# A COMPARISON OF RADISH (*RAPHANUS SATIVUS*) GROWTH IN POSSIBLE FUTURE CLIMATE CHANGE CONDITIONS AND IN CURRENT CONDITIONS

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Production yields in agricultural zones depend heavily on climate, irrigation, and nutrients. Thus, agriculture is threatened by climate change, specifically predictions of elevated soil temperatures and more erratic rainfall. Solving these potential problems depends on studying the effects of these predicted conditions, as well as how they interact with agricultural practices such as nutrient additives. We studied the impact of increased soil temperature, intermittent floods, and nutrient addition on radish growth. The radish plants were mainly impacted in their belowground growth; high temperature was linked to lower mass of the root systems. The effect of the watering regime was unclear; daily watering as well as floods increased growth in plants grown under different temperature and nutrient combinations. Additionally, higher nutrient levels lowered germination rates of the plants. These findings indicate complex relationships between climate conditions, nutrient treatments, and the plants.

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## Abstract

Production yields in agricultural zones depend heavily on climate, irrigation, and nutrients. Thus, agriculture is threatened by climate change, specifically predictions of elevated soil temperatures and more erratic rainfall. Solving these potential problems depends on studying the effects of these predicted conditions, as well as how they interact with agricultural practices such as nutrient additives. We studied the impact of increased soil temperature, intermittent floods, and nutrient addition on radish growth. The radish plants were mainly impacted in their belowground growth; high temperature was linked to lower mass of the root systems. The effect of the watering regime was unclear; daily watering as well as floods increased growth in plants grown under different temperature and nutrient combinations. Additionally, higher nutrient levels lowered germination rates of the plants. These findings indicate complex relationships between climate conditions, nutrient treatments, and the plants.

## Introduction

Climate change is predicted to cause a variety of drastic changes in worldwide weather patterns. There will be disproportionate temperature increases, torrential rains, and droughts (Rosenzweig *et al.*, 2001). Besides a general increase in temperature, higher night temperatures and higher frequency of warm days are predicted (Meehl *et al.*, 2000).

These changes are causing new agro-ecological zones to emerge, and agricultural systems must be altered to meet the current and predicted results of climate change (Norton, 2014). Specifically, the yield gaps (difference between actual crop yield and attainable crop yield of a region) of many agricultural regions are widening (Mueller et al., 2012). Narrowing these gaps will be important when facing the uncertain yields due to changing temperature and precipitation. These gaps are largely determined by climate, irrigation, and nutrients (Mueller *et al.*, 2012). Adding nutrients is a known practice in combatting these yield gaps (Baloch *et al.*, 2014). Additionally, despite advances in agricultural technology, food production is still extremely dependent on climate (Rosenzweig *et al.*, 2001). Air temperature can be used to predict soil temperature (Brown *et al.*, 2000); thus, the rising air temperature will lead to higher soil temperatures, affecting both aboveground and belowground biomasses of plants. Therefore, it is imperative to study the impact of the predicted climate change effects on the growth of food.

Radishes (*Raphanus sativus*) are a good choice for investigating the influence of climate change conditions on agricultural plants. Besides their small size, short growth period, and low minimum temperature, radishes allow easy differentiation between roots and shoot, making understanding resource allocation convenient (Kostka-Rick & Manning, 1993). Previous studies have shown that soil temperature changes affect mainly the hypocotyl (edible portion of the radish root), not the shoot (Thompson *et al.*, 1984). Additionally, it has been shown that radishes grow very well at 24°C, but growth decreases as temperature increases (Idso & Kimball, 1989), and they tend to prefer frequent and consistent watering. These factors are the opposite of predicted climate change conditions (Wan & Kang, 2005).

In this study, we investigated how increased temperatures and watering patterns affect the growth of radishes. Specifically, we were interested in the most extreme climate model which predicted a climb in average temperature of 6°C (Intergovernmental Panel on Climate Change, 2007). We were also interested in the impact of the other predicted changes, such as maintained elevated temperature overnight and extended periods of high temperature (Meehl *et al.*, 2000) The drought and intermittent flood conditions are also relevant for radishes. Because nutrients are also important in agriculture, especially as a factor in yield gaps (Mueller *et al.*, 2012), different nutrient concentrations were studied as well. In accordance with findings from previous studies, we predict higher nutrient levels will produce more aboveground and belowground biomass (Pell *et al.*, 1989). Ambient temperature of 20°C, consistent daily watering, and higher nutrients are predicted to result in the better growth of the radishes.

