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Article

Exploring unconventional growing methods to promote healthy growth in common household plants: *Tagetes patula* L. and *Lepidium sativum*

Andrew Nguyen, Ryan Nguyen, Erika Williams
Fountain Valley High School, Fountain Valley, California

SUMMARY

Chemical fertilizers have been used in increasing quantities for household gardening and commercial agriculture worldwide since their advent during the Green Revolution. Such fertilizers have detrimental impacts on the environment, contributing to nutrient runoff and aquatic dead zones. At the same time, water consumption for agricultural needs has skyrocketed. Alternative growing methods are urgently needed to reduce the impacts of plant cultivation. This study focused on finding more sustainable growing methods that reduce chemical fertilizer or water usage and can be used at the household level for garden plants. We hypothesized that the alternative growing methods would better encourage healthy plant growth as compared to a control. Several marigold (*Tagetes patula* L.) and garden cress (*Lepidium sativum*) plants were observed over a 13-week period. Metrics for healthy plant growth were height at first bloom, growing time, and survival rate. The results indicated that the treatments did not have a statistically significant effect on marigold and garden cress growth times in addition to marigold heights. However, the Deep Water Culture (DWC) treatment for garden cress plants significantly increased the height at first bloom compared to the control group. For rates of surviving plants, the treatments had little effect on garden cress, but the Eggshell Grounds, Wick System, and DWC system groups outperformed the control group for marigolds.

INTRODUCTION

During the late 20th century, a series of technological and agricultural innovations revolutionized commercial agriculture (1). Known as the Green Revolution, the era intended to increase crop productivity for higher yields and featured the application of chemical fertilizers and pesticides (1). Such chemical products have repercussions for the environment, namely increased phosphorous and nitrate concentrations from runoff (2). Excess nutrients enter bodies of water to create large algal blooms that can clog waterways and create "dead-zones," where aquatic species cannot thrive, due to the oxygen-consuming decomposition of dead algae (3).

In addition to affecting animal ecosystems, fertilizers also have the potential to directly harm humans. Chemical runoff in waterways can make its way into fish, poisoning them and the humans that consume them (3). Nitrates from fertilizers may also easily enter the groundwater, poisoning surrounding communities, and causing life-threatening diseases and conditions in humans due to the toxicity of elevated nitrate levels in the body (4). With approximately one-third of the world not having access to clean drinking water, the continued heavy application of chemical fertilizers presents an issue to human society (5).

At the same time, global water usage for agricultural purposes such as crop irrigation has skyrocketed (6). To reduce the environmental impacts of plant cultivation, alternative growing methods that reduce chemical fertilizer use and water consumption are desperately required. One alternative growing method is recycling common household wastes to provide nutrients to plants. Another alternative involves hydroponics, where plants are grown in a non-soil substrate and a nutrient reservoir system that recirculates and reuses water. A study conducted by Blok, Jackson, et al. demonstrates higher growth yields from substrate-based growing, such as hydroponics, compared to soil-based growing due to superior transport rates of water, nutrients, and oxygen (6). These alternatives lessen the demands for water and chemically produced fertilizer.

We hypothesized that the application of alternative growing methods on the common garden plants dwarf French marigolds (*Tagetes patula* L.) and garden cress (*Lepidium sativum*) would better improve plant health, as determined by plant height at first bloom, plant survival rate, and growth time, in comparison to the controls. We used common household items as sources of nutrients required by plants, which include nitrogen, phosphorus, potassium, calcium, and magnesium (7). Human urine was used as a natural fertilizer for its accessibility and high nitrogen content from its chief component, urea (8). Eggshells were another natural fertilizer used due to their calcium content via calcium carbonate. Another selected fertilizer was wood ash, which is produced from slash-and-burn agriculture and contains partially water-soluble calcium, potassium, and magnesium (9). We also selected two common hydroponic systems for this project:

Table 1. Sample size for marigolds and garden cress for the six experimental treatments.

	Control (Group 1)	*Urea Solution* (Group 2)	*Burnt Foliage* (Group 3)	*Eggshell Grounds* (Group 4)	*Wick System* (Group 5)	*DWC System* (Group 6)
Marigold	5	6	4	5	6	5
Garden Cress	6	6	6	4	6	6

wick and deep water culture (DWC). Wick systems use a wick to deliver the nutrient solution to the substrate while DWC systems partially submerge plant roots directly into the nutrient solution. The DWC system was found to significantly increase plant height at first bloom while the Eggshell Grounds, Wick System, and DWC System treatments improved the survival rate of marigolds. This experiment demonstrated how certain alternative growing methods can have beneficial effects on plant growth in terms of increasing plant height at first bloom, increasing plant survival rates, and decreasing plant growth time.

