Analyzing the growth of wheatgrass (*Triticum aestivum*) in an automated growth chamber

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Abstract

As computer technologies increase in performance and complexity, so do the possibilities for consumer-based solutions to complex problems. Recent advancements in technology grant individual consumers the ability to utilize automation techniques that were previously only seen in commercial applications. By taking out the possibility for human error and variability, many repetitive tasks can see an increase in efficiency and accuracy. How might this technological revolution apply to growing plants? Can one, for example, decrease germination time of a plant and increase biomass production by mitigating variability in the growth conditions? A growth chamber was designed with the needs of the specific plant in mind, and it was found that it is possible to increase biomass production of a plant through automation. After 7 days, the plant grown in the chamber was 80% taller than the control plant grown outside. These findings have large implications for designing scalable, automated solutions for better agricultural production.

Introduction

Automation is now one of the biggest industries in the world, with target customers ranging from high-complexity manufacturing to individual consumers on the basis of convenience. With the use of a cheap selection of electronics and a basic understanding of computer programming, scalable and convenient automation solutions have been achieved (Shifa, 2018). In regard to agriculture, large-scale growth chambers have been designed that grow plants exceptionally well (Katagiri, 2015). These chambers aim to grow plants under the ideal temperature, moisture, humidity, and lighting conditions needed by the respective species. Irrigation, lighting, humidity, and airflow are several factors needed to be controlled by the system. Systems controlled remotely have been designed to control environmental conditions from anywhere in the world (Grindstaff, 2019). Hagopian et al. controlled the gaseous content of a growth chamber utilizing artificial nitrogen fixation (2018). Temperature and pH levels of soil have been customized (Amelia, 2019). With such a consistent and optimal environment possible with growth chambers, plants can be grown quicker and more reliably. While some commercial growth chambers may be expensive, some researchers have found success building their own at much smaller costs (Katagiri, 2015).

Growth chambers can be efficiently designed to reduce resource-use to the bare minimum required by the plant. Automatic watering lowers the overall water consumption by limiting the amount of water dispensed based off of the moisture level of the soil and needs of the plant (Ojha, 2016). The automatic toggling of growing lights reduces energy consumption and limits the possibility of damage to the plant from over-stimulation (Katagiri, 2015). Temperature must also be precisely controlled because fluctuations can affect photosynthesis and respiratory efficiency, which may in turn affect plant growth and productivity (Whittington, 2012). Future systems will most likely be able to sense extremely small changes in environmental variables and respond accordingly (Kolapkar, 2016). Plant germination rates may also be increased from the environmental consistency made available by a growth chamber. The pairing of highly sophisticated technological systems with agriculture is called precision agriculture (Thakur, 2018). This study analyzed the possibility of decreasing germination times and increasing biomass production with the use of an automated growth chamber environment.

Materials and Methods

System control.

A small computer called a Raspberry Pi was used as the central processing unit for the growth chamber. These are credit-card-sized devices that are ideal for automation purposes because of their small profile, low energy cost, and low price (Grindstaff, 2019). A Raspberry Pi 3 Model B+ was used for this study. The growth chamber utilized a single program for all work involved.

Programming.

All automation software was written in Python utilizing Adafruit sensor packages for interfacing with the sensor suite of the growth chamber. The program (Fig. 1) checked sensors every 5 minutes and logged this data to a spreadsheet. If necessary, fans or a water pump were then activated. Making small adjustments to the growth chamber environment every 5-minute cycle conserved water, prevented overwatering, and kept fresh air moving through the system. It should be noted that at the end of the program the growth chamber activated the fans for 10 seconds. This was done to ensure that, even if the temperature or humidity were not above their thresholds, the growth chamber would

