VERMICOMPOST APPLICATION AS A FERTILIZER SOURCE AND SUBSTRATE AMMENDMENT FOR SEEDLINGS AND TRANSPLANTS: PRACTICAL APPLICATION AND MICROBIAL ACTIVITY ANALYSIS

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ABSTRACT

VERMICOMPOST APPLICATION AS A FERTILIZER SOURCE AND SUBSTRATE AMMENDMENT FOR SEEDLINGS AND TRANSPLANTS: PRACTICAL APPLICATION AND MICROBIAL ACTIVITY ANALYSIS

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Fertility management of seedlings/transplants can be difficult especially when they are grown in an organic production system. Transplants are grown in small containers with substrates that usually contain a low nutrient holding capacity. Organically supplied nutrients are primarily slow release and depend on biological processes to convert organically bound nutrients into a plant available form. Temperature influences both microbial activity and plant growth. Little information is currently available on the effect of vermicompost additions on microbial activity and subsequent plant performance in soilless substrates. Commercially produced vermicompost (VC) is a worm processed form of compost that can be used to provide fertility in organic systems. The source and method for producing VC are extremely variable. Therefore, the objective of this work was to test performance of seedlings/transplants in response to fertilizers, temperature, and sources of vermicompost. In addition, the microbial activity in vermicompost will be determined. Germination and transplant experiments were conducted using various quantities, sources and application methods of VC. Seeds of pepper ‘Calwonder’ (*Capsicum annuum* L.), tomato ‘Rutgers 39’ (*Solanum lycopersicum* L.), petunia ‘Celebrity White F1’ (*Petunia x hybrid)* and snapdragon ‘Rocket Mix F1’ (*Antirrhinum majus* L.) were included. Topdressing VC instead of incorporating led to higher fresh weight (FW) of tomato, pepper,

petunia, and snapdragon. The source of VC had significant effect on plant growth of tomato and peppers in seedling and transplant stages. Vermicompost extract (VCE) applied at 5 applications per week was adequate to produce marketable seedlings of the four species above. A trial was conducted to compare the performance of several different granular organic fertilizers on 10 cm containers of ‘Celebrity’ tomato transplant growth at average daily temperatures of 10, 15, or 20 °C. The results indicate that the fertilizers perform well at 15 and 20 °C, but plant growth and nutrient availability was reduced at 10 °C. Results indicate that at 15 and 20°C Sustane, Verdanta, and Microstart can be substituted for conventional synthetic fertilizers for quality plant growth and decreased leaching. In another trial, VC, autoclaved VC and Sustane were applied in six combinations to determine if the microbial community in VC facilitated nitrogen mineralization. Plant growth and microbial parameters were measured at 2 week intervals for 6 weeks. By week 6, the FW of trts with VC or autoclaved vermicompost (AVC) applied performed better than the control. Very little difference in plant growth was found between VC or AVC treatments. Microbial activity measurements found that most of the activity of the microbes was concentrated in week 0 and 2. Respiration decreased in week 4 and then increased in week 6. The microbial activity was greatest in the first 2 weeks and coincided with the highest levels of N in the substrate and leachate.

BIOGRAPHICAL SKETCH

Stephanie (Beeks) Brace was born in NorthWest Arkansas to Gina and Jesse Beeks. She has one younger sibling, Jonathan. Growing up on a cattle and small vegetable farm she learned to appreciate and ask where her food was produced. She attended the University of Arkansas after graduating High School with Honors. After years of searching she discovered a love of growing plants and working in greenhouses. She graduated in 2007 with a B.S. in Horticulture, Turf and Landscape Science. After two years working as a landscaper Stephanie decided to continue her career in academia and received her M.S. in Horticulture in 2011, from the University of Arkansas. Her work with biodegradable containers and subirrigation systems furthered her love of research and sustainable horticulture practices. Next she moved to Ithaca, NY to attended Cornell University. She studied Organic greenhouse vegetable transplant production and nutrient management. While in Ithaca she met her husband, Adam, and the two now have two daughters, Evelyn and Lillian.

DEDICATION

This dissertation is dedicated to my family and friends who have supported me throughout everything. To my parents who instilled a love of learning and are always there to listen and support me. To my brother who can always make me laugh and reminds me to enjoy the simple things. To the wonderful and amazing friends that I made in Ithaca. You all helped make moving across the country the best decision of my life. I dedicate this especially to my husband, Adam, who has supported me through everything including: pregnancies, new parenthood, and long hours of writing, editing, statistical analysis and practice presentations. I cannot imagine completing this journey without you, Evelyn, and Lillian.

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I want to acknowledge the many individuals who have supported me through this process over many years. Including my family and friends who made moving to Ithaca a wonderful adventure. My committee members, Eric Nelson, Steve Reiners, and Marty Petrovic who have offered guidance and support throughout this journey. Neil Mattson my advisor who was willing to accept me into his program. He has helped every step along the way and is always available to mentor and answer questions. I would also like to acknowledge the USDA-NRCS; WormPower, LLC; TSF; and others who provided financial support to allow me to complete my Ph.D.

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Chapter 1: Vermicompost source, application method, and quantity as the sole fertilizer for bedding plant and vegetable seedlings and transplants

Abstract

Fertility management of seedlings and transplants can be difficult especially when they are grown in an organic production system. Transplants are grown in small containers with substrates that usually contain a low nutrient holding capacity. Commercially produced vermicompost (VC) is a worm-processed form of compost that can be used to provide fertility in organic systems. The feedstocks (sources) and methods for producing VC are extremely variable. Therefore, the objective of this experiment was to test performance of seedlings/transplants in response to VC as the sole fertilizer source. Germination experiments were conducted using various quantities, sources and application methods of VC. Plant materials used included pepper 'Calwonder' (*Capsicum annuum* L.), tomato 'Rutgers 39' (*Solanum lycopersicum* L.), petunia 'Celebrity White F1' (*Petunia x hybrid)* and snapdragon 'Rocket Mix F1' (*Antirrhinum majus* L.) at both the seed germination stage for seedling production and at the transplant stage in 10 cm containers. Non-aerated VC extract (VCE) was also tested as a fertilizer source. The substrates used had various VC sources, VC application volumes, and frequency of VCE drenches. Topdressing VC instead of incorporating led to higher FW of tomato, pepper, petunia, and snapdragon seedlings. The source of VC had significant effect on plant growth of tomato and peppers in seedling and transplant stages. VCE applied at 5 applications per week was adequate to produce marketable seedlings of the four species above.

Introduction

The demand for organic products has risen steadily in the U.S. Wholesale value of vegetable, melon and potatoes increased from 690 million in 2007 to 1.33 billion in 2014 for (USDA 2014; USDA 2007). Organic production in greenhouses has also risen and was valued at 27 million in 2014, (USDA 2014). There is need for quality organic vegetable and floriculture transplants for organic greenhouse and field producers. Transplants aid people in creating uniform disease free plants earlier in the season than they could otherwise produce them (Russo, 2005). This gives the plants a longer growing season and more time to yield produce. Fertility management has been cited as one of the largest barriers to producing these plants since organic growers do not have as many tools to correct nutrient deficiencies as conventional growers (Burnett et al., 2009).

Thermophilic composts have long been used as media amendment to supply some fertility, to increase organic matter, and because they divert waste from landfills (Alexander, 2009; Carlile, 2008). Composts can be used for organic production as long as they meet the approval of the U.S. National Organic Program (NOP) guidelines (2015). There are also independent agencies such as the Organic Materials Review Institute (OMRI) that check and review products for certified organic production (Organic Materials Review Board, 2014). The NOP has stated that composts must not cause buildup of heavy metals in soil and must be made from allowed feedstock materials (non-synthetic), and composts must be heated to 55°C for three or more consecutive days (NOP 2015). There are some issues with compost including: immature compost can release high levels of ammonia and volatile organic compounds as well as tie up nitrogen and reduce its availability for growing plants (Alexander, 2009; Carlile, 2008).

The shortcomings of compost have, in part, led to an increased interest in vermicompost (VC). VC is a worm worked material that can be produced from food scraps, manures, yard waste, or other organic inputs. Similar to compost one way to have manure based VC approved for organic production is to heat the feedstock to 55 °C for three or more consecutive days before vermicomposting. Then the material is applied in thin layers at 1-3 day intervals to maintain aerobic conditions, moisture levels are held between 70-90%, and high temperatures (>35°C). This is continued until a finished product is produced which can take varying lengths of time depending on vermicomposting system (USDA 2011).

The way a VC is produced or used makes a difference in the final product and the plants grown in it (Belda et al., 2013; Surrage 2010; Tringovska 2014; Yang, 2015). Studies have been conducted on application rate of VC used as a fertilizer or incorporated as a substrate replacement for peat in marigold (*Tagetes species* L.), tomato (*Solanum lycopersicum* L.), pansies (*Viola wittrockiana*) and primulas (*Primula vulgaris* L.) (Chander et al., 2015; Lazcano & Dominguez, 2010; McGinnis et al., 2009; Moreno-Resendez et al., 2013; Zaller 2007). Marigolds were grown in containers with sand and either VC, pig manure or farmyard manure (Chander et al., 2015). Plant height and spread increased significantly with the addition of up to 1 kg manure kg soil^{-1}. Pansies and primula grown in peat-based media with 5-25% pig manure VC exhibited a general decrease in growth at the higher application rates of 20 and 25% for both species (Lazcano & Dominguez, 2010). Hibiscus plants were grown in pine bark substrates with pig manure based VC and conventional fertilizer added (McGinnis et al., 2009). The treatment with VC and N as the only added fertilizer performed better in terms of dry weight (DW) than the pine bark with conventional N, P, and K added. Tomato seedlings were larger when grown with pig manure based VC incorporated into a commercial substrate at 25-50% VC by volume (Moreno-Resendez et al., 2013). Tomato plants were grown in a peat based substrate with 0-100% VC added to replace the peat (Zaller, 2007). The results showed that VC effect on plant growth depended on cultivar. For example, two CV of tomato had early emergence of seedlings when 100% VC was applied. The third variety had earliest emergence at 20% VC.

Non-aerated VC Extracts (VCE), or aerated vermicompost teas (VCT) can have plant growth benefits (Marquez-Quiroz et al., 2014; Avila-Juarez et al., 2015; Ayyobi et al., 2013; Yatheesh et al., 2010; Pant et al., 2011). Extract is made by soaking and stirring VC solids into water and stirring occasionally while minimizing aeration of the solution. VCTs are aerated during preparation and must be used within a few hours of production, whereas extract has a longer shelf life. VCE and VCT must be made with potable water and organic compliant VC, equipment must be cleaned and sanitized before use (USDA 2006). In a greenhouse study 'Saladette' tomatoes were grown using combinations of sand compost and VC (Marquez-Quiroz et al., 2015). The yield and plant size was largest for the treatment with conventional fertilizer and sand and smallest with the treatment of sand, compost, VC and VCT. The best organic treatment for plant growth and yield was found with the VCT and sand treatment. VC and VC leachate (VCL) from three sources was used to grow tomato plants (Avila-Juarez et al., 2015). The VCL treatments decreased accumulation of phytotoxic ions such as Mn and B by 99% but none of the treatments affected plant growth parameters. Peppermint plants were treated with VC, conventional fertilizer, and VC leachate (Ayyobi et al., 2013). Plant height and number of leaves were increased with the application of VC or VC leachate as compared to the conventional fertilizer and non-fertilized control.

Mulberry plants were foliar sprayed with VCE or cow manure wash (liquids) in combination with VC applied to the substrate (Yatheesh et al., 2010). Both of the foliar sprays enhanced the shoot mass and leaf area of the plants as compared to conventional fertilizer and organic soil amendments. Pak choi plants were treated once per week for 4 weeks with 10%, 5%, 3%, and 1% VCT (Pant et al., 2011). The plant growth response was greatest in the 5% and 10% treatments. VCT increased plant shoot and root growth regardless of other additions.

Clearly, from existing literature, VC and VCE can have both beneficial and negative impacts on plant growth depending on the experiment. Therefore, the objective of this research is to conduct a series of expeirments to determine effects of commercially available VC and VCE used as the sole organic fertilizer in greenhouse environments to grow quality vegetable and floriculture seedlings and transplants.

Materials and Methods

A series of greenhouse experiments with VC and VCE were conducted in a glass-glazed greenhouse at Cornell University, Ithaca, NY. Greenhouse temperature set points were 18 °C (heating) and 20 °C (ventilation) with ambient light levels and photoperiod. Experiments were conducted at two different growth stages 1) germination and growth of seedlings for four to five weeks after seeding in 200-cell seedling trays and 2) growth of transplants in 10-cm containers for six weeks following transplanting. All seeds were from Harris Seeds (Rochester, NY). The germination trays used were 200 cell germination trays (18.9 mL $cell^{-1}$, T.O. Plastics, Inc. Clearwater, MN) that had been cut into 4 sections to create 50 cell trays for experiments 2 and 3.

Trays for experiment 1 were cut into 8 sections of 25 cells each. Experiments 2, 3, 5 and 6 used VC or VCE from Worm Power, LLC (Avon, NY). The 10-cm containers (experiments 4, 5, and 6) had a volume of 495 ml (Dillen Products, Middlefield, OH). The germination experiments were terminated four weeks after seeding for vegetables and 5 weeks for floriculture crops; germination percentage was recorded (percent of seeds in which radical emergence occurred) as well as the shoot fresh and dry weights (following 3 d in an oven at 70 °C) of 10 representative seedlings (seedlings pooled together for one measurement) from the 25- or 50-cell tray. The transplant (10 cm) experiments were terminated six weeks after transplanting. Data were collected on plant height, from the substrate surface to the tallest part of each plant; plant width, the average of two measurements, width at the widest part of the plant and at a 90° angle; leaf chlorophyll index using a soil plant analysis development machine (SPAD) of three recently mature leaves per plant (Minolta Chlorophyll Meter SPAD-502; Spectrum Technologies, Plainfield, IL); shoot fresh weight (FW) as destructively harvested at the substrate surface; and dry weight following 3 d in an oven at 70 °C.

Experiment 1: VC source for seedlings

This experiment was conducted to compare performance of four different VCs applied at different incorporation rates on germination and growth of seedlings. VC from one of four sources (Worm Power, RT Solutions, LLC Avon, NY; TerraVesco Sonoma Valley Worm Farm, Sonoma, CA; Pure Black Castings, Vermitechnology Unlimited, FL; Mega Worm, Vital Earth, Central Point, OR) was incorporated at 0%, 2.5%, 5%, 10% or 20% by volume into a peat:perlite (75:25) substrate amended with 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone (Oldcastle Industrial

Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0. Seeds of pepper (*Capsicum annuum* L.) 'Lady Bell' and tomato (*Solanum lycopersicum* L.) 'Celebrity' were then seeded in germination trays and covered with a ca. 3 mm layer of fine vermiculite. Trays were watered as needed with tap water. A representative sample of each VC was sent to a commercial laboratory (Agricultural Analytical Services Lab, Pennsylvania State University, University Park, PA) for nutrient analysis of the four VC sources (Table 1). The experiment was conducted from May 5, 2014- June 2, 2014.

The experiment was conducted as a completely randomized design. Each 25-cell tray was an experimental unit and there were five experimental units per treatment per cultivar. An analysis of variance was conducted to determine whether measured parameters were affected by VC volume and source. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VC volume within a source. Statistical procedures were conducted in JMP Pro 10 (SAS Institute Inc., Cary, NC).

Experiment 2: VC application method for seedlings

This experiment was conducted to compare application methods (substrate-incorporated vs. top-dressed) of vermicompost on germination rates and seedling growth. Based on its performance in experiment 1, the VC chosen for the experiment was Worm Power (Table 1). Sun Gro Sunshine Natural and Organic #1 (Sun Gro Horticulture, Bellvue, WA) a peat: perlite blend was used as the base substrate for germination of seedlings in 50-cell tray. Worm Power VC was either incorporated just prior to (INC), or topdressed (TD) two weeks after sowing seeds at 0%, 4%, 8% or 12% by volume added to the base substrate. Rates were chosen based on observations in experiment 1 (of declining growth, in some cases, when incorporation rate exceeded 10%). The species included in the trial were: pepper ‘Calwonder’, tomato ‘Rutgers 39’, petunia (*Petunia x hybrid)* ‘Celebrity White F1’ and snapdragon (*Antirrhinum majus* L.) ‘Rocket Mix F1’. The seeds were then sown in germination trays which were watered as needed with tap water. The experiment was conducted from May 7, 2012- June 11, 2012.

The experimental design was a completely randomized design. Each 50-cell tray was an experimental unit and there were three experimental units per treatment per cultivar. An analysis of variance was conducted to determine whether measured parameters were affected by VC volume or application method. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VC volume.

Experiment 3: VCE for seedlings

This experiment was designed to test a commercially available non-aerated VCE (Worm Power, RT Solutions, LLC Avon, NY) as the sole fertilizer for seedlings. The VCE was applied at different weekly frequencies as the sole fertilizer source for seedlings in germination trays. The base substrate described in experiment 2 was used to fill germination trays. Seeds of pepper ‘Calwonder’, tomato ‘Rutgers 39’, petunia ‘Celebrity White F1’ and snapdragon ‘Rocket Mix F1’ were sown into the trays with 1 seed on the surface of each cell. The trays were then randomly assigned to receive a 200 mL (4 mL per cell) drench treatment of VCE 0, 1, 3 or 5 times per week. The drenches were started two weeks after seeding and continued for two weeks. All trays received a drench treatment of clear water or VCE each day. Trays were watered as needed with tap water between drenches. The experiment was conducted from June 25, 2012-July 30, 2012.

The experimental design was a completely randomized design. Each 50-cell tray was an experimental unit and there were three experimental units per treatment per cultivar. An analysis of variance was conducted to determine whether measured parameters were affected by VCE application frequency. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VCE application frequency.

Experiment 4: VC source for transplants

To look at how different VCs would perform for older plants growing in larger containers, this experiment compared performance of four different VCs applied at different incorporation rates on growth of plants in 10 cm containers. VC from the four sources (as in experiment 1, Table 1) was incorporated at 0%, 2.5%, 5%, 10% or 20% by volume into a peat:perlite (75:25) substrate amended with limestone. A rate of 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) was added to adjust the substrate pH.to 6.0. Four week old organically grown plugs of pepper ‘Lady Bell’ or tomato ‘Celebrity’ were seeded in germination trays filled with a peat:perlite (75:25) substrate amended with limestone and covered with a ca. 3 mm layer of fine vermiculite. The germination trays used were 200 cell germination trays. Trays were watered as needed with tap water and twice per week were fertilized with a 50 $mg \cdot L^{-1}$ drench of Verdanta PL-2 (2-0-4.98, N-P-K) (BioWorks Inc., Victor, NY). At experiment initiation these plants were then transplanted into 10-cm containers containing the different mixes. Following transplanting, plants were irrigated with tap water as needed with no supplemental fertility. The experiment was conducted from June 16, 2014 –July 28, 2014. DW was not measured for this experiment.

The experimental design was a completely randomized design. Each container was an experimental unit and there were 5 experimental units (replicate) per species per treatment combination. An analysis of variance was conducted to determine whether measured parameters were affected by VC source and volume. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VC volume.

Experiment 5: VC volume on leachate and transplant growth

This experiment was conducted to determine plant growth effects and leaching from different incorporation rates of a dairy manure solids based VC (Worm Power, LLC) for growing larger size transplants in 10 cm containers. This VC source was selected based on preliminary trials with multiple VC sources. Batches of substrate were made with 0%, 5%, 10%, 15%, 20% or 30% vermicompost (Worm Power, LLC) (v/v) added to the base substrate described in experiment 1. The 10 cm containers were filled with the substrates and then transplanted with four week old organically grown plugs grown as described in Experiment 4. Pepper 'Calwonder', tomato 'Rutgers 39', petunia 'Celebrity White F1' and snapdragon 'Rocket Mix F1' were transplanted. Containers were watered as needed with tap water. Each week leachate samples were taken from five randomly selected containers of each treatment of the tomato and petunia trials. The EC and pH of the leachate following the pour-through nutrient extraction method (Wright, 1986) was measured using handheld meters ECTestr 11 and pHTestr 20, respectively (Oakton Instruments, Vernon Hills, IL), that were calibrated before each use.

Samples were saved for analysis of elemental concentrations of calcium (Ca^{2+}), Chloride (Cl^-), potassium (K^+), sodium (Na^+), ammonium-nitrogen (NH_4^+-N), and nitrate-nitrogen (NO_3-N) using a multi-ion meter (CG001; CleanGrow, Vacaville, CA). The experiment took place from July 21, 2012- August 25, 2012.

The experiment was arranged as a completely randomized design. Each plant/container was an experimental unit and there were 10 experimental units (replicates) for each treatment combination per species. An analysis of variance was conducted to determine whether measured parameters were affected by VC volume. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VC volume.