## Materials and Methods

### *Materials*

We used small paper cups and potting soil (MiracleGro: Potting Mix) (Table 1) to plant the individual radishes, which were store-bought seeds. Plant food (Expert Gardener: Tomato and Vegetable Garden Plant Food) (Table 2) was added to simulate high nutrient levels. Aquaria (size: 10 gallon) held the plants and growth lights were rested on top. A photometer was used to measure light output of the lights. Plant heating mats (iPower seedling heat mats) were employed to regulate temperature and a turkey baster was used to regulate watering amounts.

### *Plant Manipulation*

We planted the radish seeds on 7/26/18. The 12 ounce paper cups were filled with approximately 9 ounces with potting soil. We added a teaspoon of plant food to the treatments requiring added nutrients and mixed it in before planting. A single seed was placed in each cup

0.5 inches below the soil. There were eight treatments with 12 replicates each for a total of 96 seeds planted.

Immediately after planting, they were placed in tanks on or off the heating mat in accordance with their assigned treatment. We watered all of the seeds with 5ml of water the day they were planted to initiate germination. The plants were exposed to 12 hour light cycles during their period of growth (light from 8:00am to 8:00pm, no light 8:00pm to 8:00am). We grew the radishes form 7/26/18 to 8/6/18. Light readings were taken at the end of the growth period.

The radishes were manipulated using three variables: temperature, nutrients, and water. (Table 3). We had four treatments at 20°C and four at 26°C. The temperatures were kept constant throughout the light cycles. Within these temperatures, there were four treatments varying by nutrients and watering. One was watered daily with 5ml of water with no nutrients added, the second was watered daily with nutrients added, the third was watered every three days with 15ml of water and no nutrients, and the final treatment was watered every three days with nutrients added.

*Statistical Analysis*

The number of plants that germinated per treatment was counted. We compared treatments with added nutrients to treatments without added nutrients using a t-test in SPSS. The aboveground length (cm) and mass (g) were measured as well as the belowground length and mass of all the germinated plants.

All following analyses were run in Rstudio.

We analyzed the difference in aboveground length and mass of all of the plants in low nutrient treatments using a two-way ANOVA (variables: water regime and soil temperature). This analysis was repeated for belowground length, and belowground mass. There was no statistical analysis run on the aboveground length and mass nor on the belowground length and mass for the plants grown in high nutrient treatments.

The root to shoot mass ratio (R/S) was calculated for all germinated radishes. The ratio for plants from ambient nutrient treatments were analyzed with a two-way ANOVA. A t-test was used to compare the R/S for the plants in elevated nutrients (variable: watering regimen).

## Results

There were significantly fewer seeds that germinated in treatments with added nutrients (df=3.503, t=5.233) (Fig. 1). An average of 18.75% of seeds planted with added nutrients germinated, while an average of 93.725% of seeds germinated in the ambient nutrient treatments. Of the high nutrient treatments, only treatment 6 and 8 showed any germination.

The plants in treatment 6 had a higher average above ground length than plants in treatment 8. The same trend was seen in the aboveground mass of these treatments. No statistical analyses were run between all four high nutrient treatments on aboveground length and mass due to lack of equal variance. The impacts of watering, temperature, and the interaction between water and temperature on the aboveground masses and aboveground lengths of the ambient nutrient treatments were not significant (df=1) (Fig. 2 & Fig. 3).

For treatments in high nutrients, the belowground length and mass of plants in the treatment watered daily (6) were observably higher than those of the plants in treatment watered every 3 days (8). No statistical analyses were run due to the lack of equal variance between all four high nutrient treatments. The belowground lengths of plants in low nutrients grown in 20C (treatments 1,3) were significantly different from the from the plants grown in 26C (treatments

5,7) (df=1). Treatments 3 and 7 showed significantly different belowground lengths due to their intermittent watering when compared to treatments 1 and 5 (df=1). However, the interaction between temperature and watering did not significantly impact the growth of the radishes (df=1) (Fig. 4). The belowground mass was significantly higher in the ambient temperature treatments, but was not significant for water or the interaction between water and temperature (df=1) (Fig. 5).

There was no significant difference in the root to shoot mass ratio of the high nutrient plants (df=1) (Fig. 6). Only treatments 6 and 8 were compared, as treatments 2 and 4 did not germinate. The root to shoot mass ratio varied significantly due to temperature. The differences in the ratios were not significant by water treatment. The interaction between water and temperature also had no significant impact on the ratio (df=1) (Fig. 7).

