

Feasibility of Plug Production Utilizing Digestate from Home-Waste to Energy Systems (H-WEF)

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Abstract

The integration of sustainable technologies in waste management systems has become imperative in addressing the escalating challenges of agricultural productivity and sustainability. Plugs are essential when starting crop production in controlled environment agriculture (CEA) setups and greenhouses. Horticultural crops such as vegetables, fruiting, and ornamental plants that utilize plugs have demonstrated higher success rates, healthier plants, and higher total yields. The APS Laboratory for Sustainable Agriculture explored the innovative utilization of digestate from the Home Water-Energy-Food Systems (H-WEF). The H-WEF system converts household food waste into biogas, electricity, and nutrient-rich digestate. The digestate from the H-WEF system was used to produce agricultural plugs, presenting a novel approach to circular resource utilization. We carried out the growth of Rex Butterhead Lettuce *Lactuca sativa* plugs with 1) control system (synthetic fertilizer) and seven different treatments, 2) 5% Digestate—95% RO Water (5D–95RO); 3) 10% Digestate—90% RO Water (10D–90RO); 4) 15% Digestate—85% RO Water (15D–85RO); 5) 20% Digestate—80% RO Water (20D–80RO); 6) 25% Digestate—75% RO Water (25D–75RO); 7) 30% Digestate—70% RO Water (30D–70RO); 8) 35% Digestate—65% RO Water (35D–65RO). The plugs were cultivated for 15 days in a controlled environment until two leaves had developed after the cotyledon. After 15 days, we collected data on wet weight (g), plug

head area (cm²), total leaf area (cm²), total chlorophyll content (mg/cm²), and dry weight (g). In addition, we collected data on the Leaf Area Index (LAI, cm²/cm²) and Specific Leaf Area (SLA, cm²/g). The synthetic fertigation yielded a higher wet weight than the following treatments: 5D–95RO, 10D–90RO, and 35D–65RO. While the 30D–70RO treatment produced a larger plug head than all other treatments. The digestate-based fertilizers were comparable to the synthetic fertilizer at dilutions of 25D–75RO and 30D–70RO. This study underscores the viability of using digestate for plug production, providing crucial insights for growers navigating the challenges of sustainable agricultural practices.

Keywords

Controlled Environments, Fertigation, Plugs, Digestate, Anaerobic Digestion

1. Introduction

As the global population continues to increase, we are faced with food insecurity and the dilemma of how to effectively manage the organic waste that we produce. In the United States, an estimated 30% to 40% of the food supply becomes food waste, with much of the organic food waste ending up in landfills where it is unable to decompose into the soil [1] [2]. With the organic waste being stored in landfills, it is not reintroduced into the soil, which plays a role in soil degradation. An average household in the United States wastes 31.9% of purchased foods, resulting in a total annual cost of \$1886 per capita in wasted foods [3]. Since 1974, food waste per capita has increased by 50% and is expected to continue growing [4]-[6].

Current methods of managing organic waste include incineration, landfills, and anaerobic digestion, with anaerobic digestion being the most sustainable of the three [7]. One potential solution for both the management of organic waste and global food insecurity is using a Home Water-Energy-Food system (H-WEF system). An H-WEF system is a type of bioreactor that converts household food waste into biogas, electricity, and nutrient-rich digestate through the process of anaerobic digestion [8]. The H-WEF system includes a digester, temperature controller, treatment system, an aeration tank to neutralize the liquids, a system to convert biogas into electricity, a composter to neutralize any pathogens in the solids, and a hydroponic system to produce foods [8]. Food waste is shredded inside the garbage disposal. The food waste is then moved into the bioreactor where it undergoes the process of anaerobic digestion, which produces biogas and a liquid digestate [8]. The biogas moves from the bioreactor to a pressurized biogas storage tank where the biogas can be used as a source of energy. The liquid digestate is removed from the bioreactor and fed to either a release valve or a storage tank [8]. The H-WEF system utilized in this experiment was designed to convert food scrap into renewable energy and nutrient-rich fertilizer, a schematic described in **Figure**

1 below.

