A COMPARISON TRIAL OF VERMICOMPOST TEAS AS HYDROPONIC NUTRIENT SOLUTIONS AGAINST COMMERCIAL FERTILIZERS: IDENTIFYING NUTRIENTS AND PLANT PRODUCTION

by

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iv

LIST OF TABLES vi

LIST OF FIGURES vii

LIST OF ABBREVIATIONS viii

ABSTRACT ix

CHAPTER

I. INTRODUCTION 1

II. LITERATURE REVIEW 5

III. MATERIALS AND METHODS 15

IV. RESULTS AND DISCUSSION 21

APPENDIX SECTION 33

REFERENCES 36

LIST OF TABLES

Table **Page**

1. Plant production metrics by treatment 25

2. Nutrient levels by treatment 30

LIST OF FIGURES

Figure **Page**

1. Experimental design 15

2. Example of floating raft system 16

3. Experimental timeline..17

4. Germination station for Chicarita seedlings...18

5. Average wet leaf weight 21

6. Average dry leaf weight...22

7. Average chlorophyll 23

8. Average wet root weight. 24

9. Average dry root weight 24

10. Average root length 25

11. Average nitrate 26

12. Average ammonium..27

13. Average phosphate..28

14. Average potassium..28

15. Average calcium 29

16. Average magnesium 29

17. Average sulfate...30

LIST OF ABBREVIATIONS

Abbreviation	Description
CF	compost fertilizer
IF	inorganic fertilizer
OF	organic fertilizer
PGH	plant growth hormones

ABSTRACT

While vermicompost teas have many documented benefits, including increased plant growth and pest and disease suppression, less is known about the use of vermicompost teas as a source of nutrients in hydroponic systems. This experiment explored the application of vermicompost tea in hydroponically grown lettuce (*Lactuca sativa*), as compared with commercially fertilized plants. *Lactuca sativa* was grown hydroponically in floating rafts over two consecutive three-week cycles and was applied with commercial inorganic fertilizer, commercial organic fertilizer, or vermicompost fertilizer. Wet and dry above- and below-ground biomass, chlorophyll levels, and root length were measured for plant productivity. Levels of soluble nitrate, ammonium, phosphate, potassium, magnesium, calcium, and sulfate were analyzed to determine nutrient levels of fertilizer type. Average above-ground biomass, root length, and chlorophyll were significantly lower for vermicompost treatments as opposed to the other two treatments. Although the vermicompost treatment showed significantly lower mean plant production metrics, mean nutrient levels were not significantly different from commercial fertilizers except for ammonium and sulfate. More research is needed to further explore nutrient levels and plant production with vermicompost tea applications in hydroponic systems. Further studies may also indicate if vermicompost teas alone can enable yields that are similar to commercial fertilizer or if a combination of vermicompost tea and an additional fertilizer application is necessary.

I. INTRODUCTION

Background

Limited land and water resources challenge current production methods to produce increasing amounts of nutritious foods, with increasingly limited resources. While global food production has risen to meet food demand, it has primarily been achieved through genetically modified crops, and the reliance on inorganic fertilizers and pesticides. Farmers have been meeting food demand for the world's population, but this paradigm has had unintended consequences to the environment. Fertilizers and pesticides cause widespread pollution of ground and surface waters (Higa and Parr, 1995). Despite this, many pests and weeds have become increasingly resistant to these toxins and many pesticides end up in surface waters. The salt fertilizers often used in agriculture are retained in the soil creating saline conditions, or if applied in excess can runoff into surface water. Pesticide residues often affect non-target species decreasing the populations of many pollinators and fertilizer runoff is known to cause massive algal blooms that can spread for miles (Diaz and Rosenberg, 2008). These algal blooms quickly deplete waters of oxygen when decomposed, creating large dead zones where aquatic life cannot survive (Diaz and Rosenberg, 2008). Several dead zones are exacerbated seasonally from agricultural inputs around the world; two major dead zones lie off the coast of China and in the Gulf of Mexico (Diaz and Rosenberg, 2008).

In response to these agricultural challenges, many regulatory agencies encourage organic agriculture. The Food and Agriculture Organization for the United Nations (FAO) has stated that organic agriculture enriches the biodiversity, structure, and nutrient cycling of soils when used. Organic nutrients have higher nutrient retention in soils, runoff less, and are less susceptible to surface and ground water pollution. Organic agriculture also helps increase carbon sequestration and contributes less to climate change than inorganic fertilizers which are produced using large amounts of fossil fuels. Since organic agriculture uses recycled organic material, it is a renewable resource which is sustainable over the long term. Organic agriculture is also known to increase the biodiversity within ecosystems which increases its ability to establish or bolster ecosystem services within crop production system that may be lacking or non-existent.

Hydroponic agriculture allows for high production of vegetable and herb crops. In areas where water shortages or degraded soils give rise to limitations, hydroponics is viewed as a suitable substitution for traditional agriculture. Hydroponic agriculture allows for precise control, and increased efficiency of water, nutrients, and aeration directly in contact with the root interface. Water usage can be reduced by 70-90% when using hydroponics compared to conventional agriculture (Raviv and Lieth, 2008). Empirical nutrient formulas have allowed precise applications of fertilizer salts to decrease excess nutrient application and closed systems recirculate any excess nutrients until used, improving nutrient efficiency. If these empirical formulas can be created for compost tea applications, then nutrient and microbial inputs could be generated from recycled waste.

Experimental framework

This study conducted experimental observation of vermicompost tea, organic fertilizer solution, and inorganic fertilizer solution aerated for 72 hours and applied weekly to hydroponic systems for two three-week crop cycles.

Purpose of the study

The purpose of this study was to explore vermicompost teas as a compost fertilizer (CF) as a hydroponic nutrient solution by comparing it to commercial organic fertilizers (OF), and commercial inorganic fertilizers (IF) specifically examining the various amounts of nitrogen across compost, organic, and inorganic fertilizers as well as other macronutrients. Finally, chlorophyll, the fresh and dry weight of both above- and below-ground biomass and root length were investigated to determine if treatment effects significantly increased plant production metrics.

Research objectives

1. Analyze the soluble nitrate and ammonium levels of vermicompost teas and commercial fertilizer solutions at daily resolution.

2. Investigate differences in soluble macronutrients of vermicompost teas and commercial fertilizer solutions weekly.

3. Determine any difference in crop production by investigating above- and below-ground biomass, chlorophyll levels, and root length from vermicompost teas or commercial fertilizers.

Significance

Efficient hydroponic systems can conserve water and nutrients within a closed recirculating system, while vermicompost is a nutrient-rich compost capable of making biologically active and organic-based nutrient solutions on site. The unification of these systems can reduce the costs of synthetic fertilizers and some pesticides while replacing them with sustainable, organic nutrients. Since compost teas rely on nutrients contained in organic matter such as bacterial bodies, as opposed to water soluble salts, runoff and leaching of nutrients into surface and ground water are greatly reduced or eliminated. Additionally, if whole microbial communities can be shown to establish and survive in hydroponic systems, then future techniques could reduce nutrient inputs even further.

Keywords

Hydroponics, bioponics, vermicompost, compost tea, nutrient solution, mineralization, rhizosphere.

Research limitations

This study used a commercial vermicompost, an amendment highly dependent on biology which may vary widely from other vermicompost sources. Furthermore, no pH adjustments were used during the trial, which may limit commercial comparisons of inorganic fertilizer production. Data was collected using instruments which require the assumption that these devices were accurately recording data. The study did not investigate mixing vermicompost tea mixes with organic or inorganic fertilizer solutions. The study also did not investigate microbial populations, or their biochemical additions such as plant growth hormones.

II. LITERATURE REVIEW

Vermicompost

Vermicomposting is the process of recycling organic material through the digestion of annelid worms such as *Eisenia fetida* and their gut microbiome. This process modifies the make-up of the microflora and microfauna of the source matter, as well as its nutrient content, when material is ground up in the annelid gut and redispersed throughout the media (Edwards et al. 2011; Lores et al. 2006).

Vermicomposting has become the favored method for many to compost food waste and manures due to its relative ease of production (Edwards 1998). Furthermore, microbial biomass, disease reduction, plant growth hormones (PGH), and ability to mineralize nutrients is higher in vermicompost compared to traditional thermophilic compost (Edwards 1998). Vermicomposting, and composting in general, is predominantly controlled by microbial decomposition (Mehta et al., 2014). In vermicomposting, the microbiome of earthworms is the primary source and regulator of sanitization. One pass through the digestion tract of *E. fetida* reduces total coliform bacteria by 98%, however no method detailing optimal composting times exists due to lack of systematic investigation (Edwards et al. 2011).

Higa and Parr (1995) categorized favorable microbes into effective microorganisms, which are specific species of microbes with known symbiosis or benefits (i.e. *Nitrobacter winogradsky*), and beneficial microorganisms, which are not defined by genus or species but are still known to have a positive effect (i.e. Glomeromycota fungi). Many of these organisms are found readily available in vermicompost (Edwards et al. 2011). The soil food web contained in vermicompost includes a wide range of biodiverse organisms including archaea, bacteria, fungi and many others which play a role in the decomposition of most organic material (Steele and Bert, 2011). These microbes are essential in natural systems due to their ability to mineralize and release nutrients slowly, feeding other organisms and plants along the root-soil solution interface and keeping nutrients held within the system (Lowenfels and Lewis, 2010).