Experiment 6: Transplants grown with and without VC plus VCE

This experiment examined the effects of separate or combined applications of VC and VCE on larger size transplants in 10 cm containers. Half of the 10 cm containers were filled with unamended base substrate described in experiment 1 and the other half were filled with base substrate plus 10% dairy manure solids based vermicompost (Worm Power, LLC) (v/v). Four week old organically grown plugs as described in experiment 4 of pepper ‘Calwonder’, tomato ‘Rutgers 39’, petunia ‘Celebrity White F1’ and snapdragon ‘Rocket Mix F1’ were transplanted in containers containing the two different mixes. Containers were then randomly assigned a drench treatment of 100 mL of VCE 0, 1, 3 or 5 times per week. When not receiving drenches the containers were watered as needed with tap water. The experiment was conducted from July 21, 2012- August 25, 2012.

The experiment was arranged as a completely randomized design. Each plant/container was an experimental unit and there were 10 experimental units (replicates) for each treatment combination per species. An analysis of variance was conducted to determine whether measured parameters were affected by VC, VCE, or their interaction. Linear and quadratic regressions were conducted to determine the quantitative effect of increasing VCE frequency within a given VC treatment.

Results

There were large differences in the chemical properties of the four vermicomposts (Table 1). The Vital Earth (VE) VC had a pH of 4.1, much lower than the other three VCs that were all near 7. Soluble salts were highest at 16.2 mmhos cm^{-1} for the Worm Power (WP) VC and second highest at 8.98 mmhos cm^{-1} for the TerraVesco (TV). WP had the highest levels of most nutrients including: total-N, ammonium-N, nitrate-N, P, K, Ca, Mg, S, Na, Cu, and Zn. The lowest levels of some nutrients were found in the Vermitechnology (VT) (Total N, ammonium-N, nitrate-N, S and Na) and VE (P, K, Ca, and S).

Experiment 1: VC source for seedlings

The mean germination percentage for tomato (Table 2) varied from 89.3 for the WP at 20% to 97.6 for all treatments with no VC and VE and WP at 5%. The WP treatment had significant linear (L) and quadratic (Q) effects, whereby increased application rate led to decreased percentage of germination. The other VC materials did not affect germination percentage. FW ranged from 2.33 g for VE at 2.5% to 12.5 g for WP at 20%. For all VC sources tomato FW and

DW increased as application rate increased. However, much higher FW and DW was found with WP, followed by TV as compared to the other materials.

Table 1: Nutrient analysis of four different sources[z] of commercially available vermicompost. Samples taken spring 2014 and analysis was conducted by Agricultural Analytical Services Lab, Pennsylvania State University, University Park, PA.

	Units	Vital Earth	Vermi-Technology	Terra Vesco	Worm Power
pH	Std	4.10	7.40	7.60	7.10
Soluble Salts	mmhos/cm	2.23	1.83	8.98	16.21
Solids	%	42.90	62.40	34.10	45.50
Organic Matter	%	41.60	23.90	67.90	72.60
Total Nitrogen	%	1.50	1.10	2.50	3.90
Organic Nitrogen	%	1.50	1.10	2.50	3.90
Ammonium N	mg/kg	5.00	<4.90	<5.00	132.30
Nitrate N	mg/kg	590	504	2378	4896
Carbon	%	22.90	14.20	37.10	40.00
Phosphorous	%	0.17	0.18	0.97	1.45
Potassium	%	0.09	0.10	2.07	3.09
Calcium	%	0.61	3.45	2.14	3.98
Magnesium	%	0.17	0.22	0.46	0.96
Sulfur	%	0.30	0.23	0.43	0.68
Sodium	mg/kg	241	82	3979	7685
Aluminum	mg/kg	19656	7909	1970	634
Iron	mg/kg	10692	12770	3576	3920
Manganese	mg/kg	101	341	236	200
Copper	mg/kg	51	41	31	1017
Zinc	mg/kg	38	44	199	215

[Z] Mega Worm, Vital Earth, Central Point, OR; Pure Black Castings, Vermitechnology Unlimited, FL; TerraVesco Sonoma Valley Worm Farm, Sonoma, CA; Worm Power, RT Solutions, LLC Avon, NY.

The mean germination percentage for pepper (Table 2) varied from 58.7 for WP at 20% to 90.4 for the TV at 10%. The WP treatment exhibited reduced germination percentage as incorporation volume increased. Other VC materials did not affect germination. Pepper FW varied from 1.35 g for VE at 2.5% to 4.04 g for the WP at 20%. For TV and WP, the FW and DW increased as

Table 2: Vermicompost source effect on seedlings incorporated at one of five rates (V/V). The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.The germination trays used were 200 cell germination trays (18.9 mL $cell^{-1}$, T.O. Plastics, Inc. Clearwater, MN that had been cut into 8 sections to create 25 cell trays. Fresh weight (FW) and germination percentage were determined 6 weeks after sowing seeds. FW was a combined weight of 10 seedlings. Data represent means ± standard error of five experimental units per treatment combination.

	0			2.5			5			10			20			Significance
Fresh Weight (g)																
Tomato																
Vital Earth	2.48	±	0.10	2.33	±	0.14	2.43	±	0.14	2.12	±	0.03	3.2	±	0.06	L * Q ***
Vermitechnology	2.48	±	0.10	2.6	±	0.09	2.74	±	0.03	2.93	±	0.13	3.46	±	0.18	L *** Q ***
Terra Vesco	2.48	±	0.10	4.2	±	0.14	5.1	±	0.26	5.88	±	0.30	6.27	±	0.58	L *** Q ***
Worm Power	2.48	±	0.10	6.36	±	0.15	8.3	±	0.54	8.66	±	0.39	12.49	±	0.87	L *** Q ***
Pepper																
Vital Earth	1.56	±	0.07	1.35	±	0.06	1.6	±	0.08	1.42	±	0.07	1.4	±	0.21	$L^{NS}Q^{NS}$
Vermitechnology	1.56	±	0.07	1.62	±	0.04	1.36	±	0.03	1.7	±	0.03	1.63	±	0.12	L^{NS}Q **
Terra Vesco	1.56	±	0.07	2.21	±	0.21	2.14	±	0.13	3.02	±	0.11	3.67	±	0.16	L *** Q ***
Worm Power	1.56	±	0.07	2.88	±	0.19	3.72	±	0.33	3.3	±	0.35	4.04	±	0.62	L *** Q ***
Germination (%)																
Tomato																
Vital Earth	98	±	1.60	95	±	2.33	98	±	1.60	96	±	2.19	95	±	1.33	$L^{NS} Q^{NS}$
Vermitechnology	98	±	1.60	95	±	3.88	97	±	0.80	96	±	1.79	96	±	0.00	$L^{NS} Q^{NS}$
Terra Vesco	98	±	1.60	96	±	2.19	92	±	1.26	97	±	1.50	97	±	1.33	$L^{NS} Q^{NS}$
Worm Power	98	±	1.60	97	±	2.33	98	±	1.60	97	±	1.96	89	±	3.53	L ** Q **
Pepper																
Vital Earth	82	±	6.65	83	±	4.27	83	±	2.33	86	±	2.99	83	±	9.33	$L^{NS} Q^{NS}$
Vermitechnology	84	±	6.65	90	±	5.46	82	±	1.60	83	±	1.50	67	±	4.81	$L^{NS} Q^{NS}$

Terra Vesco	70	±	6.65	82	±	4.31	80	±	6.69	90	±	1.60	85	±	4.81	L ^{NS} Q ^{NS}
Worm Power	82	±	6.65	78	±	2.99	84	±	4.20	78	±	3.49	59	±	5.33	L * Q *

Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

[Z] Mega Worm, Vital Earth, Central Point, OR; Pure Black Castings, Vermitechnology Unlimited, FL; TerraVesco Sonoma Valley Worm Farm, Sonoma, CA; Worm Power, RT Solutions, LLC Avon, NY.

volume increased. Overall growth was greatest in response to WP. VT increased FW in a quadratic fashion, but very was only a very slight increase, from 1.56 g at 0% to 1.63 g at 20%. Growth of pepper plants did not respond to increasing volume of VE.

Experiment 2: VC application method for seedlings

Tomato germination was not effected by either method (TD or INC) of VC application (Table 3). Mean DW varied from 0.16 (TD 0%) to 1.3 g (TD 12%). DW increased as volume applied increased for both application methods. The heaviest plants were TD at 12 % (1.3g) which was similar to TD 4 and 8%, and INC 8, and 12%. This indicates that a lower amount of VC can be applied via TD to get the same plant biomass as INC.

Petunia germination was not affected by increasing volume of VC for either TD or INC (Table 3). TD at 4 to 12% was similar to INC at 8-12%. Again, indicating that a lower amount of VC can be applied via TD to get the same biomass as INC-fertilized plants.

Pepper and snapdragon showed similar trends. DW increased in response to increasing application volume for both INC and TD. TD at 4 to 12% was similar to INC at 8-12%.

For each of the four crops TD performed the best based on DW.

Experiment 3: VCE for seedlings

Germination percentage of tomato was unaffected by VCE application frequency (Table 4). FW increased from 1.3 to 4.7 g as application frequency increased from 0 to 5 drenches weekly. DW varied from 0.19 to 0.61 g as application frequency increased from 0 to 5 drenches weekly.

Table 3: Vermicompost (VC) application method effect on seedlings. VC was either incorporated preplant or top-dressed 2 weeks after seeding at one of four application rates (V/V). Dry weight (DW) and germination percentage were determined 6 weeks after sowing seeds. DW was the combined weights of 10 seedlings. Data represent means ± standard error of 3 trays per treatment combination. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0. The germination trays used were 200 cell germination trays (18.9 mL cell-1, T.O. Plastics, Inc. Clearwater, MN that had been cut into 8 sections to create 25 cell trays.

	VC application (%)	Germination (%)				Dry Weight (g)			
Tomato					Sig				Sig
0	Incorporated	95	±	1.76	NS	0.29	±	0.03	B
4		98	±	1.15		0.6	±	0.08	AB
8		91	±	3.71		0.72	±	0.1	A
12		93	±	3.53		0.74	±	0.04	A
0	Topdressed	91	±	1.76		0.16	±	0.02	C
4		91	±	0.67		0.65	±	0.11	BC
8		93	±	2.91		1.03	±	0.01	AB
12		83	±	2.67		1.3	±	0.24	A
Pepper									
0	Incorporated	61	±	2.4	NS	0.14	±	0.02	B
4		68	±	2.31		0.14	±	0.01	B
8		65	±	6.36		0.27	±	0.05	A
12		51	±	1.76		0.19	±	0.02	AB
0	Topdressed	84	±	3.06		0.09	±	0	B
4		81	±	2.4		0.3	±	0.01	A
8		79	±	3.33		0.38	±	0.01	A
12		83	±	3.71		0.34	±	0.07	A
Petunia									
0	Incorporated	85	±	4.37	NS	0.09	±	0.01	C
4		92	±	3.06		0.13	±	0.03	BC
8		88	±	4		0.25	±	0.02	A
12		85	±	0.67		0.21	±	0.01	AB
0	Topdressed	67	±	2.4		0.06	±	0.01	BC
4		59	±	7.69		0.21	±	0	A
8		51	±	6.96		0.25	±	0.03	A
12		59	±	10.91		0.26	±	0.03	A

Snapdragon									
0	Incorporated	90	±	4	NS	0.08	±	0.01	B
4		88	±	1.15		0.1	±	0.01	B
8		94	±	2.31		0.21	±	0.02	A
12		78	±	7.02		0.17	±	0.02	A
0	Topdressed	75	±	13.53		0.04	±	0.01	B
4		79	±	3.53		0.17	±	0.02	A
8		77	±	1.76		0.21	±	0.02	A
12		75	±	2.4		0.14	±	0.02	A

Letters represent mean separation comparison using Tukey HSD alpha= o.o5.

[Z] Worm Power, RT Solutions, LLC Avon, NY.

Germination percentage of pepper was unaffected by VCE application frequency (Table 4). FW increased from 0.5 to 2.7 g as application frequency increased from 0 to 5 times weekly. DW increased from 0.05 to 0.31 g as application frequency increased from 0 to 5.

Petunia germination was unaffected by VCE application frequency (Table 4). FW increased from 0.3 to 2.8 g as application frequency increased from 0 to 5 times weekly. DW increased from 0.04 to 0.27 g as application frequency increased from 0 to 5.

Snapdragon germination was unaffected by VCE application frequency (Table 4). FW increased from 0.2 to 1.9 g as application frequency increased from 0 to 5 times weekly. DW increased from 0.05 to 0.25 g as application frequency increased from 0 to 5.

Experiment 4: VC source for transplants

Tomato FW increased for all VC sources in response to increasing application volume (Table 5). However, WP and TV performed much better than the other two VCs. For example, FW increased from 1.74 to 53.79 g as WP increased from 0 to 20% while for VE, FW only increased

Table 4: Vermicompost extract (VCE) application effect on seedlings. VCE applied at one of four application frequencies each week._ VCE from Worm Power, RT Solutions, LLC Avon, NY. The germination trays used were 200 cell germination trays (18.9 mL cell-1, T.O. Plastics, Inc. Clearwater, MN that had been cut into 4 sections to create 50 cell trays (T.O. Plastics, Inc. Clearwater, MN). Fresh weight (FW), dry weight (DW) and germination percentage were determined 6 weeks after sowing seeds. FW and DW were combined weights of 10 seedlings. Data represent means and standard errors of five replications of each treatment.

VCE application frequency	**Germination (%)**			**Fresh Weight (g)**			**Dry Weight (g)**		
Tomato									
0	85	±	6.57	1.29	±	0.26	0.19	±	0.04
1	81	±	10.67	1.47	±	0.24	0.20	±	0.04
3	79	±	13.78	2.97	±	0.33	0.41	±	0.04
5	86	±	6.43	4.73	±	0.44	0.61	±	0.07
Significance	L NS Q NS			L*** Q***			L*** Q***		
Pepper									
0	52	±	11.02	0.51	±	0.07	0.05	±	0.01
1	51	±	6.36	0.72	±	0.06	0.09	±	0.01
3	55	±	7.69	1.38	±	0.20	0.16	±	0.03
5	67	±	6.36	2.72	±	0.20	0.31	±	0.04
Significance	L NS Q NS			L*** Q***			L*** Q***		
Petunia									
0	82	±	3.06	0.28	±	0.05	0.04	±	0.01
1	71	±	7.51	0.77	±	0.17	0.09	±	0.02
3	74	±	5.03	1.83	±	0.19	0.20	±	0.02
5	63	±	9.33	2.84	±	0.23	0.27	±	0.03
Significance	L NS Q NS			L*** Q***			L*** Q***		
Snapdragon									
0	79	±	3.71	0.21	±	0.05	0.05	±	0.01

1	87	±	3.33	0.54	±	0.07	0.08	±	0.01
3	89	±	2.40	1.32	±	0.11	0.20	±	0.01
5	87	±	6.36	1.89	±	0.14	0.25	±	0.01
Significance	L NS Q NS			L*** Q***			L*** Q***		

Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

from 1.71 to 5.83 g as volume increased from 0% to 20%. Tomato height increased for all VC sources in response to incorporation volume. For example, height increased from 8.3 to 25.5 cm as WP increased from 0% to 20%; while for VT, height only increased from 7.2 to 10.6 cm as volume increased from 0% to 10 %, and at 20% no further increase in height was observed. Plant width increased in response to increasing application volume for all VC materials. For example, width increased from 8.4 to 22.3 cm as WP increased from 0% to 20%. SPAD chlorophyll index did not respond consistently to increasing application rates. For WP SPAD chlorophyll index increased from 33.8 to 48.8 as volume increased from 2.5% to 20%. For VT, SPAD chlorophyll index increased from 40 to 42.55 as volume increased from 0% to 10%; and at 20% no further increase in SPAD chlorophyll level was observed

Pepper FW increased for all VC sources in response to increasing application volume (Table 5). However, WP and TV performed much better than the other two VCs. For example, FW increased from 0.69 to 53.79 g as WP increased from 0 to 10% while for VE, FW only increased from 0.49 to 1.12 g as volume increased from 0 to 20%. Pepper height increased for all VC sources in response to incorporation volume. For example, height increased from 5.4 to 18.9 cm as WP increased from 0% to 10%; while for VE, height only increased from 4.5 to 7 cm as volume increased from 0% to 20%. Plant width increased in response to increasing application volume for all VC materials. For example, width increased from 5.5 to 17.95 cm as WP increased from 0% to 10%. SPAD chlorophyll index increased in response to increasing application rates.

Table 5: Vermicompost[z] (VC) source effect on transplants incorporated at one of five rates (V/V) . Four week old seedlings were transplanted into 10 cm containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.Data represent means ± standard error of five experimental units per treatment combination.

	Tomato					
	0	2.5	5	10	20	
			Height (cm)			
						Significance
Vital Earth	8.1 ± 0.36	9 ± 0.32	8 ± 0.73	8.1 ± 0.23	11.25 ± 0.60	L^{**} Q^{***}
Vermitechnology	7.2 ± 0.35	9.3 ± 0.35	10.3 ± 0.26	10.6 ± 0.29	10 ± 0.74	L^{**} Q^{***}
Terra Vesco	8.7 ± 0.60	12.7 ± 0.37	14.1 ± 0.25	16.6 ± 0.66	18.63 ± 0.30	L^{***} Q^{***}
Worm Power	8.3 ± 0.42	15.3 ± 0.79	19.4 ± 0.24	22.7 ± 0.71	25.5 ± 1.30	L^{***} Q^{***}
			Width (cm)			
Vital Earth	8.35 ± 0.40	9.3 ± 0.34	8.35 ± 0.34	8.45 ± 0.23	10.9 ± 0.59	L^{**} Q^{***}
Vermitechnology	7.65 ± 0.60	9.7 ± 0.50	10.65 ± 0.50	11 ± 0.73	11 ± 0.40	L^{**} Q^{***}
Terra Vesco	9.2 ± 0.54	13.45 ± 0.30	15.2 ± 0.46	17.7 ± 0.71	17.7 ± 0.80	L^{**} Q^{*}
Worm Power	8.4 ± 0.70	16.15 ± 0.42	20.45 ± 0.20	23.85 ± 0.34	22.25 ± 0.60	L^{*} Q^{**}
			SPAD			
Vital Earth	39.58 ± 2.40	39.32 ± 1.30	39.32 ± 1.37	41.16 ± 1.06	41.2 ± 1.44	L^{NS} Q^{NS}
Vermitechnology	40 ± 2.13	40.6 ± 0.86	40.28 ± 1.18	42.8 ± 0.60	40.55 ± 0.81	L^{NS} Q^{NS}
Terra Vesco	40.42 ± 0.57	34.54 ± 0.91	35.42 ± 1.23	33.98 ± 1.63	35.38 ± 0.84	L^{NS} Q^{**}
Worm Power	40.38 ± 0.69	33.76 ± 1.01	35.68 ± 0.86	36.3 ± 1.25	48.8 ± 2.59	L^{**} Q^{***}
			Fresh Weight (g)			
Vital Earth	1.71 ± 0.18	2.77 ± 0.28	2.26 ± 0.39	1.81 ± 0.20	5.83 ± 0.18	L^{***} Q^{***}
Vermitechnology	1.48 ± 0.09	3.21 ± 0.20	3.97 ± 0.26	4.73 ± 0.32	6.48 ± 0.51	L^{***} Q^{***}

Terra Vesco	2.36 ± 0.35	8.96 ± 0.46	12.36 ± 0.38	16.53 ± 0.37	24.13 ± 1.19	L *** Q ***
Worm Power	1.74 ± 0.18	15.25 ± 0.61	24.65 ± 0.89	37.54 ± 1.21	53.79 ± 2.12	L *** Q ***
			Pepper			
			Height (cm)			
Vital Earth	4.5 ± 0.28	5.4 ± 0.24	5.4 ± 0.41	5 ± 0.22	7 ± 0.69	L *** Q ***
Vermitechnology	4.7 ± 0.31	5.9 ± 0.24	7.1 ± 0.28	6.7 ± 0.54	7.5 ± 0.25	L *** Q ***
Terra Vesco	5.5 ± 0.15	10.7 ± 0.12	12.2 ± 0.30	13.8 ± 0.42	16 ± 1.29	L *** Q ***
Worm Power	5.4 ± 0.21	13.4 ± 0.34	15.5 ± 0.47	18.9 ± 0.67	16.5 ± 1.04	L ** Q ***
			Width (cm)			
Vital Earth	4.6 ± 0.40	5.55 ± 0.54	5.45 ± 0.53	5.35 ± 0.53	7.05 ±	L *** Q ***
Vermitechnology	4.95 ± 0.60	5.85 ± 0.70	7.1 ± 0.34	6.55 ± 0.54	7 ±	L *** Q ***
Terra Vesco	5.4 ± 0.54	10.55 ± 0.32	12.1 ± 1.40	13.7 ± 0.65	13.85 ±	L *** Q ***
Worm Power	5.5 ± 0.78	13.25 ± 0.60	15 ± 0.65	17.95 ± 1.30	15.5 ±	L ** Q ***
			SPAD			
Vital Earth	31.42 ± 4.13	38.92 ± 1.02	41.04 ± 1.37	37.1 ± 1.42	40.23 ± 0.69	L NS Q NS
Vermitechnology	36.86 ± 2.54	37.96 ± 1.95	38.8 ± 1.14	39.04 ± 0.34	42.65 ± 2.12	L NS Q NS
Terra Vesco	38.52 ± 1.97	26.28 ± 0.86	25.66 ± 1.33	29.5 ± 0.68	32.65 ± 1.20	L NS Q **
Worm Power	31.02 ± 4.14	33.45 ± 3.77	36.04 ± 1.04	40.76 ± 1.56	44.49 ± 2.15	L *** Q **
			Fresh Weight (g)			
Vital Earth	0.49 ± 0.12	0.64 ± 0.08	0.78 ± 0.08	0.68 ± 0.09	1.12 ± 0.22	L * Q **
Vermitechnology	0.57 ± 0.08	0.78 ± 0.09	1.13 ± 0.14	1.18 ± 0.19	1.4 ± 0.17	L *** Q ***
Terra Vesco	0.66 ± 0.05	4.07 ± 0.15	4.52 ± 1.10	8.51 ± 0.20	12.11 ± 1.08	L *** Q ***
Worm Power	0.69 ± 0.07	10.18 ± 2.76	11.7 ± 0.30	17.57 ± 2.04	15.32 ± 1.98	L *** Q ***

Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

[Z] Mega Worm, Vital Earth, Central Point, OR; Pure Black Castings, Vermitechnology Unlimited, FL; TerraVesco Sonoma Valley Worm Farm, Sonoma, CA; Worm Power, RT Solutions, LLC Avon, NY.