RESULTS

To understand how recycled household wastes can be applied to plants to improve plant health, we applied a urine-based urea solution (Group 2), wood ashes from burnt lawn clipping and foliage (Group 3), and finely-ground eggshells (Group 4) to seeds planted in plain soil weekly. One set of seeds had no treatments applied to serve as the control (Group 1). Similarly, to examine the effectiveness of hydroponics systems compared to plain soil, we also grew marigold and garden cress seeds in a wick-style hydroponics system (Group 5) and a Deep Water Culture system (Group 6). The plants were grown and observed to create sample sizes of at most 6 (**Table 1**). Plant growth was monitored over a 13-week period.

First, we examined the average plant height at first bloom, which was the height at which the first flower bud opened

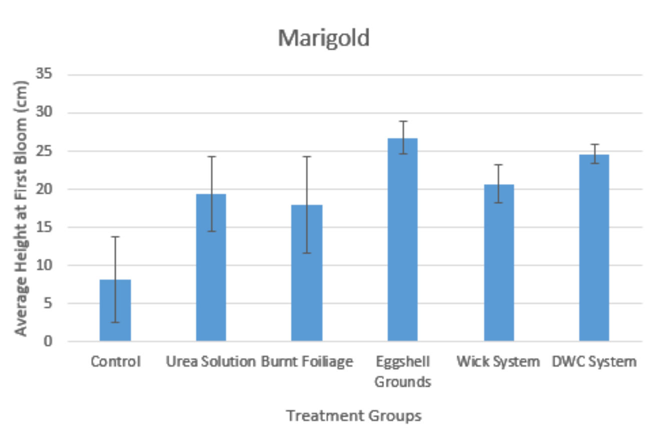
Table 2. Descriptive statistics for marigolds and garden cress for three plant health metrics.

Marigold	Average Plant Height (cm)				Average Growth Time (days)		
Treatment	Mean	Standard Deviation	Standard Error	Survival Rate	Mean	Standard Deviation	Standard Error
Control	8.10	12.67	5.67	0.40	68.50	20.51	14.50
Urea Solution	19.37	11.89	4.85	0.83	56.00	6.20	2.77
Burnt Foliage	17.95	12.56	6.28	0.75	53.00	17.32	8.66
Eggshell Grounds	26.76	4.78	2.14	1.0	57.00	10.68	4.78
Wick System	20.68	6.11	2.49	1.0	49.33	3.61	1.47
DWC System	24.60	2.82	1.26	1.0	53.00	8.00	3.58

Garden Cress	Average Plant Height (cm)				Average Growth Time (days)		
Treatment	Mean	Standard Deviation	Standard Error	Survival Rate	Mean	Standard Deviation	Standard Error
Control	10.77	2.00	0.82	1.0	33.33	2.07	0.85
Urea Solution	5.98	3.55	1.45	0.83	34.00	2.65	1.19
Burnt Foliage	8.15	4.37	1.78	0.83	41.20	15.96	7.14
Eggshell Grounds	10.28	1.29	0.65	1.0	40.25	2.63	1.32
Wick System	11.75	6.67	2.72	0.83	32.80	4.92	2.20
DWC System	25.50	4.59	1.87	1.0	26.67	5.13	2.09

completely measured from the base of the stem to the tallest point of the plant. For the marigolds, there was variation in average plant height, but no statistical significance between the six treatments (p = 0.058) (**Table 2, Figure 1**). For the garden cress, there was variation in average plant height at first bloom as well. Plant height was significantly higher in Group 6 (20.25 cm ± 1.87 cm) while lowest in Group 2 (5.98 cm ± 1.45 cm) (p-value < 0.05, one-way ANOVA) (**Table 2, Figure 1**). A post hoc Tukey-Kramer test with treated garden cress groups compared to the control revealed statistical significance only for the DWC treatment.