## Discussion

Plant germination in nutrient-high soil was greatly reduced. This is contrary to previous studies that showed higher levels of nitrogen lead to more growth in radishes (Baloch *et al.,* 2014) (Pell *et al*., 1989). Additionally, studies have demonstrated that radishes do not respond strongly to nutrient extremes (Sanchez, Lockhart & Porter, 1991). However, these results indicate a significant negative impact of high nutrient levels on the plants. Further inquiry into the effects of nutrients on germination of radishes is required to explain this unexpected result.

The watering regimens and temperature difference did not impact the aboveground length and mass. The data do indicate a trend of higher nutrient treatments not having higher average aboveground mass in comparison to the low nutrient treatments. However, this was not possible to analyze statistically as the low germination rate of the high nutrient treatments eliminated a majority of the replicates.

However, the average belowground mass and length of low nutrient plants did differ in relation to watering and temperature. Radishes allocate energy to belowground growth (Thomson, Weston, & Thomas, 1984), thus the changes in belowground mass were expected. However, the treatments in higher temperatures did not demonstrate more massive roots on average, unlike in previous studies (Thomson, Weston, & Thomas, 1984) (Idso & Kimball, 1989)). While the average belowground mass was different due to temperature differences, the average belowground length differed between the two watering treatments. The treatments watered every 3 days with 15ml appeared to have plants with higher average root length. These findings refute the original hypothesis, but other findings have demonstrated that optimal growth of radishes occurs with drip irrigation every 3 days (Wan & Kang, 2005).

The radishes in the high nutrient treatments that were watered daily had higher average belowground length and mass than those watered every 3 days, which supports our initial prediction. This was not significant, however, because the number of germinated replicates was so low. Additionally, it was not possible to examine the difference in belowground growth due to soil temperature because the plants in the low temperature and high nutrients did not germinate.

The root to shoot rations of plants grown at high nutrient levels also were not significantly different due to water regimen nor to soil temperature. This could be due to the small sample size again due to the low germination rates. The radishes from low nutrient treatments grown at low soil temperature had relatively high average root to shoot ratios. This differed significantly from the average root to shoot ratio of the high soil temperature plants. While the difference in root to shoot ratio between the low and high nutrient treatments was not analyzed statistically due to the low germination of high nutrient radishes, the apparent trend indicates a higher average ratio in low nutrients. This is corroborated by previous studies that have shown that radishes have bigger roots and smaller shoots in nutrient poor soil; the plants allocate growth resources to the roots in order to take up nitrogen (Pell *et al.*, 1989).

The effect of high nutrient treatments on the radish plant growth indicates that nutrients are not a simple solution to yield gap issues. Though added nitrogen has been shown to narrow yield gaps, (Baloch *et al.*, 2014), our results indicate that their complicated interactions with plants must be investigated before they are employed as a solution.

The low biomass of the radishes in the elevated soil temperature indicates that predicted increases in temperature will negatively impact this food crop. In addition, higher soil temperatures can cause higher volumes of carbon being released from the soil. This would cause a positive feedback cycle, with carbon further increasing heat retention in the atmosphere (Davidson & Jansens, 2006). Therefore, the negative effects of elevated soil temperature on crop growth could increase exponentially. Other studies have found that higher carbon levels do relate to higher radish growth, but only up to 24°C. At higher temperatures, including the predicted 26°C, the growth decreased (Idso & Kiball, 1989).

The watering regimens require further inquiry. The difference between watering daily and flooding every 3 days was not clear. In fact, our drought conditions may have even improved the growth of the radishes, which has also been found in other studies (Wan & Kang, 2005). Future studies would require longer periods of drought to fully understand the impact of future climate change conditions on radishes and other crops.

In sum, the belowground growth of the radishes was impacted most by the changing conditions. We consume this part of the plant, and thus the response of the biomass to the conditions is particularly concerning for food yield. The possibility that this could also be the fact in other root vegetables must be investigated. Climate change is already causing the emergence of new agricultural zones (Norton, 2014). Creating new farming practices and understanding how the changes in climate impact these crops are essential if we hope to mitigate the results on agriculture and food supply.