Experiment 5: VC rate on leachate and transplant growth

Height, FW, DW, and SPAD chlorophyll index of tomato increased significantly as VC incorporation rate increased from 0% to 30% by volume (Table 6). For example, FW increased from 4.7 to 32.6 g as volume increased from 0% to 30%. DW increased from 1.4 to 5.4 g as volume increased from 0% to 30%. SPAD chlorophyll index increased from 21.1 to 30.9 as volume increased from 0% to 30%.

Height, FW, DW, and SPAD chlorophyll index of pepper increased significantly as VC incorporation rate increased from 0% to 30% by volume (Table 6). For example, FW increased from 3.2 to 15.2 g as volume increased from 0% to 30%. DW increased from 1.0 to 2.4 g as volume increased from 0% to 30%. SPAD chlorophyll index increased from 20.9 to 37.6 as volume increased from 0% to 30%.

Height, FW, DW, and SPAD chlorophyll index of petunia increased significantly as VC incorporation rate increased from 0% to 10% by volume (Table 6). For example, FW increased from 3.1 to 11.1 g as volume increased from 0% to 10% further increase in application rate did not increase plant weight. DW increased from 0.8 to 1.3 g as volume increased from 0% to 10% further increase in application rate did not increase plant weight.

Height, FW, DW, and SPAD chlorophyll index of snapdragon increased significantly as VC incorporation rate increased from 0% to 10% by volume (Table 6). For example, FW increased from 3.1 to 8.2 g as volume increased from 0% to 10%; further increases in application rate did not increase plant weight. DW increased from 1.1 to 1.5 g as volume increased from 0% to 10 %; further increase in application rate did not increase plant weight. SPAD chlorophyll index increased from 34.7 to 45.5 as volume increased from 0% to 10 %, further increase in application rate did not increase plant SPAD index level.

Table 6: Vermicompost (VC) effect on transplants incorporated at one of five rates (V/V). VC used was from Worm Power, RT Solutions, LLC Avon, NY. Four week old seedlings were transplanted into 10 cm containers filled with base substrate. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0. Data represent means and standard errors of 10 replications.

VC (%)	Height (cm)	Width (cm)	SPAD	Fresh Weight (g)	Dry Weight (g)
			Tomato		
0	16.2 ± 0.59	11.8 ± 0.47	21.09 ± 0.80	4.73 ± 0.33	1.39 ± 0.07
5	21.3 ± 0.73	16.5 ± 0.33	22.21 ± 0.86	10.40 ± 0.62	2.30 ± 0.12
10	32.3 ± 0.70	26.2 ± 0.88	27.25 ± 0.91	27.84 ± 0.77	4.84 ± 0.16
20	29.2 ± 1.11	23.6 ± 1.33	29.66 ± 1.07	23.68 ± 2.97	4.15 ± 0.49
30	31.9 ± 1.23	27.0 ± 0.70	30.91 ± 1.33	32.63 ± 1.71	5.39 ± 0.34
	L*** Q***	L*** Q***	L*** Q***	L*** Q***	L*** Q***
			Pepper		
0	14.2 ± 0.42	12.5 ± 0.35	20.94 ± 0.85	3.22 ± 0.16	0.95 ± 0.04
5	16.7 ± 0.50	14.5 ± 0.69	24.17 ± 0.72	5.15 ± 0.43	1.21 ± 0.06
10	23.7 ± 0.58	20.7 ± 0.57	35.67 ± 1.31	12.23 ± 0.43	1.99 ± 0.13
20	19.2 ± 0.80	17.85 ± 1.10	30.28 ± 1.44	8.08 ± 0.92	1.54 ± 0.14
30	21.3 ± 1.22	23.95 ± 0.77	37.58 ± 1.10	15.18 ± 0.94	2.38 ± 0.15
	L*** Q***	L*** Q***	L*** Q***	L*** Q***	L*** Q***
			Petunia		
0	4.8 ± 0.55	9.3 ± 0.51	19.31 ± 0.78	3.08 ± 0.41	0.80 ± 0.04
5	4.3 ± 0.53	10.6 ± 0.48	20.79 ± 1.09	4.94 ± 0.58	0.99 ± 0.08
10	6.6 ± 0.48	13.5 ± 0.57	25.12 ± 1.03	11.15 ± 1.33	1.29 ± 0.12
20	6.5 ± 0.67	11.9 ± 0.85	18.34 ± 1.52	10.27 ± 1.69	1.11 ± 0.09
30	5.5 ± 0.45	12.4 ± 0.67	14.61 ± 2.08	7.96 ± 1.16	0.96 ± 0.08
	L NS Q*	L*** Q***	L** Q***	L** Q***	L NS Q**
			Snapdragon		
0	20.4 ± 0.81	8.8 ± 0.57	34.71 ± 1.02	3.08 ± 0.18	1.12 ± 0.05
5	23.2 ± 1.10	9.85 ± 0.51	37.08 ± 0.89	3.08 ± 0.38	1.16 ± 0.07

10	25.2	±	0.57	11.85	±	0.33	45.52	±	1.36	8.16	±	0.29	1.49	±	0.09
20	17.4	±	2.12	12.25	±	1.03	36.19	±	2.40	5.38	±	0.78	1.36	±	0.13
30	14.9	±	1.16	10.75	±	0.69	30.13	±	2.52	3.76	±	0.47	1.14	±	0.09
	L*** Q***			L* Q***			L* Q***			L NS Q***			L NS Q**		

Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Nutrient concentration in leachate generally decreased over time. The highest levels of nutrients were found in the higher application rates (Table 7). For example, NO_3-N concentration decreased from 84 (20% VC week 1) to 2 mg L^{-1} (20% week 4) for tomatoes. NO_3-N concentration increased as application volume increased from 5 (0% VC week 1) to 146 mg L^{-1} (30% VC week 1).

Leachate pH increased over the 4 week experimental period regardless of VC volume. For example, petunia leachate for 20% VC increased from 7 (week 1) to 7.7 (week 4). The pH of petunia week 1 increased from 6.6 (0%) to 7.2 (30%). EC, a measure of total salts (fertilizer and non-fertilizer) generally decreased over time. For example, tomato with 30 % VC applied decreased from 3.7 (week 1) to 2.0 (week 4). The EC increased with increasing amounts of VC. For example, petunia week 2 increased from 0.5 (0%) to 4.1 (30%).

Experiment 6: Transplants grown with and without VC plus VCE

For tomato, 10% VC significantly increased FW and DW as compared with 0% VC plants (Table 8). For the plants that received 10% VC the application of drenches did not have any effect on the DW (Table 8). SPAD chlorophyll index increased from 22.6 (0 drenches) to 28.2 (5 drenches). For 0% VC height, FW, DW, and SPAD chlorophyll index of tomato increased significantly as drench frequency increased. For example, FW increased from 4.9 to 21.5 g as drenches increased from 0 to 5 per week.

Table 7: Nutrient levels of leachate collected weekly from tomatoes grown with one of five levels of vermicompost (v/v) added. A peat:perlite (75:25) substrate amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0 was used as the base. Plants were grown for 5 weeks. Data represents means from five randomly sampled containers.

VC[z] (%)	Week 1	Week 2	Week 3	Week 4
		Tomato		
		Ca (mg L^{-1})		
0	22 ± 1.14	16 ± 3.04	21 ± 3.51	14 ± 1.79
5	20 ± 2.12	15 ± 1.54	16 ± 2.10	8 ± 1.30
15	35 ± 2.32	18 ± 3.43	17 ± 3.79	6 ± 2.09
20	18 ± 2.06	22 ± 8.79	8 ± 2.31	4 ± 0.92
30	21 ± 3.22	8 ± 1.42	10 ± 1.46	7 ± 1.18
	L NS Q NS	L NS Q NS	L*** Q***	L* Q***
		Cl (mg L^{-1})		
0	37 ± 3.29	89 ± 15.63	114 ± 6.17	118 ± 8.37
5	109 ± 10.27	210 ± 47.50	194 ± 18.43	139 ± 42.49
15	430 ± 23.00	655 ± 90.88	592 ± 77.26	332 ± 127.42
20	488 ± 66.97	813 ± 188.91	543 ± 140.92	306 ± 102.86
30	841 ± 106.82	942 ± 243.57	801 ± 111.88	759 ± 152.44
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
		K (mg L^{-1})		
0	30 ± 7.20	2 ± 0.76	6 ± 1.49	4 ± 2.34
5	122 ± 4.95	75 ± 11.85	65 ± 1.75	39 ± 4.04
15	410 ± 19.99	244 ± 34.62	186 ± 22.76	69 ± 7.49
20	587 ± 70.08	456 ± 110.70	311 ± 59.31	244 ± 25.02
30	843 ± 63.32	619 ± 118.33	396 ± 43.51	333 ± 13.00
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
		Na (mg L^{-1})		
0	39 ± 3.61	40 ± 5.65	58 ± 3.08	40 ± 8.80
5	61 ± 3.74	121 ± 18.58	113 ± 10.82	111 ± 25.90

15	151	±	6.44	229	±	23.10	282	±	23.64	238	±	58.31
20	173	±	15.36	268	±	58.92	253	±	46.88	220	±	46.79
30	278	±	24.23	361	±	78.43	322	±	31.04	387	±	49.65
	L*** Q***			L*** Q***			L*** Q***			L*** Q***		
						NH_4^+-N (mg L^{-1})						
0	0	±	0.03	0	±	0.00	0	±	0.02	0	±	0.00
5	0	±	0.04	1	±	0.09	0	±	0.11	0	±	0.02
15	2	±	0.09	2	±	0.38	1	±	0.15	0	±	0.06
20	3	±	0.32	3	±	0.61	2	±	0.41	1	±	0.17
30	4	±	0.42	4	±	0.79	2	±	0.21	2	±	0.14
	L*** Q***			L*** Q***			L*** Q***			L*** Q***		
						NO_3-N (mg L^{-1})						
0	5	±	1.12	2	±	0.54	3	±	0.61	2	±	0.92
5	17	±	1.84	10	±	5.81	3	±	1.16	1	±	0.17
15	71	±	2.50	12	±	4.65	5	±	0.98	2	±	0.20
20	84	±	13.47	37	±	23.51	5	±	1.60	2	±	0.26
30	146	±	17.40	42	±	13.88	4	±	0.96	2	±	0.17
	L*** Q***			L** Q NS			L NS Q NS			L NS Q NS		
						EC						
0	0.5	±	0.02	0.6	±	0.02	0.6	±	0.03	0.6	±	0.04
5	0.9	±	0.10	0.9	±	0.10	0.9	±	0.09	0.7	±	0.04
15	2.3	±	0.02	1.8	±	0.16	1.9	±	0.17	1.1	±	0.16
20	2.4	±	0.22	2.5	±	0.46	2.0	±	0.21	1.4	±	0.37
30	3.7	±	0.28	2.8	±	0.52	2.5	±	0.13	2.0	±	0.24
	L*** Q***			L*** Q***			L*** Q***			L*** Q***		
						pH						
0	6.6	±	0.06	7.5	±	0.03	7.8	±	0.02	7.1	±	0.07
5	6.8	±	0.04	7.0	±	0.02	7.7	±	0.03	7.5	±	0.04
15	6.8	±	0.02	7.3	±	0.02	7.5	±	0.08	7.3	±	0.04
20	7.0	±	0.05	7.7	±	0.08	7.6	±	0.09	7.7	±	0.04
30	7.1	±	0.04	7.5	±	0.08	8.0	±	0.05	7.7	±	0.04
	L NS Q***			L*** Q***			L* Q NS			L*** Q***		
						Petunia						
						Ca (mg L^{-1})						
0	29	±	2.64	24	±	2.71	32	±	3.80	16	±	2.79
5	23	±	3.66	11	±	0.94	15	±	1.35	8	±	1.43
15	28	±	5.14	21	±	2.26	22	±	5.36	9	±	2.79
20	33	±	1.02	27	±	5.35	21	±	5.24	6	±	1.47
30	15	±	2.10	24	±	5.68	20	±	3.20	5	±	1.23

	L NS Q NS	L NS Q NS	L NS Q NS	L** Q**
	Cl (mg L^{-1})			
0	43 ± 9.70	72 ± 3.78	105 ± 8.23	62 ± 6.60
5	123 ± 19.05	118 ± 10.70	182 ± 38.46	109 ± 27.57
15	348 ± 70.54	333 ± 44.15	348 ± 79.73	302 ± 44.28
20	719 ± 62.77	755 ± 114.36	671 ± 149.39	261 ± 102.93
30	467 ± 82.41	1056 ± 301.03	770 ± 95.33	445 ± 103.42
	L*** Q***	L*** Q***	L*** Q***	L*** Q**
	K (mg L^{-1})			
0	29 ± 6.20	10 ± 3.88	8 ± 2.53	2 ± 0.79
5	150 ± 14.31	72 ± 3.52	79 ± 14.83	43 ± 8.63
15	412 ± 75.64	275 ± 56.03	371 ± 46.62	179 ± 35.62
20	775 ± 55.04	726 ± 76.08	652 ± 107.32	274 ± 78.44
30	656 ± 90.56	1017 ± 186.29	851 ± 100.79	536 ± 59.02
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
	Na (mg L^{-1})			
0	34 ± 3.22	35 ± 2.79	52 ± 1.89	34 ± 4.70
5	64 ± 6.83	59 ± 4.18	90 ± 10.56	78 ± 13.18
15	138 ± 21.94	142 ± 20.32	202 ± 20.04	162 ± 13.42
20	234 ± 12.28	329 ± 41.15	309 ± 55.12	144 ± 36.29
30	193 ± 21.28	403 ± 83.12	371 ± 42.73	242 ± 45.14
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
	NH_4^+-N (mg L^{-1})			
0	0 ± 0.06	0 ± 0.02	0 ± 0.02	0 ± 0.00
5	1 ± 0.09	0 ± 0.03	0 ± 0.08	0 ± 0.05
15	2 ± 0.36	2 ± 0.31	2 ± 0.19	1 ± 0.21
20	4 ± 0.31	4 ± 0.46	4 ± 0.66	2 ± 0.48
30	3 ± 0.45	6 ± 1.06	5 ± 0.58	4 ± 1.00
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
	NO_3-N (mg L^{-1})			
0	8 ± 1.69	4 ± 1.11	2 ± 0.48	1 ± 0.06
5	22 ± 4.67	7 ± 2.16	3 ± 0.81	11 ± 0.10
15	73 ± 13.86	51 ± 13.55	51 ± 12.87	2 ± 0.55
20	141 ± 13.29	165 ± 25.21	123 ± 27.44	15 ± 5.61
30	102 ± 15.92	241 ± 49.40	150 ± 34.10	544 ± 14.98
	L*** Q***	L*** Q***	L*** Q***	L*** Q***
	EC			
0	0.5 ± 0.04	0.5 ± 0.04	0.7 ± 0.03	0.5 ± 0.04
5	0.9 ± 0.12	0.9 ± 0.17	0.9 ± 0.10	0.8 ± 0.11

15	2.1	±	0.26	1.7	±	0.22	2.2	±	0.21	1.3	±	0.10
20	3.4	±	0.22	3.4	±	0.25	3.2	±	0.52	1.9	±	0.33
30	2.7	±	0.25	4.1	±	0.63	3.8	±	0.28	2.3	±	0.20
	L*** Q***			L*** Q***			L*** Q***			L*** Q***		
				pH								
0	6.6	±	0.02	7.4	±	0.05	7.5	±	0.08	7.4	±	0.04
5	6.8	±	0.02	7.4	±	0.06	7.4	±	0.02	7.4	±	0.04
15	6.9	±	0.07	7.4	±	0.07	7.5	±	0.04	7.4	±	0.06
20	7.0	±	0.00	7.3	±	0.02	7.3	±	0.11	7.7	±	0.05
30	7.2	±	0.04	7.4	±	0.06	7.6	±	0.08	7.6	±	0.02
	L*** Q***			L NS Q NS			L NS Q NS			L*** Q***		

[Z] Vermicompost (VC)

Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

For pepper, 10% VC significantly increased FW/DW as compared with 0% VC plants (Table 8). For the plants that received 10% VC the application of drenches did not have any effect on height, width, SPAD chlorophyll index, FW, and DW (Table 8). For 0% VC height, width, FW, DW, and SPAD chlorophyll index of pepper increased significantly as drench frequency increased. For example, FW increased from 2.57 to 10.99 g as drenches increased from 0 to 5 per week.

For petunia, 10% VC significantly increased FW and DW as compared with 0% VC plants (Table 8). For the plants that received 10% VC the application of drenches did not have any effect on height, width, SPAD chlorophyll index, FW, and DW (Table 8). For 0% VC height, width, FW, DW, and SPAD chlorophyll index of petunia increased significantly as drench frequency increased. For example, FW increased from 4.7 to 21 g as drenches increased from 0 to 5 per week.

For snapdragon, 10% VC significantly increased FW and DW as compared with 0% VC plants. For the plants that received 10% VC the application of drenches did not have any effect on

Table 8: Vermicompost (VC) incorporation rate and drench (VCE) frequency effect on transplants (Worm Power, RT Solutions, LLC Avon, NY). VC applied at 0% or 10% (V/V). VCE applied at one of four application frequencies each week. Data represent means ± standard error of five replicates per treatment combination.