Nutrient analysis of various vermicompost was conducted by Brace (2017), who found wide variation. Total nitrogen ranged from 1.5% to 3.9%, carbon percentage ranged from 14.2% to 40.0%, organic matter ranged from 23.9% to 72.6%, and phosphorous percentage ranged from 0.17% to 1.45% (Brace, 2017). Other factors also widely varied such as soluble salts ranging from 1.83 mmhos/cm to 16.21 mmhos/cm and pH ranging from 4.1 to 7.6, however most samples were found in the range of 7 to 8 pH (Brace, 2017). Micronutrients also displayed wide variation with aluminum ranging from 634 mg/kg to 19,656 mg/kg and iron ranging from 3,576 mg/kg to 12,770 mg/kg (Brace, 2017). This variation is likely due to different subspecies of composting worms in commercial use, as well as variations in feedstocks used for production. Brace (2017) reported yard trimmings, food waste, and manure as possible sources of feedstock used in the investigated vermicompost sources. However, this high variation makes consistent nutrient estimates of vermicompost difficult to estimate on a large scale.

Hargreaves et al. (2009) also showed that vermicompost teas applied to the soil can meet the nutrient requirements for successful production of strawberries at lower costs. Lazcano et al. (2009) showed that incorporating vermicompost into peat substrates of potted tomatoes at levels above 50% by volume, up to 100% replacement, produced significantly greater root biomass and leaf biomass over peat substrates alone. Kavroulakis et al. (2005) applied aqueous compost solutions to potted tomato trials and found that it could induce systemic resistance to fungal pathogens. Arancon et al. (2012) utilized chicken manure that had been vermicomposted and found it high in PGH. Vermicomposted chicken manure also increased germination and seedling growth in both lettuce and tomatoes. Hussey (2015) discusses many benefits of vermicompost tea use such as disease suppression, the extension of root systems, reduced fertilization application, reduced pesticide application, as well as the enhancement of taste and nutrition.

However, immature compost can harbor harmful pathogens or their phytotoxic compounds that can compromise the beneficial effects of compost application (Seneviratne et al., 2011). Edwards et al. (2011) note that unfortunately no systematic evaluation of maturity and stability has been undertaken, and as such, much is still unknown about when vermicompost is free of toxins and pathogens.

Bioponics

Bioponics is a term used to describe the combination of biological services with hydroponic systems. It is commonly used to describe systems that utilize organic nutrients and the microbial communities required to mineralize them. It also incorporates bio-controls, the use of biological management to combat disease and pests. Bioponics specializes in the application of organic fertilizers, bio-controls, compost or vermicompost teas, incorporation of compost or vermicompost into hydroponic substrates, and biological primers or inoculants.

Churilova and Midmore (2019) showed that vermicompost leachate application led to statistically similar Pak Choi yields as did application with fertilizer salts. Anarcon et al. (2019) determined that nutrient solutions diluted as low as 25% of the recommended concentration with a 3.2% by volume addition of vermicompost tea could produce lettuce yields statistically similar to 100 % fertilizer concentration. Dilutions of 50% fertilizer solutions mixed with both 1.2% and 3.2% vermicompost by weight also produced statistically similar yields to 100% fertilizer concentrations. Bidabadi et al. (2016) showed that a mix of inorganic fertilizer and vermicompost tea had highest biomass production when compared to inorganic-only and vermicompost-only treatments; however, vermicompost-only treatments had the highest biochemical markers for growth and the highest photosynthetic efficiency in Stevia cultivation. Bidabadi et al. (2016) showed these results despite soluble nutrients in vermicompost tea being significantly lower: 1.7% N vs 20% N, 0.7% P vs. 20% P, and 0.9% K vs 20% K. Bidabadi et al. (2016) suggested this may be due to nutrients being concentrated within microbe bodies rather than being free in solution for measuring.

Arancon et al. (2006) investigated the effects of humic acid from three different vermicompost types--cattle, food, and paper wastes--and compared their effectiveness to commercially produced humic acids and indole acetic acid as a control. Arancon et al. (2006) found that humic acids and indole acetic acid generated similar significant increases in yield over controls, however noted that a combination of both had highest yield increases. They also noted that humic acids from food waste vermicompost outperformed other forms and was significantly greater than commercial humic acids. Haghighi et al. (2012) also investigated the effects of humic acid, on nitrogen assimilation. Humic acid was shown to increase nitrogen reductase, utilized in nitrogen metabolism, as well as significant increases in photosynthetic rates, transpiration, and chlorophyll concentration. Fresh weight, protein, and nitrogen content of fresh above-ground biomass was also significantly increased with humic acid additions to inorganic fertilizers. Rodda et al. (2006) also compared humic extracts from vermicomposted cattle manures for lettuce seedlings for both field and hydroponic transplants and found significant increases in root growth as well as significant increases in ATPase production and metabolism within the root cells themselves. Rodda et al. (2006) also showed significantly increased lateral root growing tips and root infection sites.

Aremu et al. (2013) investigated the influence of vermicompost leachate on bulbous plants under nutrient stress conditions, 25% and 50% nutrient concentration, and determined that it increased photosynthetic pigment content. They also noted that this significantly increased antioxidant levels and secondary phytochemical production such as tannins. Sundaravadivelan et al. (2011) analyzed the nutrient and biochemical factors of vermiwash and found compost extracts to contain sufficient nutrient levels for plant growth as well as concentrations of PGH, such as auxin and Indole-3-acedic acid. This was higher in concentration than application rates for commercially sourced versions of plant hormones. Zhang et al. (2014) performed mass spectrometry on vermicompost teas and found quantifiable amounts of auxins, several cytokinin hormones, abscisic acid, and gibberellins indicating a large spectrum of PGH present within vermicompost teas, indicating high potential for growth promotion.

It is more challenging to apply organic fertilizers, as compared to inorganic fertilizers, in soilless production systems since a robust microbiome is often needed to mineralize organic nutrients into inorganic, plant available forms. Mineralizing microbes are particularly important for agricultural production, as this conversion process takes organic forms of nutrients, and produces plant-available inorganic nutrients. Kawamura-aoyama et al. (2014) found that adding food waste directly to hydroponic reservoirs could induce successful nitrogen ion generation, and that nitrogen ion retrieval could be increased by avoiding anaerobic conditions which aided denitrification. Shinohara, et al. (2011) investigated using composted bark as a mineralization inoculum for lettuce and tomato crops in hydroponics and determined that microbial cultures were necessary to keep plants alive with organic fertilizers. A C:N ratio <11 was determined to allow nitrate production from organic fertilizers in hydroponic systems. The composted bark studies were continued by Saijai, et al., (2016) who observed *Nitrosomas* and *Nitrobacter* species along with *Bacillus* and *Pseudomonas* within the hydroponic ecosystem. Saijai et al. (2016) also noted that organic fertilizer use in hydroponics is extremely limited by the ability of ammonia-oxidizing bacteria and nitrite-oxidizing bacteria to colonize within the hydroponic reservoir. *Bacillus* and *Pseudomonas* have been found on the root surfaces of wheat, soybean, and lettuce grown in recirculating hydroponic systems (Strayer, 1994) and indicate that these organisms can be captured indigenously and can colonize many different root types. However, it is likely that indigenous mineralizing communities are present in most water sources and develop in a large range of hydroponic systems as seen with fish ecosystems (Saha et al., 2016). Higa and Parr (1995) debate weather adding organic residues to feed and trigger microbial growth or directly applying microbes to build diversity is the best strategy for colonization.

Hydroponic systems are uniquely vulnerable to many aquatic and anaerobic pathogens, such as *Pythium aphanidermatum* which has swimming zoospores and can devastate hydroponic crops in both recirculating and run-to-waste systems (Vallance et al., 2011). Soilless cultivation can create a biological vacuum by eliminating organic matter. While this vacuum creates initially sterile conditions, pioneer organisms colonize much quicker and with little resistance or competition. While some pathogens and pests may be removed because no soil substrate is present, aquatic organisms have taken on new importance (Vallance et al., 2011). Vallance et al. (2011) suggested that, while recirculating solutions can create favorable conditions for the spread of pathogenic zoospores and oomycetes, evidence shows it can also be used as a tool for preventative biocontrol treatments as well. And diverse microbial communities have been shown to have a biocontrol effect in helping prevent pathogens from finding a foothold in hydroponic systems (Raviv and Lieth, 2008; Vallance et al., 2011; Lee at al., 2006).

While organic agriculture has many advantages in soil ecosystems, establishing a new, healthy microbiome with organic nutrients in hydroponic systems is challenging. Organic fertilizers and compost blends may clump or have debris large enough to clog pumps or drip lines. Organic solutions are also capable of breeding pathogens, especially in oxygen-limited or anaerobic conditions (Durham 2006). Many plants can also excrete organic acids from the roots which can accumulate in reservoirs recycling nutrient solutions which inhibit plant or microbial growth which should be accounted for (Lee et al., 2006).