The effect of each treatment on the survival of each plant was also assessed. At the end of the 13-week experiment, the plant survival rate was calculated by dividing the number of plants continuing to grow after the first bloom by the number of plants that sprouted. The control group for marigolds had the lowest proportion of surviving plants, 0.4 growing/sprouted (2 plants), while the Eggshell Grounds, Wick System, and DWC System groups had the highest proportion of plant survival, 1.0 growing/sprouted (5 or 6 plants) (**Table 2, Figure 2**). For garden cress, every treatment group had roughly equal ratios



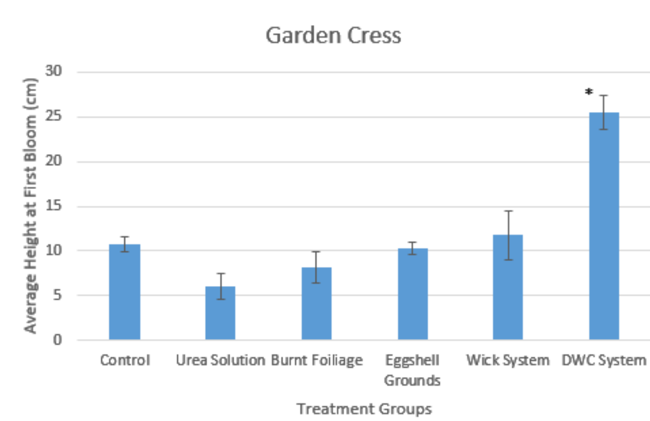


Figure 1. Average plant height at first bloom. The average height (cm) at first bloom for marigolds (left) and garden cress (right). Plant heights were measured for six experimental groups: Control (n = 5), Urea Solution (n = 6), Burnt Foliage (n = 4), Eggshell Grounds (n = 5), Wick System (n = 6), and DWC System (n = 6). Error bars represent one standard error above and below the mean. An asterisk (*) represents statistical significance p < 0.05, one-way ANOVA with post hoc Tukey-Kramer test.

of plant survival. The Urea Solution, Burnt Foliage, and Wick System groups had a survival ratio of 0.83 growing/sprouted (5 plants) while the Control, Eggshell Grounds, and DWC System groups had a ratio of 1.0 growing/sprouted (6 plants) (**Table 2, Figure 2**).

The average growth time, defined as the number of days the average plant took to bloom from the time of sprouting, was also assessed for each treatment. For the marigolds, there were no statistically significant differences between the average growth times for all six treatments ($p = 0.077$) (**Table 2, Figure 3**). For the garden cress, there was a statistically significant difference in average growth time between treatments (p-value < 0.05, one-way ANOVA) (**Table 2, Figure 3**). However, follow-up post hoc Tukey-Kramer tests between the control and other treatments revealed no statistical significance.

We also evaluated qualitative observations in both plant varieties. Starting on day 82 of experimentation, marigolds in the Urea Solution, Burnt Foliage, and Eggshell Grounds Groups developed a purple color around the edges and tips of their lower leaves (**Figure 4**). There were no significant qualitative changes in any treatment groups of the garden cress plants.

DISCUSSION

Select growing methods from this study encouraged healthy plant growth, as shown by them yielding taller plants at first bloom, increasing survival rates, and decreasing growth times. The initial hypothesis was correct in some respects. This study demonstrated that simple, more environmentally conscious growing methods that can be applied to household gardens, using common objects often overlooked in the house to reduce chemical fertilizer usage as well as using water-efficient hydroponic systems to reduce water consumption.