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## Tables and Figures

| *Nutrient* | **Percent** |
|---|---|
| *Nitrogen* | 0.21 |
| *Available phosphate* | 0.11 |
| *Soluble potash* | 0.16 |

**Table 1.** The nutrient makeup of the MiracleGro: Potting Mix soil was primarily nitrogen, with small levels of available phosphate and soluble potash.

| *Nutrient* | **Percent** |
|---|---|
| *Nitrogen* | 12.00 |
| *Available phosphate* | 10.00 |
| *Soluble potash* | 5.00 |
| *Calcium* | 3.00 |
| *Magnesium* | 2.00 |
| *Sulfur* | 7.00 |
| *Iron* | 1.00 |
| *Manganese* | 0.20 |
| *Zinc* | 0.05 |

**Table 2.** The Expert Gardener: Tomato and Vegetable Garden Plant Food was used to increase nutrient levels. Specifically, nitrogen and phosphate were present in the plant food in the largest amounts. Micronutrients such as manganese and zinc were also part of the added nutrients.

| **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 |

**Table 3.** Our treatments were exposed to one of two temperatures (26°C and 20°C), one of two watering treatments (daily with 5ml or every three days with 15ml), and one of two nutrient levels (potting soil only as low or potting soil with plant food added as high). We had a total of 8 treatments.

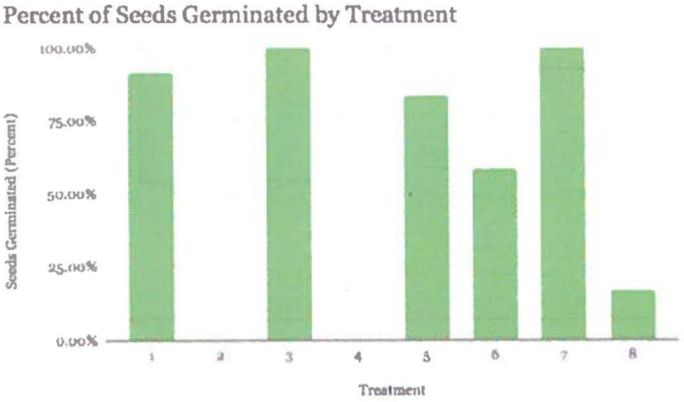

**Figure 1.** Treatments 2 and 4 were treated with high nutrients and showed no germination. The other two high nutrient treatments (6 and 8) had significantly less germination than the four low nutrient treatments (1,3,5,7). (df=3.503, t=5.233, p=0.009)

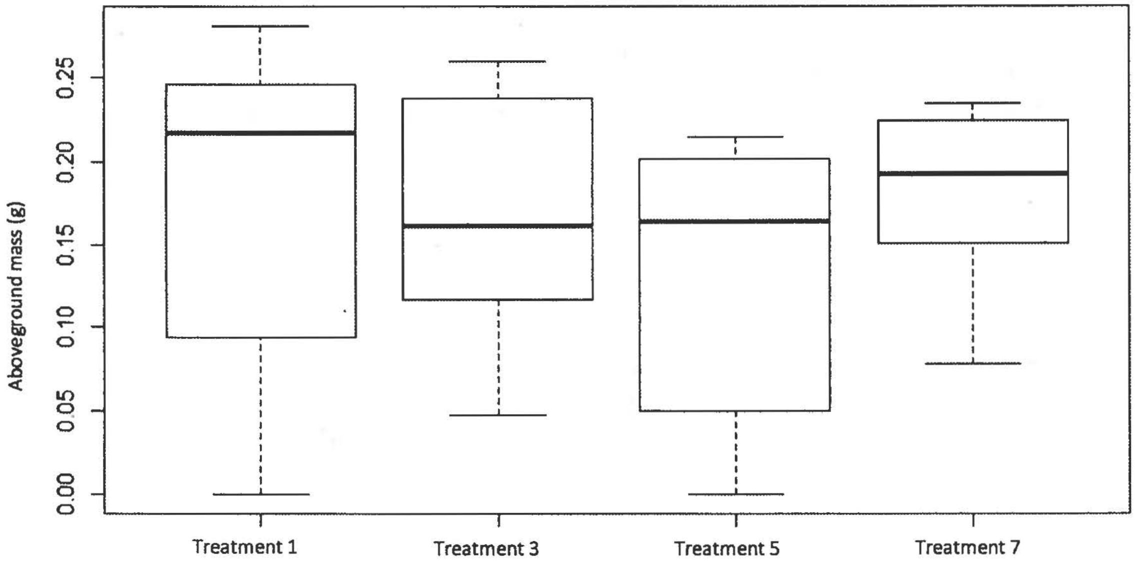

**Figure 2.** Boxplot of aboveground mass of low nutrient treatments. There was no significant difference in aboveground mass due to temperature (df=1, F=0.511, p=0.479), water (df=1, F=0.902, p=0.347), or temperature/water (df=1, F=1.538, p=0.222).