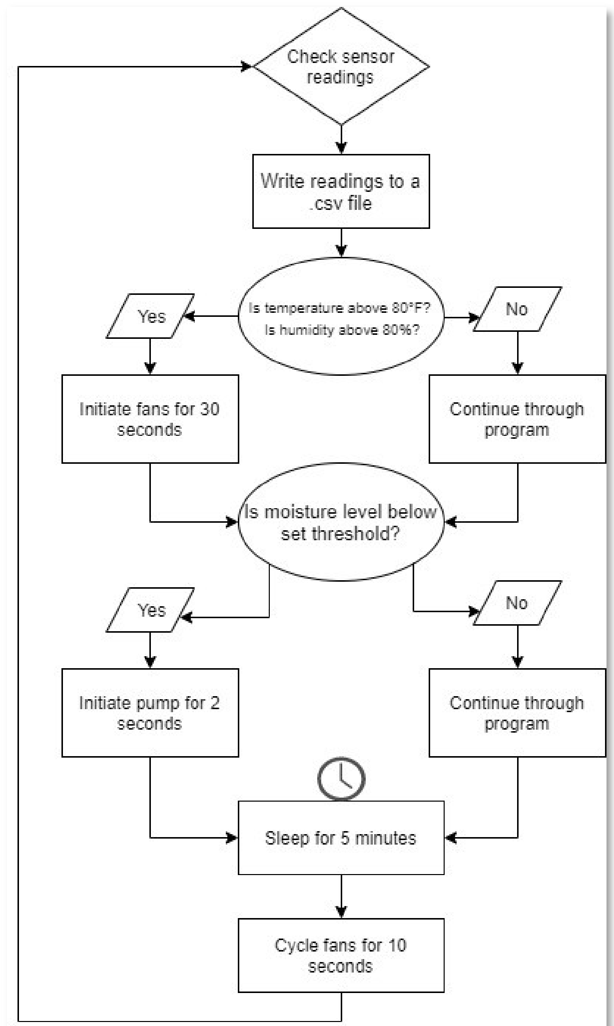

Figure 1. Logic flow of the growth chamber

still have fresh air cycling through it -- regardless of whether or not the environment needed to be corrected.

Sensors.

Two sensors were used: a DHT22 sensor was used to measure relative humidity and temperature (Fig. 2), and one YL-69 dual-prong sensor (Fig. 3) was used to measure soil moisture. Data from these sensors was read directly by the control computer.

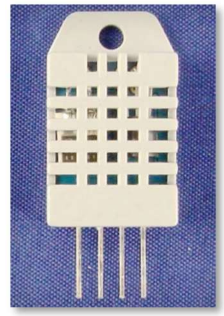

Figure 2. DHT22 sensor

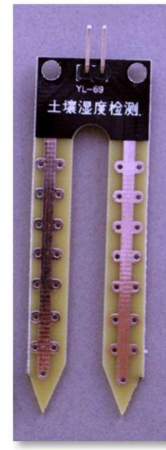

Figure 3. YL-69 sensor

The moisture sensor was capable of outputting an analog signal (0-100%) or a digital binary signal. The binary option was used for this study, and a physical dial on the sensor, called a potentiometer (Fig. 4), was adjusted manually to properly calibrate the sensor to the desired moisture threshold level.

Figure 4. YL-69 sensor potentiometer for adjusting moisture threshold

Lighting.

A 5-volt, 10 watt, dual-head LED growing light was used in conjunction with a 6-hour timer. The light had an output of 300 lumens. The LED lights emitted red and blue wavelengths of light to ensure optimal growth of the plant.

Watering.

A small 5-volt, submersible water pump (Fig. 5) was used as the watering system for the growth chamber. Vinyl tubing was attached to

Figure 5. Watering pump submerged in water reservoir

the pump and sent directly into the growth chamber, approximately 1 inch above the soil. The pump's flow rate was set to the lowest level to ensure minimal soil disruption and to avoid dislodging the sensitive roots of the young plants.

Airflow.

Two 30mm fans were used for air circulation in the growth chamber. One was placed near the floor of the growth chamber pointing inward so that it was bringing fresh air into the chamber. The other fan was placed on the lid facing outward so that hot air that had risen would be pumped out of the chamber.

Soil and propagation.