VC (%)	Drench Frequency (times per week)	Height (cm)	Width (cm)	SPAD	Fresh Weight (g)	Dry Weight (g)
				Tomato		
0	0	15.7 ± 0.62	13.3 ± 0.29	18.6 ± 0.76	4.93 ± 0.18	1.01 ± 0.05
0	1	18.5 ± 0.54	15.8 ± 0.45	25.5 ± 0.68	7.4 ± 0.36	1.32 ± 0.09
0	3	26.2 ± 0.73	19.5 ± 0.70	29.8 ± 0.66	13.83 ± 0.33	2.29 ± 0.11
0	5	27.4 ± 0.76	23.7 ± 0.71	32.7 ± 0.89	21.49 ± 0.91	3.56 ± 0.15
Significance		L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***
10	0	27.2 ± 1.27	22.7 ± 0.87	22.6 ± 0.95	20.33 ± 1.48	3.83 ± 0.28
10	1	28.3 ± 1.61	21.1 ± 0.92	23.7 ± 0.72	20.71 ± 2.26	3.59 ± 0.43
10	3	31.1 ± 1.39	25.5 ± 1.13	27.7 ± 0.66	25.26 ± 1.99	4.37 ± 0.37
10	5	32.8 ± 1.14	28 ± 0.67	28.2 ± 1.04	25.05 ± 0.91	4.17 ± 0.17
Significance		L * Q *	L *** Q ***	L *** Q ***	L * Q NS	L NS Q NS
				Pepper		
0	0	11.4 ± 0.50	11.8 ± 0.40	19.2 ± 0.95	2.57 ± 0.14	0.26 ± 0.04
0	1	14.8 ± 0.65	13.7 ± 0.35	21.7 ± 0.58	4.03 ± 0.23	0.51 ± 0.06
0	3	17.6 ± 0.43	17.2 ± 0.35	29 ± 0.77	7.64 ± 0.26	1.04 ± 0.06
0	5	22 ± 0.91	19.1 ± 0.50	31.8 ± 0.55	10.99 ± 0.45	1.45 ± 0.06
Significance		L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***
10	0	22.2 ± 1.07	19.9 ± 0.70	32.4 ± 1.39	11.92 ± 0.79	1.23 ± 0.31
10	1	20.9 ± 1.09	17.7 ± 1.32	31.2 ± 1.21	11.37 ± 1.14	1.42 ± 0.16
10	3	22.8 ± 0.79	19.9 ± 0.52	30.1 ± 0.73	11.84 ± 0.75	1.47 ± 0.10
10	5	20.3 ± 0.76	19.7 ± 0.56	30.1 ± 0.66	10.36 ± 0.40	1.41 ± 0.09

Significance		L NS Q NS	L NS Q NS	L NS Q NS	L NS Q NS	L NS Q NS
				Petunia		
0	0	5.4 ± 0.67	8.9 ± 0.70	15 ± 0.58	4.68 ± 0.57	0.53 ± 0.09
0	1	6.8 ± 0.73	10.2 ± 0.47	24.2 ± 1.32	7.19 ± 0.72	0.6 ± 0.11
0	3	10.1 ± 0.71	15.1 ± 0.44	28.3 ± 0.77	15.86 ± 0.90	1.61 ± 0.09
0	5	11.6 ± 0.81	13.9 ± 0.41	29.1 ± 0.71	20.99 ± 1.48	1.78 ± 0.15
Significance		L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***
10	0	10.2 ± 0.85	11.7 ± 0.48	25.8 ± 1.91	12.19 ± 1.58	1.19 ± 0.15
10	1	10.2 ± 1.09	13 ± 0.82	24.6 ± 0.81	15.08 ± 1.86	1.33 ± 0.16
10	3	10.4 ± 1.18	12.2 ± 0.64	24.6 ± 1.99	15 ± 1.76	1.22 ± 0.18
10	5	11.7 ± 0.58	12.7 ± 0.55	27.1 ± 1.89	18.61 ± 1.83	1.5 ± 0.15
Significance		L NS Q NS	L NS Q NS	L NS Q NS	L NS Q NS	L NS Q NS
				Snapdragon		
0	0	18.1 ± 0.81	9.8 ± 0.33	31.2 ± 1.29	3.09 ± 0.24	0.54 ± 0.03
0	1	21.4 ± 0.56	10.4 ± 0.13	33.6 ± 0.78	3.91 ± 0.17	0.58 ± 0.03
0	3	29.5 ± 1.00	10.8 ± 0.25	40.4 ± 1.08	8.56 ± 0.33	1.15 ± 0.05
0	5	31.2 ± 1.03	11.7 ± 0.43	44.6 ± 1.77	10.26 ± 0.50	1.36 ± 0.09
Significance		L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***	L *** Q ***
10	0	27.5 ± 0.86	13 ± 0.44	45.6 ± 2.25	10.91 ± 0.43	1.59 ± 0.09
10	1	26.5 ± 0.85	11.7 ± 0.33	40.3 ± 4.06	8.71 ± 0.44	1.26 ± 0.08
10	3	27.4 ± 0.58	10.7 ± 0.40	44.3 ± 0.81	8.57 ± 0.36	1.1 ± 0.07
10	5	24.7 ± 1.58	13 ± 0.30	44.7 ± 0.91	7.13 ± 0.65	1.02 ± 0.09
Significance		L NS Q NS	L NS Q***	L NS Q NS	L *** Q ***	L *** Q ***

Significance of linear (L) or quadratic (Q) regression within a vermicompost level: NS, *, **, *** denotes nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

height, width, and SPAD chlorophyll index (Table 8). The FW and DW decreased with increasing drench rate. For example, FW decreased from 10.9 to 7.1 g as drenches increased from 0 to5 per week. For 0% VC height, width, FW, DW, and SPAD chlorophyll index of snapdragon increased significantly as drench frequency increased. For example, FW increased from 3.1 to 10.3 g as drenches increased from 0 to 5 per week.

Discussion

Seedlings

When comparing VC sources, WP produced the largest seedlings of pepper and tomato. We believe this is due to the high levels of nutrients in the WP VC (Table 10) in particular the N (total, NH_4-N, and NO_3-N) levels are higher in WP than the other VCs. In a 2007 study with tomatoes it was found that increasing application amount of VC increased the plant DW which was similar to our results (Zaller 2007). Our results also demonstrate that seedling growth benefits of VC depend greatly on the particular VC material used. TD performed better than INC for all crops tested. We believe the results can be explained in part by the fact that there are high levels of nitrate in VC (Table 1) and nitrate is easily leached. During the two week period of germination for the INC treatment, the seeds had lower nutrient requirements, during this period much of the nutrients were leached (as suggested by Table 7). Whereas when applied as TD two weeks after seeding, the plants are likely more able to take up nutrients and less is leached out and lost. Similar to our second study, the germination percentage was not affected by the drench application frequency. This was an expected result because drenches were not initiated until two weeks after seeding, allowing the seeds to germinate and grow. The addition of VCE had no effect on germination but did increase seedling weight for all four crops, suggesting it is a viable liquid fertilization method for organic seedling production. Arancon et al. (2012) also found that VCT increased tomato and lettuce growth. They found that it had a stimulatory effect on germination as well, but that was not observed in our experiment. The difference might be explained by the fact that we did not record total germination percentage until experiment termination Also, the source or application method/timing may have caused the differences to occur vs. Arancon et al. (2012) study in which a chicken manure based VCT was used and the seeds were soaked instead of drenched at several intervals.

Sea tea, a compost tea fertilizer, was used successfully to grow seedlings of bell pepper that were taller and heavier than conventional treated seedlings (Russo, 2005). It was applied at 2 or 4 times the labeled application rate and the four times application rate produced plants that were larger than the conventional control. This was similar to our results in that each species responded to increasing application frequency of VCE by growing larger and heavier.

Transplants

WP VC generally produced the heaviest, tallest and widest tomato and pepper plants compared to the other three VC sources. While all VCs increased plant growth, degree of growth enhancement varied greatly according to VC material. The manure base of the WP and TV VC added to the high levels of fertility that were available for the plants. Similar to our results Chander et al. (2015) tested VC and two manures on marigold growth and found that VC and manures increased plant height, width, and fresh weight of flowers.

In the study on amount of WP VC to apply (experiment 5) plant weight was heaviest at 30% incorporation rate for the tomato and pepper plants. The petunia and snapdragon reached heaviest DW at 10%. This is important to note as species or cultivar effect will change a plants reaction to the VC, and some crops are more sensitive to VC than others. In this case it is possible that due to petunia being an iron (Fe) inefficient crop, with a lower optimum pH than other bedding plants (Fisher et al., 2003) the plants were stunted by the decreased access to Fe at the higher pH of the higher application rates (Cavins et al., 2000). Snapdragon plants are sensitive to high levels of salts and this could have led to the decrease in growth at the higher application rates (Cavins et al., 2000). This was observed in a study conducted on tomato where each cultivar had a different optimum application rate of VC or manure (Zaller, 2007). The pH increased over time and with increasing levels of VC. The pH should be adjusted to allow for the slight rise over time. EC increased with the increasing level of VC and decreased over time. The pH and EC values are typical of compost applications. K and Na levels were high especially at the 30% rate and this could be detrimental to salt-sensitive species.

Regarding experiment 6 with applications of VC, VCE, or both. The addition of VC without drenches significantly increased plant growth measurements for all crops tested. Chander's (2015) results were similar to ours where treatments with 10% VC were generally taller and wider and had higher dry weights than those without the addition of VC. Lopez-Espinosa (2013) conducted a container study on Jalapeno peppers. And found that the treatments with combinations of VC and VC tea produced the tallest plants and had highest yields. In our study this was only true for the tomato and petunia crops. The individual crops differed on which level of fertilization was optimum. For example, highest FW for petunia was the 5 drenches per week treatment treatment without any addition of VC while tomato had the highest FW with 3 drenches per week with 10% VC. The differences in these two crops was observed repeatedly in these trials. These differences may be explained by tomato being a heavy feeding crop that requires high levels of nutrients. Petunia is a salt and pH sensitive crop (Citation such as Cavins). At the high pH levels petunia cannot access the iron/manganese necessary for growth.

Conclusion

The source of VC had dramatic effects on growth and the optimum application volumes. VC nutrient levels can be drastically different based on the feedstock and method used. Therefore, laboratory VC nutrient analysis and growth trials should be used by growers any time a new VC material is being considered. Seedlings can be successfully grown with VCE as well as TD fertilization. The rates that are optimal will differ based on species. Transplants can be successfully grown with VC and VCE as fertilizer sources. The optimal treatments will depend on the species being grown. VC/VCE can be used as an organic fertilizer to produce quality vegetable and floriculture transplants in greenhouse environments.

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Temperature effects on tomato (*Solanum lycopersicum* L.) growth and nutrient release in substrates amended with organic or conventional fertilizers.

Abstract

Fertility management of transplants can be difficult. Transplants are grown in small containers with nutrients that can be easily leached during irrigation practices. Organically supplied nutrients are primarily slow release and depend on biological processes to convert organically bound nutrients into a plant available form. Temperature influences both microbial activity and plant growth. The objective of this work was to evaluate the effects that temperature has on plant growth and nutrient release rate including leaching of nutrients to the environment as compared with conventional (non-organic) production. An experiment was conducted to compare the performance of several different commercially available granular organic fertilizers on 10 cm containers of 'Celebrity' (*Solanum lycopersicum* L.) tomato transplants grown at average daily temperatures of 10, 15, or 20 °C. A peat perlite mix with no added fertility was used as the base substrate for the trial. The organic fertilizers included Sustane, vermicompost (WormPower, LLC.), Verdanta, and Microstart. Osmocote (CRF) and constant liquid fertilizer (CLF) were used as conventional fertilizer comparison. The granular fertilizers were incorporated prior to planting (400 $mg \cdot L^{-1}$ N) and for the CLF treatment it was applied at 150 $mg \cdot L^{-1}$ N at each watering, plants were grown in controlled environment chambers set at 10, 15, or 20 °C. No additional fertilizer was applied throughout the trial. Leachate was collected every two weeks. After 6 weeks the plants were destructively harvested and height, width, SPAD chlorophyll index, shoot and root dry weights were measured. The results indicate that the fertilizers perform well at 15

and 20 °C, but plant growth and nutrient availability was much reduced at 10 °C. Fertilizers were compared within each temperature treatment. At 10 °C plants were small and some had died. At 15 °C vermicompost plants were smallest and other fertilizers performed similarly well. At 20 °C CLF plants were the largest and all other treatments performed similarly. This indicates that the organic fertilizers can be used as a substitute for CRF at 20 °C. At 10, 15, and 20 °C vermicompost had the lowest shoot concentration of N. At 15 °C Sustane, Verdanta, and Microstart had similar levels of N as CRF. Based on our results, Sustane, Verdanta, and Microstart can be substituted for conventional synthetic fertilizers for quality plant growth and decreased leaching at 15 and 20 °C, with a slight compromise in growth at 20 °C.

Introduction

The demand for organic products has risen steadily in the U.S. Wholesale value of organic vegetable, melon and potatoes increased from 690 million in 2007 to 1.33 billion in 2014 for (USDA 2014; USDA 2007). This has led to an increased interest in managing organic fertility both in the field as well as in “starts”, i.e. young transplants typically grown in greenhouse in soilless substrates which are transplanted into the field. Transplants are used by field producers to get a head start on the growing season as well as to ensure that plant establishment is uniform. Fertilizer management is cited as one of the most problematic areas of organic production because there are less tools available to correct nutrient imbalances/disorders as compared with conventional production (Burnett et al., 2009). Also organic fertilizers tend to be more expensive and there is the difficulty of matching nutrient supply to plant needs (Alexander, 2009; Carlile, 2008; Hartz & Johnstone 2006; Hartz et al., 2010).

The US National Organic Program (NOP) has established guidelines about what inputs can be used in organic production systems. Organic fertilizer sources are typically composed of animal and plant residues as well as some allowable mined materials (Burnett et al., 2016). Other certifying agencies such as the Organic Materials Review Board (OMRI) have made lists of approved products to aid growers in selecting approved products (Organic Materials Review Board, 2014).

Organic fertilizers typically have a small proportion of readily available nutrients, additional nutrient availability occurs over time and relies on microbial activity to release these nutrients (Khaliq et al., 2006; Zhoa et al., 2016). For example, nitrogen (N) is often a limiting element for healthy plant growth and organic N must be converted to plant available forms. Through mineralization microbes break down organic compounds and release NH_4 which plants can utilize. Further transformation can occur when the microbial community converts NH_4 into NO_3 via nitrification creating another plant available form of N (Zhang et al., 2006). Microbial community activity is mitigated by temperature (Zhang et al., 2006) so when growers are trying to save money on greenhouse heating costs by growing at cold temperatures the nutrients are potentially bound in the soil. Controlled release conventional fertilizers do not rely on microbial activity but temperature and moisture to release the nutrients within the polymer coating (Merhaut et al., 2006). One study that compared growth and nutrient uptake of conventional controlled release and constant liquid feed fertilizer (CLF) applications on *Argyranthemum frutescens* L., *Calibrachoa* Llave & Lex., *Diascia barberae* Link & Otto, and *Sutera cordata* Roth (Camberato et al., 2013) found that CLF applications led to increased leaching and similar plant growth as the controlled release fertilizer.

Vermicompost (VC) is an organic fertilizer that has been of increasing interest for organic growers. VC is a worm worked material that can be produced from food scraps, manures, yard waste, or other organic inputs. VC can suitable for use in organic production so long as specific protocols are followed. The feedstock should reach temperatures of 55° C for three or more consecutive days before vermicomposting. The material is then applied to worm beds in thin layers at 1-3 day intervals to maintain aerobic conditions, moisture levels between 70-90%, and temperatures above 35 °C are to be avoided. This is continued until a finished product is produced (USDA 2011). VC may be a beneficial organic fertilizer source due to its high availability of nutrients (Brace, Chapter 1). The way a VC is made or used makes a difference in the final product and the plants grown in it (Belda et al., 2013; Surrage et al., 2010; Tringovska, 2014; Yang et al., 2015; Brace, Chapter 1). Studies have been conducted on quantity of VC used as a fertilizer or incorporated in exchange of peat in a soilless substrate for in marigold (*Tagetes species* L.), tomato (*Solanum lycopersicum* L.), pansies (*Viola wittrockiana*) and primulas (*Primula vulgaris* L.) (Chander at al., 2015; Lazano & Dominguez, 2010; McGinnis et al., 2009; Moreno-Resendez et al., 2013; Zaller, 2007). Marigolds were grown in containers with sand and either VC, pig manure or farm yard manure (Chander at al., 2015). Plant height and spread increased significantly with the addition of up to 1000 g manure kg soil^{-1}. Pansies and primula, grown in peat based media with 5-25% pig manure VC, exhibited a general decrease in growth at the 15 and 25% application rates for both species (Lazcano & Dominguez, 2010). Hibiscus plants were grown in pine bark substrates with pig manure based VC and conventional fertilizer added (McGinnis at al., 2009). The treatment with VC and N as the only added fertilizer performed better (DW) than the pine bark with an N-P-K conventional fertilizer added. Tomato seedlings were larger when grown with pig manure based VC, replacing the commercial media with amounts of 25-50% VC (Moreno-Resendez et al., 2013). Tomato plants were grown in a peat based substrate with 0-100% VC added to replace the peat (Zaller, 2007). Cultivar of tomato had drastic effects on plant growth measures. For example, two CVs of tomato had early emergence of seedlings when 100% VC was applied. The third variety had earliest emergence at 20% VC.

There are many commercially available organic fertilizers for container production. Some are granular substrate incorporated and others are water soluble and applied in the irrigation water. The usage depends on preference and crop management styles. Many studies have investigated the effect of organic fertilizers on growth of greenhouse plants in soilless substrates.

For example, Morning glory (*Ipomoea carnea* L.) growth (lant weight, height, and leaf area) were largest for the Osmocote treatment as compared to organic slow release fertilizer or arbuscular mycorrhizal treatments (Carpio et al., 2005). The leachate EC levels were highest at the start of the experiment and decreased with each sampling time. In a greenhouse study 'Saladette' tomatoes were grown using combinations of sand compost and vermicompost (Marquez-Quiroz at al., 2015). The yield and plant size was largest for the treatment with conventional fertilizer and sand and smallest with the treatment of sand, compost, VC and VC tea. All sources produced plants that had optimal size and fruit production. Jalapeno peppers were grown in a greenhouse using a sand based mix with compost, VC and VC extract as fertilizers (Lopez-Espinosa at al., 2013). The treatments with 25% and 50% horse and goat manure based VC had the largest number of fruit on the plants.

Commercially available organic substrates were compared for plant growth and chemical parameters (Russo 2005). Watermelon, bell pepper, and onion were germinated in the substrates and no effect was noted on total emergence and then transplanted into the three substrates being tested. The plants were fertilized with two or four times the label rate of Sea Tea 2.1-3.3-2.2 (N-P-K, Garden-Ville, San Antonio, TX) or conventional fertilizer; six weeks later plant height and dry weight was measured. Regardless of substrate the four times label rate of Sea Tea produced the heaviest and tallest plants. In a study on tomatoes, they were fertilized with either manure, VC, conventional fertilizers, or a combination (Chaitanya at al., 2015). The largest N uptake and fruit growth was observed in the 25% VC and 75% conventional fertilizer treatment. Another experiment looked into marigold growth and flowering in response to fertilizer type (Bi, 2010). Chicken based manure organic fertilizers, Osmocote and a liquid conventional fertilizer were applied. The conventional liquid fertilizer increased plant growth with increasing levels. The organic manures increased plant shoot growth but decreased root growth possibly due to the high EC levels. The above studies did not report the effect of organic fertilizer treatments on nutrient leaching from containers.

With both conventional and organic fertilizers nutrient leaching is a concern. The high levels of N and P that have been leached into waterways have caused extensive damage such as the dead zone in the Gulf of Mexico and contamination of well-water in some intensively irrigated agricultural areas (Hargitt, 2001). The rate of loss of the fertilizer depends on various factors such as quantity of fertilizer used, fertilizer solubility, nutrient retention properties (cation exchange capacity) of the growing media, and frequency and volume of applied irrigation water (Hargitt, 2001). Studies have been conducted to compare these rates of loss typically in conventional fertilization systems (Merhart et al., 2006; Albano 2006). The leachate levels of all fertilizers were high to optimum and decreased after four weeks in response to CRF (Albano et al., 2006). Four commercially available synthetic controlled release fertilizers (CRF) were used to stimulate the growth of nursery shrubs (Merhart at al., 2006). The CRFs had different temperatures of release and Osmocote had the lowest and steadiest release rates of N. Organic fertilizers may potentially have reduced nutrient leaching due to slower release and availability of nutrients as compared with conventional liquid fertilizers. In many of the cited studies, when fertilizers were compared treatments were not equilibrated in terms of total nutrient (or N) supplied. In addition, few studies have looked at the temperature response to nutrient release and plant performance for organic fertilizers in greenhouse crop studies.

The objective of this research is to determine the effects of temperature on nutrient release/leaching, plant accumulation, and plant quality when using one of several organic fertilizers as compared to conventional controlled release and liquid fertilizers for growth of tomato (*Solanum lycopersicum* L.) transplants in a soilless substrate.

Materials and Methods

This experiment compared tomato plant growth, nutrient uptake, and leaching of fertilizer nutrients in response to six different fertilizers and three different temperatures in the growing environment. Four of the fertilizers were labeled for organic production and listed by the Organic Material Review Institute (OMRI): Worm Power (W) 1.5-0.31-1.25 (N-P-K, dairy manure vermicompost) (Worm Power, RT Solutions, LLC, Avon, NY), Verdanta EcoVita (V) 7-2.19-8.30 (N-P-K, derived from hydrolyzed feather meal, fermented sugar beet and sugar cane molasses, bone meal, soybean meal, and cocoa shell meal) (Bioworks, Inc. Victor, NY, U.S.), Microstart 60 plus (M) 7-3.06-1.66 (N-P-K, derived from feather meal and pasteurized poultry litter) (Perdue AgriRecycle, Seaford, DE, U.S.), and Sustane (S) 8-1.75-3.32 (N-P-K, derived from aerobically composted turkey litter, feather meal and sulfate of potash) (Sustane, Cannon

Falls, MN, U.S.). The conventional fertilizer controls included a slow release treatment using Osmocote Bloom (O) 12-3.06-14.94 (N-P-K) (Everris, Dublin, OH, U.S.) and a constant liquid feed treatment of 150 mg·L^{-1} N using Peter's Professional (CLF) 20-4.4-16.6 (N-P-K) (J.R.Peters, Allentown, PA). The organic fertilizers and the conventional slow release fertilizer were applied at 400 mg·L^{-1} N incorporated into the base potting substrate just prior to planting. The base substrate was prepared using 80:20 (v:v) peat and coarse perlite to which 2.95 g·L^{-1} pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) was added to adjust the substrate pH.to 6.0. No additional fertilizers were applied. Prior to the experiment, seedlings of tomato 'Celebrity' (untreated seeds, Harris Seeds, Rochester, NY) were grown for four weeks after seeding in 200- cell trays (18.9 mL $cell^{-1}$, T.O. Plastics, Inc. Clearwater, MN) in 80:20 (v:v) peat and coarse perlite to which 2.95 g ·L^{-1} pulverized dolomitic limestone was added to adjust the pH to 6.0. Greenhouse temperature set points for the seedlings were 18 °C (heating) and 20 °C (ventilation) with ambient light levels. The seedlings were fertilized with a 50 mg·L^{-1} drench of Verdanta PL-2 2-0-4.98 (N-P-K) (BioWorks Inc., Victor, NY) liquid organic fertilizer twice per week. Seedlings were watered as needed with tap water the rest of the week.