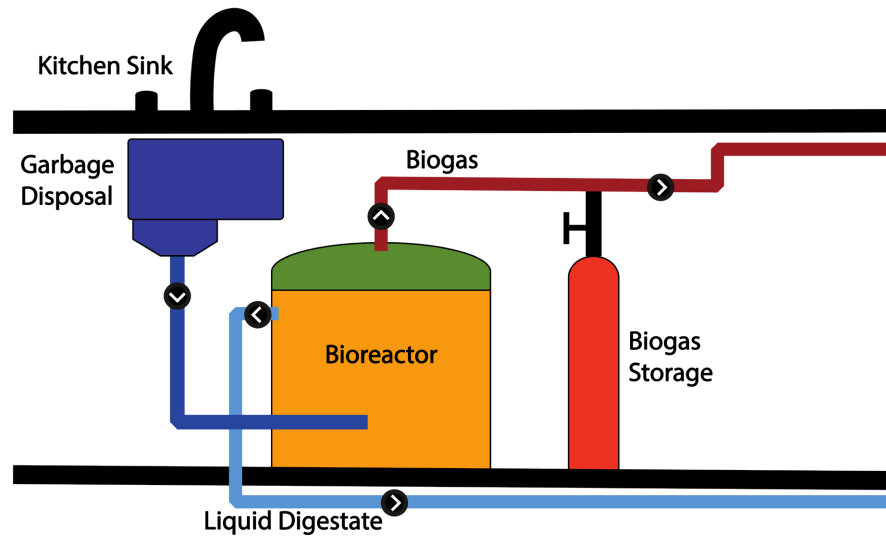


Figure 1. Schematic of a Home Waste-Energy-Food (H-WEF) system. The bioreactor in an H-WEF system converts food waste into liquid digestate and biogas through anaerobic digestion. The products of this process move from the bioreactor into storage tanks.

Digestate is one of the by-products that is produced through the process of anaerobic digestion [9]. Anaerobic digestion is a method where organic matter is decomposed by microbes in an aqueous and oxygen-free environment [10] [11]. Anaerobic digestion is used to produce biogas as a form of renewable energy as well as nutrient-rich digestate that can be used in agriculture as a fertilizer [9].

The liquid digestate produced by H-WEF systems can be used in a hydroponic system to recover the available nutrients and sustainably produce fresh food [12]. With most hydroponic implementations on a large industrial scale, new developments explore small-scale household options and the use of food waste digestate as a nutrient solution [12].

Digestate poses many advantages compared to other types of fertilizers. One of these advantages includes the abundance of nitrogen (N), phosphorus (P), and potassium (K). One of the properties of digestate is the slow release of its nutrients; this characteristic provides the plants with a more sustained flow of nutrients [13]. The production of digestate through anaerobic digestion has a lower carbon footprint when compared to other synthetic fertilizers because it is derived from recycled organic waste products that might otherwise be discarded [13]. Anaerobic digestion is a more sustainable method of waste management when compared with practices such as landfilling or the incineration of waste [14].

A plug is a plant during the regenerative phase of the plant life cycle [15]. The growth period between when a seed is planted and when it becomes a developed plug significantly influences the health and vitality of the matured plant, underscoring the significance of the plug development stage in plant cultivation [16]. The cultivation of healthy and optimally sized plugs is essential for the successful

production of ornamental, fruiting, or vegetable crops.

Employing plant plugs in crop production presents several advantages, including: 1) Enhanced quality and consistency of crops; 2) Greater flexibility in transplanting dates; 3) Opportunities for mechanical transplanting; 4) Improved water management during transplant establishment when compared to fresh bare root transplants [17]. Additionally, plants cultivated using plugs require less time to reach maturity in comparison to field-produced bare root transplants [17]. Plugs are also not exposed to soilborne pathogens during their development phase, from planted seeds to viable seedlings [17]. Leafy bare-root transplants necessitate 1000 times more water for successful establishment when contrasted with plugs, posing significant environmental implications [18].

Many industries, including the floral [19], agricultural [19], and controlled environment agriculture (CEA) industries, utilize and are heavily reliant on the growth and transport of plant plugs. Producing over \$2.5 billion worth of plugs annually, the plug production sector has grown into a substantial industry. Therefore, exploring various techniques for cultivating the healthiest plugs is imperative [19]. Many countries utilize plant plugs, including the United States of America, Japan, the Netherlands, China, Mexico, Korea, Israel, Australia, and Canada [19].