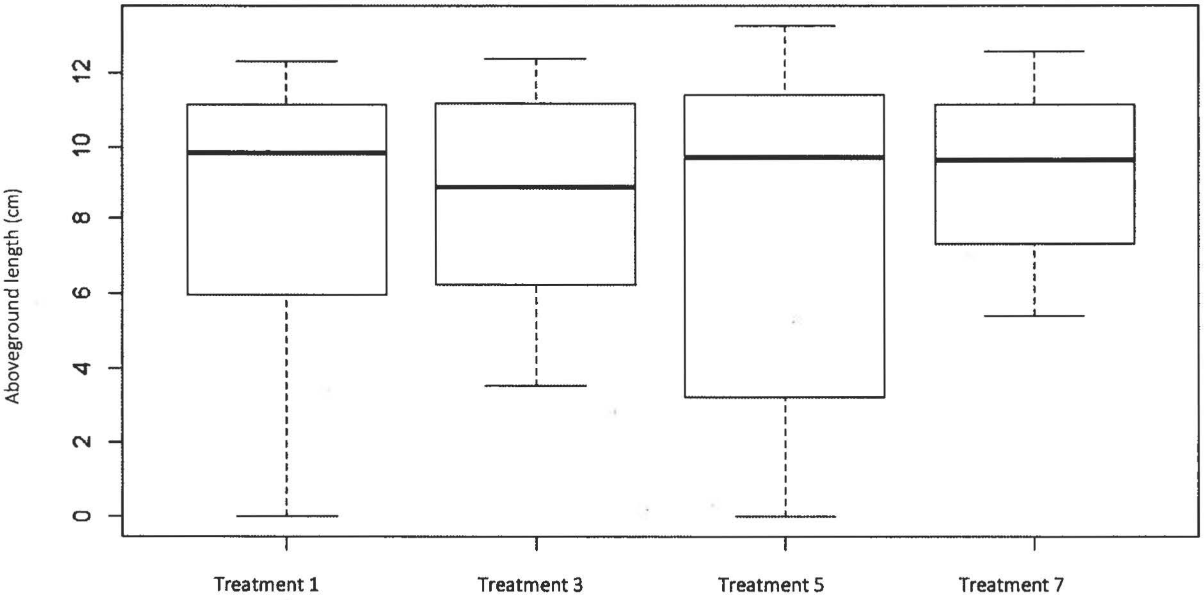

**Figure 3.** Boxplot of aboveground length for low nutrient treatments. There was no significant difference in aboveground length due to temperature (df=1, F=0.001, p=0.973), water (df=1, F=0.808, p=0.374), or temperature/water (df=1, F=0.322, p=0.573).

