Effect of Climate Change Conditions on Radish (*Raphanus raphanistrum)* Growth and its Implications on Crop Production

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Abstract

Climate change means a warmer and more unpredictable climate. The effect of higher temperature and more frequent extreme weather events on many areas of study is under evaluated. In this study we investigated these climate change situations and their effects on radish growth. We found that there is a reduced radish (*Raphanus raphanistrum)* growth in below ground structures at 26°C compared to 20°C. Also, infrequent watering also has a significant effect on below ground growth of radishes (df=44, F=9.218, p=0.00402). These results show that radishes, and potentially other root vegetables, have reduced growth when faced with certain environmental stresses, and that more research needs to be done on mitigation of climate change in agriculture.

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Introduction

Climate change is a current and long-term problem. Anthropogenic climate change effects such as heatwaves, altered transmission of disease, and extreme weather events take 150,000 human lives annually (Patz *et al.*, 2005). But it also affects humans indirectly. Global scientists predict that the global average temperature will be around 2-6°C higher than 1980-1999 global temperatures (Projections of future changes in climate (IPCC), 2007). In addition to rising temperatures, extreme weather events such as droughts, hurricanes, and tornados are likely to increase. Also, there will be a greater frequency of warm weather days and a lower frequency of cold weather days (Meehl *et al.,* 2000). These changes will likely affect plant growth.

These higher temperatures and variable precipitation patterns also lead to a larger crop vulnerability to pests and infections, and higher latitudes will be subject to these normally warmer diseases and pests (Rosenzweig *et al.,* 2001). Droughts followed by intense rains can reduce soil water absorption and increase potential for flooding, soil erosion, and nutrient runoff (Rosenzweig *et al.,* 2001). This is already evident in places in Africa, where persistent droughts have caused continuing reduction in crop yield (Rosenzweig *et al.,* 2001).

Rising temperatures also indirectly affect soil, which is a large carbon reservoir. Warming of soil would accelerate decomposition and lead to a positive feedback loop of more carbon entering the atmosphere (Davidson & Janssens 2006).

We used radishes (*Raphanus raphanistrum sativus)* as a model organism in the system we created for the experiment. Radishes are root vegetables that has a short growing season. Additionally, its below ground storage organ is most of its energy is stored (Kostka-Rick & Manning. 1993). The organ is sensitive to many environmental factors, which makes it a great indicator for various environmental stresses (Kostka-Rick & Manning.1993).

We sought to evaluate the effects of higher temperatures and intermittent drought conditions to act as a climate change scenario. We hypothesized that radishes exposed to ambient temperature and consistent daily watering are expected to have the longest belowground and aboveground length as well as the largest biomass. We expect plants with more nutrients to also have a greater aboveground and belowground mass than plants without nutrients. We expect radishes grown in climate change conditions to have an overall reduced growth.

Materials and methods:

Radish plants were exposed to 3 different variables: soil temperature, nutrients in soil, and watering regime (Fig. 1). Every individual plant was planted in a 12 oz. wax-coated paper cup. There was half an inch of aquarium rocks at the bottom and small holes in the cup to drain excess water. We filled each cup with 4 inches of Miracle-Gro® Potting Mix and planted one seed per cup half an inch below the soil surface.

A total of 8 different treatment groups were made (Fig. 1), with 12 seeds planted in each group. The treatments are numbered 1-8 for clarity and will be referred to their treatment numbers throughout the paper (Fig 1).

For treatments 2,4,6, and 8, a teaspoon of Expert Gardener® Tomato & Vegetable Garden Plant Food was mixed in with the soil. The plant food contains concentrated amounts of nitrogen, phosphate, calcium, sulfur, and other minerals. All treatments were grown in empty aquaria with overhead UV grow lights with 115+/- lux. Treatments 1,2,3 and 4 were grown with an ambient temperature of 20°C. Treatments 5,6,7, and 8 had a heating pad at 26°C placed under the plants. We chose 26°C was chosen to simulate the predicted 6°C temperature change by 2100 (Projections of future changes in climate (IPCC), 2007).

Treatments 1,2,5 and 6 were watered daily. Each plant was given 5ml of water. Treatments 3,4,7, and 8 were watered every three days to simulate intermittent drought and storm conditions that are predicted by climate change models. Each plant was given 15ml of water every three days (table 1).

