Bean Yield and Resource Allocation in Drought and Well-Watered Conditions

UNIVERSITY of WASHINGTON

Abdullah Bhurgri, Rebal Hassouneh, Patrick Ngo, Mina Niki, Ali Haider Shah

INTRODUCTION

As static organisms, the growth and development of plants are very heavily dependent on their environmental conditions. One of the critical environmental conditions which dictate plant growth is water availability. Water content is an integral component of many plant processes, including cell expansion, photosynthesis, germination, and much more. This report analyzes the growth of many vital parts of the whole plant to focus on and characterize the difference in the development and allocation of resources in a water-stressed environment. Specifically, this report will analyze the parameter of photosynthetic activity in drought and well-watered conditions to look at variations in leaf area and root growth and their relationship to bean yield. The photosynthetic output is significant because one of the primary avenues of water loss is transpiration, in which plants open stomata to intake CO2 for carbon fixation. Therefore, in water-stressed environments, photosynthetic efficiency may play a significant role due to its ability to produce sugars needed for growth. The leaf area and root length will further help understand the plant's source and sink dynamics. Based on past research, it is hypothesized that in drought conditions, plants will allocate resources to the roots to increase water uptake while simultaneously reducing growth in leaves. The result of this is that the plant will better allocate resources to the beans as a sugar sink rather than prioritizing leaf growth.

Past literature mentions that root: shoot ratio increases under water stress to facilitate water absorption. Drought-sensitive plants were found to have a decrease in root length under water stress. Stem length decreased if plants were subjected to water stress during early growth. Reduced leaf area under water stress is also linked to decreased net photosynthesis. Drought stress reduced plant biomass when compared to well-watered. Studies have shown that well-watered condition favors plant growth and development. On the other hand, drought condition elicits adverse effects. Drought condition can be defined as a condition in which the water content of a plant and turgor are reduced enough to alter the normal physiology of the plant. According to several studies, drought condition can adversely affect the growth of weeds, alter the rate of photosynthesis in peanuts, and cause a diminished loss of nutrient acquisition in groundnut.

In this study we asked if drought can elicit decrease in some plant yield and growth but not in others. We hypothesized that in drought conditions, drought tolerant plants will allocate resources to the roots to increase water uptake whilst simultaneously reducing growth in leaves. The plant would do this via an increased photosynthetic efficiency. The result of which would be increased bean yield. This increase in bean yield will help to increase reproductive success and viability.

METHODS

PHI2 is a proxy for measuring photosynthetic efficiency where a device called Licor 6400 is used to analyze intake and output of gases within a closed environment with the plant of focus. The higher the score produced in the results means the higher photosynthetic efficiency.

Bean Yield is found through taking the reproductive units (beans) and measuring the mass as is without drying them out in grams

Leaf area was found through images of various beans lines. These images were then run through a program called ImageJ where using a scaled object can help us find the leaf area of leaves of focus. This was performed for well-watered and drought treatments

Root length images were given of both water and drought conditions for the bean lines of focus. From here, they were also inserted into ImageJ where length was found specifically in regards to depth in centimeters

With all of this data being collected, they were sorted by line and water condition, averaged (since there are multiple lines undergoing the same condition) and an ANOVA test was run to determine significance between lines and between treatment (Well Watered and Water Stressed).

OBSERVATIONS

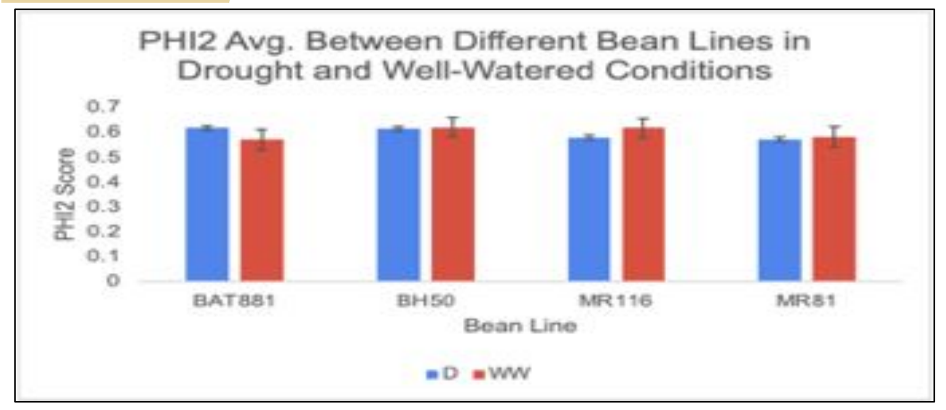

Figure #1: The PHI2 photosynthetic efficiency for various different bean lines in drought (D) and well-watered conditions (WW). ANOVA on the PHI2 efficiency as a result of the various water treatments gave P=0.55