Various methods can be used to cultivate plugs, including planting directly in the field or within controlled environments such as greenhouses [20]. Regardless of the method used for plug production, fertigation is essential as plants rely on nitrogen, phosphorous, and potassium to sustain normal cellular functions [21]. Ensuring the correct fertilizer source and concentration is necessary for plug production to promote optimal growth. A lack of nitrogen can lead to slow and poor growth [22], while excessive nitrogen use can delay maturity and result in low-quality leaves [23].

Numerous methods can be utilized to fertilize plugs and provide the necessary nutrients for growth. Both synthetic and organic fertilizers can be used as a method of fertilization. Synthetic fertilizers, unlike their organic counterparts, are mined from non-living materials or artificially synthesized and consist of chemical compounds to which the composition is known [21] [24]. Referred to as chemical or inorganic fertilizers, synthetic fertilizers offer the advantage of a relatively quicker and more efficient absorption of nutrients by plants compared to organic alternatives [21]. However, the widespread use of synthetic fertilizers has revealed numerous drawbacks, particularly when mismanaged, leading to negative environmental consequences [25]. The environmental issues caused by synthetic fertilizers include diminished crop yields over time resulting from soil degradation and nutrient imbalances [26]. Synthetic fertilizers can also contribute to a range of other adverse environmental consequences, such as increased soil salinity, accumulation of heavy metals, eutrophication of water bodies, and nitrate buildup [27].

Organic fertilizers are considered fertilizers that are sourced from biological or living materials such as livestock manure, green manure from young plants,

notably legumes, and compost from agricultural and food waste [21]. Organic fertilizers possess the ability to supply the essential nutrients required for sustaining plant growth while also efficiently suppressing plant pest populations [28]-[32].

With digestate-based fertilizers being a type of organic fertilizer, the goal of this experiment was to determine the viability of utilizing the digestate from the H-WEF system for fertigation in plug production. This experiment aims to assess the plug's growth and biomass production using different dilutions of digestate and Reverse Osmosis (RO) water with synthetic fertilizer as control. The results from this study may help growers make a decision when choosing between digestate-based fertilizers and synthetic fertilizers as well as provide information on the ideal digestate concentration when growing plant plugs.

2. Materials and Methods

2.1. Location

The experiment was carried out at Florida Gulf Coast University (FGCU), located in the city of Fort Myers, Florida, United States of America. The experimental setup was in the Aquarium Room 114 of Academic Building 9 at the Water School. The Florida Gulf Coast University Work Management Center maintained the Aquarium Room 114 between 20.5°C and 22.2°C for the experiment duration.

2.2. Experimental Setup

The plug production experiment was conducted in a controlled environment, including a thermally insulated grow tent, LED lighting source, and environmental controls that monitored humidity, and temperature. The components of this controlled environment allowed us to maintain stable growing conditions for plug production with reduced interference from external influences. The experimental setup was similar to the arrangements used by the Yang Laboratory at the University of Connecticut [33]-[37].

The thermally insulated grow tent (The Original Gorilla Grow Tent® 5 × 5, Gorilla Inc., Santa Rosa, California) had dimensions of 1.52 × 1.52 × 2.12 m and weighed 33.9 kg. The artificial lighting element consisted of six light fixtures (FREELICHT 4 ft LED Grow Light 60W, Amazon Inc., Seattle, Washington) installed in the tent to provide sufficient light energy for photosynthesis. The lights were attached from the tent ceiling by support ratchets (Heavy-Duty StainlessSteel Gear Ratchets, AC Infinity, Los Angeles, California). The six linked lights collectively produce 18,000 lumens of light and 21,000 K color temperature. The lights were positioned 40 cm above the top of the plug trays for the experiment duration.

We utilized a ventilation system using a high-powered fan (CLOUDLINE T6, 6" Inline Duct Fan with Temperature Humidity Controller, AC Infinity, Los Angeles, California) with a duct opening size that is 0.15 m in diameter, an air-flow capacity of 11.38 cubic meters per minute (CMM), and a power rating of 38 watts. The fan was placed in the top opening of the grow tent in an orientation that directed air outwards. The bottom vent was left open to provide an inflow to the

recirculating system of air.