Vermicompost teas

Compost teas can be made using either aerobic or anaerobic methods, however aerobic teas typically harbor less pathogens and phytotoxins, and have higher nutrient levels (Hargreaves et al., 2009). Compost teas that maintain aerobic conditions by continuously adding oxygen to the tea solution typically mature in 24-72 hours and should be used within a day or two (Scheuerell and Mahaffee, 2002).

Additions to vermicompost teas such as molasses and kelp or fish meal have been shown to create favorable conditions for bacterial and fungal growth (Higa and Parr, 1995; Duffy et al., 2004). Other additions include humic acid, rock dust, fish emulsion, and kelp powder (Diver, 2001). These tea amendments provide nutrients for bacterial and fungal growth. Unprocessed molasses allows rapid bacterial growth, however if too much is present then growth can deplete available oxygen and create anaerobic conditions (Higa and Parr, 1995). Pathogenic outbreaks have been known to occur within compost teas from their amendments (Durham, 2006). Fish meal and kelp additions are typically used to increase fungal growth; however, these also contain nitrogen which help start the bacterial nitrification process.

Compost teas are intended to prevent nutrient deficiencies by providing communities that slowly mineralize nutrients to mitigate the rapid rise and fall of soluble inorganic nutrient levels which must be maintained and monitored during hydroponic production with inorganic fertilizers (Gershuny, 2011). Studies have shown that vermicompost teas can increase yields due to both the release of biochemicals such as plant growth hormones and mineralization of organic nutrients (Edwards et al. 2011).

While vermicompost can provide long term disease suppression and fertilization, vermicompost teas provide quick and effective benefits but for a much shorter duration of time, however this trade-off is still largely unexplored (Mokhtar and El-Mougy, 2014). While Churilova and Midmore (2019) found vermicompost leachate capable of producing statistically similar yields as inorganic fertilizers, Allahyari et al. (2014) found that vermicompost teas produced higher yields than vermicompost leachate.

Vermicompost teas can turn relatively small amounts of compost into larger quantities of compost teas capable of covering large land areas or filling large reservoirs volumes (Diver, 2001). However, successful inoculations of organisms applied to plants depend not only on environmental factors but also on the adaptability and persistence of the organisms themselves (Van Overbeek et al., 1997). Other factors of survival include microbial ability to regulate physiochemical conditions including pH, nutrient concentrations, temperature, oxygen and water availability (Higa and Par, 1995).

Rhizosphere interactions

Complex ecological interactions enable disease suppression in soil. These ecological interactions include antagonistic mechanisms such as predation, parasitism, competition, inhibition and can even provide induced systemic resistance (ISR) and acquired systemic resistance (ASR) in plants (Vallance et al., 2011). However, this ecosystem-based disease suppression can be achieved in soilless agriculture as well. Eparvier et al. (1991) showed that Fusarium wilt was suppressed by both non-pathogenic *Fusarium* and *Pseudomonas*, and suppression was greatest when used in tandem. However, rhizosphere biocontrol in soilless culture is often limited by the lack of colonization space for the establishment and growth of beneficial species, and thus limits the amount of benefit they can contribute (Vallance et al., 2011).

Furthermore, root exudates may either inhibit or promote microbial growth, actively selecting organisms to colonize the root environment (Rosberg, 2014). These compounds usually select microbes for three important mechanisms: 1) to select for organisms which produce PGH, 2) to select for organisms which aid in nutrient mineralization in the rhizosphere, and 3) to select against pathogenic organisms by active antagonism or predator signaling. Inoculating systems with microbes that produce PGH has shown to increase biomass production, while inoculation with biocontrol microbes can either directly defend against pathogens or upregulate immune responses within the plant (Jimenez-Gomez, et al., 2016).

III. MATERIALS AND METHODS

The controlled environment experiment was conducted in a lab setting at Texas State University. Lettuce seeds of the cultivar Chicarita were used for the experiment purchased from Johnny's Selected Seeds©.

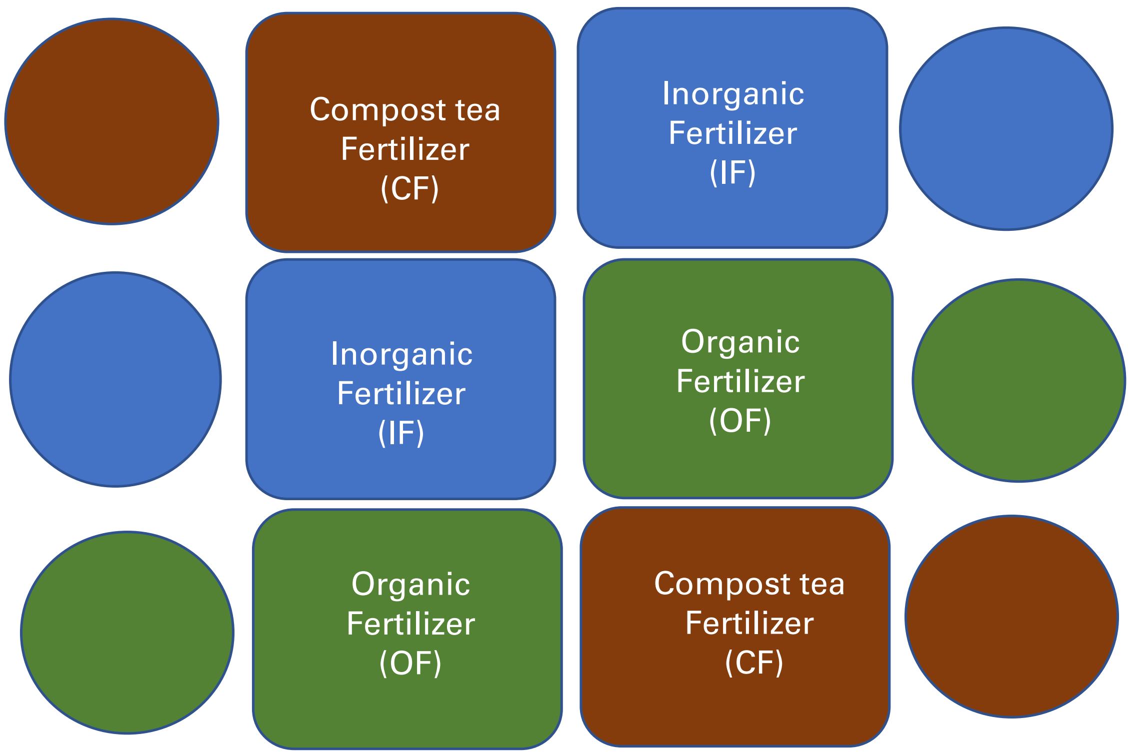

Figure 1. Experimental design.

Six tubs, each with a capacity of 27 L, were used as hydroponic ponds. Each tub was covered with a flat top Styrofoam raft, which had eight holes filled with two-inch net cups and rooter plugs spaced six inches apart, and three inches from the sides. Tubs were outfitted with aquarium air pumps and air stones rated for 37 L tanks. Tubs were then filled with 19 L of water and nutrient solution mixed according to each treatment (Figure 1).

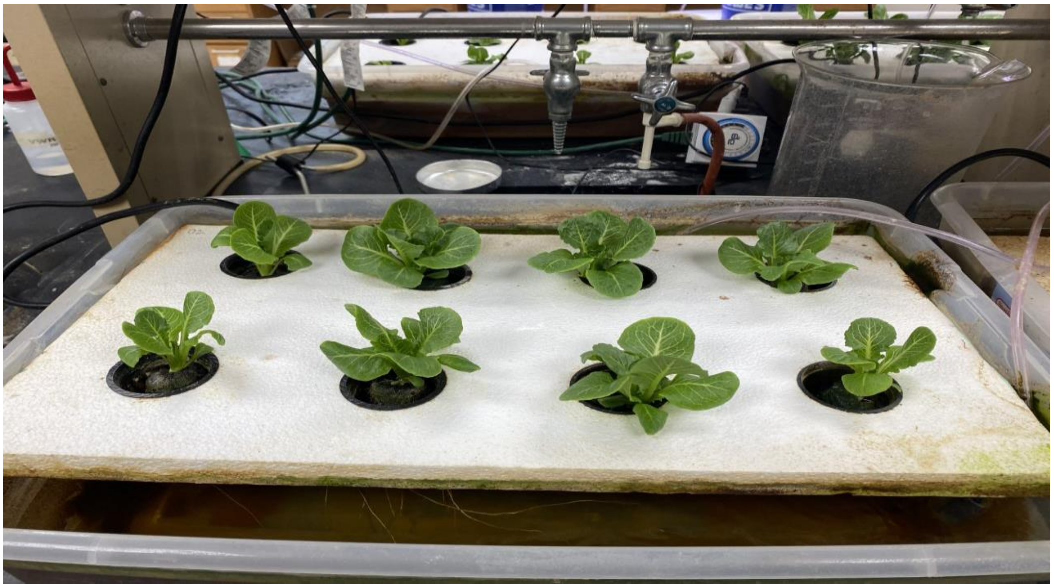

Figure 2. Example of floating raft system.