We harvested the plants after 14 days of growth. We then measured the aboveground and belowground length in centimeters. We then took the wet weight of the belowground plant and aboveground plant in grams.

The aboveground and belowground mass and length of the different treatments was compared using an ANOVA test to determine if there were any differences in plant growth between differing temperature and watering regimes.

Root mass to shoot mass ratios of individual plants were calculated by dividing the below ground weight by the above ground weight and compared with an ANOVA.

Treatments with different nutrient levels were not compared due to insignificant plant data. All statistics was done in R Studio®.

Results

Most (>80%) of the seeds without additional nutrients added germinated (treatments 1,3,5,7) (Fig. 2). An average of 93.725% of seeds germinated without additional nutrients added. This is significantly different from the 18.75% of seeds that germinated when given Expert Gardener® Tomato & Vegetable Garden Plant Food (df=3.503, t=5.233, p=0.009) (Fig. 2). The two treatments at 20°C with nutrients added (treatments 2 and 4) did not have any germinated seeds and thus there are no data for those groups.

The results were not statistically significant for any aboveground length or mass data. Average aboveground mass for plants without nutrients ranged from 0.129-0.192 grams. Average aboveground length for plants without nutrients ranged from 2.74-5.60 cm.

The difference in the below ground length among treatments 1,3,5, and 7 were significant (Table 2) (Fig. 3). Belowground length of plants grown under 20°C and the belowground length of plants grown under 26°C were significantly different (df=44, F=6.491 p=0.01441). Belowground length of plants grown with daily watering and the belowground length of plants grown with intermittent drought were significantly different (df=44, F=9.218, p=0.00402) (Table 1). The way that temperature interacted with belowground length was also found to be dependent on water and vice versa (df=44, F=4.866, p=0.03266).

The difference in belowground mass between the 20°C and 26°C treatments without additional nutrients added was found to be significant (df=44, F=5.740, p=0.0209) (Fig. 4).

The root mass to shoot mass ratio of plants growing in 26°C and no nutrients added is significantly smaller in plants growing at a temperature of 20°C and no nutrients added (df=40, F=8.062, p=0.00707) (Fig. 5). The root mass to shoot mass ratio of plants growing with nutrients added was not found to be significant.

Discussion

The fact that only 18.75% of the seeds growing in additional nutrients germinated is not what we expected. Other studies show that higher levels of nitrogen in the soil lead to greater plant mass (Pell *et al.,* 1990). In terms of our study, we expected to see that the radishes growing in soil with additional nutrients to be larger in mass. One hypothesis for the low germination rate is mold. There were signs of mold growing on the paper cups when we harvested the plants. Excess nutrients may have accelerated mold growth and inhibited germination.

The data on the radishes growing without additional nutrients added show that radishes are affected by both temperature and precipitation. Specifically, belowground length and mass are reduced when growing in warmer conditions and intermittent drought conditions. Also, when radishes are stressed by warmer weather, they allocate less energy towards their belowground growth compared to their aboveground growth.

These results are troublesome considering climate change predictions. If belowground growth is stunted, these root vegetables will have less biomass and contain less nutritional value. This means that crop production of radishes will decrease unless more effort and control over crops are used. Other studies show that other root vegetables, such as carrots, are similarly affected (Idso & Kimball. 1989).

Additionally, radishes are sensitive to water, and need a consistent and frequent supply of water. As precipitation becomes less predictable, it will be harder to consistently grow radishes without irrigation systems (Wan & Kang. 2006). Radishes are a very important crop in areas in China, and climate change could lead to malnutrition and even famine.

There are some positives to climate change and its effects on crop growth. CO_2 in the atmosphere is expected to continue to rise past levels we have not seen in 50 million years (Foster *et al.*, 2017). Plant growth increases at higher CO_2 concentrations (340 vs. 640 ppm CO_2). For radish and carrot plants, this increase in growth only happens up to 24°C (Idso & Kimball. 1989). Another study shows that cotton plants in elevated CO_2 have a dry weight 2-3.5x of cotton growing in ambient CO_2 levels, but it was dependent on nitrogen nutrient levels (Wong. 1990).

Much more work needs to be done on the effect of climate change on crop production and how to mitigate those effects. More studies can be done on which plants grow best in increased temperature and CO_2 concentration. Those results can reveal to us what plants and growth mechanisms work best in these changing conditions.