We used light sensors (FUTUREHORTI Light PAR Meter PPF Tester, Amazon Inc., Seattle, Washington) to collect data on the photosynthetic photon flux density (PPFD) and daily light integral (DLI) in moles per meter square day ($\text{mol}/\text{m}^2\cdot\text{day}$). To collect air moisture content and temperature data, we utilized the built-in environmental sensor of the fan (CLOUDLINE T6, 6" Inline Duct Fan with Temperature Humidity Controller, AC Infinity, Los Angeles, California). Sensors were placed in the center of the grow tent at the same elevation as the plug trays to represent the environmental conditions to which the plugs were exposed. The sensors continuously recorded humidity, temperature, and the ppm of carbon dioxide throughout the growth cycle.

We placed the plugs on a tray stand (SKU number HGC706122, Fast Fit Ltd., Hawthorne Gardening Company, Vancouver, Washington) whose dimensions were 1.22×1.22 m. On the stand, we placed eight smaller trays (Living Whole Foods Seed Starter Grow Trays, Amazon Inc., Seattle, Washington) with the dimensions of 0.25×0.51 m, which housed the growth medium (Horticube XL 104-Cell Sheets, Oasis[®] Grower Solutions, Kent, Ohio). The trays were sowed with "Rex Butterhead" Lettuce *Lactuca sativa* seeds (Johnny's selected seeds, Fairfield, Maine) and were subjected to different fertigation treatments.

The digestate utilized in this experiment was received from a H-WEF system setup at the Emerging Technologies Institute (ETI) at Florida Gulf Coast University. The digestate was then diluted with RO water to create the treatments, the percentage of digestate ranged from 5% to 35% with each treatment having a difference of 5%. The range of digestate concentrations from 5% to 35% was chosen to assess the impact on plant growth. The 5% concentration serves as a baseline, while incremental increases allow for the evaluation of potential response effects, and we chose the higher limit of 35% based on the pH and electrical conductivity, not being too high and allowing for viable crop growth.

The synthetic fertilizer utilized for the control tray consisted of (Jack's Nutrients 5-12-26 Part A FeED) and (Jack's Nutrients 15-0-0 Calcium Nitrate Part B), both produced by JR Peters Inc., Allentown, Pennsylvania. The 5-12-26 Part A fertilizer was formulated from potassium nitrate, magnesium sulfate, monopotassium phosphate, iron DTPA, iron EDTA, iron EDDHA, copper EDTA, manganese EDTA, zinc ETDA, boric acid, and ammonium molybdate. Plant growth was supported by the specific available nutrients that were 5% total nitrogen (N), 12% available phosphate (P_2O_5), 26% soluble potash (K_2O), 6.3% available magnesium (Mg), and 8.5% available sulfur (S). Additionally, the Part A fertilizer contained micronutrients such as 0.05% boron (B), 0.015% copper (C), 0.3% iron (Fe), 0.05% manganese (Mn), 0.019% molybdenum (Mo), and 0.015% zinc (Zn). The 15-0-0 Part B fertilizer (Jack's Nutrients 15-0-0 Calcium Nitrate Part B, JR Peters, Inc., Allentown, Pennsylvania), derived from calcium nitrate ($\text{Ca}(\text{NO}_3)_2$), provided 15% total nitrogen (N) and 18% calcium (Ca). Together, these components facilitate the development of robust roots and leaves, which are crucial for successful

plug production in vegetative plants.

The organic fertilizers were derived from the digestate from the H-WEF system. We conducted tests for the Electrical Conductivity (EC), pH, Nitrates (NO_3), Potassium (K^+), Calcium (Ca^{2+}), Ammonium, and Phosphorus Pentoxide (P_2O_5) within a temperature range of 22.6°C to 23.3°C. This temperature control was implemented to minimize fluctuations in EC and its potential impact on other parameters. We average three readings for NO_3 , K^+ , and Ca^{2+} values to ensure accuracy. A singular test was performed to find the EC, pH, ammonium, and P_2O_5 on every sample. **Table 1** presents the EC, pH, Ammonium, and Phosphorus Pentoxide (P_2O_5) values as well as the average values for Nitrates (NO_3), Potassium (K^+), and Calcium (Ca^{2+}) for the different dilutions of the digestate-based fertilizers.

Table 1. Digestate and RO mix EC, pH, ammonium, and phosphorus pentoxide (P_2O_5) values for digestate-RO mix.