General Hydroponics inorganic fertilizers FloraGrow (2% N, 1% P, 6% K), FloraBloom (0% N, %5 P, 4% K,1.5% Mg, 1% S), and FloraMicro (5% N, 0% P, 1% K, 5% Ca, 0.01% B, 0.0005% Co, 0.01% Cu, 0.1% Fe, 0.05% Mn, 0.0008% Mo, 0.015% Zn) were added to two tubs using supplier guidelines of 3.96, 2.64, and 1.32 ml/ 1 L respectively (see Appendix). General Organics organic fertilizers BioThrive Grow (4% N, 3% P, 3% K, 0.5% Mg, 1% S, 0.002% Mo), CaMg+ (1% N, 5% Ca, 1% Mg), BioRoot (1% P, 1% K), and BioWeed (0.05% K) were added to two tubs using supplier guidelines of 2.6, 1.3, 2.6, and 1.3 ml/ 1 L respectively (see Appendix). Vermicompost tea was added to two tubs. pH adjustment solutions were avoided in all trials for consistency. Tubs contained eight lettuce plants each with two tubs per treatment, and three treatments total: nutrient salt fertilizer, organic fertilizer, and vermicompost tea fertilizer.

Vermicompost source and preparation

Vermicompost was sourced from Texas Worm Ranch in Garland, Texas. Vermicompost was microscopically observed and analyzed by Earthfort LLC to determine biologic diversity for the vermicompost producer (See Appendix). Feedstock for the vermicompost was mostly yard and landscape trimmings.

Vermicompost tea biofertilizer was brewed using 700 grams of vermicompost in mesh bags suspended in 19L of water with 50 ml of Medina© horticulture molasses and 25 grams of Soil Mender© kelp meal added. Compost tea recipe was taken from Ingham (2005) and modified from 50 gallons to 19 L for use in floating raft tubs. Compost tea was aerated using the bucket-bubbler method (Diver 2001), using Bubble Snake© aerators. The bucket-bubble method can take from 24-72 hours to produce a mature product (Lowenfels and Lewis, 2010), and tea was transferred to reservoirs after the full 72 hours.

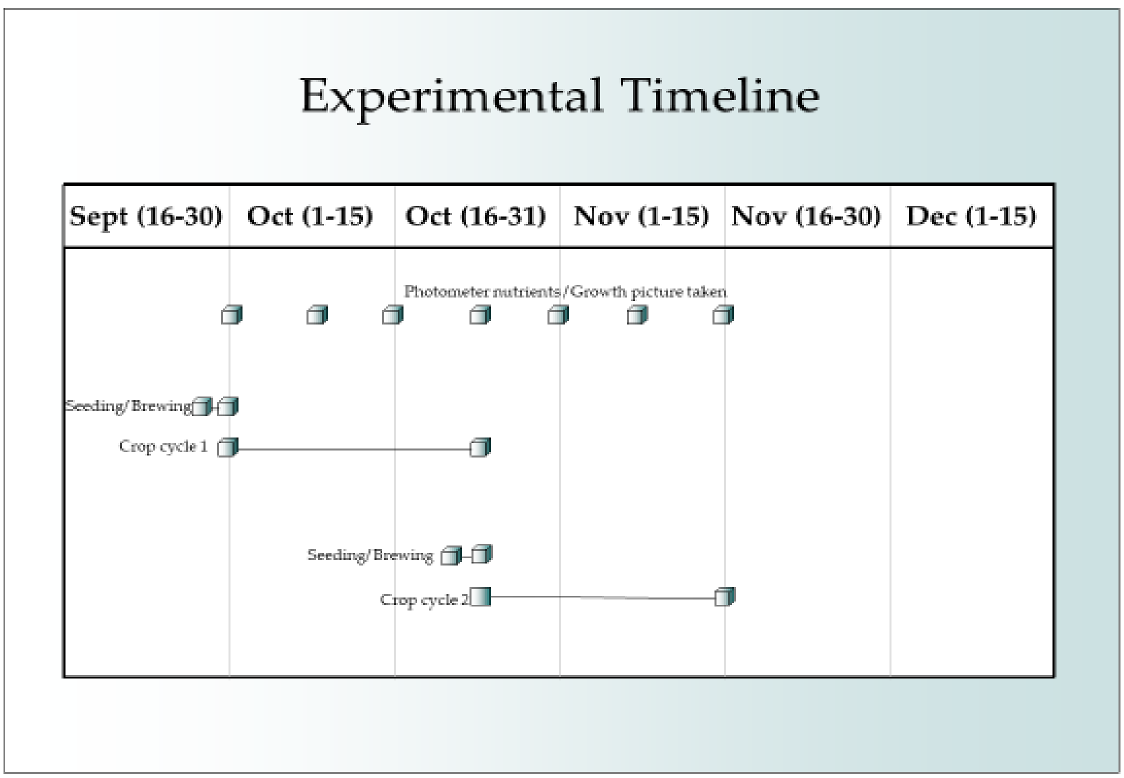

Figure 3. Experimental timeline.

Seeding

Pelleted seeds were imbibed in a paper towel and plastic bag using 50:50 mix of tap water and reverse osmosis water. On September 27, 2021 and October 19, 2021 (Figure 3), seeds were transferred to plugs after imbibing for 48 hours, when clay pellet coating began to split open, and were left under a grow light with adequate water for 72 hours to sprout (Figure 4). Sprouted seedlings with at least three leaves were then transferred into floating rafts on October 1, 2021 and October 22, 2021.

Figure 4. Germination station for Chicarita seedlings.

Maintenance

Reservoir volume was checked daily and was replenished up to 19L, if volume fell below, using municipal tap water. Fertilizer solutions and vermicompost teas were added weekly in accordance with manufacturer directions and compost tea brewing manuals. Fertilizer solutions were prepared in buckets for each treatment before transfer to reservoirs. Dissolved oxygen and electrical conductivity were checked daily to monitor for system malfunctions.

Nutrient Analysis

Nitrogen ions were measured daily and collected using a YSI Professional Plus Quatro© cable with ammonium (NH_4^+), nitrate (NO_3^-). Measurements were taken by submerging the YSI quarto probe in each reservoir solution and waiting for approximately three to five-minutes for readings to stabilize before recording.
Besides nitrogen, other nutrient levels were measured using a Hanna Instrument nutrient analysis photometer (HI 83325) and associated reagents, according to the user manual. Nutrient levels measured with the Hanna Instruments photometer included: phosphate, potassium, calcium, magnesium, and sulfate.

Measuring plant response

Chlorophyll levels were investigated as a production metric approximating photosynthetic activity. Chlorophyll levels were measured using a handheld Konica chlorophyll meter as a proxy for photosynthetic production. The instrument was calibrated at each start-up. Each sample included ten readings taken from random leaf tissue and averaged according to manufacture specifications. Readings were taken every three weeks.

Plant biomass was collected at the end of each three-week trial period and measured for fresh weight. Green leafy material was collected and weighed as wet above-ground biomass, and wet root biomass was also collected and weighed as below ground biomass. Once fresh weight was measured, the above- and below-ground biomass were then dehydrated at 70°C for 48 hours for dry weight measurements to observe for any biases from differences in water content of fresh weights.

Statistical analysis

Statistical analysis was performed in Excel using one-way Analysis of Variance (ANOVA) and Least Significant Difference (alpha = 0.05) for each treatment and each analyzed parameter: all biomasses, chlorophyll, root length, nitrate, ammonium, phosphate, potassium, calcium, magnesium, and sulfate.

IV. RESULTS AND DISCUSSION

Plant growth performance

Wet biomass production was significantly different when comparing all three treatments ($p \leq 0.05$). Both wet and dry biomass were not significantly different between OF and IF treatments and CF treatments produced lowest wet and dry biomass, which was significantly lower than either other treatment by Least Significant Difference. Lower biomass in vermicompost only solutions was also noted by Arancon et al (2019), although they showed statistically similar yields were observed with as little as 25% inorganic fertilizers added. However, Churilova and Midmore (2019) noted statistically similar yields with vermicompost leachate alone. All trials appeared to be pest and disease free, however since vermicompost teas are biologic systems anaerobic pockets could have formed and produced pathogens or phytotoxins as one possible mechanism to explain the lower production metrics. Another possible mechanism is the lack of pH adjustments may have allowed to system to get too basic or acidic.

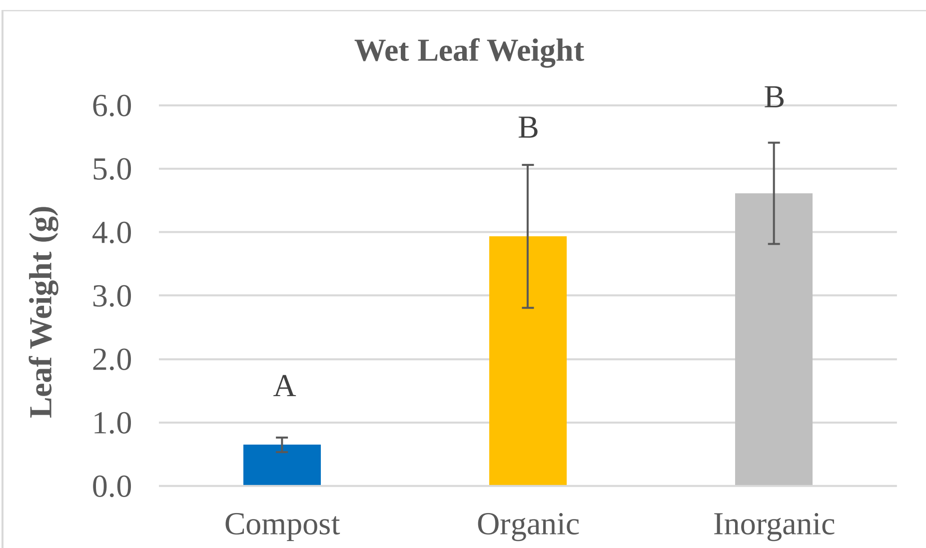

Figure 5. Average wet leaf weight. Similar letters indicate statistically similar means.