This study revealed that growing garden cress with a DWC

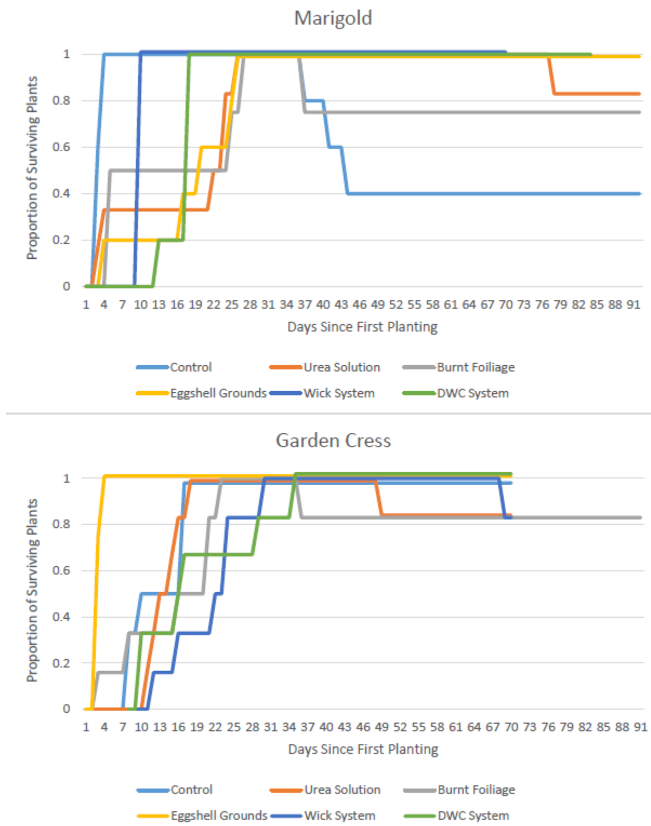


Figure 2. Plant survival rates. Survival rate of marigolds (top) and garden cress (bottom). The survival rate (growing/sprouted) was calculated for six experimental groups: Control (light blue), Urea Solution (orange), Burnt Foliage (gray), Eggshell Grounds (yellow), Wick System (dark blue), and DWC System (green). Lines that stop abruptly indicate the point at which only qualitative observations on the group were made.

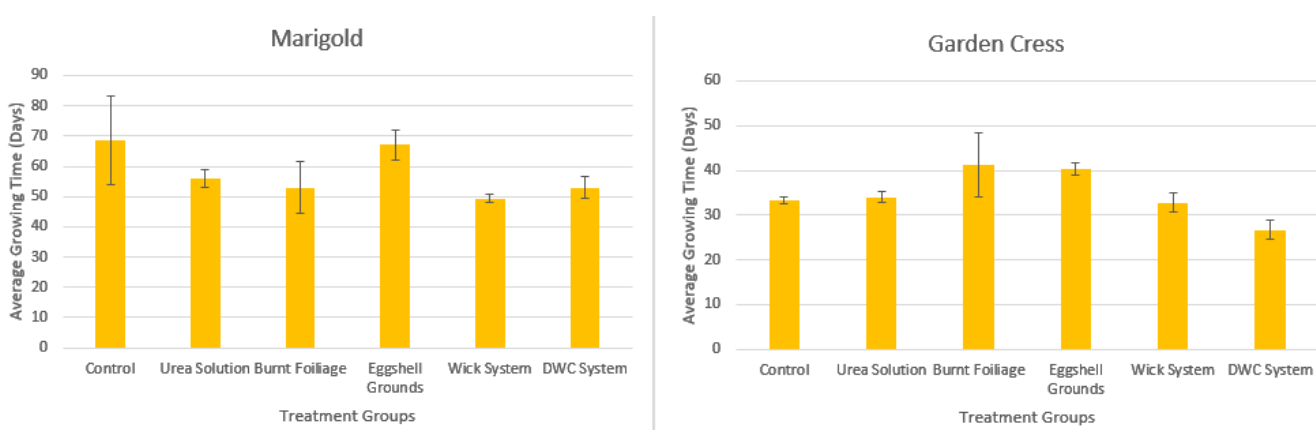


Figure 3. Plant average growth time. Average growth time (days) for marigolds (left) and garden cress (right). Growth times were measured for six experimental groups: Control (n = 6), Urea Solution (n = 6), Burnt Foliage (n = 6), Eggshell Grounds (n = 4), Wick System (n = 6), and DWC System (n = 6). Plants that died during the experiment or never bloomed were not included. Error bars represent one standard error above and below the mean. There was no statistical significance between groups, finding $p > 0.05$, one-way ANOVA with post hoc Tukey-Kramer test.