ANOVA:

P-Value Between Bean Lines: 0.9299

P-Value Between Drought & Well-Watered Conditions: 0.5457

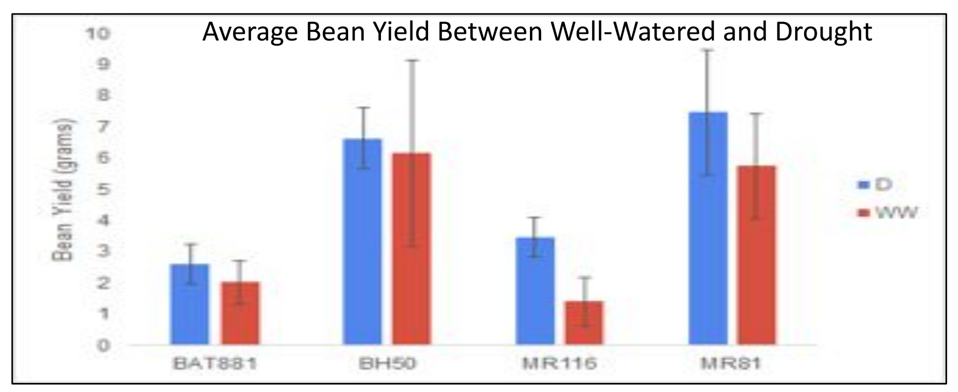

Figure #2: The average bean yield for various bean lines in well-watered(WW) and drought (D) conditions. On average bean lines showed greater yield in drought conditions. Two factor ANOVA on the treatment gave P= 0.05 for in between the water treatments on bean yield.

ANOVA:

P value: Between Bean Lines: 0.007557

P value between WW and Drought Treatments: 0.05

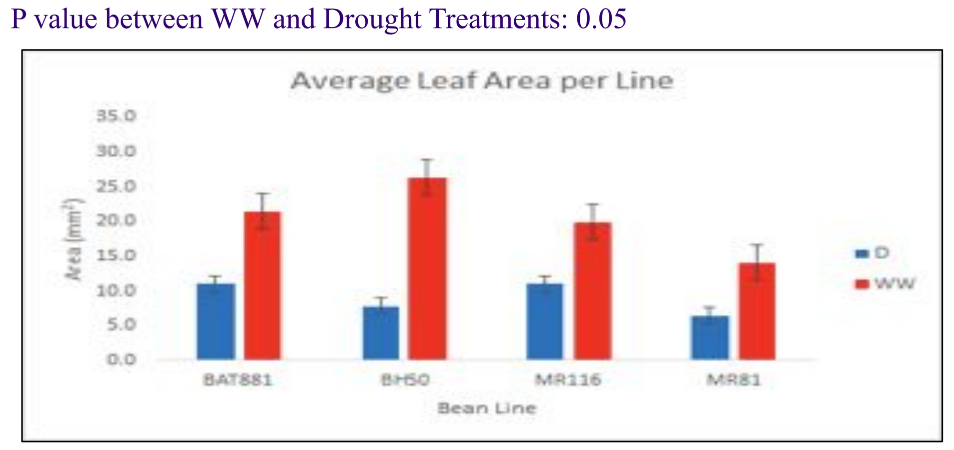

Figure 3: Average leaf area of various bean lines in Well-Watered (WW) and Drought (D) Conditions. On average the leaf area was lower in the D conditions than in WW. Two factor ANOVA on the leaf area as a product of water treatment gave P=0.02

ANOVA:

P-value between bean lines: 0.3608

P-value between WW and D: 0.019064

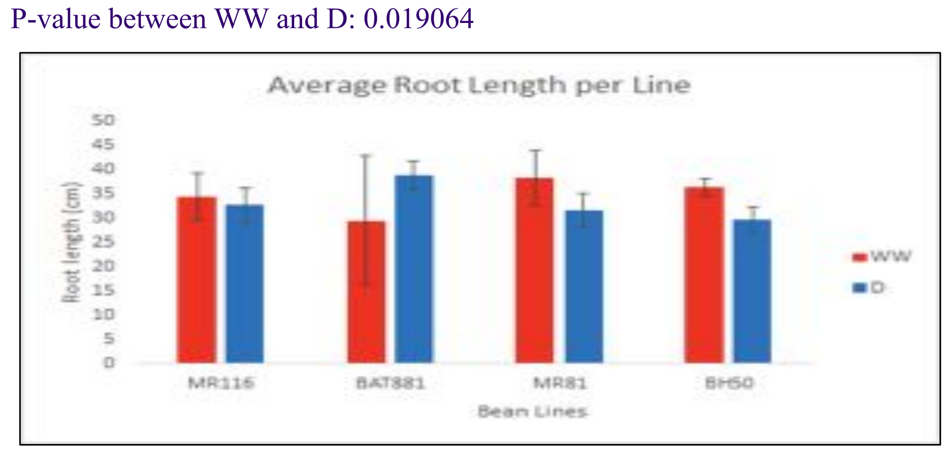

Figure 4: The average root length for various bean lines in well-watered (WW) and drought (D) conditions. The average root length was slightly higher in all but one bean line. Two factor ANOVA on root length as a product of the water treatments gave P=0.98

ANOVA:

P-value between treatments: 0.7285

P-value between lines: 0.9849

DATA ANALYSIS

Line	Treatment	Root Length (cm)/Leaf Area (cm²)	Bean Yield (g)
MR116	WW	1.73	1.415
MR116	WS	2.97	3.47
BAT881	WW	1.38	2.02
BAT881	WS	3.53	2.61
MR81	WW	2.73	5.75
MR81	WS	4.88	7.47
BH50	WW	1.38	6.17
BH50	WS	3.78	6.64

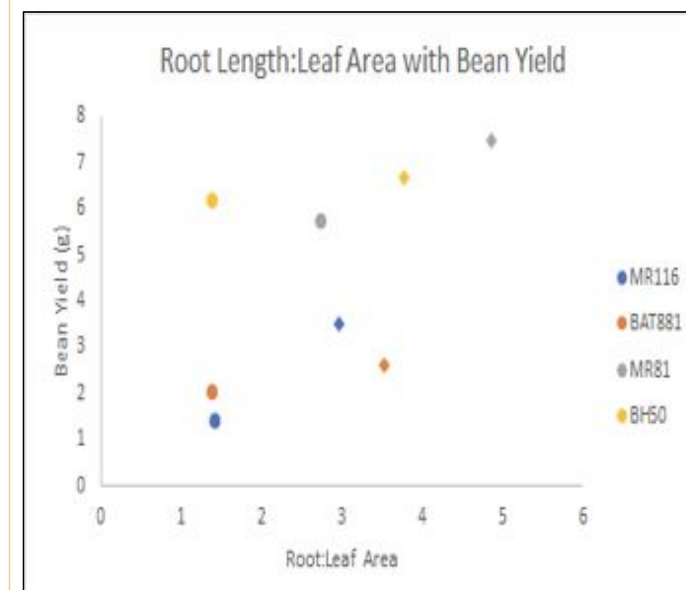

Figure 5a: The average bean yield for various different bean lines as a factor of their root length: leaf area ratio in well-watered (WW) and drought (D) conditions. On average the drought conditions showed greater proportional investment in root length over leaf area. Diamonds indicate drought treatment. Two factor ANOVA on bean yield as a factor of root length: leaf area gave P=0.000151 and Two factor ANOVA comparing root length: leaf area and water treatment on bean yield gave P=0.012