Also, better management techniques must be made. For example, we have invented restorative land practices to reduce carbon depletion such as using cover crops, crop residue mulch, and sustainable management practices (Lal. 2004). Further studies can be done on improved techniques to lower soil carbon and nutrient loss. Improved irrigation systems and aquifers must be made to contain water and efficiently water crops when droughts occur.

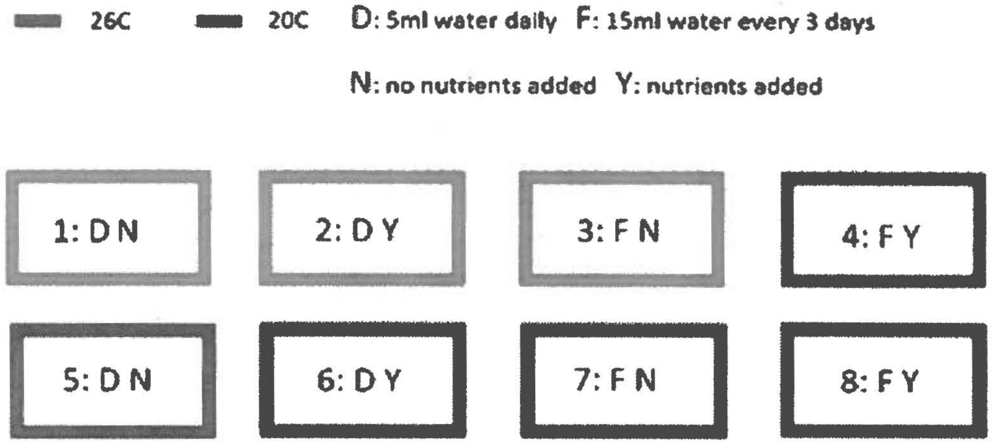

Figure 1: A key to each of the 8 different treatments for the growth of radish plants.

Table 1: The 8 different treatments and their variables for the growth of radish plants

Treatment	Temp: 20°C	Temp: 26°C	Daily Water (5mL)	Intermittent Flood (15mL)	Nutrients Added
1	X		X		
2	X		X		X
3	X			X	
4	X			X	X
5		X	X		
6		X	X		X
7		X		X	
8		X		X	X

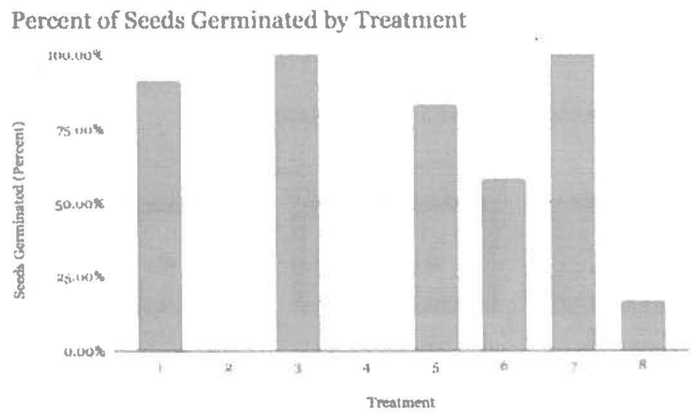

Figure 2: Percent of seeds germinated by treatment df=3.503, t=5.233, p=0.009.