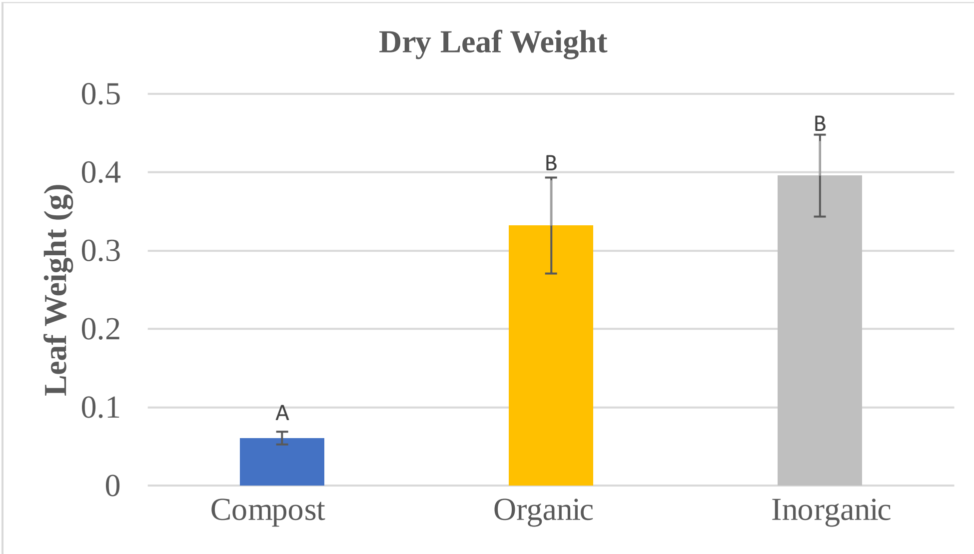

Figure 6. Average dry leaf weight. Similar letters indicate statistically similar means.

Chlorophyll trend consistently showed CF having lowest chlorophyll, IF having the highest chlorophyll, and OF treatment relatively in the middle, and all treatments were significantly different ($p \leq 0.05$). All treatments were significantly different from each other by LSD test, however, CF was significantly lower than both other trials. Significantly lower chlorophyll levels indicate chlorosis may be occurring in the CF treatments despite statistically similar nitrate levels, indicating nutrient uptake may be deficient.

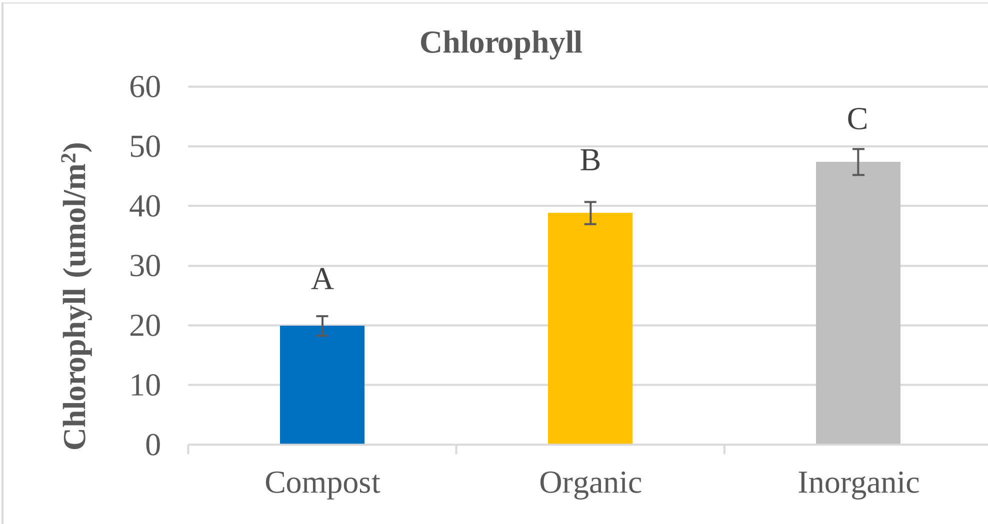

Figure 7. Average chlorophyll. Similar letters indicate statistically similar means.

Root observations

Root length ($p \leq 0.05$) was significantly different among treatments, however OF and IF treatments had the least significant difference by LSD analysis, and were not significantly different from each other. Both CF and OF had more lateral root hairs, while IF had no root hairs at all. The physiological makeup of the roots for the IF treatment were observed to be long straight primary roots, with no branching patterns or lateral root hairs observable on the primary roots emerging from the rooting plug. Roots were typically whiter in appearance as well. Alternatively, both the OF and the CF treatments had much greater observance of lateral roots and root hairs. Lateral roots were typically observed on every primary root emerging from the rooting plug. Interval of lateral roots appeared to occur approximately every 5-10mm in both CF and OF treatments. Roots were typically off-white or light tan in appearance. Although the trial was done in greenhouse pots, Lazcano et al. (2009) was able to show increased dry root biomass when vermicompost was incorporated into substrates at rates greater than 50% by volume.

CF treatments had observable biota grow after brewing. Namely, despite screening for organisms before being weighed, multiple earthworm observations occurred within both brewing bags in the second and third trials. Similarly, observations of fungal fruiting bodies were observed growing on both compost tea bags after the final trial. Neither the IF nor OF treatments had any observable macro-biota growth besides algae, which was minimal on the tub sides, and was removed between trials.

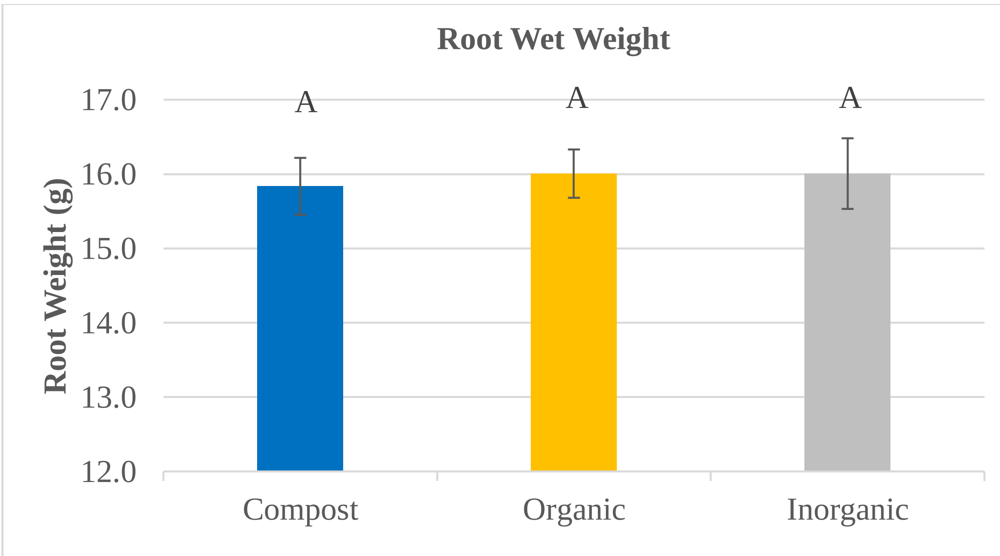

Figure 8. Average wet root weight. Similar letters indicate statistically similar means.

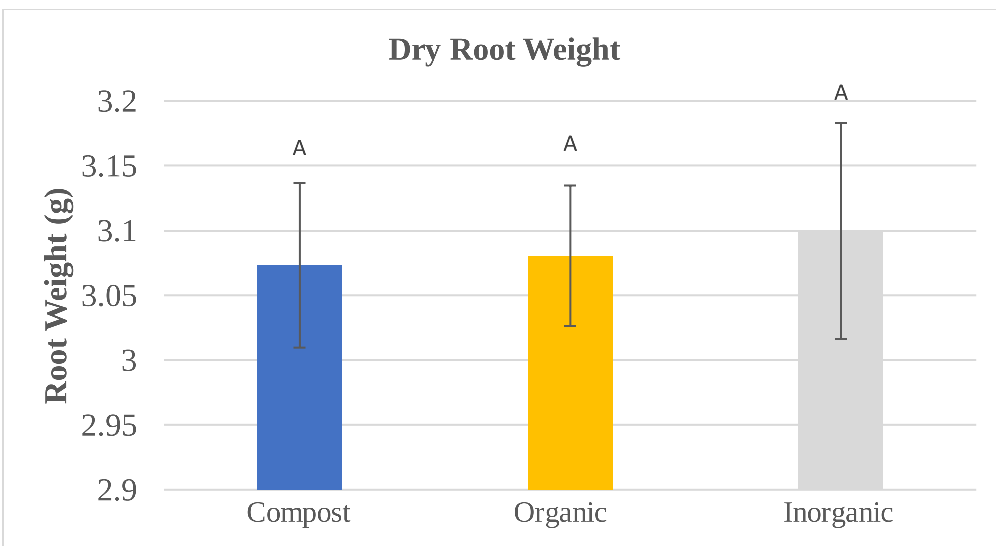

Figure 9. Average dry root weight. Similar letters indicate statistically similar means.