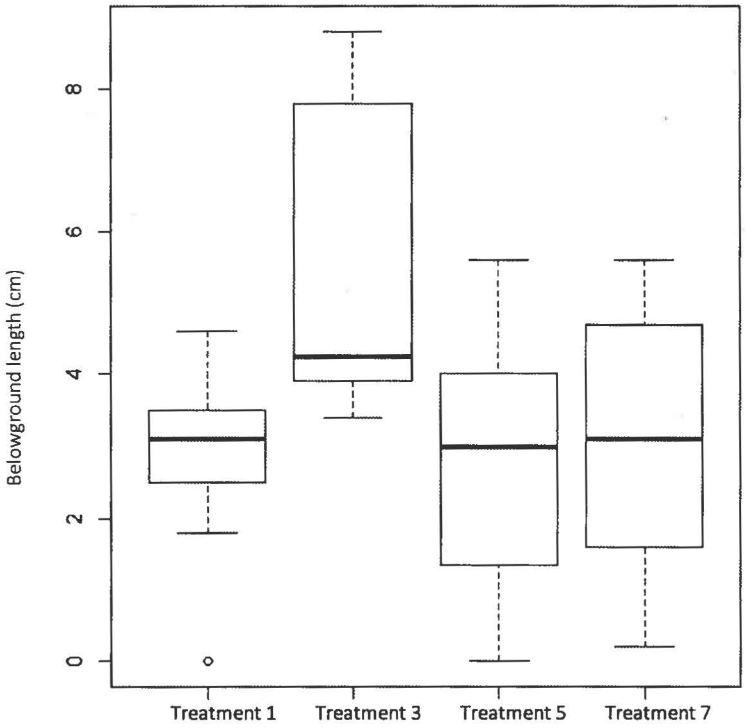

**Figure 4.** Boxplot of belowground length for treatments grown in low nutrients. The treatments differed significantly due to temperature (df=1, F=6.491, p=0.01441), water (df=1, F=9.218, p=0.00402), and the interaction between the two variables (df=1, F=4.866, p=0.03266). Treatment 3 had the highest aboveground length.

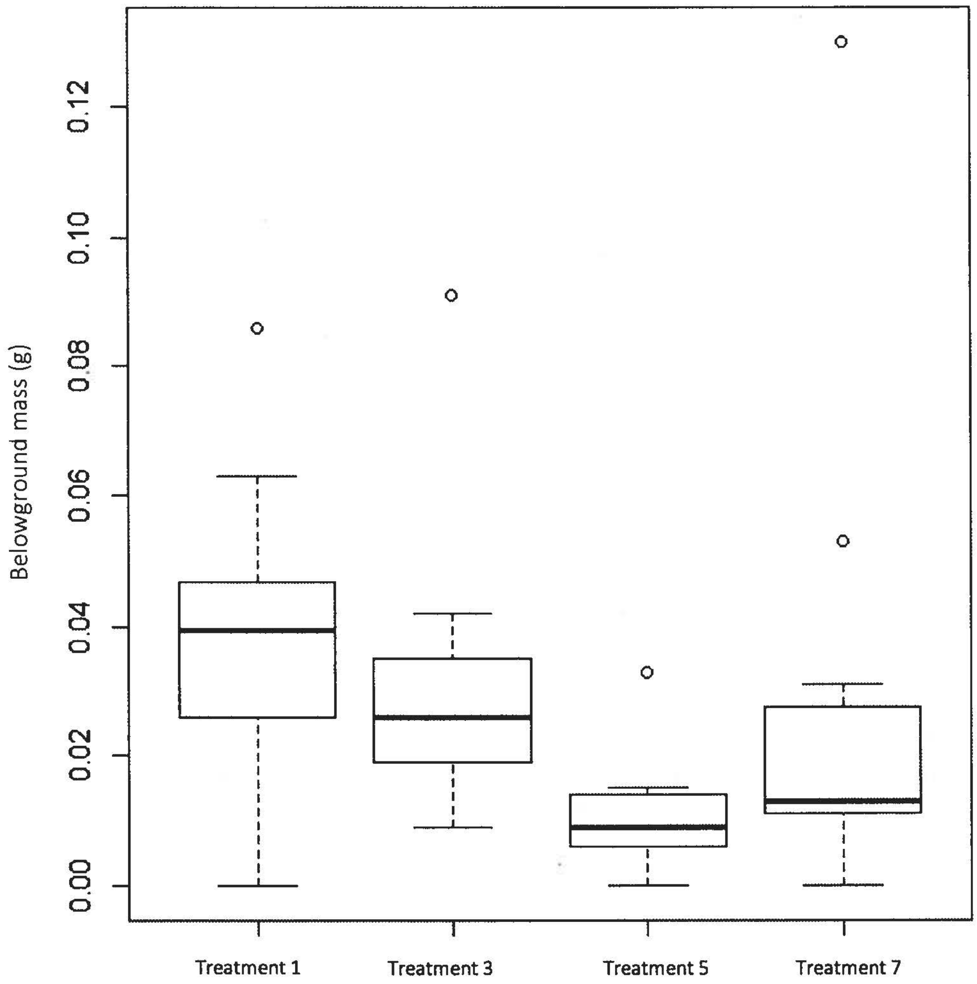

**Figure 5.** Boxplot comparing the belowground mass between low nutrient treatments. There was a significant difference in belowground mass due to temperature (df=1, F=5.74, p=0.0209). Treatment 5 had the lowest belowground mass.