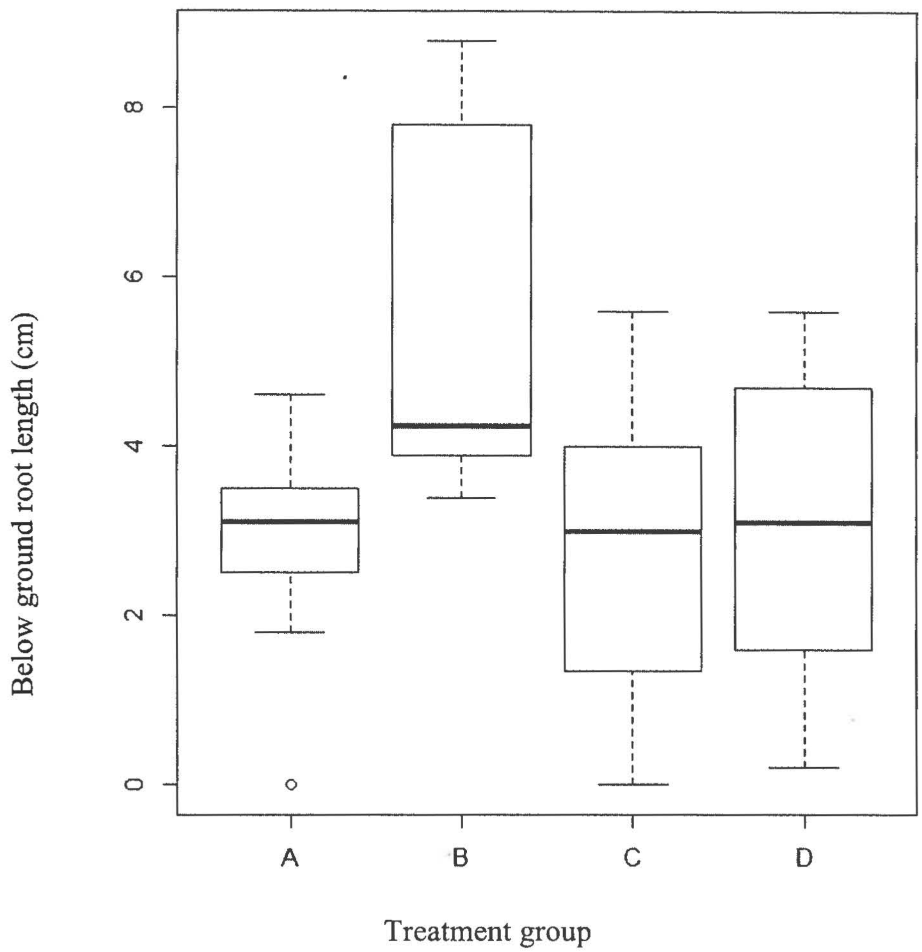

Figure 3: Below ground plant length in centimeters of the four treatments without added nutrients. A=treatment 1, B=treatment 3, C=treatment 5, D=treatment 7. df=44, F=6.491 p=0.01441

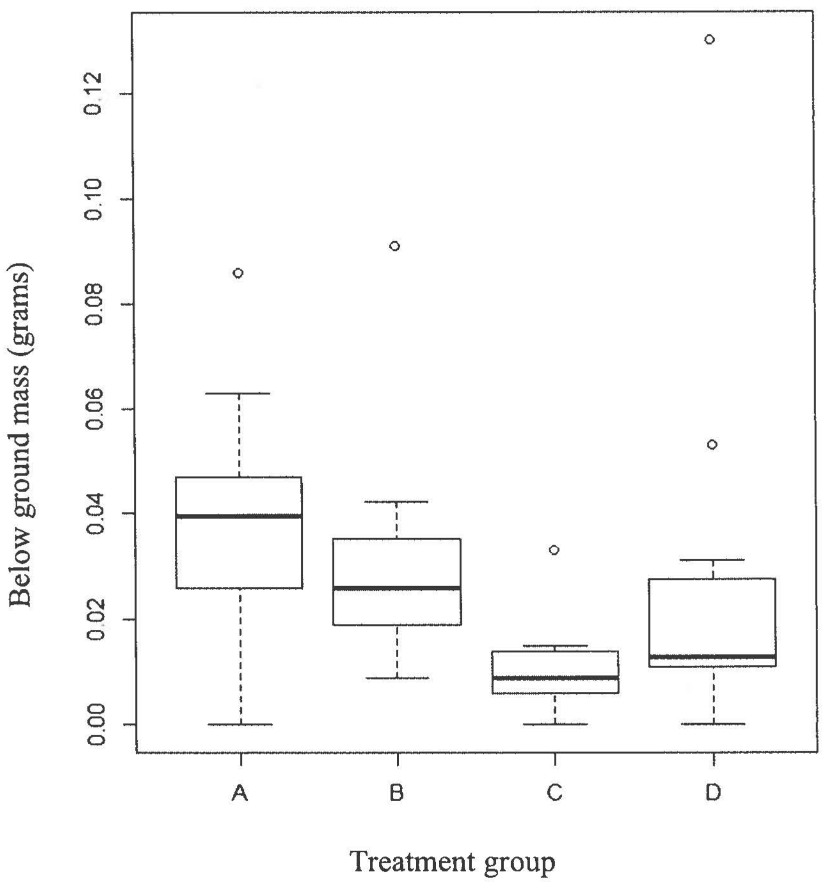

Figure 4: Below ground plant mass in grams of the four treatments without added nutrients. A=treatment 1, B=treatment 3, C=treatment 5, D=treatment 7. df=44, F=5.740, p=0.0209