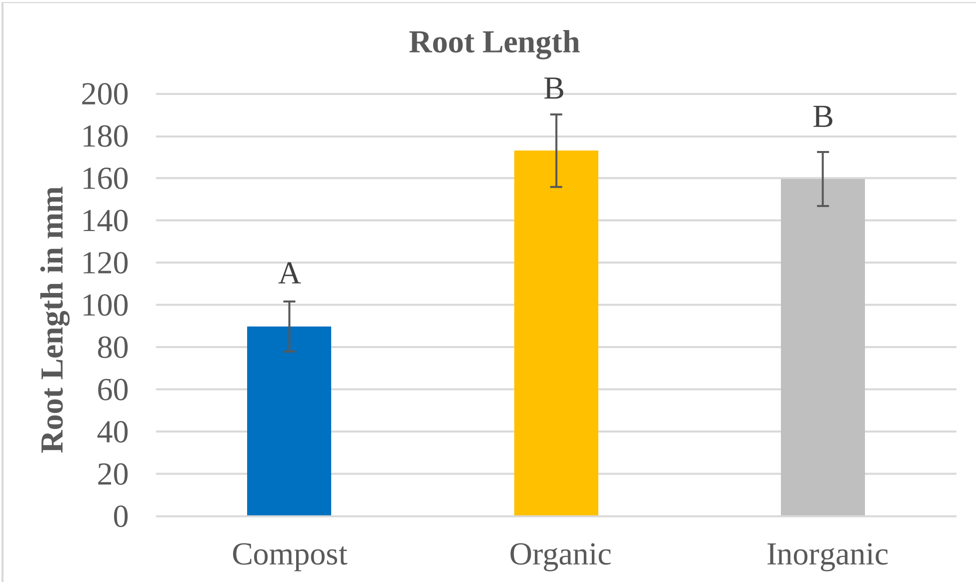

Figure 10. Average root length. similar letters indicate statistically similar means.

Table 1. Plant production metrics by treatment. * indicates significant difference.

Treatment	Wet Leaf Biomass	Dry Leaf Biomass	Chlorophyll	Wet Root Biomass	Dry Root Biomass	Root length
Compost	0.648 g*	0.060 g*	19.8 $umol/m^2$*	15.8 g*	3.07 g	89.8* mm
Organic	3.935 g	0.331 g	38.8 $umol/m^2$	16.0 g	3.08 g	173.1 mm
Inorganic	4.614 g	0.395 g	47.3 $umol/m^2$	16.0 g	3.09 g	159.7 mm

Nutrient performance

All treatments were not significantly different for nitrate but were significantly different for ammonium. CF treatments were not significantly lower, nor even lowest in nitrate but were significantly lower in ammonium by LSD.

Nitrate was elevated each week in IF treatments, as was expected using a commercial feeding schedule, however it seemed to dip and then rebound at the end of the week. OF treatments appeared to remain more constant from week to week but also seemed to dip and rebound at the end of the week. CF treatments seemed to ebb and flow between weeks in a cyclic nature, indicating rewetting to be a key factor to nutrient release, however nutrient concentration seemed to decline sharply over the week, with little tendency to rebound.

Ammonium was increased each week in IF treatments, however seemed to drop off rapidly as the week progressed. During the OF treatments ammonium regularly peaked during the second week of application, rather than increase weekly and also seemed to peak during the middle of the week. CF treatments seemed to stay relatively constant from week to week, and throughout the week.

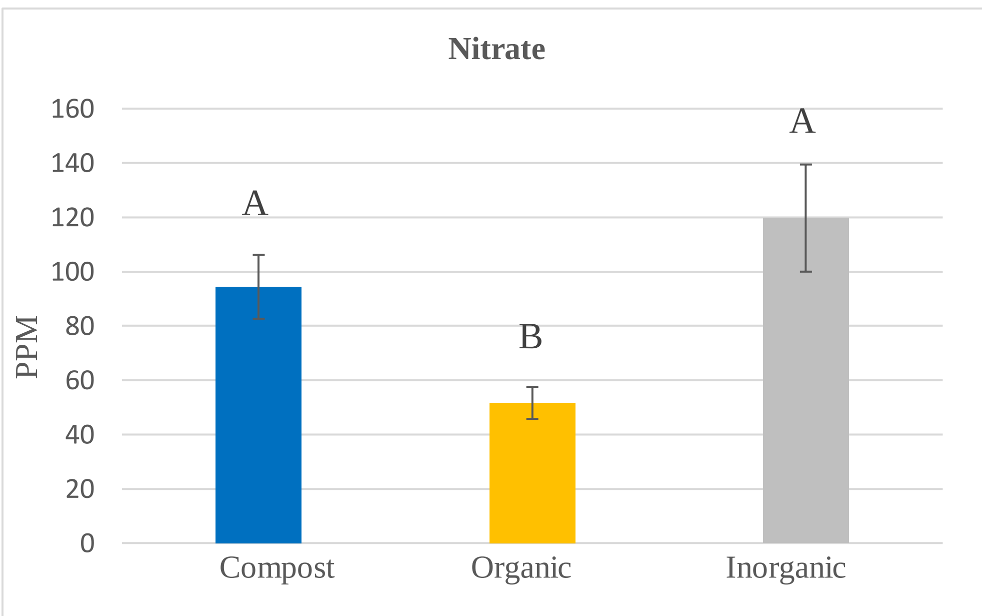

Figure 11. Average nitrate. Similar letters indicate statistically similar means.

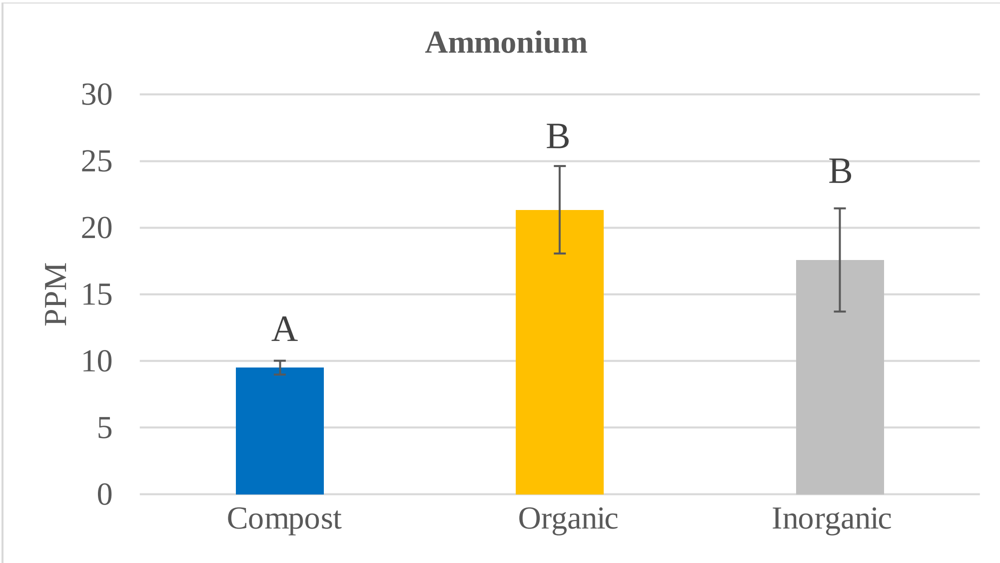

Figure 12. Average ammonium. Similar letters indicate statistically similar means.

Treatments did not produce significantly different amounts of phosphate, potassium, calcium, or magnesium (*p*≤0.05). However, sulfate was significantly different. Although CF was not significantly different from IF, but both were lower than OF treatments. Brace (2017) also noted that other nutrients vary widely based on vermicompost source as well. This is observable as Edwards et al. (2011) suggested that vermicompost has sufficient micronutrients to meet plant requirements and that this may translate to teas and leachate, while Arancon et al. (2019) suggested the vermicompost added to reservoirs in their trials were lacking in micronutrients.

Phosphate was not significantly different among means, and CF was not lowest among the trials. Phosphate is a major plant nutrient for all plants but particularly flowering crops, indicating VC teas may also have potential for flowering crops or trees.