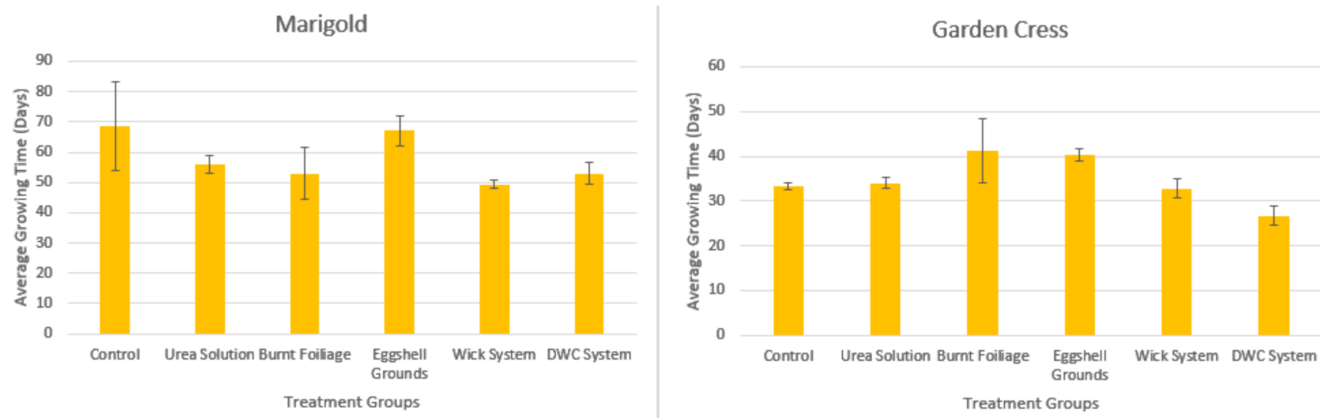


Figure 4. Representative photograph of the marigold plants with lower leaves that acquired a purple color. Certain marigold plants in the Urea Solution, Burnt Foliage, and Eggshell Grounds groups developed a purple hue around the edges and tips of leaves lowest on their stems. Marigolds in the Urea Solution (left) and Burnt Foliage (right) groups are shown.

hydroponics system increased garden cress height at first bloom at a statistically significant level compared to the control group, indicating its success in encouraging healthy plant growth. Taller plants, as compared to short plants, indicate the presence of critical nutrients and minerals required for healthy plant growth. However, the selected growing methods applied to marigolds did not result in significantly different plant heights at first bloom. This is despite the Eggshell Grounds group having the highest average plant height at first bloom, implying a possible lack in statistical power. Had there been more marigolds grown and observed, the results for marigold plant height at first bloom might have been significant as power can be increased with a greater sample size.

The experiment also indicated that plant growth time was affected for only garden cress, though there was no significant difference between the control and other treatments. Longer growth times would indicate slower growth due to a lack of nutrients, which is consistent with the findings (10). The lowest average growth time for garden cress came from the DWC treatment while the higher average growth times came from the in-ground treatments and control, which had fewer supplied nutrients. Shorter growth times would indicate heathy plant growth due to the presence of necessary nutrients. For marigolds, there was no meaningful difference between average growth times for all the treatments, demonstrating a difference in treatment efficacy based on plant types.

The discrepancy between the ANOVA results, which found statistical significance between the garden cress groups for growth time, and the post hoc Tukey-Kramer test, which found no statistical significance between the control and other treatments, is likely due to a lack of statistical power. Due to the small sample sizes, statistical power was low, thus reducing the chance a post hoc test would be able to detect a difference between treatments.

The study additionally demonstrates the impact each treatment has on the survival rate of both types of plants. While the survival rate for garden cress plants were roughly similar, the rates for marigolds varied. Group 1 marigolds (the control) had the lowest survival rate while Groups 4, 5, and 6 (Eggshell Grounds, Wick System, and DWC System) had the highest survival rates. A higher survival rate indicates healthy plant growth as the soil contains the necessary nutrients. For the marigolds, the reason for a lower survival rate for the control group is obvious, as no nutrient-bearing treatment was applied. However, the higher survival rates for the Eggshell Grounds, Wick System, and DWC System treatments demonstrate their contribution to healthy plant growth since all were successful in sustaining every marigold that sprouted. For the cress, similar survival rates, where up to one plant died for each treatment, reveal the limited impact each treatment had in sustaining the garden cress plants.

Notably, across all the plant health metrics (height, survival rate, and time to bloom), DWC System groups consistently outperformed or were equal to other growing methods. This may point to the DWC System's overall high capability of providing nutrients to plants. A similar case may be made for the Eggshell Grounds and Wick System groups for marigolds. However, in the case of the Burnt Foliage groups, this does not apply. In both marigolds and the garden cress, the plant survival rate remained the same, at a rate of approximately 0.8 growing/survived with a similar rate of decline (dying off around the 40-day mark). This suggests that the Burnt Foliage treatment may not be a very effective natural fertilizer. Similarly, Urea Solution groups across both plants had a similar survival rate; however, there was a greater disparity between when plant sprouts started to die off.