Readings	Digestate and RO Mixes						
	35% Digestate/ 65% RO	30% Digestate/ 70% RO	25% Digestate/ 75% RO	20% Digestate/ 80% RO	15% Digestate/ 85% RO	10% Digestate/ 90% RO	5% Digestate/ 95% RO
EC	1100 ppm	900 ppm	760 ppm	760 ppm	510 ppm	350 ppm	190 ppm
pH	7.21	7.12	7.08	6.95	6.9	6.83	6.79
NO_3 Average	27.3 ppm	23.3 ppm	22 ppm	25.7 ppm	19 ppm	17 ppm	13.7 ppm
K^+ Average	84 ppm	57 ppm	48.3 ppm	50.3 ppm	32 ppm	23 ppm	11 ppm
Ca^{2+} Average	13.3 ppm	13.3 ppm	12.7 ppm	12 ppm	11 ppm	9 ppm	6.3 ppm
Ammonium	222 ppm	223 ppm	220 ppm	232 ppm	106 ppm	103 ppm	45 ppm
P_2O_5	54 ppm	67 ppm	54 ppm	68 ppm	61 ppm	49 ppm	45 ppm

The EC values varied between 190 and 1100 ppm. Among the digestate-based fertilizers, the 35D–65RO treatment had the highest EC, while the 5D–95RO treatment had the lowest. The pH levels ranged from 6.79 to 7.21 across all seven digestate treatments. The 35D–65RO treatment recorded the highest pH, whereas the 5D–95RO treatment had the lowest. NO_3 (ppm) values ranged from 13.7 to 27.3 ppm, with the 35D–65RO treatment showing the highest and the 5D–95RO treatment showing the lowest values. The K^+ concentrations varied between 11 and 84 ppm. The 35D–65RO treatment had the highest K^+ concentration, while the 5D–95RO fertilization had the lowest. The Ca^{2+} concentrations ranged from 6.3 to 13.3 ppm. Both the 35D–65RO and 30D–70RO fertilization treatments recorded the highest Ca^{2+} concentrations, each at 13.3 ppm, while the 5D–95RO treatment had the lowest at 6.3 ppm. Ammonium levels ranged from 45 to 232 ppm, with the 20D–80RO treatment showing the highest and the 5D–95RO treatment showing the lowest levels. The P_2O_5 values stretched from 45 to 68 ppm, with the 20D–80RO fertilization recording the highest value and the 5D–95RO fertilization recording the lowest. For the NO_3 , the 20D–80RO fertilization had the second-highest concentration of nitrates. The 20D–80RO fertilization had a greater concentration

of K^+ than the 25D–75RO, 15D–85RO, 10D–90RO, and 5D–95RO treatments. The 20D–80RO fertigation treatment had the greatest value for both ammonium and P_2O_5 .

2.3. Experimental Procedure

The entire plug production process took 15 days, between December 8–22, 2023. We began the experiment by placing eight Horticulture growth mediums in black 0.25×0.51 m starter trays and thoroughly saturated the Horticulture with reverse osmosis (RO) water. We then put a single pelleted “Rex Butterhead” Lettuce *Lactuca sativa* seed in each cell of the growth cubes, totaling 104 seeds. We repeated this process seven additional times until we had eight seed-filled Horticulture trays. Next, we placed a layer of newspaper over each of the eight trays and placed the covered trays inside the grow tent, where the lighting element was turned off for 48 hours to replicate the natural seed imbibition process. After 48 hours, we used a programmable timer (Mechanical 24-Hour Programmable Dual Outlet Timer, BN Link, Santa Fe, California) to provide 16 hours of continuous light for plug production between 06:00 to 22:00 for the duration of the plug production cycle. The experimental setup allowed us to maintain ideal environmental conditions throughout the growth cycle for plug production. Using light sensors, we determined the DLI ranged from 7.76 to 13.36 mol/m²·d with an average of 11.40 mol/m²·d, which falls above the minimum recommended range of 6.5 - 9.7 mol/m²·d [38]. Utilizing the fan’s built-in environmental sensor component, we could monitor the environmental conditions over the plug production cycle. The temperature varied between 21 °C and 26.7 °C with an average value of 24.4 °C. The relative humidity over the growth period varied between 37.6% and 89.3%, averaging 58.7%.