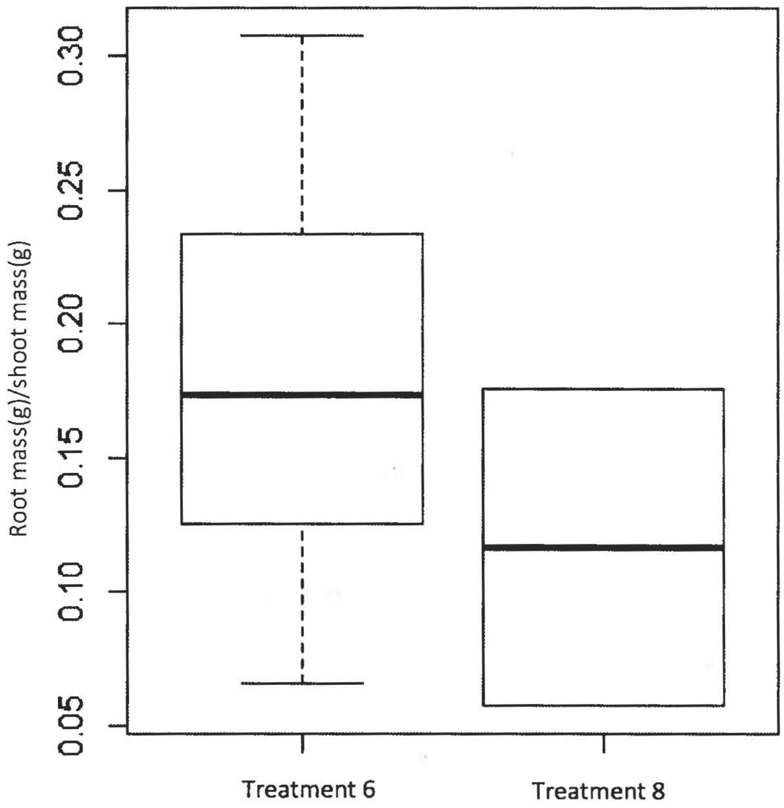

**Figure 6.** Boxplot comparing the R/S of treatment 6 and treatment 8. These treatments were grown in elevated nutrients and 26°C. There was no significant difference in the ratio due to their separate watering regimens (df=1, F=0.891, p=0.377).

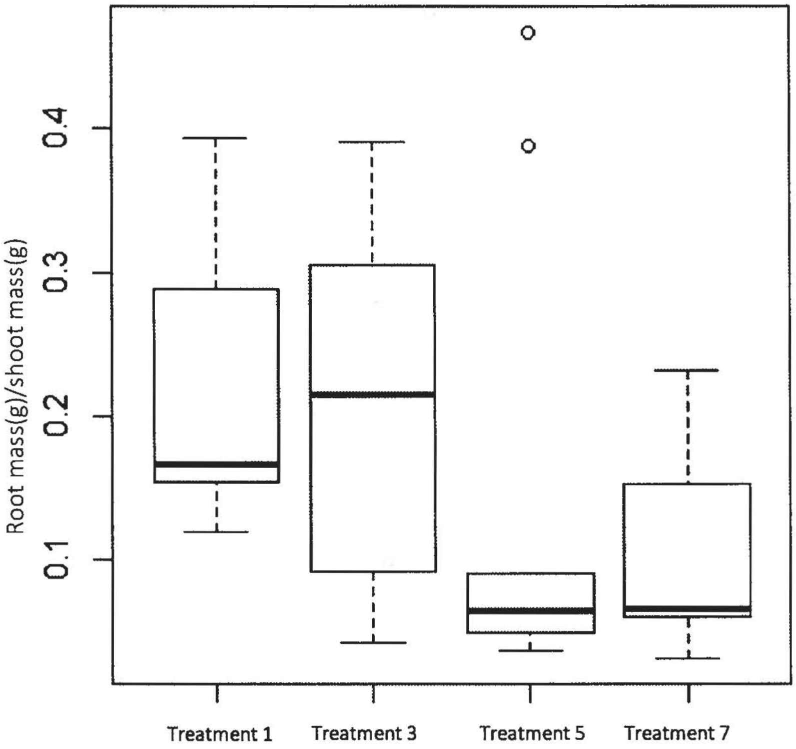

**Figure 7.** Boxplot comparing the R/S of the low nutrient treatments. There was no significant impact of water (df=1, F=0.256, p=0.616) or the interaction between water and temperature (df=1, F=0.112, p=0.74001). Temperature had the biggest impact on the difference in root to shoot ratio (df=1, F=8.062, p=0.00707).