The development of a purple color in the leaves of marigolds in Groups 2, 3, and 4 indicate a phosphorus deficiency in the soil (11). As none of the treatments applied to the in-ground plants supplied phosphorus, this is not surprising. Further research may consider other unconventional growing methods to supplement the lack of phosphorus or repeating this study with phosphorus applied to each in-ground treatment.

There are multiple limitations within this study. Only a maximum of six plants for each treatment were tracked over the 13-week period. Additionally, only two types of plants were taken into consideration for this experiment. Future studies should include a greater number of individual plants for each treatment to create a larger sample size. Though marigolds and garden cress (a flower and an herb) were selected to represent an average garden, a greater variety of garden plants such as fruits, vegetables, and legumes, which have different growing requirements, could be experimented on in further research. The narrow range of plant types also raises the question of whether these treatments would be practical on the wide-scale commercial agricultural level.

Other limitations of this study involve the manner in which it was conducted and the way the data was collected. This study was conducted for only 13 weeks. Further research may track these plants over months or years across different annual seasons and multiple growing seasons to evaluate the long-term effects of each treatment on the plants. Furthermore, this experiment only considered height at first bloom, survival rate, and growing time as metrics for plant health. Additional studies may consider more indicators of plant health such as plant weight and root condition. Moreover, plant height may be a slightly biased indicator due to natural variations in height that occur due to changing leaf positions at the time of daily data collection. Likewise, we only tracked height until the plant first bloomed. Changes in overall plant height may have occurred after data collection stopped and may have therefore been missed.

This study demonstrates more sustainable growing methods a household can employ to yield greater, healthier, and more sustainable plant growth and highlights the potential common items and wastes can be utilized for agricultural purposes. Similarly, our findings confirm the superiority of substrate-based systems for growing plants over the traditional in-ground soil method, which may be useful as the global supply of arable soil decreases (12). Future researchers may aim to extract other minerals and nutrients from household wastes or experiment with different non-soil growing mediums to examine their effects on plant growth.

METHODS

Germination and planting

To germinate the marigold and garden cress seeds, seeds were placed between moistened paper towels in an airtight plastic bag for 1 – 2 days at room temperature (70°F), until the seeds were hydrated. Once roots or sprouts began emerging, the seeds were transferred into the soil or growing medium at a depth of 0.25 inches (6 mm). Two marigold seeds and six garden cress seeds were planted in separate soil pots. The soil used to plant marigold and garden cress seeds was obtained from the same location. Two marigold seeds were planted in a 1:1 ratio of vermiculite and perlite for the Wick System treatment while only one seed was planted in perlite alone for the DWC treatment. Six garden cress seeds were planted in a 1:1 ratio of vermiculite and perlite for the Wick System treatment while only one seed was planted in perlite for the DWC treatment.

Plant maintenance

Plants grown in dirt were watered daily. Each watering session thoroughly moistened the top of the soil. The plants were watered between two and six times daily, depending on the time of year and weather conditions. Watering was sufficient to keep plants from wilting. The marigold and garden cress pots and hydroponic systems were placed in an area with full sun. Any plants that died and all weeds were removed upon detection.

In-ground treatment preparation and application

To create the Urea Solution treatment, samples of urine and tap water were combined into a 1:1 ratio. The solution was applied directly to the soil, enough to saturate the surface. To create the Burnt Foliage treatment, dried lawn clippings and woodchips were burnt. About one teaspoon of ashes were spread on the surface of the soil. To create the Eggshell Grounds treatment, several eggshells were washed and then ground into fine shards using a mortar and pestle. About 1 teaspoon of grounds was spread on the surface of the soil.

Hydroponics systems construction

To create the Wick System treatment, a plastic juice bottle was rinsed and cleaned before being cut along its neck. The top of the bottle was inverted to serve as a pot. The bottom of the bottle was filled with the nutrient solution (detailed below). The wicks were created from recycled socks cut and plugged tightly into the bottle opening. Each wick clearly extended into the nutrient solution. The growing medium was a 1:1 mixture of perlite and vermiculite filling the pot to approximately 80% capacity (**Figure 5**).