The experiment was conducted in controlled environment chambers at Cornell University, Ithaca, NY from July 8 - August 19, 2013. Three chambers were used; each had a different temperature set point: 10, 15, or 20°C. Light within chambers was provided by T5 fluorescent lamps adjusted to a light intensity of 300 μmol·m^{-2}·s^{-1} at bench height. Lights were on for 12 h daily, providing a daily light integral of 13.0 mol·m^{-2}·d^{-1} The four week old tomato seedlings were transplanted into 10 cm containers (495 mL, Dillen Products, Middlefield, OH) containing the base substrate with one of the six fertilizer treatments. There were five replicate plants for each fertilizer and temperature treatment combination.

All leachate was collected during the experimental period to determine NO_3-N and NH_4-N concentration in leachate. Containers with plants were placed on top of 3.8 L buckets with holes cut into the lids to hold the 10 cm containers. The 3.8 L buckets were used to collect the leachate from the individual 10 cm containers. Containers were watered to a 20% leaching fraction with clear tap water. This was done by weighing representative containers from each treatment before each watering event and adding 120% of the amount of water that was lost since the previous watering. The CLF treatment was watered with 150 mg N kg^{-1} fertilizer as described above at each irrigation. This is a typical rate and method of fertilizing tomato plants and was thus used as a conventional comparison. Leachate volume was recorded and a 50 mL sample was taken for nutrient analysis at 2 week intervals. To each 3.8 L container 2 mL of 2N Sulfuric acid was added at the first irrigation and re-added after each leachate sample collection and emptying of containers so as to inhibit nitrification (Merhaut et al., 2006).

After 6 weeks the experiment was destructively harvested. Data were collected on plant height, from the substrate surface to the tallest part of each plant; plant width, the average of two measurements, width at the widest part of the plant and at a 90 ° angle; leaf chlorophyll index (SPAD) of three recently mature leaves per plant (Minolta Chlorophyll Meter SPAD-502; Spectrum Technologies, Plainfield, IL); shoot dry weight (SDW) harvested at the substrate surface and dried following 3 d in an oven at 70 °C. Root dry weight (RDW) was measured by removing substrate and washing roots then drying in an oven for 3 d at 70°C. Dried root and shoot samples were ground and sent to Cornell Nutrient Analysis Lab (Cornell University, Ithaca, NY) for digestion and nutrient analysis using their standard methods (Handbook of Reference Methods for Plant Analysis, Kalra, Y.P. 1998). Leachate was analyzed for ammonium-nitrogen (NH_4^+-N), and nitrate-nitrogen (NO_3-N) using an AQ-2 discrete analyzer

(SEAL-Analytical Inc., Mequon, WI) with spectrophotometric analysis. Accumulation was determined by measuring the concentration of N, P, or K in the shoot tissues, taking the mean concentration and multiplying by the mean dry weight of tissue samples. Use efficiency was calculated by dividing accumulation in plant by the nutrient applied per pot and multiplying by 100.

The experiment was a randomized complete block design, with three blocks (temperature) and six fertilizer treatments randomized within each block. Each plant/container was an experimental unit and there were five experimental units (replicates) for each treatment combination. An analysis of variance was conducted to determine whether measured parameters were affected by fertilizer source within a temperature treatment. Tukey's mean separation tests (alpha=0.05) were conducted to determine differences in fertilizer treatments within a temperature treatment.

Results

Plant growth response to fertilizer and temperature

At the 15 and 10 °C treatments no differences in plant height were observed among the fertilizers (Fig. 1). At 20 °C the only difference in height was observed between plants grown with CLF (22 cm) and those grown with V (34.4 cm). Height of other fertilizer treatments were not significantly different from each other or from CLF or V.

Plant width at 10 °C did not respond to fertilizer treatment (Fig. 1). At 15 °C the greatest plant width was from CLF (20.4 cm), followed by O and S, and followed by M and V. The smallest plant width was observed in the W treatment

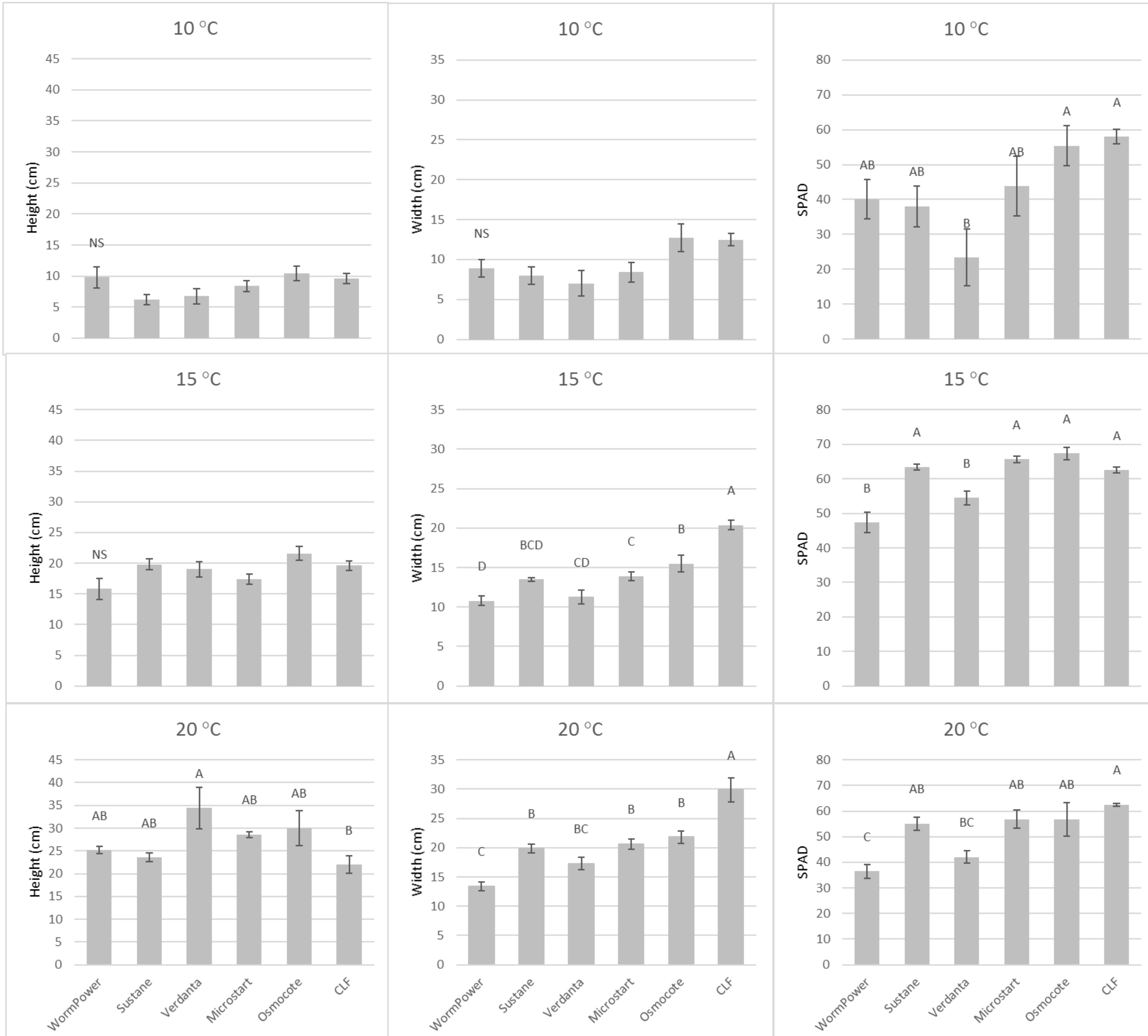

Figure 1. Effect of temperature and fertilizer on tomato 'Celebrity' grown for 6 weeks in an 80:20 (v:v) peat and coarse perlite substrate with 2.95 g·L^{-1} pulverized dolomitic limestone. Organic fertilizers (N-P-K) were: Worm Power 1.5-0.31-1.25, Verdanta EcoVita 7-2.19-8.30, Microstart 60 plus (M) 7-3.06-1.66, and Sustane 8-1.75-3.32, The conventional fertilizer controls included a controlled release fertilizer Osmocote Bloom 12-3.06-14.94 and a constant liquid feed treatment using Peter's Professional (CLF) 20-4.4-16.6. Fertilizers were incorporated pre plant at 400 mg L^{-1} except for the CLF which was applied at 150 mg·L^{-1} N per irrigation. Letters represent mean separation comparison of the 6 different fertilizers within a given temperature using Tukey's HSD, alpha=0.05. NS denotes non significance.

(10.8 cm) and this was similar to S and V. At 20 °C the widest plants were grown with CLF (29.9 cm). The next widest were O, M, V, and S. The smallest shoot width was found in the W (13.4 cm) treatment.

SPAD chlorophyll index at 10 °C was highest for the CLF treatment (58.0) and did not differ from O, M, S, and W (Fig. 1). The smallest chlorophyll index was found in the plants grown in V (23.4) and did not differ from M, S, and W. At 15 °C, M exhibited the greatest chlorophyll index (65.6) and this did not differ from C, O, and S. The smallest index was found with W (47.4) and this did not differ from V. At 20 °C the highest index was found with the CLF (62.5) and this did not differ from O, M, and S. The smallest index was found with W (36.5) and this was similar to V.

SDW did not respond to fertilizer treatment at 10 °C (Fig. 2). At 15 °C, W and V were similar and had the smallest dry weights. The M, V, S, O, and CLF treatments had the largest SDW. At 20 °C, SDW of CLF plants was the largest. W was the smallest and did not differ from S, V, M and O.

RDW at 10 and 15 °C did not respond to fertilizer treatment (Fig. 2). (1.3 g, CLF). At 20 °C, RDW of W (0.78 g) was smallest and did not differ from S, V, M, and O while SDW ofCLF (1.28 g) was the largest and did not differ from S, V, M, and O.

Shoot nutrient concentration

At 10 °C shoot N concentration (Table 1) was lowest for W (2.31%) and highest for S (4.9%). At 15 °C N concentration was lowest for W (0.67%) and highest for CLF (1.79%). At 20 °C N

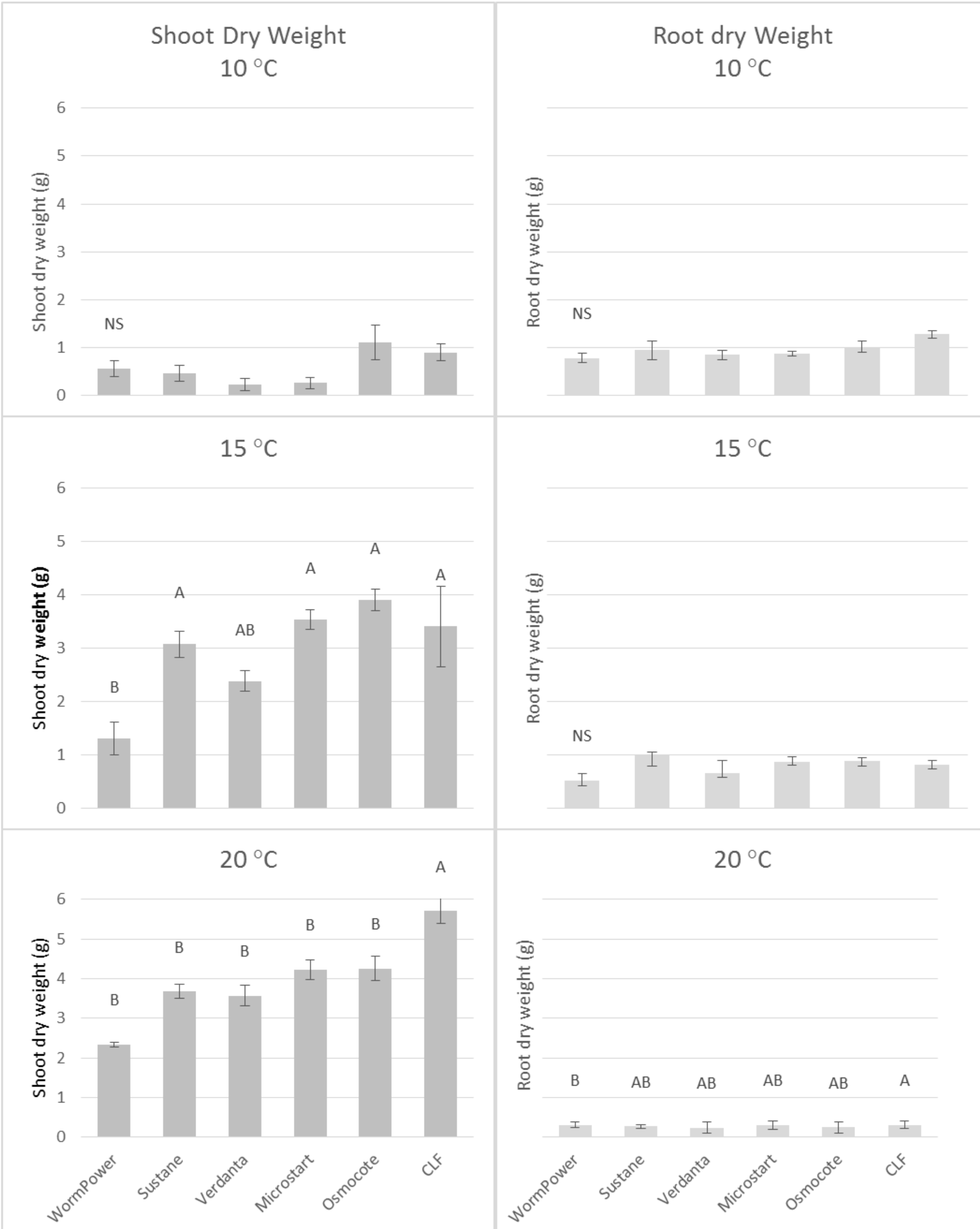

Figure. 2: Effect of temperature and fertilizer on tomato 'Celebrity' grown for 6 weeks in an 80:20 (v:v) peat and coarse perlite substrate with 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone. Organic fertilizers (N-P-K) were: Worm Power 1.5-0.31-1.25, Verdanta EcoVita 7-2.19-8.30, Microstart 60 plus (M) 7-3.06-1.66, and Sustane 8-1.75-3.32, The conventional fertilizer controls included a controlled release fertilizer Osmocote Bloom 12-3.06-14.94 and a constant liquid feed treatment using Peter's Professional (CLF) 20-4.4-16.6. Fertilizers were incorporated pre plant at 400 mg L^{-1} except for the CLF which was applied at 150 $mg \cdot L^{-1}$ N per irrigation. Letters represent mean separation comparison of the 6 different fertilizers within a given temperature using Tukey's HSD, alpha=0.05. NS denotes non significance.

concentration of W (0.74%) was again the lowest. Plants with V had the greatest N concentration (1.47%).

Regarding P concentration, at 10 °C plants fertilized with O (0.3%) had the lowest concentration of P (Table 1). Plants with V had the highest concentration of P (1.47%). At 15 °C the lowest shoot P concentration was found with M (0.11%) and the highest was found in the V treatment (0.64%). At 20 °C the lowest shoot P concentration was found with plants grown with O (0.14%) and the highest shoot P concentration was found in V (1.01%).

Potassium concentration at 10 °C (Table 1) was greatest in V (4.3%). The lowest level was found in plants grown with M (1.65%). At 15 °C K levels were highest in V (2.96%) and lowest in plants grown with M (0.71%). At 20 °C K levels were highest in V (3.3%) and lowest in plants grown with S (0.07%).

At 10 °C no differences in Ca concentration of tomato plants were observed (Table 1). At 15 °C the highest level of Ca was found in plants fertilized with V (1.22%) and lowest in M (0.53%). At 20 °C the highest concentration of Ca was found in V, W, S, and M (ca. 1.7%). The lowest concentration was in plants grown with CLF and O (0.92% to 1.25%).

Table 1. Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) concentration (%) in tomato 'Celebrity' shoots as a result of three temperature treatments and six fertilizers. Plants were grown in 10 cm containers with an 80:20 (v:v) peat and coarse perlite with 2.95 g·L^{-1} pulverized dolomitic limestone. Fertilizers were incorporated pre plant at 400 mg L^{-1} except for the CLF which was applied at 150 mg·L^{-1} N per irrigation. Plants were grown for 6 weeks in controlled environment chambers under their respective temperature conditions. Data represent means ± standard error with a temperature treatment.

Fertilizer[z]			**N (%)**				**P (%)**				**K (%)**				**Ca (%)**				**Mg (%)**		
										10°C											
W	10	2.31	±	1.27	B	0.71	±	0.08	BC	2.12	±	0.21	B	1.62	±	0.11	NS	0.94	±	0.08	NS
S	10	4.90	±	0.34	A	0.86	±	0.09	B	2.76	±	0.16	AB	1.50	±	0.14		0.98	±	0.12	
V	10	4.77	±	0.85	A	1.47	±	1.47	A	4.30	±	4.30	A	1.79	±	1.79		0.85	±	0.85	
M	10	4.42	±	0.40	A	0.36	±	0.09	C	1.65	±	0.37	B	1.10	±	0.31		0.63	±	0.18	
O	10	3.06	±	0.25	AB	0.30	±	0.04	C	1.86	±	0.24	B	1.20	±	0.06		0.81	±	0.05	
CLF	10	3.12	±	0.21	AB	0.50	±	0.06	CD	1.86	±	0.10	B	1.28	±	0.08		0.94	±	0.08	
										15°C											
W	15	0.67	±	0.40	C	0.32	±	0.02	C	2.42	±	0.20	A	0.98	±	0.10	AB	0.50	±	0.04	C
S	15	1.19	±	0.28	B	0.21	±	0.01	D	1.27	±	0.08	BC	0.96	±	0.05	AB	0.70	±	0.04	B
V	15	1.25	±	0.54	B	0.64	±	0.05	A	2.96	±	0.22	A	1.22	±	0.12	A	0.59	±	0.07	B
M	15	1.30	±	0.02	B	0.11	±	0.02	E	0.71	±	0.09	C	0.53	±	0.05	C	0.38	±	0.04	B
O	15	1.22	±	0.07	B	0.18	±	0.01	DE	1.53	±	0.04	B	0.97	±	0.10	AB	0.68	±	0.05	B
CLF	15	1.79	±	0.03	A	0.44	±	0.01	B	2.58	±	0.11	A	0.84	±	0.06	BC	0.73	±	0.03	A
										20°C											
W	20	0.74	±	0.10	C	0.47	±	0.03	B	2.38	±	0.08	B	1.63	±	0.10	AB	0.78	±	0.06	B
S	20	1.21	±	0.06	AB	0.29	±	0.01	CD	1.58	±	0.07	C	1.43	±	0.13	AB	0.82	±	0.04	B
V	20	1.47	±	0.08	A	1.01	±	0.07	A	3.30	±	0.24	A	1.72	±	0.11	A	0.73	±	0.04	BC
M	20	1.36	±	0.03	AB	0.23	±	0.01	CD	1.16	±	0.03	C	1.69	±	0.10	A	1.00	±	0.05	A
O	20	1.08	±	0.02	B	0.14	±	0.00	D	1.29	±	0.04	C	1.25	±	0.02	BC	0.82	±	0.03	B

CLF	20	1.33	±	0.09	AB	0.34	±	0.02	BC	1.60	±	0.07	C	0.92	±	0.05	C	0.66	±	0.02	C

[z] Fertilizers used W: WormPower (1.5-0.31-1.25), S: Sustane (8-1.75-3.32), V: Verdanta (7-2.19-8.30), M: Microstart (7-3.06-1.66), O: Osmocote (12-3.06-14.94), CLF: Constant liquid feed (CLF) of Peter's Professional (20-4.4-16.6)

[Y] Letters represent mean separation comparison, within a temperature and week, using Tukey's HSD, alpha=0.05 NS denotes non significance.

At 10 °C no differences in Mg concentrations of tomato plants were observed (Table 1). At 15 °C CLF (0.7%) had the highest concentration of Mg. The lowest concentration was observed with the W fertilizer (0.5%). At 20 °C M fertilized plants had the highest Mg concentrations (1%). The smallest concentration was found with CLF (0.66%) grown plants.

Nutrient accumulation and nutrient use efficiency

For substrate incorporated fertilizers (W, S, V, M and O), N applied per pot was the same (198 mg) at all temperatures (Table 2). The CLF applied varied by temperature treatment, due to varying water use (and therefore fertilizer applied in the irrigation water). At 10, 15, and 20 °C, 74.8 mg, 128.8 mg, and 259.69 mg N from the CLF fertilizer was applied.

N Accumulation varied by temperature but W was consistently the lowest and CLF was highest for the 15 and 20 °C. The UE varied but again W had the smallest UE and CLF had the highest for all temperature treatments.