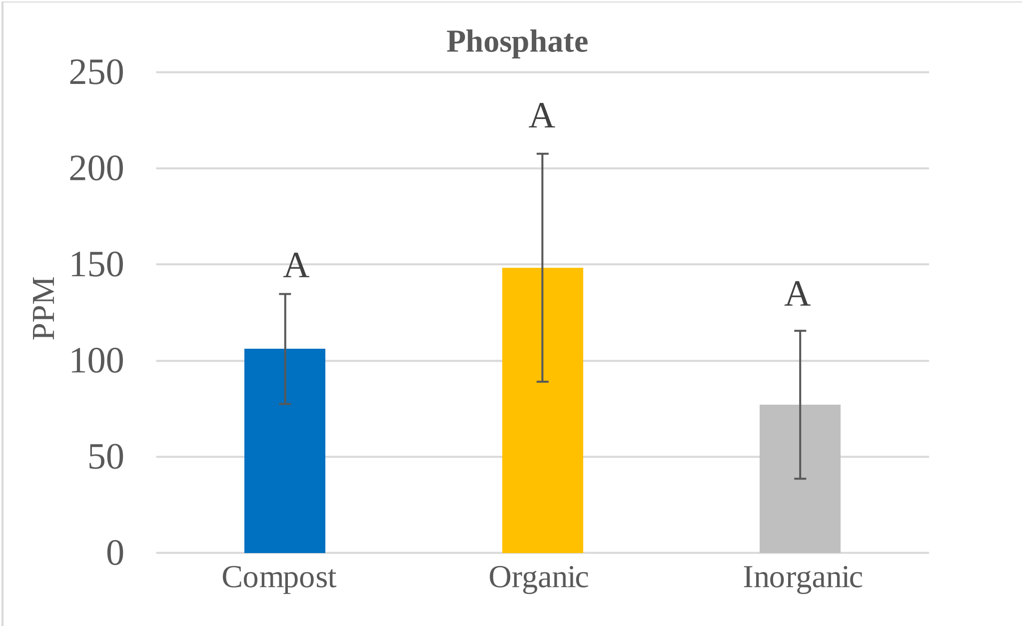

Figure 13. Average phosphate. Similar letters indicate statistically similar means.

Potassium was not significantly different among means, and CF was not the lowest. Since potassium is one of the main plant nutrients examined with guaranteed analysis, the fact that it is not significantly lower shows promise for VC teas at least as an amendment.

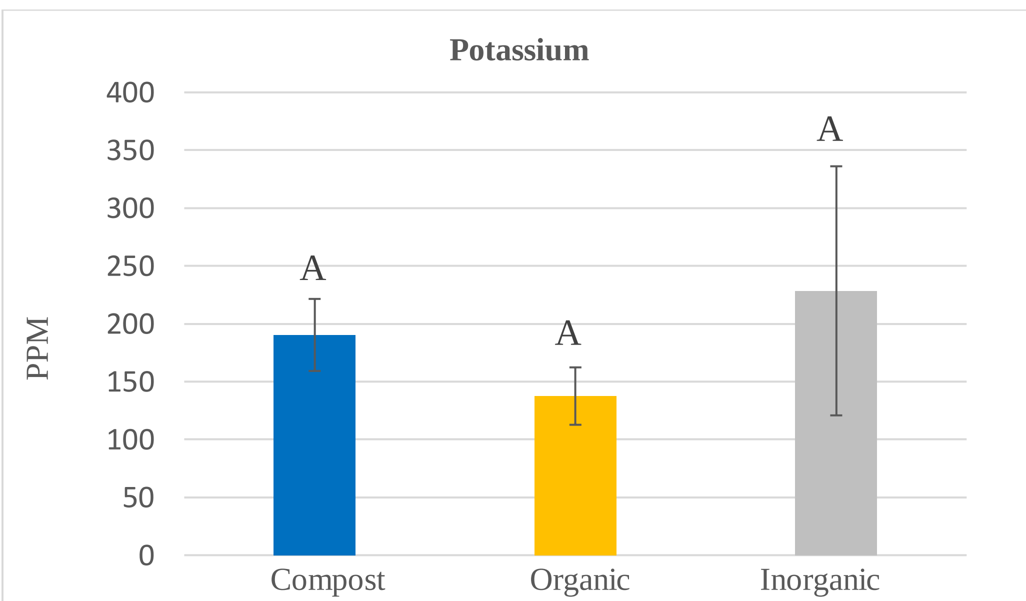

Figure 14. Average potassium. Similar letters indicate statistically similar means.

Calcium was not significantly different among means, and CF treatments produced the highest means.

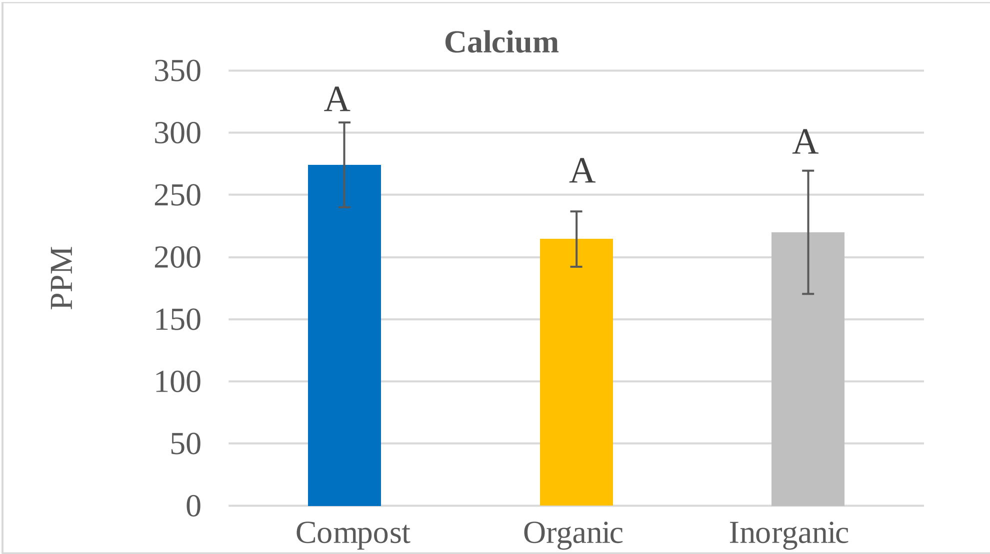

Figure 15. Average calcium. Similar letters indicate statistically similar means.

Magnesium was not significantly different among means, and CF treatments produced the highest means. Magnesium had wide variation in vermicompost, since nutrient mineralization is based off selected microbial populations, it is possible these populations may have experienced a wide range of activity as well.

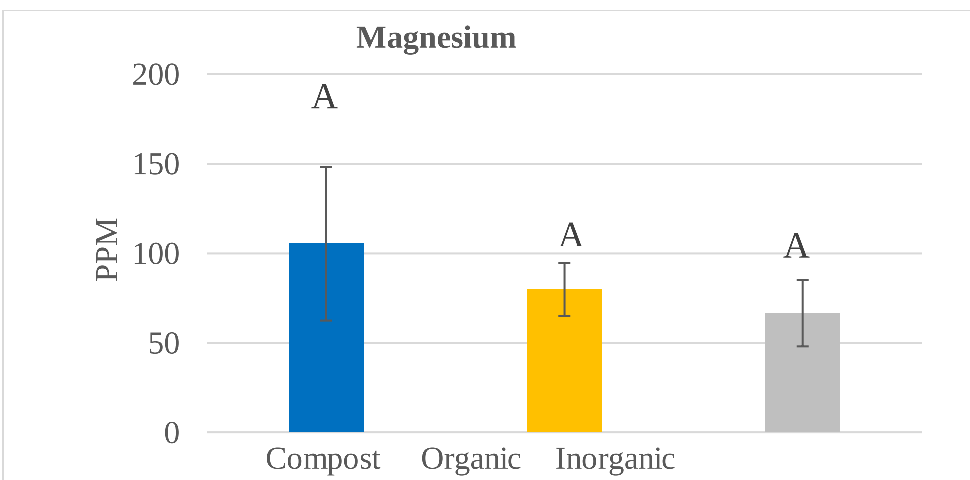

Figure 16. Average magnesium. Similar letters indicate statistically similar means.

Sulfate was significantly different amount treatments. CF and IF were significantly lower than OF and CF had the lowest mean. The large difference in sulfur levels for the OF trial is likely due to a higher baseline of sulfur in organic fertilizers to help feed selected microbial populations. Sulfate was not a nutrient that Edwards et al. (2011) indicated would be sufficient in vermicompost, however it was statistically similar to the IF treatment.

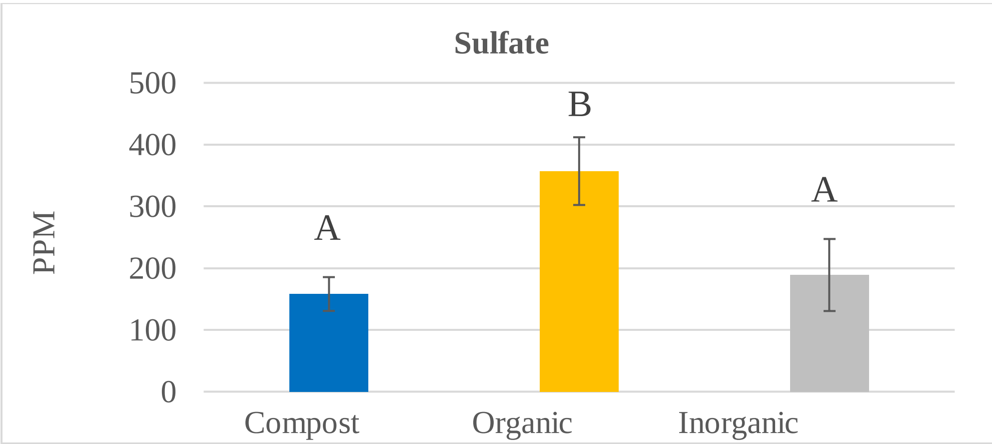

Figure 17. Average sulfate. Similar letters indicate statistically similar means.