To create the DWC System treatment, 6 oz. yogurt containers were recycled into nest pots. Four slits longitudinally were cut in each container and four openings were made at the bottom corners (**Figure 6**). Twelve holes the size of a nest pot were cut into a block of Styrofoam large enough to fit into the top of the container. Each fashioned nest

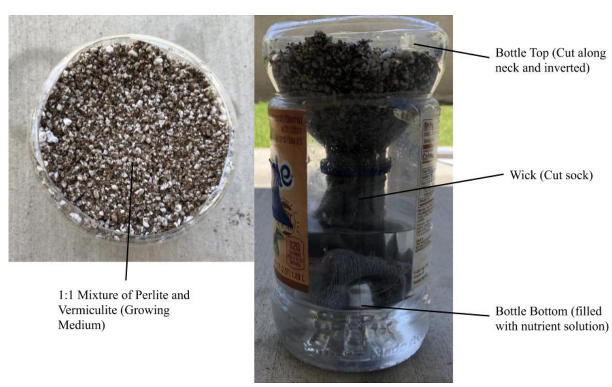


Figure 5. Wick system set-up. No plants are in the system for photographic purposes. A cleaned juice bottle was cut with the top inverted to use as a pot and the bottom as the nutrient reservoir. The growing medium is composed of a 1:1 ratio of perlite and vermiculite, which filled each pot to about 80% capacity.

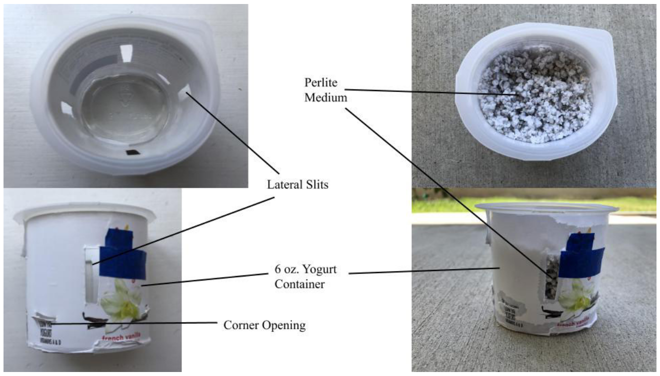


Figure 6. Nest pot construction and DWC system set-up. No plants are in the nest pot for photographic purposes. A 6 oz. yogurt cup was recycled into a net pot by cutting slits and holes into the sides. Perlite filled each nest pot to about 75% capacity.

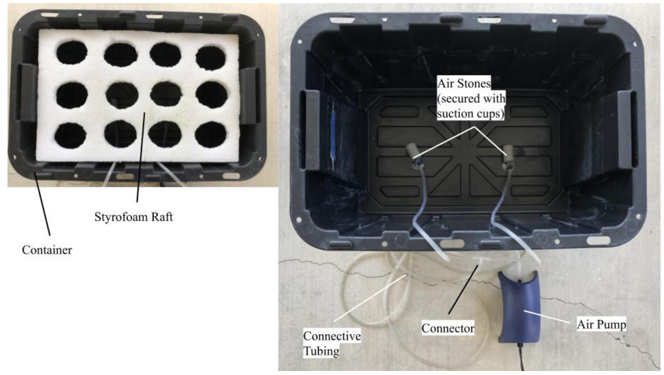


Figure 7. DWC system set-up. No plants are in the system for photographic purposes. The DWC treatments for both plants were housed in a 7-gallon container. Twelve nest pots were placed into a block of Styrofoam and floated atop the nutrient solution.

pot was filled with perlite to about 75% capacity. The block was made to float on top of the nutrient solution. At the bottom of the container, two air stones were attached on each side. Both air stones were attached to an air pump by plastic tubing and connectors (**Figure 7**).

Hydroponics maintenance

All hydroponically grown plants were given a nutrient solution composed of water and plant food. The plant food was water-soluble and contained 10% nitrogen, 5% phosphate, and 14% potash (a soluble potassium compound). The Wick System plants were grown in a solution composed of 0.25 gallons of water and 0.5 teaspoons of plant food. The DWC system plants were grown in a solution composed of 5 gallons of water and 7 teaspoons of plant food. Each week, the nutrient solutions were drained and replaced. Any occurrences of algae were removed with a 3% hydrogen peroxide solution and thorough rinse with water.

Data collection

Each day in the early evening, the height of every plant was measured, from base of stem to the highest point of the plant (bud, flower, or leaf) using a length of string and ruler. The height at first bloom (when a bud opened into a flower) was used for statistical analysis. The plants were allowed to grow in a Southern California climate during the months of May to August for up to 13 weeks. Once a plant bloomed, we stopped tracking its plant height and observed only qualitative changes.

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