The total P applied per pot was the same for each temperature but varied by fertilizer source. This is because fertilizer sources except CLF were equilibrated so as to apply the same amount of N, but they inherently had different proportions of P. P applied per pot was: W (40.37 mg), S (43.2 mg), V (74.01 mg), M (24.62 mg), and O (86.49 mg) (Table 2). The P applied in the CLF treatment varied by temperature: 10 °C (15.54 mg), 15 °C (25.76 mg) and 20 °C (53.32 mg) was applied.

Table 2. Fertilizer effect on Nitrogen (N), Phosphorus (P), and Potassium (K) accumulation in plant tissue and use efficiency in tomato 'Celebrity' shoots as a result of three temperature treatments and six fertilizers. Plants were grown in 10 cm containers with an 80:20 (v:v) peat and coarse perlite with 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone. Fertilizers were incorporated pre plant at 400 mg L^{-1} except for the CLF which was applied at 150 $mg \cdot L^{-1}$ N per irrigation. Plants were grown for 6 weeks in controlled environment chambers under their respective temperature conditions. Accumulation was determined by measuring the concentration of N, P, or K in the shoot tissues, taking the mean concentration and multiplying by the mean dry weight of tissue samples. Use efficiency was calculated by dividing accumulation in plant by the nutrient applied per pot and multiplying by 100.

	Nutrient applied per pot (mg)			Accumulation in plant (mg)			Use efficiency (%)		
Fertilizer[z]	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
					10 °C				
WormPower	198	40.37	164.56	9.1	5.16	15.42	4.6	12.78	9.37
Sustane	198	43.20	82.18	13.3	3.44	12.23	6.7	7.96	14.88
Verdanta	198	74.01	281.54	9.8	13.23	38.67	5.0	17.87	13.73
Microstart	198	24.62	46.84	17.8	1.82	10.10	9.0	7.41	21.57
Osmocote	198	86.49	254.26	29.8	2.68	18.62	15.1	3.10	7.32
CLF	75	15.54	59.11	25.6	4.07	16.00	34.2	26.22	27.07
					15 °C				
WormPower	198	40.37	164.56	8.7	4.20	30.05	4.4	10.41	18.26
Sustane	198	43.20	82.18	41.9	7.44	44.87	21.2	17.23	54.60
Verdanta	198	74.01	281.54	29.9	15.06	69.38	15.1	20.35	24.64
Microstart	198	24.62	46.84	40.4	3.38	22.50	20.4	13.74	48.04
Osmocote	198	86.49	254.26	47.7	7.05	59.89	24.1	8.15	23.55
CLF	129	26.76	101.78	62.1	15.12	88.82	48.2	56.50	87.27
					20 °C				
WormPower	198	40.37	164.56	17.3	11.11	55.88	8.7	27.53	33.96
Sustane	198	43.20	82.18	51.6	12.03	67.23	26.0	27.84	81.81
Verdanta	198	74.01	281.54	52.6	36.15	117.89	26.6	48.85	41.87
Microstart	198	24.62	46.84	49.8	8.59	42.68	25.2	34.89	91.13
Osmocote	198	86.49	254.26	46.5	5.81	55.15	23.5	6.71	21.69
CLF	257	53.32	202.86	75.8	19.22	91.15	29.5	36.05	44.93

[z] Fertilizers used WormPower (1.5-0.31-1.25), Sustane (8-1.75-3.32), Verdanta (7-2.19-8.30), Microstart (7-3.06-1.66), Osmocote (12-3.06-14.94), CLF: Constant liquid feed (CLF) of Peter's Professional (20-4.4-16.6)

V had the highest application rate of P and it had high rates of accumulation. The PUE was highest at 10 and 15 °C for the CLF treatment. At 20 °C V fertilizer resulted in the greatest PUE. PUE was lowest in all temperatures in the O fertilized treatments.

K applied per pot was the same for W (164.6 mg), S (82.2 mg), V (281.5 mg), M (46.8 mg), and O (254.26 mg) at each temperature, but K input rates varied by fertilizer due to their inherent varying proportions (Table 2). The CLF supplied K varied by temperature, at 10 °C 59.11 mg, 15 °C 101.78 mg, and 20 °C 202.86 mg.

K application level was highest for the V fertilized plants. This was evident also in K accumulation at the 10 and 20 °C temperatures. At 15 °C V was second highest in K application but CLF had a greater uptake. No clear patterns emerged in the KUE, but CLF had the highest KUE for both 10 and 15 °C

N leaching over time

NH_4-N and NO_3-N N concentration changed over the 6 week experimental period. In general, the NH_4-N concentration in leachate decreased over time (Table 3). The exception to this was the CLF which remained at a higher level than the others throughout the experimental period.

Patterns of NO3-N concentration in leachate did not show as consistent a pattern as NH4-N. The CLF for 10 and 15 increased at week 4 all others decreased or stayed about the same.

In terms of total N (NH4-N + NO3-N) concentration in leachate, CLF again exhibited increased N concentration in the leachate at 15 and 20 °C. The four organic and controlled release fertilizer

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Table 3. Ammonium-Nitrogen (NH4-N), Nitrate-Nitrogen (NO3-N), and Total-N (NH4-N + NO3-N) concentration in leachate measured at 2 week intervals as a result of three temperature treatments and six fertilizers in a growth chamber experiment. All leachate was collected in a container underneath the individual pots. At sampling time the volume of leachate was measured and a sample was taken. The buckets were then dumped and placed back under the pots. Tomato 'Celebrity' was grown in an 80:20 (v:v) peat and coarse perlite with 2.95 g·L-1 pulverized dolomitic limestone. Organic fertilizers (N-P-K) Worm Power 1.5-0.31-1.25, Verdanta EcoVita 7-2.19-8.30, Microstart 60 plus 7-3.06-1.66, and Sustane 8-1.75-3.32, The conventional fertilizer controls included a slow release treatment using Osmocote Bloom 12-3.06-14.94 and a constant liquid feed treatment using Peter's Professional (CLF) 20-4.4-16.6. Fertilizers were incorporated pre plant at 400 mg L-1 except for the CLF which was applied at 150 mg·L-1 N per irrigation.

Fertilizer[z]	Week	NH4-N (mg L^{-1})	Sig[Y]	NO3-N (mg L^{-1})	Sig	Total N (mg L^{-1})	Sig
			10 °C				
WormPower	2	15.39 ± 3.85	NS	24.81 ± 5.46	A	36.35 ± 9.31	A
Sustane	2	15.65 ± 3.13		0.60 ± 0.11	C	13.12 ± 3.21	B
Verdanta	2	14.44 ± 3.07		0.85 ± 0.26	C	12.40 ± 3.25	B
Microstart	2	15.69 ± 0.02		1.35 ± 0.12	C	17.05 ± 0.14	AB
Osmocote	2	15.56 ± 0.04		18.14 ± 3.93	AB	33.70 ± 3.96	A
CLF	2	13.52 ± 2.84		10.55 ± 1.90	BC	21.37 ± 3.98	AB
WormPower	4	5.29 ± 0.98	B	0.94 ± 0.39	C	6.22 ± 0.82	C
Sustane	4	10.85 ± 1.32	A	4.62 ± 1.23	BC	15.47 ± 2.26	BC
Verdanta	4	12.01 ± 0.54	A	3.45 ± 1.42	BC	15.46 ± 1.35	BC
Microstart	4	14.41 ± 0.68	A	4.03 ± 2.47	BC	18.45 ± 2.54	B
Osmocote	4	13.59 ± 0.89	A	10.38 ± 2.96	B	23.97 ± 3.63	B
CLF	4	14.32 ± 0.74	A	25.69 ± 2.41	A	40.01 ± 2.92	A

WormPower	6	4.29 ± 2.65	B	1.83 ± 0.67	B	6.12 ± 3.32	C
Sustane	6	12.66 ± 1.69	A	2.83 ± 1.50	B	15.49 ± 2.86	BC
Verdanta	6	15.05 ± 0.45	A	0.75 ± 0.11	B	15.80 ± 0.54	BC
Microstart	6	15.60 ± 0.06	A	0.94 ± 0.23	B	16.54 ± 0.27	B
Osmocote	6	11.41 ± 1.37	A	4.05 ± 0.67	B	14.66 ± 1.97	BC
CLF	6	13.67 ± 0.82	A	19.79 ± 1.85	A	33.46 ± 2.65	A
			15 °C				
WormPower	2	11.07 ± 2.78	NS	22.87 ± 2.20	A	33.94 ± 4.30	A
Sustane	2	15.38 ± 0.08		0.51 ± 0.18	C	15.89 ± 0.24	C
Verdanta	2	6.32 ± 3.87		0.70 ± 0.27	C	8.60 ± 4.59	C
Microstart	2	15.33 ± 0.13		0.97 ± 0.24	C	16.30 ± 0.22	BC
Osmocote	2	15.66 ± 0.04		15.04 ± 1.58	B	30.70 ± 1.60	A
CLF	2	12.94 ± 2.34		15.62 ± 2.01	B	28.56 ± 3.56	AB
WormPower	4	0.97 ± 0.53	B	0.26 ± 0.05	B	1.24 ± 0.53	B
Sustane	4	1.59 ± 0.65	B	0.97 ± 0.34	B	2.56 ± 0.76	B
Verdanta	4	1.48 ± 0.55	B	1.98 ± 1.48	B	3.46 ± 1.20	B
Microstart	4	4.46 ± 2.95	AB	6.63 ± 6.11	B	11.09 ± 8.94	B
Osmocote	4	1.03 ± 0.40	B	0.72 ± 0.52	B	1.76 ± 0.87	B
CLF	4	12.30 ± 3.08	A	27.64 ± 2.79	A	39.94 ± 5.83	A
WormPower	6	1.18 ± 0.48	B	1.54 ± 0.48	B	2.72 ± 0.67	B
Sustane	6	2.87 ± 1.02	B	0.79 ± 0.21	B	3.67 ± 1.05	B
Verdanta	6	3.22 ± 0.52	B	0.74 ± 0.13	B	3.96 ± 0.52	B
Microstart	6	3.67 ± 0.76	B	1.08 ± 0.15	B	4.75 ± 0.79	B
Osmocote	6	4.45 ± 2.85	B	0.90 ± 0.18	B	5.34 ± 2.96	B
CLF	6	15.53 ± 0.05	A	29.04 ± 0.18	A	44.57 ± 0.21	A
			20 °C				

WormPower	2	8.39 ± 0.78	B	14.25 ± 1.55	A	22.64 ± 1.98	B
Sustane	2	15.39 ± 0.16	A	1.06 ± 0.30	C	16.45 ± 0.18	B
Verdanta	2	15.09 ± 0.28	A	0.59 ± 0.28	C	15.68 ± 0.51	B
Microstart	2	12.47 ± 2.97	AB	1.75 ± 0.54	BC	14.22 ± 2.48	B
Osmocote	2	14.25 ± 0.65	A	7.70 ± 2.65	B	21.95 ± 3.21	B
CLF	2	15.56 ± 0.06	A	19.78 ± 1.54	A	35.33 ± 1.57	A
WormPower	4	3.63 ± 0.67	B	2.57 ± 1.79	B	6.20 ± 2.39	B
Sustane	4	6.20 ± 1.58	B	1.55 ± 1.33	B	7.75 ± 2.18	B
Verdanta	4	6.40 ± 1.52	AB	1.33 ± 1.11	B	7.73 ± 0.98	B
Microstart	4	6.03 ± 0.95	B	3.48 ± 1.98	B	9.51 ± 2.02	B
Osmocote	4	4.13 ± 1.32	B	0.38 ± 0.14	B	4.51 ± 1.35	B
CLF	4	12.55 ± 1.98	A	19.60 ± 4.44	A	32.15 ± 6.17	A
WormPower	6	1.37 ± 0.29	C	1.98 ± 0.48	B	3.35 ± 0.45	B
Sustane	6	4.63 ± 0.65	B	1.05 ± 0.22	B	5.68 ± 0.68	B
Verdanta	6	4.41 ± 0.94	B	1.09 ± 0.22	B	5.50 ± 0.91	B
Microstart	6	2.30 ± 0.51	BC	0.74 ± 0.12	B	3.05 ± 0.59	B
Osmocote	6	1.43 ± 0.30	C	1.62 ± 0.37	B	3.04 ± 0.51	B
CLF	6	15.48 ± 0.04	A	28.32 ± 0.56	A	43.80 ± 0.58	A

[z] Fertilizers used W: WormPower (1.5-0.31-1.25), S: Sustane (8-1.75-3.32), V: Verdanta (7-2.19-8.30), M: Microstart (7-3.06-1.66), O: Osmocote (12-3.06-14.94), CLF: Constant liquid feed (CLF) of Peter's Professional (20-4.4-16.6)

[Y]Letters represent mean separation comparison using Tukey's HSD, alpha=0.05 NS denotes non significance.

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(O) showed a slow decrease in leachate concentration as the experiment progressed. The 10 °C pattern was not as clear, the W decreased sharply at week four and then plateaued. S had a linear decrease. CLF increased at week four and then decreased. The other three fertilizers remained somewhat stable and changed very little over the six weeks.

Discussion

Plant Growth

Temperature had a major effect on plant growth with all treatments at 10°C being the smallest and increasing as the temperature increased. This is typical of tomatoes which prefer a warm season for optimal growth. A study by Chander et al. (2015) supports the height results at 20 °C by finding that plant height of marigold increased with the addition of organic manures. Chander et al. (2015) had different results in marigold where it was found that organic manures increased plant width. In our experiment the CLF had the widest shoots. The similar plant growth metrics SDW and SPAD at 15 °C and RDW, SDW, width, height and SPAD at 20 °C, RDW indicate that growers could change from a controlled release conventional fertilizer such as O to an organic fertilizer without a significant decrease in plant growth. Similarly, Burnett et al. (2016) determined that organic fertilizers could be used successfully as long as close management was utilized.

Nutrient uptake by plants

Tomato shoots grown with W consistently had the lowest N concentrations regardless of temperature. The S, V, M, and O grown plants were similar at the 10 and 15 °C temperatures and this indicates that these fertilizers are supplying the plants with similar amounts of plant available N. At all temperatures the plants grown with V had the highest level of P, likely because V was the fertilizer with the highest proportion of P supplied. For all temperatures plants grown with V had the highest concentrations of K. This is potentially due to the fact that V had the highest rates of K applied to the plants and thus more available for the plants to uptake. This amount was six times more than the lowest application of K which was found in the M treatment. For the 15 and 20 °C treatments V had the highest concentration of Ca. Ca is very important in preventing BER (blossom end rot) which is a common problem in fruiting tomatoes. It was interesting to see that CLF had low levels of Ca, Ca is not added to this particular CLF so substrate and tap water Ca would be the only sources to the plant. At 15 °C, S, V and M had Mg levels similar to O indicating that these three organic fertilizers provided similar amounts of Mg to the growing tomato plants.

The N concentration in the leaves of Hibiscus with 20% VC and the addition of conventional N was significantly larger than treatments with pine bark or VC with N-P-K added (McGinnis et al., 2009). This was the same for P, Ca, Mg measured in leaves. K was highest in the pine bark substrate with N-P-K added. Chaitanya et al. (2013) measured nutrient uptake in field grown tomatoes. The authors found that at the vegetative stage N uptake was highest for the conventional fertilizer control and 75% fertilizer 25% VC. We found similar results with the CLF and O treatments. For the P uptake it was highest in the 75:25 conventional: VC. We observed that P accumulation was highest in V treatments for 20 and 10 °C. The accumulation at 15 °C was highest for CLF and V. Chaitanya again found the highest K uptake in the 75:25

conventional: VC. In our study V again was highest at 10 and 20. The 15 °C was highest at CLF. This was expected because a constant (and plant available) fertilizer addition was being supplied to the plants.

At 15 and 20 °C the S, V, M, and O had similar (statistical analysis not possible based on calculation method) NUE and this could indicate that the fertilizers could be used in place of one another without detriment to the N usage. Further tests would need to be done to confirm this.

In the V trt the N leached very quickly and rapidly. The CLF was fairly consistent in its leaching levels. At 15 °C total N and NO_3-N levels for W were the highest concentrations in week 2 and had dropped to one of the lowest by week 4. This indicates that the plants are utilizing the N in the fertilizer to grow or the NO_3-N is leaching out of the container and being lost before 4 weeks. After week 2, CLF became the fertilizer with the highest total N leachate concentration. This demonstrates that the controlled release O and the organic fertilizer could be better for the environment by decreasing N leaching from fertilization. The organic fertilizers and the CRF had much slower and lower levels of N leaching and this indicates that the n is more slowly plant available and will contribute to N pollution to a lower amount.

Conclusion

Several organic fertilizers in our experiment can be used successfully at 15 and 20 °C. We determined that S, V, and M could be substituted for a CRF or in some instances (at 15 °C) a CLF without compromising plant growth. The amount of nutrient used by the plant was strongly affected by the fertilizer source and subsequent amount of fertilizer applied. In general, W had the highest concentration of N loss in the leachate during the first 2 weeks. The other fertilizers had a more constant release pattern of nutrients. The W fertilizer source which is high in nitrate (Brace, Chapter 1) should be utilized with actively growing plants to avoid the potential for N runoff. CLF had the highest accumulation of N and V had high accumulation rates of P and K due to the high rates of these nutrients in the fertilizer. N, P, and K use efficiency was high with CLF, likely due to our precise irrigation practices (with a 20% leaching fraction) commercial practices (especially overhead hand or boom watering) may not be as precise leading to decreased UE compared with our observations. When switching to an organic fertilizer small trials will aid the user in determining the best practices for their individual growing environment, but success is possible as demonstrated by this study.

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Interactive effects of dairy manure vermicompost and poultry-based fertilizer on plant growth and microbial activity of tomato (*Solanum lycopersicum* L.) in a soilless substrate

Abstract

Fertility management of organic transplants can be difficult. Organically supplied nutrients are primarily slow release and depend on biological processes to convert organically bound nutrients into a plant available form. Little information is currently available on the effect of vermicompost additions on microbial activity and subsequent plant performance in soilless substrates. The objective of this work was to evaluate the effects that treatments of a dairy manure based vermicompost (VC) and Sustane (S), a poultry-based organic fertilizer, or a combination of the two have on tomato (*Solanum lycopersicum* L.) growth and microbial activity. VC applied at 5% substrate volume, autoclaved VC at 5% volume and Sustane at 4.75 $g \cdot L^{-1}$ were applied in six combinations to determine effects on nitrogen mineralization and microbial community activity. Plant growth parameters were measured at 2 week intervals for 6 weeks. Microbial tests, measured every two weeks, included potentially mineralizable N, respiration, extracellular enzyme activity, and microbial biomass. By week 6, the FW of trts with VC or AVC applied performed better than the control. Very little difference in plant growth was found between VC or AVC treatments. Microbial activity measurements found that most of the activity of the microbes was concentrated in week 0 and 2. Respiration decreased in week 4 and then increased in week 6. The microbial activity was greatest in the first 2 weeks and coincided with the highest levels of N in the substrate and leachate.

Introduction

The demand for organic products has risen steadily; wholesale value of organic vegetables, melon and potatoes increased from 690 million in 2007 to 1.33 billion in 2014 for (USDA 2014; USDA 2007). Organic production in greenhouses, was valued at 27 million in 2014, has also risen both in terms of producing vegetables for sale in the greenhouse and especially to produce high quality organic transplants for establishing for field production (USDA 2014). This has led to an increased interest in managing organic fertility in container plants with soilless substrates. Fertility management is one of the most problematic areas of organic production because there are not as many ways to correct nutrient imbalances as in the conventional world, also organic fertilizers tend to be more expensive and there is difficulty of matching nutrient supply to plant needs (Burnett et al., 2009; Alexander, 2009; Carlile, 2008; Hartz & Johnstone, 2006; Hartz et al., 2010).

Thermophilic composts have long been used as media amendments to supply some fertility, to increase organic matter, and because they divert waste from landfills (Alexander, 2009; Carlile, 2008). There are some problems with compost though. Immature compost can release high levels of ammonia and volatile organic compounds, and immature compost can tie up nitrogen and keep it from being available for growing plants (Alexander, 2009; Carlile, 2008). This in part has led to an increased interest in vermicompost (VC). VC is a worm worked material that can be produced from food scraps, manures, yard waste, or other organic inputs. The vermicomposting process makes nutrients more plant available, in particular, nitrogen (Brace, Chapter 1). VC can meet National Organic Program standards as an approved input for organic production so long as their process/input specifications are followed. For example, one processing method for manure based VC to be approved for organic production is to heat the feed stock to 55 °C for four or more consecutive days before vermicomposting. The material is then applied at thin layers at 1-3 day intervals to worm beds to maintain aerobic conditions. Moisture levels in worm beds must be maintained between 70-90%, and temperatures above 35 °C must be avoided, This is continued until a finished product is produced (USDA 2011).