After 48 hours had elapsed, we began the fertigation of both: 1) Control system (synthetic fertigation treatment) and seven dilutions of digestate-based fertigation treatments; 2) 5% Digestate—95% RO Water (5D–95RO); 3) 10% Digestate—90% RO Water (10D–90RO); 4) 15% Digestate—85% RO Water (15D–85RO); 5) 20% Digestate—80% RO Water (20D–80RO); 6) 25% Digestate—75% RO Water (25D–75RO); 7) 30% Digestate—70% RO Water (30D–70RO); 8) 35% Digestate—65% RO Water (35D–65RO). Each tray was fertigated by adding 200 - 400 mL of each fertigation source to their respective trays daily for 13 days; volume added depended on the rate of evaporation and uptake from the plugs. Each tray received 200 - 400 mL of their respective fertigation between the hours of 12:00 and 16:00 every day for 13 days. The volume added was based on the plug’s uptake as well as the rate of evaporation. The experimental setup is illustrated in **Figure 2**.

2.4. Data Acquisition

To find the comparative growth performance of the plugs with different fertigation treatments, we collected biomass data at the end of the growth cycle. On the 15th day of growth, we harvested 20 plugs from each treatment tray in a randomized

manner for data collection.

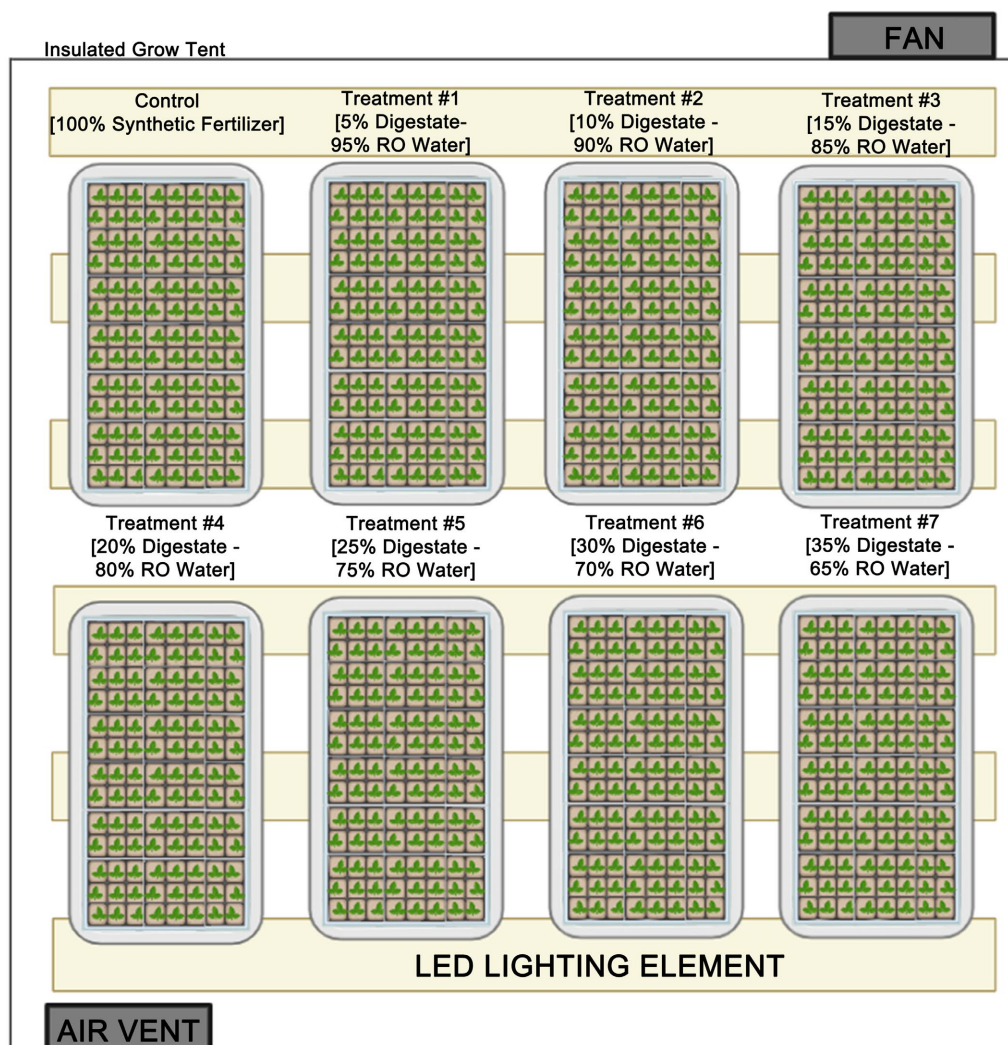


Figure 2. Top view of the experimental setup with 1) control synthetic fertilizer and seven fertigation treatments; 2) 5% Digestate—95% RO Water (5D–95RO); 3) 10% Digestate—90% RO Water (10D–90RO); 4) 15% Digestate—85% RO Water (15D–85RO); 5) 20% Digestate—80% RO Water (20D–80RO); 6) 25% Digestate—75% RO Water (25D–75RO); 7) 30% Digestate—70% RO Water (30D–70RO); 8) 35% Digestate—65% RO Water (35D–65RO).