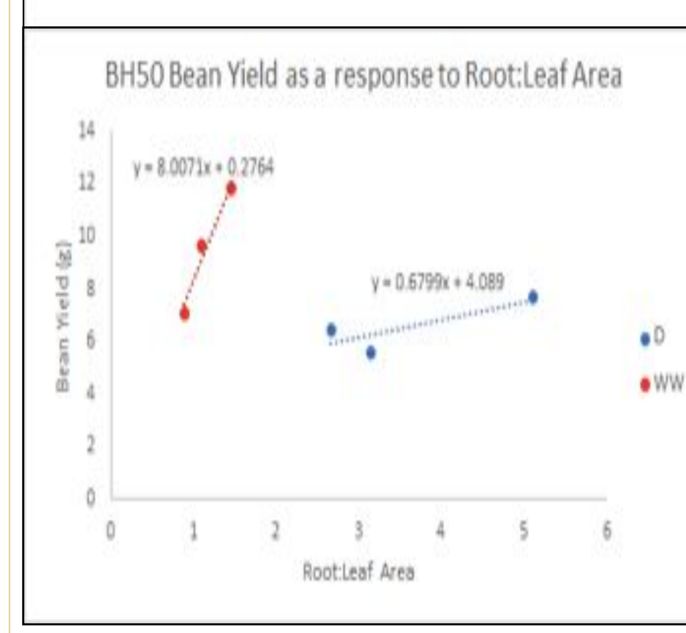

Figure 5b: The average bean yield of bean line BH50 in well watered (WW) and drought conditions (D) as a product of root length: leaf area ratio. The slope of the well-watered line is y=8.0071x + 0.2764 and the slope of the drought line is y=0.6799x +4.089

Figures 5a and 5b were designed as a culmination of all other data respectively. An increased root length to leaf area ratio can be seen to irrespective of water treatment have increased bean yield. Furthermore, when water treatment is factored in all three factors together, it shows a significant relationship with p=0.012. Interestingly enough, we can see a general trend in which in well-watered conditions is a minimal change in root length: leaf area ratio causes a much larger change in overall bean yield. However, to achieve an increase in bean yield in drought conditions, it requires a larger proportional increase in root length: leaf area ratio. Based on our previously compiled data, this seems to indicate that in a drought, the ratio increases by largely decreasing leaf area, while the root length is maintained. This experiment seems to be indicating that for plants in drought conditions resources are primarily allocated away from the leaf and diverted to the beans. Thus ensuring reproductive success by partitioning its limited resources.

CONCLUSION

This experiment was initially designed to better understand the allocation of resources within the bean plant when undergoing drought stress. In drought stress conditions a plant is limited by its water availability which in turn can impact photosynthetic rate. This is because photosynthesis in plants while the primary source of energy via carbon fixation is also the primary route of water loss. Transpiration water loss is very high during the period in which the stomata open to uptake carbon dioxide. Allocation in this system is therefore defined by limited energy reserves that the plant has access to along with deficiencies in water. In our experiment we found out that the photosynthetic efficiency itself was not significantly different between plants in well-watered (WW) and drought (D) conditions. This indicates that the plant does not increase the capacity for energy production during drought conditions. It also further supports the idea that energy would be therefore a limiting resource that must be properly allocated. When looking at allocation we primarily focused on the dynamics between the leaves and roots of the plant. We found that in drought conditions leaf area was significantly reduced while root length was insignificantly so. The final preliminary test involved looking at the bean yield as a factor of water treatment and as such the bean yield was significantly higher in drought conditions.

When all these variables are analyzed together the picture becomes clearer. In this case a higher bean yield was correlated with a higher root length: leaf area ratio in both well-watered and drought conditions. Secondary tests also indicate that looking at a single line in WW conditions the root length to leaf area ratio changing in small increments causes large changes in bean yield. For drought conditions it was vice versa where a large change in root length: leaf area causes smaller changes in bean yield. All the data together seems to indicate that this strategy would be *Drought Avoidance.* The plants allocate or maintain resources in the roots to help maintain high tissue water potential whilst also decreasing leaf area to reduce the evaporative surface available for water loss. These factors in conjunctions help the plant to maintain and even improve bean yield in drought conditions.

Beans are important agricultural crops around the world. Drought in beans has been shown to reduce the bean plant survival overall which can pose a problem for many communities which rely on it for sustenance. In totality, this experiment suggests that the mechanism which plants utilize in drought conditions is similar to our hypothesis but with a larger emphasis on allocation of available resources rather than photosynthetic energy. This better helps to understand the physiological response as it is pertinent due to global warming impacting many regions with high dependency on agricultural bean crops. Further research in the field should look at cellular mechanisms which initiate and maintain this allocation pathway. Hopefully, the culmination of which will be alleviation of agricultural stress burdened communities.

REFERENCES

Hong-Bo Shao, Li-Ye Chu, Cheruth Abdul Jaleel, Chang-Xing Zhao, Water-deficit stress-induced anatomical changes in higher plants, Comptes Rendus Biologies, Volume 331, Issue 3, 2008, Pages 215-225, ISSN 1631-0691, https://doi.org/10.1016/j.crvi.2008.01.002