying the toll increasing temperatures will take on content of this element in plants is necessary for future advancements, and is something that could not precisely be concluded from this project. Additionally, without the time constraints confining this experiment, this project would benefit from testing in an increased range of temperatures, above 32°C and below 25°C by 1-10°C or even greater, in order to further and more specifically quantify the effects of increased temperatures. Tests using a variety of plants such as rice, wheat, corn, and other worldly diet staples, would also be beneficial to creating an accurate forecasting of future element content in all plant life on Earth. Any expansion on this project has the potential to accelerate areas of research relating climate and plants, as well as help to compensate for future decreases in element content. Ultimately this could help save Earth and its lifeforms from many harmful effects to come.

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