Table 2. Nutrient levels by treatment. * indicates significant difference.

Treatment	NO_3	NH_4	P	K	Ca	Mg	S
Compost (ppm)	94.4	9.5*	106.1	190.3	274.2	105.2	158.1
Organic (ppm)	51.6	21.3	148.3	137.5	214.5	79.7	357.1*
Inorganic (ppm)	119.7	17.6	77.0	228.4	219.9	66.4	188.9

Conclusion

Results indicate that from a nutrient standpoint, levels of soluble nitrate in vermicompost teas are statistically similar to commercial nutrient fertilizers, however this same trend was not observed with soluble ammonium, as it was significantly lower in CF. All other nutrients were also not significantly different, except for sulfate. Total nutrient levels (except for ammonium and sulfate) in vermicompost teas seem to be competitive with commercial fertilizers although may require additional amendments or may require use as amendments themselves since this trend did not translate to any other production method except root weights, which were weighed with substrate to avoid damaging root structures and may have been biased. Significantly smaller yields, chlorophyll levels, and root lengths were produced with compost fertilizer alone, and these yields were not commercially viable or competitive, despite the statistically similar nutrient profiles within the reservoirs.

Further research

The use of the substrate, nutrient solution, and rhizosphere as colonizable surface areas such as Vallance et al., (2011) suggests should be investigated further. Since the ecosystems within vermicompost which produce plant hormones can successfully impart these biochemical fractions into the nutrient solutions and rhizosphere with teas, then it is plausible successful colonizers of these ecosystems could impart long-term biochemical delivery to the reservoirs themselves, including nutrient scavenging of nitrate from the atmosphere, and phosphorous from hydroponic substrates (peat moss, rockwool, and clay pebbles).

In addition to nutrient testing, screening for key biochemical additions such as plant growth hormones like gibberellic acid such as Arancon et al. (2019) observed, could also greatly advance our understanding of the benefits of vermicompost tea since commercial fertilizers often lack plant hormone additions which can increase growth or even provide acquired systemic resistance (ASR) to pests and disease. Compost teas could therefore also find use as biologic primers for establishing microbial reservoir populations if biological oxygen demand (BOD) can be met throughout the growing cycle.

Further investigation into the total amount of nutrients which can be extracted from vermicompost and the optimal frequency of extraction could aid in the understanding of best practices for brewing, as well as expected nutrient contribution.

APPENDIX SECTION

Table 1. Feeding Schedule Table for General Organics.

GENERAL ORGANICS

Soil / Soilless Feeding Schedule *all amounts: ml / Gallon*	BioThrive Grow	BioThrive Bloom	CaMg+	Bio Root	Bio Weed	Bio Bud	Bio Marine (optional)	Diamond Black (optional)
Week 1 Rooted Seedlings (18 Hour Photoperiod)	5ml	–	5ml	5ml	2.5-5ml	–	5-10ml	5-10ml
Week 2 Early Growth	10ml	–	5ml	10ml	2.5-5ml	–	5-10ml	5-10ml
Week 3 Late Growth (repeat for extra weeks of growth)	10ml	–	5ml	10ml	2.5-5ml	–	5-10ml	–
Week 4 Transition (12 Hour Photoperiod)	10ml	–	5ml	10ml	2.5-5ml	–	5-10ml	–
Week 5 Early Bloom	–	10ml	5ml	10ml	–	2.5ml	5-10ml	–
Week 6 Early Bloom	–	10ml	5ml	–	–	2.5ml	5-10ml	–
Week 7 Mid Bloom (repeat for extra weeks of blooming)	–	10ml	5ml	–	–	2.5ml	5-10ml	–
Week 8 Mid Bloom	–	10ml	5ml	–	–	2.5ml	5-10ml	–
Week 9 Late Bloom	–	10ml	5ml	–	–	2.5ml	–	–
Week 10 Late Bloom (repeat for extra weeks of blooming)	–	10ml	2.5ml	–	–	–	–	–
Week 11 Ripen / Rinse	–	–	–	–	–	–	–	–

Soil Gardening Tips:
- Keep nutrient solution temperature below 75° F (24° C).
- Use dechlorinated water for best results.
- Adjusting pH is not nessessary.
- Double BioThrive application rates for heavy feeding plants.
- Apply nutrient solution within 1 hour of mixing or aerate solution until application.
- BioMarine and Diamond Black are optional.
- Advanced soil growing techniques can be found at: http://generalhydroponics.com/site/index.php/resources/learning_center/

Table 2. Basic Applications Table for General Hydroponics.

Basic Applications Table	FloraGro tsp/gallon	FloraGro ml/100 liters	FloraMicro tsp/gallon	FloraMicro ml/100 liters	FloraBloom tsp/gallon	FloraBloom ml/100 liters
Cuttings and Seedlings	1/4	33	1/4	33	1/4	33
General Purpose - Mild Vegetative	1	132	1	132	1	132
Aggressive Vegetative Growth	3	396	2	264	1	132
Transition to Bloom	2	264	2	264	2	264
Blooming and Ripening	1	132	2	264	3	396

These values are intended to be used without supplements. When using supplements, please refer to genhydro.com for complete Feed Programs.

Table 3. Vermicompost Biologic Assays.

Nematode Detail

Report prepared for:
Texas Worm Ranch
Heather Rinaldi
2636 National Circle
null
null, TX 75238 USA

Report Sent: 13 Mar 2020
Sample #: 01-131741
Unique ID: Texas Worm Ranch
Invoice Number: 18596
Sample Recieved: 02 Mar 2020

earthfort

Earthfort, LLC
635 SW Western Blvd
Corvallis, OR 97333
+1 (541) 257-2612
info@earthfort.com
http://earthfort.com

For interpretation of this report please contact your local Soil Steward or the lab.

 # per gram
Classified by type and identified to genus.
If section is blank, no nematodes identified.

Nematode Genus	number/g	Units	Group	Common Name
Butlerius	77.46	number/g	Bacterial Feeders	
Cuticularia	18.23	number/g	Bacterial Feeders	
Rhabditidae	123.02	number/g	Bacterial Feeders	
Mononchoides	13.67	number/g	Predatory	

Assay	Below Range	Desired Range	Above Range	Range	Result
Dry Weight				0.2 - 0.85	0.29
Active Fungi				> 3 µg/g	93.38 µg/g
Total Fungi				> 300 µg/g	7,498.00 µg/g
Active Bacteria				> 3 µg/g	1,059.31 µg/g
Total Bacteria				> 300 µg/g	2,748.90 µg/g
TF:TB				0.1 - 10	2.73
AF:TF				< 0.1	0.01
AB:TB				< 0.1	**0.39**
AF:AB				0.1 - 10	**0.09**
Flagellates				> 10000 /g	145,842.90 /g
Amoebae				> 100000 /g	1,458,428.96 /g
Ciliates				< 16043 /g	14,586.00 /g
Nematodes				> 10 /g	232.37 /g

Assay Name	Result	Units	Desired Level	Commentary
Organism Biomass Data				
Dry Weight	0.29	N/A	0.20 to 0.85	Within normal moisture levels.
Active Fungi	93.38	µg/g	> 3.00	Fungal activity within normal levels. -
Total Fungi	7,498.00	µg/g	> 300.00	Good fungal biomass. - Good fungal diversity. Hyphal diameter: 1.5 to 7 µm.
Hyphal Diameter	2.90	µm		Good balance of fungi. -
Active Bacteria	1,059.31	µg/g	> 3.00	Bacterial activity within normal levels.
Total Bacteria	2,748.90	µg/g	> 300.00	Good bacterial biomass. -
Actinobacteria	**177.84**	µg/g	< 40.00	
Organism Biomass Ratios				
TF:TB	2.73		0.10 to 10.00	Balanced fungal and bacterial biomass.
AF:TF	0.01		< 0.10	Good fungal activity.
AB:TB	**0.39**		< 0.10	In thermal compost >= 0.10 could indicate unfinished compost. In worm compost this not an issue.
AF:AB	**0.09**		0.10 to 10.00	Fungal dominated, becoming more bacterial.
Protozoa (Protists)				
Flagellates	145,842.90	number/g	> 10,000.00	Should provide a good inoculum of protozoa.
Amoebae	1,458,428.96	number/g	> 100,000.00	
Ciliates	14,586.00	number/g	< 16043.00	
Nitrogen Cycling Potential	300+	lbs/acre		Nitrogen levels dependent on plant needs. Estimated availability over a 3 month period
Nematodes				
Nematodes	232.37	number/g	> 10.00	Good numbers, but lacking diversity.
Bacterial	218.70	number/g		
Fungal	0.00	number/g		
Fungal/Root	0.00	number/g		
Predatory	13.67	number/g		
Root	0.00	number/g		
Miscellaneous Testing				
E.coli	Not Ordered	CFU/g	< 800.00	For most areas, the maximum E.coli CFU/g is 800 - 1000. Please check your local regulations for more information. -
pH	Not Ordered			
Electrical Conductivity	Not Ordered	µS/cm	< 1000.00	

Compost Notes:

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