Organic fertilizers typically have a small proportion of readily available nutrients, additional nutrient availability occurs over time and relies on microbial activity to release these nutrients (Khaliq 2006; Zhou et al., 2016). For example, nitrogen (N) is often a limiting element for healthy plant growth and organic N must be converted to plant available forms. Through mineralization microbes break down organic compounds and release NH_4 which the plants can utilize (Zhang et al., 2006). Further transformation occurs when the microbial community converts NH_4 into NO_3 via nitrification creating another plant available form of N (Zhang et al., 2006). Microbial community activity is also mitigated by temperature and moisture (Gomez-Brandon et al., 2016). Adding an organic fertilizer with a microbial community or inoculating a soil with a microbial community can help facilitate the release of other organic fertilizers by making the nutrients more plant available (Zhou et al., 2016).

A study conducted on containers of crabgrass (Digitaria ischaemum, Schreb.) and bermudagrass (Cynodon dactylon, Pers.) growing in soil filled pots revealed that microbial activity was greater in containers with plants present as opposed to bulk soil (Zhu et al., 2015). Enzyme assays also showed that low levels of N fertilizer resulted in greater extracellular enzyme activity than the heavily fertilized treatment indicating that when fertilizers were limiting greater extracellular enzyme activity was needed to make nutrients available. A study conducted to test the effects of pig manure composts and inorganic fertilizers on microbial activity, found that microbial biomass C and N were highest in the treatment that contained pig manure compost at 3600 kg ha^{-}

^{1} and 30% inorganic fertilizer as compared to no fertilization, N-P-K chemical fertilization, and 50% inorganic fertilizer plus 6000 kg ha^{-1} manure (Zhao et al., 2015). The soil microorganism population was highest in composted chicken manure, followed by VC chicken manure as compared to a no fertilizer treatment in an experiment on tomato (*Solanum lycopersicum* L.) in greenhouse conditions (Yang et al., 2015). Regarding extracellular enzyme activity B-glucosidase, an indicator of cellulose degradation was found to increase over six weeks and then decrease in VC systems that had earthworms *Estinia fetida* or a microorganism cocktail introduced (Mupambwa et al., 2015). The combination of earthworms and inoculation with a microorganism cocktail caused a decrease in B-glucosidase after two weeks. The nitrification rate of soil amended with manure, compost, VC, or anaerobic manure digestate was calculated at 0, 15, and 60 days (Gomez-Brandon et al., 2016). The compost had the highest rates of nitrification as well as the highest rates of respiration. Previous research has found many plant growth benefits of VC as an organic fertilizer (Brace, chapter 1). Experiments with VC in combination with other organic fertilizers have not previously been conducted by our research group. Overall information is lacking on how introduction of VC either alone or along with other organic fertilizers sources effects microbial community dynamics (biomass, respiration, and extracellular enzyme activity) in soilless substrate production of container plants.

The objective of this research is to determine how VC effects microbial community dynamics and subsequent plant performance either alone or in combination with a separate poultry-based organic fertilizer, Sustane (S). Further, the experiment was designed to help assess if VC benefits to plants in soilless substrates were primarily due to added nutrients from VC or from microbial community in VC facilitating mineralization of N from sources by comparing standard VC vs. autoclaved vermicompost (AVC) treatments.

Materials and Methods

The experiments described below compared plant growth, microbial biomass, activity (respiration), N mineralization, and function (extracellular enzyme activity) in the soilless substrates of greenhouse tomatoes in response to six combinations of organic fertilizer: vermicompost (VC), AVC and Sustane (S). Two fertilizers were used in the study: vermicompost (VC) 1.5-0.31-1.25 (N-P-K, dairy manure vermicompost) (Worm Power, RT Solutions, LLC, Avon, NY), and Sustane (S) 8-1.75-3.32 (N-P-K, derived from aerobically composted turkey litter, feather meal and sulfate of potash) (Sustane, Cannon Falls, MN, US). Both fertilizers are approved for organic production and listed by the Organic Material Review Institute (OMRI). AVC was prepared by placing VC in an autoclave at 121 °C for 30 min. It was then allowed to rest for 48 h and autoclaved for another 30 min at 121 °C. AVC was used as a treatment in attempt to differentiate the chemical and biological effects of VC. The VC and AVC were incorporated into the substrate at 5% (v/v) and S was incorporated at 4.75 $g \cdot L^{-1}$. The poultry litter based compost (S) and its application rate was based upon previous plant growth studies (Brace, chapter 2). The base substrate was prepared using 75:25 (v:v) peat and coarse perlite to which 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone (Oldcastle Industrial Minerals Thomasville, PA) lime was added to adjust the pH to 6.0. The six substrate treatments were 1- no fertilizer added, 2- S only, 3-VC only, 4- AVC only, 5- VC and S, and 6- AVC and S. No additional fertilizers were applied. Substrates were placed into 10-cm containers with a volume of 495 ml (Dillen Products, Middlefield, OH). Prior to the experiment, four week old seedlings of tomato 'Celebrity' (untreated seeds, Harris Seeds, Rochester, NY) were grown in 200-cell trays (18.9 mL $cell^{-1}$, T.O. Plastics, Inc. Clearwater, MN) in 80:20 (v:v) peat and coarse perlite to which 2.95 g $\cdot L^{-1}$ pulverized dolomitic limestone was added to adjust the pH. The seedlings were fertilized with a 50 mg$\cdot L^{-1}$ drench of Verdanta PL-2 2-0-4.98 (N-P-K) (BioWorks Inc., Victor, NY) twice per week. Seedlings were watered as needed with tap water the rest of the week. Two days prior to experiment initiation substrates were prepared (as described above) by incorporating the VC, AVC, and S materials. At experiment initiation, tomato seedlings were transplanted into the 10-cm containers. At this time (i.e. week 0) substrate samples were collected and analyzed for indicators of microbial activity (as described below). Subsequent substrate samples were collected every two weeks for a total of 6 weeks (i.e. week 2, 4, and 6). Greenhouse temperature set points were 18 °C (heating) and 20 °C (ventilation) with ambient light levels.

Plant measurements

At 2, 4, and 6 weeks 5 replicates (plants) of each treatment were destructively harvested. Data were collected on: plant height, from the substrate surface to the tallest part of each plant; plant width, the average of two measurements, width at the widest part of the plant and at a 90° angle; leaf chlorophyll index (SPAD) average from three recently mature leaves per plant (Minolta Chlorophyll Meter SPAD-502; Spectrum Technologies, Plainfield, IL); shoot fresh (FW) and dry weight (DW) harvested at the substrate surface and dried following 3 d in an oven at 70 °C.

Respiration- microbial activity

Respiration was determined by measuring the CO_2 evolved from individual substrates (Aria et al., 2007, Saltveit, 2016). A 5-10 g sample of substrate taken from the substrate in contact with the roots was weighed and placed into to a glass centrifuge tube immediately after harvest of the shoots. The tubes were sealed with a gas tight lid with a rubber septum. The samples were allowed to equilibrate at room temperature for 3 h and then were tested for CO_2 evolved using a Sable Systems CA-10a (Sable Systems International, North Las Vegas, NV). At the start of each sampling time a calibration curve with known CO_2 concentrations was created. A 1 ml sample was taken from the headspace of each container and injected into the CO_2 analyzer. Results were reported on a per g substrate basis.

Chloroform fumigation- microbial biomass

Microbial biomass in substrate was determined by measuring microbial C and N (Wu et al., 1990, Vance et al., 1987, Jenkinson & Powlson, 1976, Jenkinson et al., 2004). A 5-10 g substrate sample from each container was weighed and placed in a sealable containers for K_2SO_4 extraction. Then, 50 mL 0.05 M K_2SO_4 was added to the containers and placed on an orbital shaker for two hours. The substrate was filtered out with no. 1 Whatman filters and the liquid transferred to a 50 mL container. The samples were frozen until analyzed for dissolved organic C and Total N levels. Samples were analyzed on TOC-TN Analyzer (Skalar Analytical B.V., The Netherlands).

An additional, 5-10 g of substrate from each container was placed in a glass Petri dish and dishes were placed into a desiccator with a wet paper towel in the bottom. A beaker with 25 ml of anhydrous chloroform was added to the desiccator. The desiccator was sealed and vacuum hose attached. The desiccator was then covered with black plastic to exclude light. After three days of chloroform fumigation the K_2SO_4 extraction was completed as described above.

Nitrogen mineralization- microbial activity

Nitrogen (N) mineralization is an indicator of microbial activity. Mineralization is the process where organic N is transformed to mineral N (ammonium-nitrogen NH_4^+-N, and nitrate-nitrogen NO_3^--N). The protocol used was taken from Thies Lab Nitrogen Mineralization Protocol (Cornell University). Two 10 g rhizosphere substrate samples were taken from each substrate at each time point. The first 10 g were added to 50 ml centrifuge containers, 40 ml of 5 M KCl were added to the containers which were capped and shaken for 30 min. After shaking, tubes were centrifuged to facilitate separation of liquid and substrate. Liquid was filtered through a no. 1 Whatman filter and frozen for later analysis. The second 10 g were placed in 50 ml centrifuge tubes, 10 ml of DI water was added and containers were sealed and incubated at 37 °C for 7 days. After incubation 40 ml 2.67 M KCl was added to the tubes and they were shaken, filtered, and frozen as described above. The samples were analyzed for ammonium-nitrogen (NH_4^+-N), and nitrate-nitrogen (NO_3-N) using an AQ-2 discrete autoanalyzer (SEAL-Analytical Inc., Mequon, WI).

Extracellular enzyme activity

Soil exoenzymes are measured as a proxy for decomposition rates (German et al., 2011, Saiya-Cork et al., 2002, DeForest, 2009). Hydrolytic tests for starch, hemi-cellulose, cellulose, chitin, and protein degradation, and phosphorus mineralization were conducted (Table 1) following the protocol of the Kao-Kniffin Lab (Cornell University) which was adapted from German et al. (2011) and Saiya-Cork et al.(2002). An enzyme that speeds oxidative reactions (peroxidase) was also tested. Samples were taken from the substrate surrounding the roots. A 2-3 g sample of each substrate was weighed and placed into plastic containers. Samples were then blended with 150 ml of 50 mM Sodium acetate buffer for 30 seconds. This slurry was pipetted into 96-well plates. Standards or substrate/buffers were added to the plates (Table 1). Enzyme assays were conducted and standard curves (soil slurry and 4-methylumbelliferone- (MUB) or 7-amino-4-methylcoumarin-(AMC) standard of 0, 2.5, 5, 10, 25, 50, 100 μM) created for each enzyme and substrate tested to determine the readings. Plates were allowed to incubate for three hours in the dark. For the oxidative enzymes within five to ten min of reading the plates the liquid was transferred into a clean clear bottom 96 well plate leaving the soil that had settled. After incubation hydrolytic plates were read using a Synergy HT micromode microplate reader (BioTek Instruments, Winooski, VT, USA) at 365 nm excitation and 450 nm emission. Oxidative plates were read at 460 nm. Once plates were read data was examined and outliers were removed using the Dixon Q test, leaving the three median replicates from each container.

Table 1. Enzyme assay substrates and targets.

Enzyme Assayed	Substrate	Enzyme Targets
α -glucosidase (AG)	4-MUB-α-D-glucopyranoside	Starch degradation
β -xylosidase (BX)	4-MUB- β -D-xylopyranoside	Hemi-cellulose degradation
β -glucosidase (BG)	4-MUB- β -D-glucopyranoside	Cellulose degradation
β -cellobiohydrolase (CB)	4-MUB- β -D-cellobioside	Cellulose degradation
N-acetyl glucosaminidase (NAG)	4-MUB-N-acetyl- β -D-glucosaminide	Chitin degradation
leucine aminopeptidase (LAP)	L-Leucine-7-amido-4-methylcoumarin hydrochloride	Protein degradation
acid phosphatase (AP)	4-MUB-phosphate	Phosphorus mineralization
peroxidase (PER)	3,4-Dihydroxy-L-phenylalanine (DOPA)	Plant defense

The experiment was arranged as a completely randomized design with samples destructively harvested at 2 week time intervals. Each plant/container was an experimental unit and there were 5 experimental units (replicates) for each treatment combination (unless noted). An analysis of variance was conducted to determine whether measured parameters were affected by VC source and volume. Tukey mean separation tests were conducted to determine differences in fertilizer treatments at each time point for plant growth parameters. Linear regression analysis across time was conducted for all other test to determine temporal patterns in response to organic fertilizer treatment.

Results

Plant growth

Data on plugs (week 0, 4 week old seedlings) was collected from a representative plant at the time of transplanting and not statistically analyzed (Table 2). At week 2, height was smallest for plants in treatments (trt) 1 (5.8 cm) and only dissimilar to trt 3 and 4 (Table 2). At week 4, height was smallest for plants in treatments (trt) 1. At week 6, height was still smallest for trt 1. The tallest plant was trt 3 which was similar to trts 2, 4, and 6.

Plant width was not affected by treatment at week 2. At week 4, width was similar between all fertilized plants (trts 2-6) and greater than unfertilized plants (trt 1). At week 6, plant width was greatest for trts 3, 5, and 6 and least for unfertilized plants (trt 1).

At week 2 SPAD chlorophyll index was similar between trts 1, 3, 4, 5, and 6. Trt 2 was smaller and similar to trt 1 and 4. At week 4 SPAD chlorophyll index was similar between all fertilized plants (trts 2-6) and in the case of trts 3 and 5 was greater than unfertilized plants (trt 1). At week

Table 2: Vermicompost (VC) and Sustane (S) effect on plant growth in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.Data represent means ± standard error of five experimental units per treatment combination.

Trt[Z]	Week	Height (cm)	Sig[Y]	Width (cm)	Sig	SPAD	Sig	Fresh Weight (g)	Sig	Dry Weight (g)	Sig
Plug	0	5.7 ± 0.4		7.6 ± 0.5				4.13 ± 0		0.2 ± 0	
1 -VC-S	2	5.8 ± 0.6	B	13.6 ± 0.7	NS	35.5 ± 1.4	AB	1.78 ± 0.2	C	0.19 ± 0	C
2 -VC+S	2	7 ± 0.8	AB	17 ± 0.8		33.9 ± 2.2	B	4.33 ± 0.5	B	0.35 ± 0.1	BC
3 +VC -S	2	8.4 ± 0.4	A	18.8 ± 0.9		39.7 ± 0.8	A	6 ± 0.6	AB	0.52 ± 0.1	AB
4 +AVC -S	2	8.6 ± 0.2	A	18.8 ± 0.8		37.4 ± 0.5	AB	6.34 ± 0.4	A	0.58 ± 0	A
5 +VC +S	2	7.8 ± 0.4	AB	17 ± 0.4		40 ± 0.7	A	5.42 ± 0.3	AB	0.48 ± 0	AB
6 +AVC +S	2	8 ± 0.8	AB	16.8 ± 0.7		39.5 ± 0.6	A	4.96 ± 0.6	AB	0.46 ± 0.1	AB
1 -VC-S	4	9.5 ± 0.5	B	14.8 ± 0.2	B	34.8 ± 2.3	B	4.14 ± 0.2	D	0.72 ± 0.1	C
2 -VC+S	4	19 ± 0.7	A	27 ± 1.3	A	38.7 ± 0.7	AB	20.05 ± 0.9	C	2.76 ± 0.1	B
3 +VC -S	4	21 ± 1.1	A	28.6 ± 1.2	A	41.3 ± 0.7	A	22.83 ± 1	C	3.56 ± 0.1	AB
4 +AVC -S	4	21 ± 3	A	31.3 ± 5.2	A	40.3 ± 2.3	AB	24.02 ± 4.3	BC	3.9 ± 0.7	A
5 +VC +S	4	20 ± 1	A	32.8 ± 1.8	A	44.2 ± 1.5	A	29.07 ± 1.7	AB	4.24 ± 0.3	A
6 +AVC +S	4	23 ± 1	A	32.4 ± 1.4	A	39.5 ± 1.3	AB	31.11 ± 2.3	A	4.14 ± 0.3	A
1 -VC-S	6	9.4 ± 0.4	C	16.2 ± 0.4	C	38.1 ± 2	A	5.13 ± 0.3	D	0.97 ± 0	D
2 -VC+S	6	22 ± 0.8	AB	25.8 ± 1.1	B	26.5 ± 2.5	B	25.77 ± 1	C	4.33 ± 0.2	C
3 +VC -S	6	25 ± 0.8	A	29.4 ± 0.5	AB	29.4 ± 1.1	B	26.67 ± 1	BC	5.21 ± 0.2	B
4 +AVC -S	6	22 ± 1.1	AB	27.8 ± 1.2	B	33.7 ± 1.4	AB	31.26 ± 0.5	B	6.03 ± 0.2	B
5 +VC +S	6	21 ± 1.5	B	33 ± 1.1	A	38.8 ± 1.2	A	41.16 ± 1.8	A	7.65 ± 0.4	A

6	+AVC +S	6	25	±	0.6	AB	29.6	±	1	AB	30.6	±	1.6	B	39.58	±	1.4	A	6.94	±	0.2	A

[Y]Letters represent mean separation comparison of the 6 different fertilizer combinations within a given week using Tukey's HSD, alpha=0.05. NS denotes non significance.

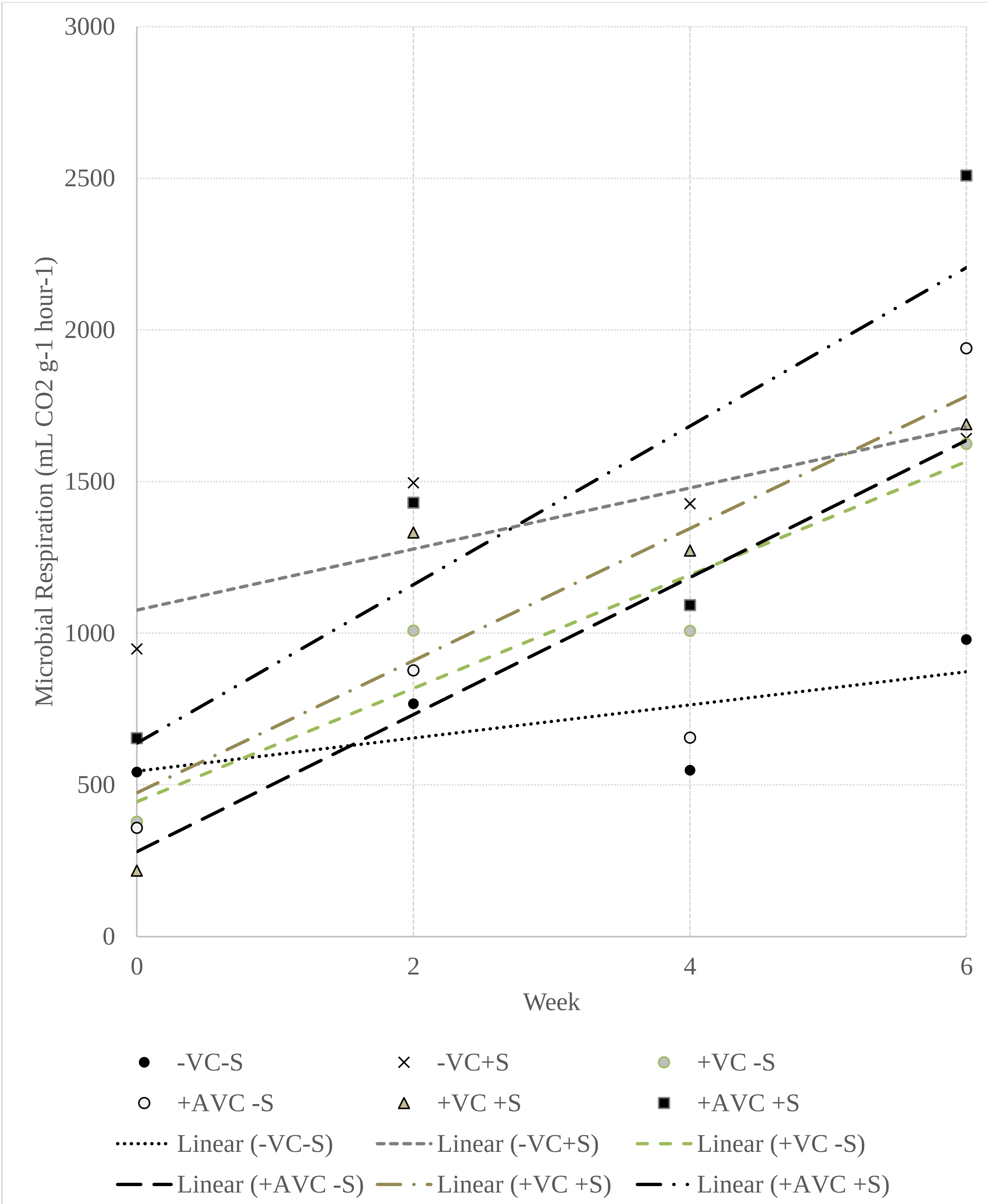
[Z] Vermicompost (VC) 1.5-0.31-1.25 (N-P-K, dairy manure vermicompost) (Worm Power, RT Solutions, LLC, Avon, NY), and Sustane (S) 8-1.75-3.32 (N-P-K, derived from aerobically composted turkey litter, feather meal and sulfate of potash) (Sustane, Cannon Falls, MN, US). The six substrate treatments were 1- no fertilizer added, 2- S only, 3-VC only, 4- AVC only, 5- VC and S, and 6- AVC and S.