A commercial soil by the name of Miracle Gro Original Choice Potting Mix was used. One small pot of soil was placed into the growth chamber and sowed with 10 wheatgrass seeds. A control pot was also sowed with 10 seeds and placed outdoors for the duration of the experiment. The control plant was checked daily and was watered throughout the experiment as was needed to keep the soil adequately damp. After 9 days, the experimental plant was removed from the growth chamber and placed outdoors next to the control plant. Both plants were then allowed to grow in outdoor environmental conditions for 25 days. This was done to analyze the acclimatization of the growth chamber plant and to see if equalization occurred in regard to height, lushness, color and density between it and the control plant.

Growth chamber design.

The chamber frame was built of wood, and the walls were made of clear vinyl (Fig. 6). This allowed the chamber to generally assume the ambient temperature of the room it was placed in, which was airconditioned to approximately 74°F (23°C).

Figure 6.
Growth chamber during operation

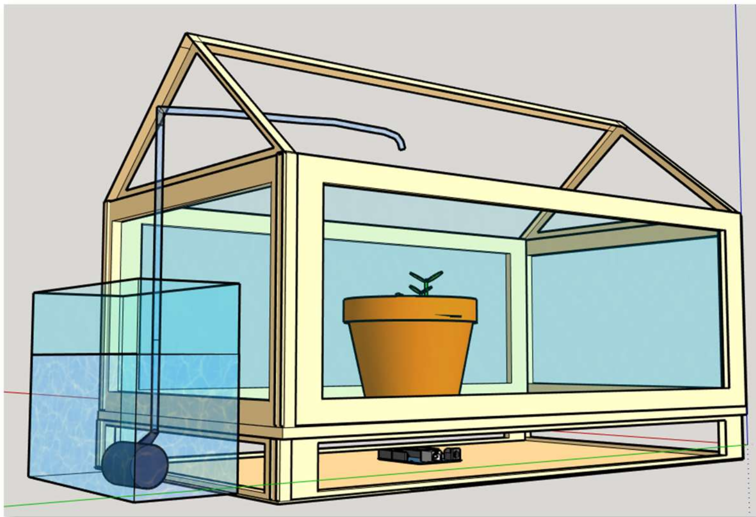

Figure 7. Computer model design of the growth chamber prior to construction

Results

Germination of the growth chamber plant (GCP) occurred one day earlier than the control plant. The GCP growth was more rapid than the control throughout the first 9 days, with both plant heights reaching a similar size after a month of growth (Table 1). The GCP was the taller plant of the two by the end of the growth chamber operational period (Fig. 8).

Table 1. Plant height with final measurement outdoors after 34-day period

	Day	Growth Chamber	Control
Plant in growth chamber	1	0 cm	0 cm
	2	0 cm	0 cm
	3	0 cm	0 cm
	4	2.5 cm	0 cm
	5	6.35 cm	0.3 cm
	6	10.8 cm	1.3 cm
	7	16.5 cm	3.2 cm
	8	20.3 cm	6.35 cm
	9	23.5 cm	10.2 cm
Plant outdoors w/ control	..	..	..
	34	26.3 cm	20.3 cm

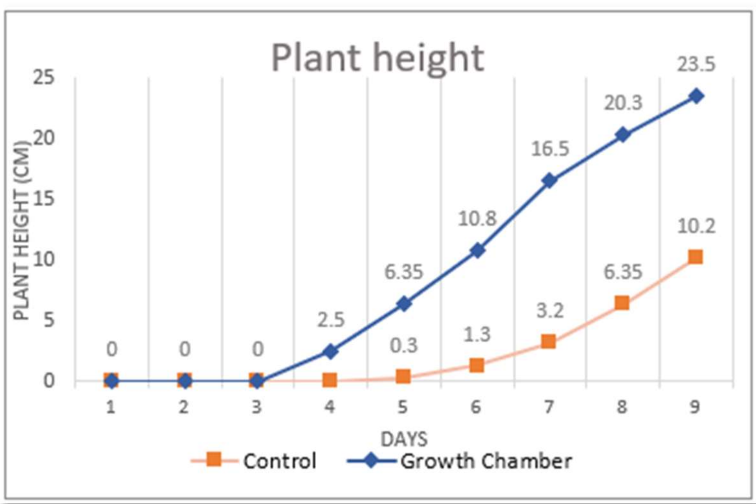

Figure 8. Plant height over the course of the first 9 days during growth chamber operation