We utilized destructive methods to obtain wet weight (g), plug head area (cm²), total leaf area (cm²), total chlorophyll content (mg/cm²), and dry weight (g) for biomass data collection. The control treatment for this experiment contains data collected from a separate experiment that was conducted under similar conditions [39]. To obtain the wet weight, we gently pulled each plug out of the Horticulture tray, separated the root material from the plug, and weighed the samples. We separated the root mass since it contained fragments of the Horticulture material, which, if weighed, would lead to an inconsistent analysis of the biomass. We measured these values first and immediately after harvest to ensure minimum water loss through plant evapotranspiration which would dry out the plugs and lead to

inaccurate measurements.

To calculate the plug head area and the plug's total leaf area, we installed the Leafscan app on a mobile device (iPhone 14, Apple Inc., Cupertino, California). To calculate the plug head area, we took the entire plug and placed it in the middle of a white sheet of paper with four black dots forming a 10.5×10.5 cm reference square, we then took a picture and uploaded it to the Leafscan application. For the plug's total leaf area, we separated and laid out the leaves of each sample on the paper with the 10.5×10.5 cm reference square, taking a picture and uploading it to the Leafscan mobile application. The Leafscan application then utilizes the camera on the mobile device to photograph the leaves and, by running an algorithm that measures the green leaf area in comparison to the blank white area, generates the total leaf area value [39]. The Leafscan app calculated the area inside the contour in pixels, and by using the given reference length of 10.5 cm, it converted the leaf pixel area into the surface area [39]. We collected the plug head area and total leaf area data of 20 samples for each treatment that was later exported in a comma-separated values (csv) format. The Leafscan app measured the leaf area in square centimeters (cm^2) with an accuracy of 0.01 cm^2 [40].

We then utilized a chlorophyll meter (AMTAST Chlorophyll Meter for Testing Plant Chlorophyll Content Unit SPAD, Amazon Inc., Seattle, Washington) to find the total chlorophyll content (mg/cm^2) of each sample. We took three chlorophyll readings per sample and then averaged the values of those readings and converted them to Soil Plant Analysis Development (SPAD) units and subsequently to total chlorophyll content (mg/cm^2). The total chlorophyll content of the crop foliage is calculated by converting the atLEAF CHL values to SPAD and considering the relationship between chlorophyll content and SPAD units [41].

To find the dry weight of the samples collected, we placed all twenty samples in individual brown paper bags and placed them in a drying oven for six days set at a temperature of 65°C for each treatment. After six days, we returned to weigh the dried samples and divided the dry weight value obtained by 20 to find the average dry weight of each sample. We averaged the values because the weighing scale we utilized had a precision of 0.001 g and, if individually sampled, would not register on the weighing scale.

2.5. Data Processing and Statistical Analysis

We utilized the collected data described in the previous section to derive leaf area index (LAI, cm^2/cm^2) and specific leaf area (SLA, cm^2/g). We also converted SPAD units to total chlorophyll content (mg/cm^2). The LAI (cm^2/cm^2) is defined as the ratio of the total leaf area (cm^2) and the ground area (cm^2). The SLA (cm^2/g) is defined by the ratio of each plug's total leaf area (cm^2) to dry weight (g). We found the SLA (cm^2/g) by dividing the average total leaf area value by the average dry weight value for each treatment. The resulting calculated value is the average SLA (cm^2/g) for each treatment.

We used statistical analysis to understand and compare the effects of synthetic

and digestate-based fertigation treatments on plug production. Descriptive statistics were used to demonstrate our results from the data collected. Due to near-perfect correlations between nitrogen and chlorophyll, and total leaf area and wet weight, only wet weight and chlorophyll were retained for further statistical analyses. Dry weight was also excluded as it tends to be strongly correlated with wet weight and the recorded values were averages instead of individual measurements. The remaining variables (wet weight, plug head area, and chlorophyll) did not satisfy multivariate normality, so a permutation multivariate analysis of variance (MANOVA) was performed using the *vegan* package [42] in R [43]. Pairwise Kruskal-Wallis tests and Dunn's tests were conducted during post-hoc analyses via the *ggstatsplot* package [44].