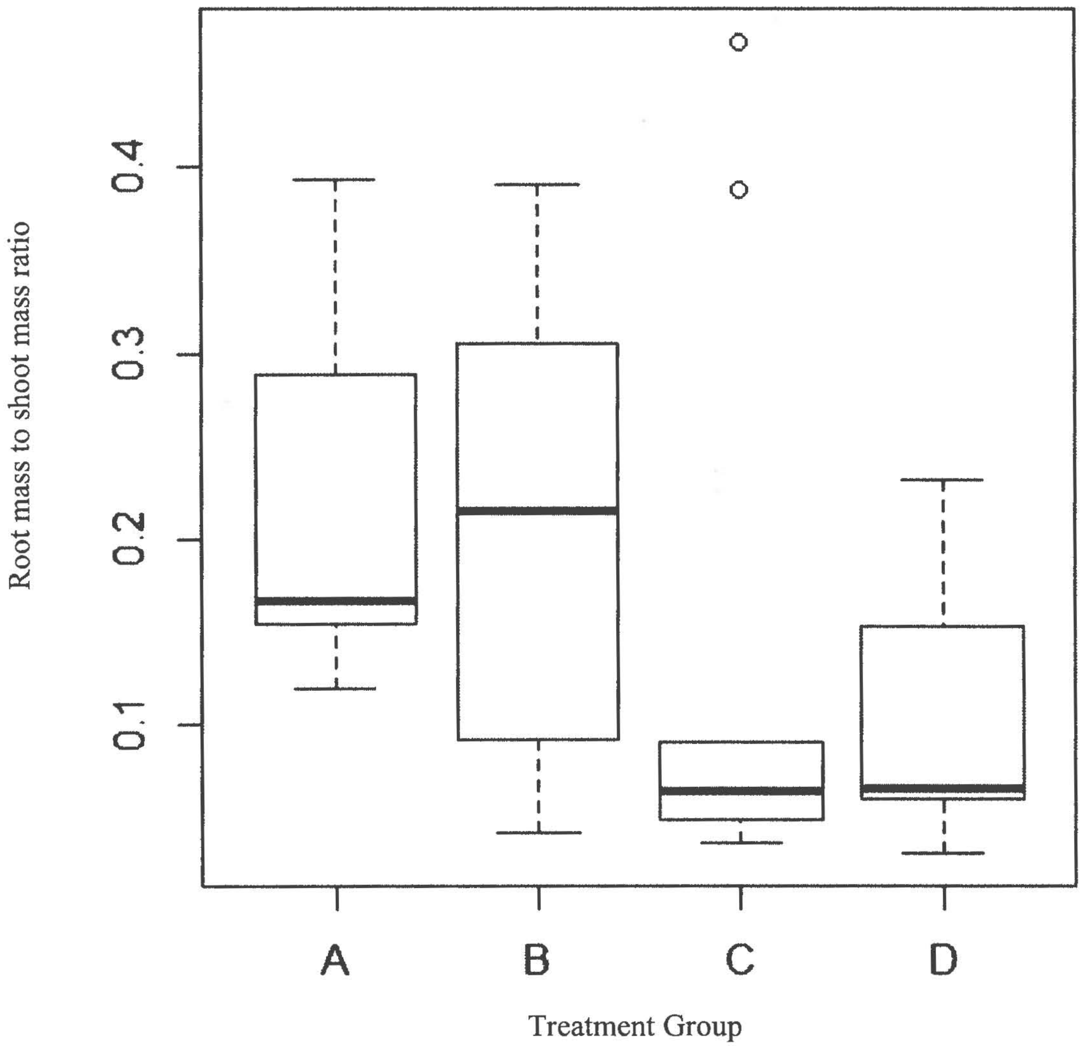

Figure 5: Root mass to shoot mass ratio of the four treatments without added nutrients. A=treatment 1, B=treatment 3, C=treatment 5, D=treatment 7. df=40, F=8.062, p=0.00707

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