Figure 9. Plant growth (from upper left) on the 5th, 6th, 8th, and 9th days of the study

Coloration of the two plants (Fig. 10) differed for the first few weeks of the study. The GCP was noticeably different from the control plant. However, coloration was comparable between both plants toward the end of the study after the GCP was placed outdoors with the control plant (Fig. 12).

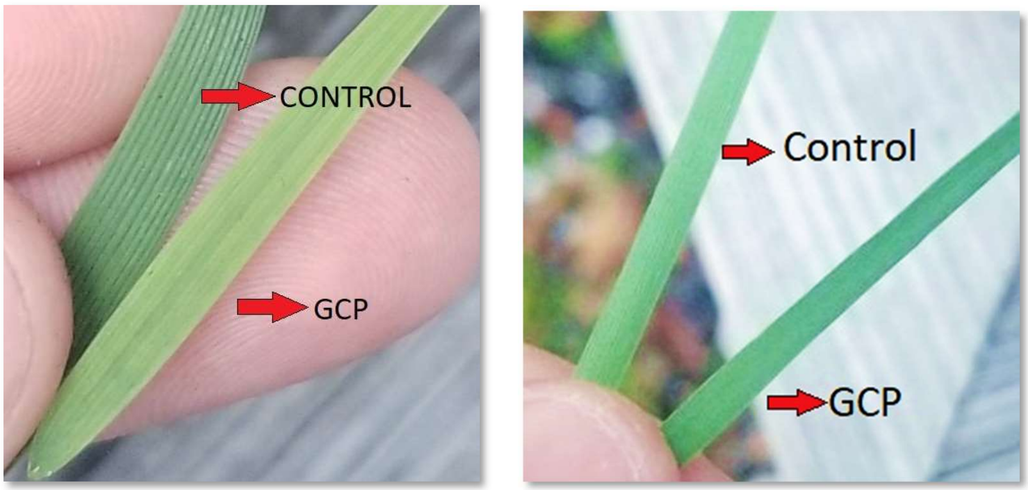

Figure 10. Plant coloration of the control plant and growth chamber plant (GCP) on day 9 (left) and day 34 (right).

Figure 11. Control (above) and growth chamber plant (GCP) (below) on day 9 of the study. Notice yellowing of GCP in comparison to control

Figure 12. Control (above) and growth chamber plant (below) on day 34 of the study.

Throughout the study, the growth chamber had an average temperature of 75.6°F (24.2°C) and an average relative humidity of 57%. Temperatures were highest during the day and lowest early in the morning. Temperature only reached threshold levels twice over the 9-day period of growth chamber operation. The growth chamber promptly responded to the levels and properly reduced the temperature and humidity levels accordingly. Temperature ranges varied more widely than anticipated, with large swings being seen in the data points as large as 12 degrees Fahrenheit.