3. Results

The utilization of synthetic fertilizers and various dilutions of digestate-based fertilizers in plug production shows a significant difference in biomass production depending on the fertigation treatment. **Table 2** provides the average values for the wet weight (g/plug), dry weight (g/plug), LAI (cm²/cm²), SLA (cm²/g), and total chlorophyll content (mg/cm²) from the different treatments utilized during plug production.

Table 2. Shows the average values for wet weight (g/plug), dry weight (g/plug), LAI (cm²/cm²), SLA (cm²/g), and total chlorophyll content (mg/cm²).

Treatment	Results				
	Wet Weight (g/plug)	Dry Weight (g/plug)	LAI (cm ² /cm ²)	SLA (cm ² /g)	Total Chlorophyll (mg/cm ²)
Synthetic Fertilizer	0.2290	0.0135	1.56	641	0.0150
65% RO/35% Digestate	0.1270	0.0190	0.83	247	0.0051
70% RO/30% Digestate	0.1975	0.0190	0.97	370	0.0070
75% RO/25% Digestate	0.1965	0.0205	1.18	356	0.0064
80% RO/20% Digestate	0.1565	0.0210	1.13	273	0.0071
85% RO/15% Digestate	0.1195	0.0185	1.17	250	0.0068
90% RO/10% Digestate	0.1000	0.0140	1.08	240	0.0050
95% RO/5% Digestate	0.0430	0.0150	0.89	60	0.0037

The data for wet weight and dry weight have a near-perfect correlation, so only the wet weight was analyzed further. The wet weight varied from 0.04 g to 0.21 g across the different fertigation treatments. The 5D–95RO treatment output, had a median wet weight of 0.04 g which was significantly less than all other treatments except for the 10D–90RO treatment with a median wet weight of 0.1 g. The synthetic fertilizer and the 25D–75RO produced the highest wet weight values with median wet weights of 0.21 g. The synthetic control and 25D–75RO fertigation treatments produced significantly more wet weight than the 35D–65RO, 15D–

85RO, 10D–90RO, and 5D–95RO treatments.

The LAI ranged from 0.83 to 1.56 cm²/cm², the synthetic treatment produced the greatest LAI, and the 35D–65RO treatment produced the least LAI. The SLA ranged from 60 to 641 cm²/g with the synthetic fertilizer having the highest SLA with a value of 641 cm²/g. The 5D–95RO treatment had the lowest SLA value at 60 cm²/g.

Across the different fertigation treatments, the total chlorophyll content of the plugs ranged from 0.0037 to 0.015 mg/cm². The synthetic treatment produced the highest total chlorophyll content, while the 5D–95RO fertigation treatment produced the lowest total chlorophyll content. The synthetic fertilizer resulted in statistically significant ($p < 0.05$) more chlorophyll than all other fertigation treatments.

The permutation MANOVA detected a significant effect of fertigation treatment ($F[7, 152] = 24.901, p = 0.001$). Kruskal-Wallis tests revealed that the treatments impacted wet weight, plug head area, and chlorophyll significantly ($p < 0.0001$).

4. Conclusion

This experiment aimed to determine if there was a significant variation in the growth performance of plugs when implementing synthetic fertigation treatments and different dilutions of digestate-based fertigation treatments from the H-WEF system. We found that we could grow plugs ready for transplant by the 15th day for all treatments except for the 5D–95RO and the 10D–90RO treatments, as two leaves after the cotyledons had not developed. Although all treatments except the 5D–95RO and the 10D–90RO treatments produced viable plugs, we can conclude that there is variation in the growth performance of “Rex Butterhead” Lettuce plugs when grown with a synthetic fertigation treatment and different concentrations of digestate-based fertilizers. We found the synthetic control and 25D–75RO fertigation produced significantly more wet weight than all other treatments except the 20D–80RO treatment. The data from this study demonstrates that digestate-based fertilizers can produce plugs comparable to synthetic fertilizers when at the correct concentration. Results from this study may inform growers about the optimal digestate-to-water ratio when synthesizing fertigation to support plug production using digestate from the H-WEF system.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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