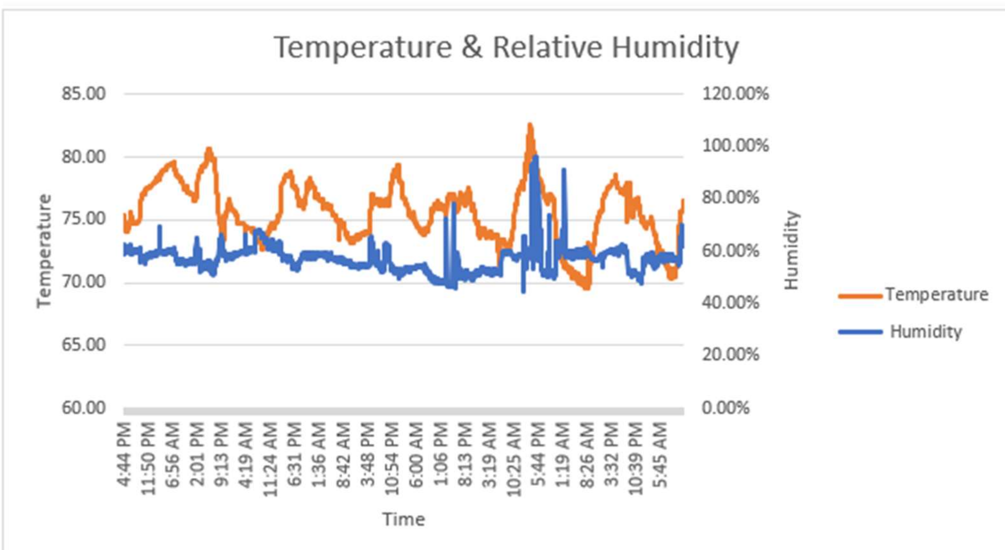

Figure 13. Temperature and humidity within the growth chamber for first 9 days

Visually and physically, the integrity of the plant stalks were not comparable through the 9-day growth chamber operation, The control had significantly stronger leaves, which did not droop or sag as obviously as the GCP. Unlike coloration, the strength of the stalks did not sufficiently equalize following acclimatization of the GCP.

On day 34 it was found that the GCP had larger leaves, but less integrity and readily sagged across the pot.

Figure 14. Control (left) and growth chamber plant (right) on day 34, the final day of the study

Discussion

The GCP germinated much faster than the control plant. On average over the first 9 days, the GCP was 81% taller than the control plant. These growth discrepancies between the two plants could be attributed to several factors. The cold night-time temperatures of the outdoors could have stifled the control plant to such a degree that growth was hampered significantly. Wind could have also played a factor in its limited growth in comparison to the GCP. However, this limitation in the initital growth probably helped the control plant focus growth on stronger stalks and chlorophyll health. The GCP was given intense, direct light for longer periods than the control was receiving sunlight. The more consistent environmental conditions of the growth chamber most assuredly aided the GCP in germinating quicker and developing faster. These findings speak to the possibility of large-scale applications in decreasing germinations times, while increasing biomass production of seedlings. The nuance of these issues speaks to the complexity of controlling ecological systems. Unforseen interactions between bacteria, fungi, improper lighting, insufficient airflow, and other factors complicate the automation processes and illustrate the overall diffiulty of designing an environment for an organism to be able to thrive in.

Once the GCP was placed outdoors, it was found to be considerably more yellow (Fig. 9) than the control. While the growing light used for the growth chamber had red and blue wavelengths of light, it lacked the other wavelengths of the light spectrum that are vital to some vitamin and chlorophyll interactions. This could possibly be why the GCP drooped considerably more than the control. However, proper acclimatization techniques and fine-tuning of the growth chamber systems could result in stronger plants that more closely match that of the control. More precise analysis of leaf and stalk structures could give more insight into what topics should be focused on to enhance plant strength (Porter, 2015).

What was not tested in this study is the production of produce and the effects of a growth chamber on those processes. However, it was found that there is indeed an increase in biomass production when using a growth chamber. It could then be assumed that, with proper technique and appropriate design of a chambered system, fruit and vegetable production could also be increased just as seedling biomass production was increased in this study.

Conclusion

This study found that controlling the environment of a plant and automating its various needs can lead to vast increasing of productivity and growth. Scaling of the methods in this study could result in large gains for food production given proper tuning of the growth chamber to the specific species of plant. Given more substantial research and thought, it could be possibly in the near future for households to have personal growth chambers for produce and herbs. This would allow individuals to grow fruits and vegetables that are out of season or difficult to grow in their climate. With the arrival of very powerful and cheap electronics, this notion is not nearly as science fiction as it might sound; it could be right around the corner.

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