6, SPAD chlorophyll index was similar in trts 1, 4, and 5. The trts 2, 3, 4, and 6 were also similar.

At week 2, FW was largest and similar for treatments 3-6 (all fertilized treatments except for the +S treatment). The unfertilized trt was smallest. At week 4, FW was greatest for trts 5 and 6 followed by trt 4 which was similar to trt 5. All fertilized treatments (trts 2-6) had greater FW than unfertilized plants (trt 1). At week 6 the greatest FW was for trts 5 and 6, this was followed by trts 3 and 4. Trt 3 was similar to Trt 2 and all fertilized plants (trts 2-6) had greater FW than trt 1. In terms of shoot DW, at week 2 this was greatest for trts 3-6. Trt 1 was smallest and similar to trt 2. At week 4 shoot DW was greatest for trts 3-6. Trt 2 was smaller and similar to trt 3. Trt 1 was smaller than all fertilizer trts. By week 6, shoot DW was greatest for trt 5 and 6, followed by trt 3 and 4, followed by trt 2. All fertilized plants trts 2-6 had greater shoot DW than unfertilized plants (trt 1).

Respiration- microbial activity

The microbial respiration rates all increased over the 6 week experimental period (Figure 1). The unfertilized trt had the lowest overall rates and slowest increase in respiration. Trt 6 (+AVC +S) had the highest overall rates and fastest rate of increase in respiration. Trts with VC (3-6) had higher rates of microbial respiration, than the trts with only S or no fertilizer.



3000
2500
2000
1500
1000
500
0
Microbial Respiration (mL CO2 g-1 hour-1)
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Figure 1. Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by respiration in 10cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

Chloroform fumigation- microbial biomass

Microbial biomass C increased over time for the various fertilizer treatments (Figure 2). The unfertilized trt had the lowest rate of increase over time followed by the S fertilized plants. All VC trts (3 and 5) had the fastest rate of change over the 6 week period.

Nitrogen mineralization- microbial activity

Total N decreased over time for the trts (Figure 3). The most drastic decrease was in trts 5 and 6 which started with of the greatest levels of total N and decreased to 0 between 4 and 6 weeks. The two trts that still had N left at 6 weeks were trts 3 and 5 which included VC or AVC without the addition of S.

The PMN of all VC and AVC treatments declined over the experimental period (Figure 4). The highest starting PMN and fastest decline was observed in trt 3 (+VC -S). Trt 6 also had a high rate of decline in PMN over time. Trt 1 (no fertilizer) and 4 (+AVC -S) had almost no PMN throughout the experimental period. This corresponds to their low levels of Total N (fig. 3).

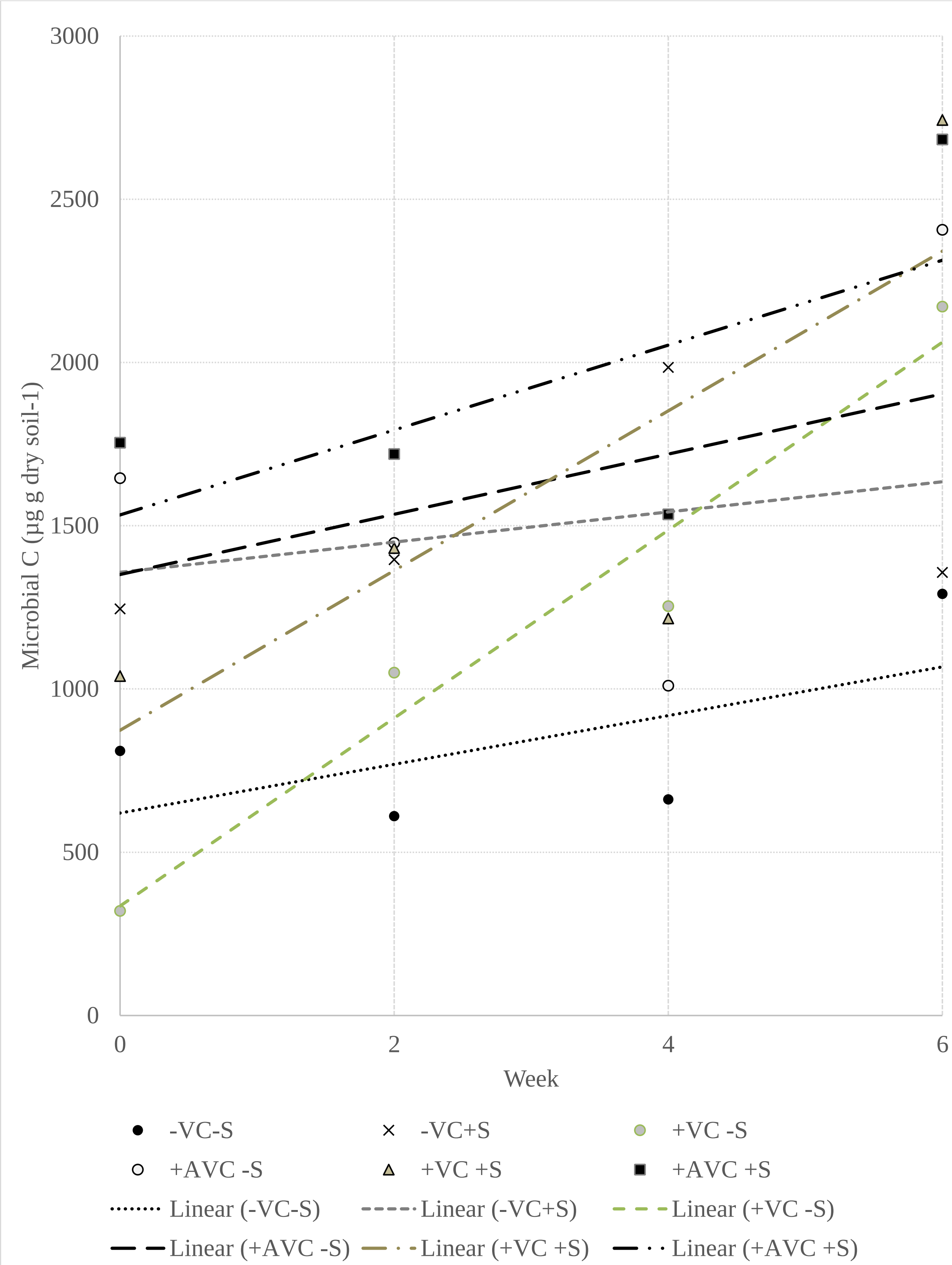

3000
2500
2000
1500
1000
500
0
Microbial C (µg g dry soil-1)
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Figure 2. Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by microbial Carbon (C) in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

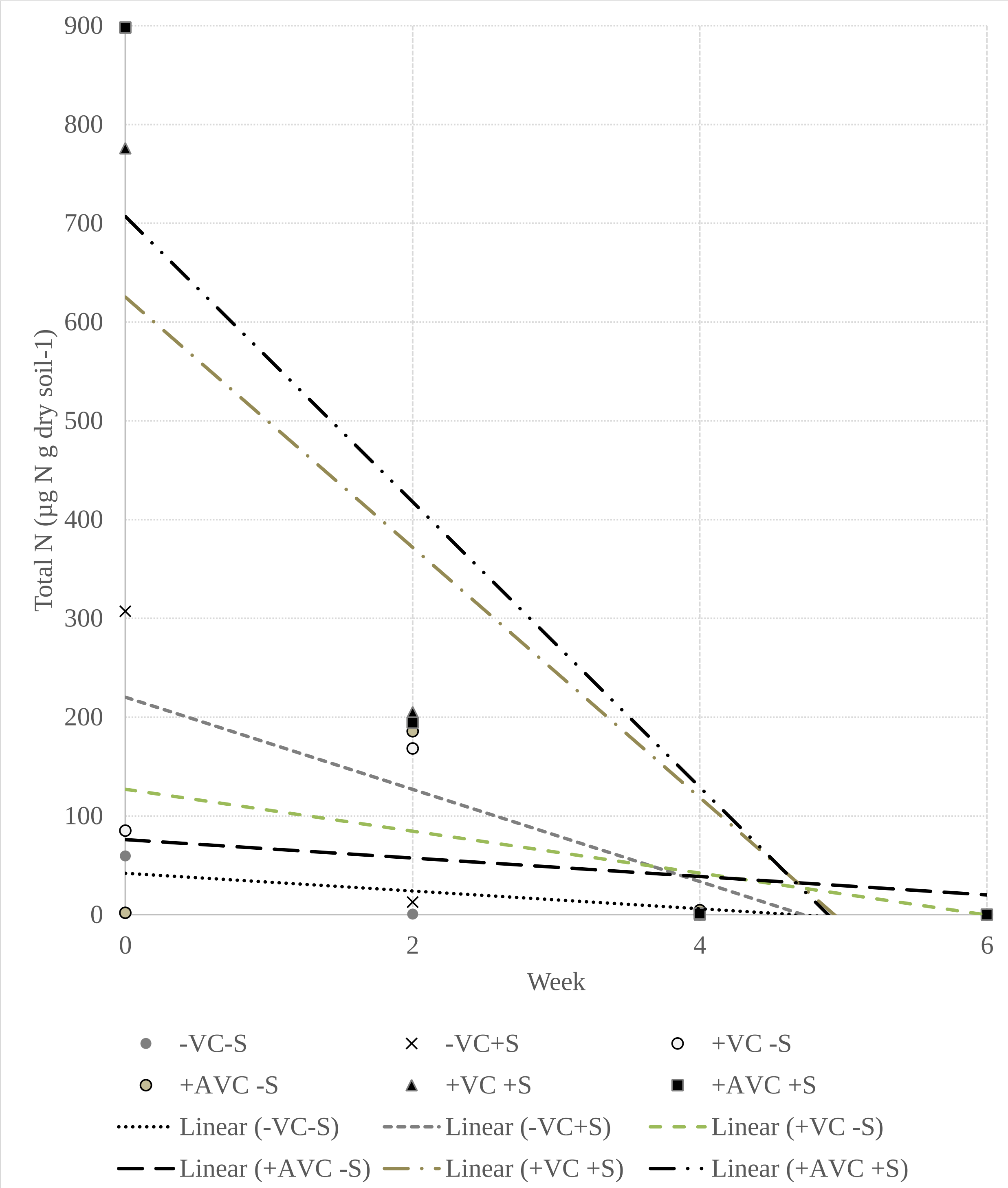


Figure 3. Vermicompost (VC) and Sustane (S) effect on total Nitrogen in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic

limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

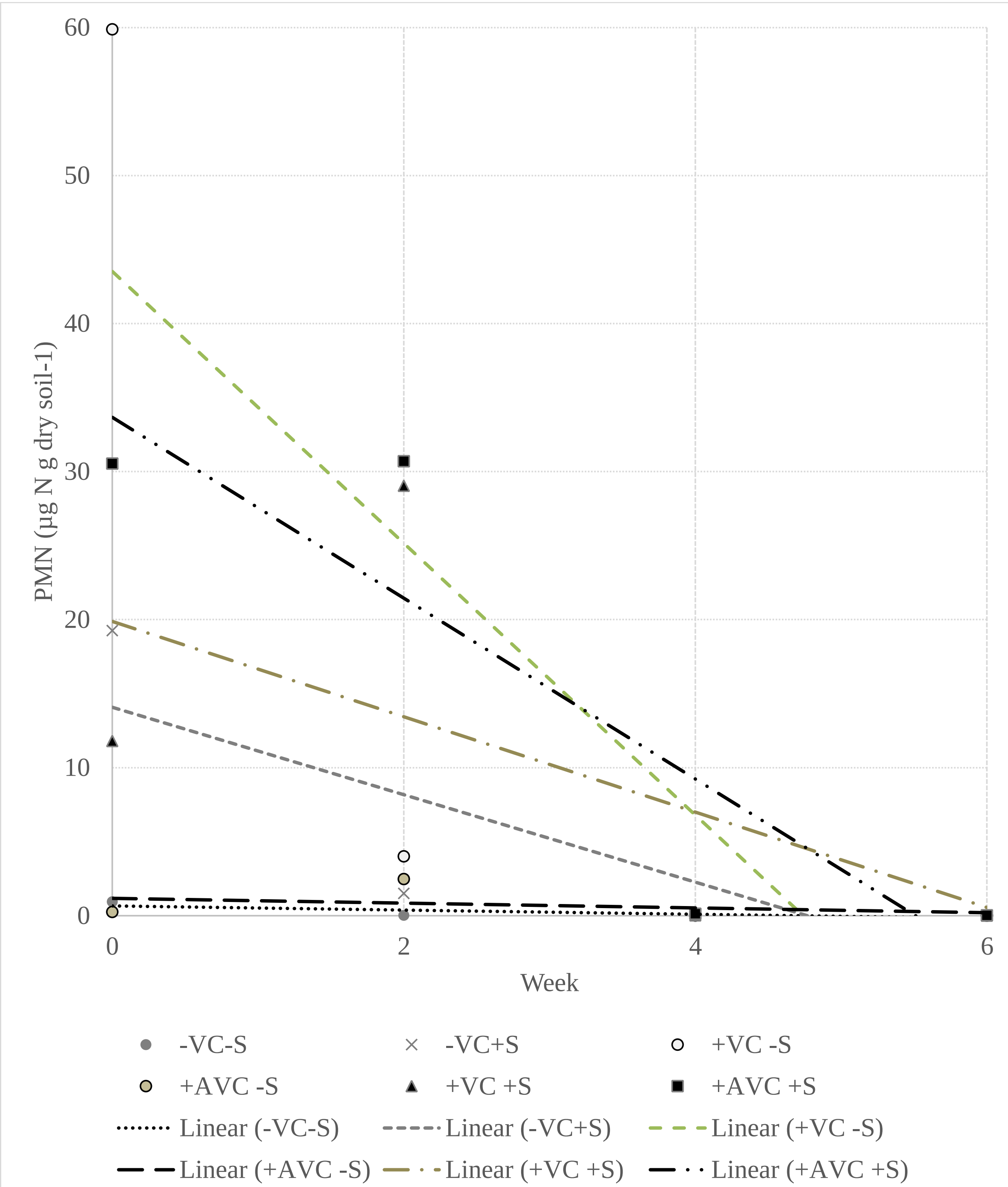


Figure 4. Vermicompost (VC) and Sustane (S) effect on potentially mineralizable Nitrogen (PMN) in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

Extracellular enzyme activity

Extracellular enzyme activity response to fertilizer treatment and harvest week varied according to specific enzyme assayed.

AG, an indicator of starch degradation, exhibited an increase in activity over time for all trts except trt 5 (VC +S) which had a relatively high and sustained level of AG activity across the 6 week period (Figure 5). BX is an indicator of potential hemi-cellulose degradation (Figure 6). Again Trt 5 had relatively high BX initially but little increase over time during the experimental period. All other trts had a noticeable increase in BX activity over time. Trts 3 and 6 had the fastest rates of increase over time. BG, an indicator of cellulose decomposition, increased for all trts over time (Figure 7). Trt 5 had the slowest increase over time, while the AVC (trt 4) had the fastest rate of increase it also began with of the greatest initial activity as compared other trts. The trt with only VC (trt 3) had the greatest rate of increase in activity over time. CB, which is also an indicator of cellulose decomposition, had similar trends as BG. (Figure 8). The combined VC and S trt (5) exhibited very little increase in activity overtime throughout the 6-week experimental period.

All trts had a positive increase in NAG activity, an indicator of chitin degradation, over the six-week experimental period (Figure 9). Trt 5 had the slowest rate of increase of NAG activity and trts 4 and 6 (AVC) had the fastest. AP, an indicator of phosphorus decomposition, increased over time for all trts except trt 5 (Figure 10). Trt 5 exhibited a decrease in AP activity over time across the experimental period. Trt 6 had the greatest increase in AP activity over time, followed by trt 2. Activity of LAP, a protein synthesis enzyme, increased over time with trt 6 having the greatest increase in activity over time, and trt 1 and 5 having little increase in activity over time (Figure 11). Activity of PER, an indicator of plant defense mechanisms, increased over time with trt 6 exhibiting the greatest increase in activity over the experimental period (Figure 12).

Discussion

We had hypothesized that standard VC plants would exhibit greater growth than plants with AVC due to greater initial microbial community numbers in VC; however this was not observed. At all weeks, treatments with VC were statistically similar to their counterpart treatments with AVC (i.e. trt 3 vs. trt 4, and trt 5 vs. trt 6). There are no previous studies, to our knowledge, that included autoclaved VC as a fertilizer treatment in soilless media. The observation of increased plant growth with combined fertilizer sources has been found in other studies. A study on tomato growth showed similar growth effects with combined organic fertilizers increasing plant growth parameters (Laxmi et al., 2015). Over time the combined fertilizer application produced the heaviest plants (week 6 FW and DW).

The results of the respiration indices indicate that the addition of VC (either autoclaved or as is) increased the microbial activity at a faster rate. This may have been due to the increased levels of available N in these treatments as compared to no fertilizer added or the addition of a slow elease fertilizer. Agricultural field soils have microbial C values 200-1000 ug g^{-1} soil. (Martens,

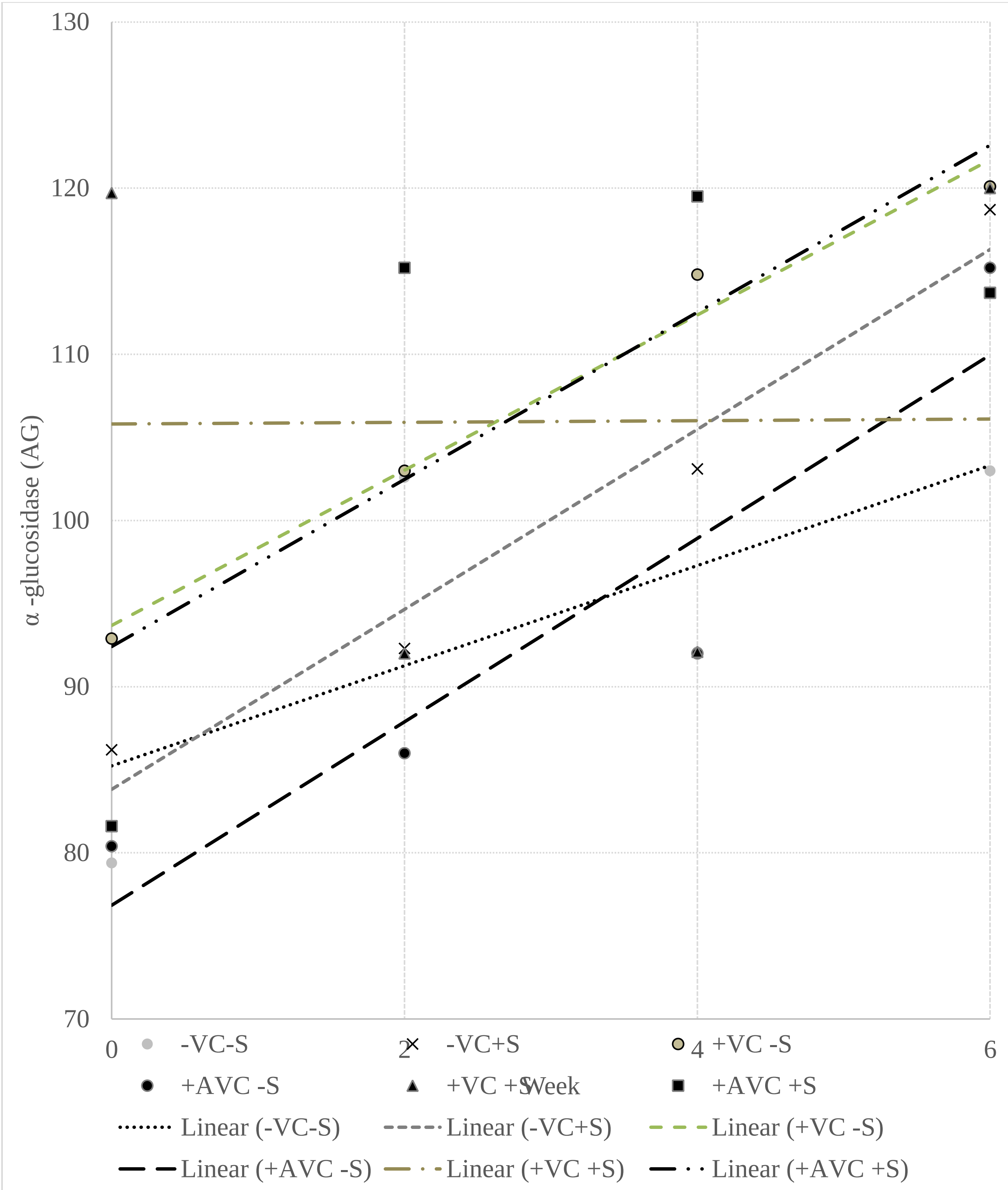


Fig. 5 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by α - glucosidase (AG) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite

(75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

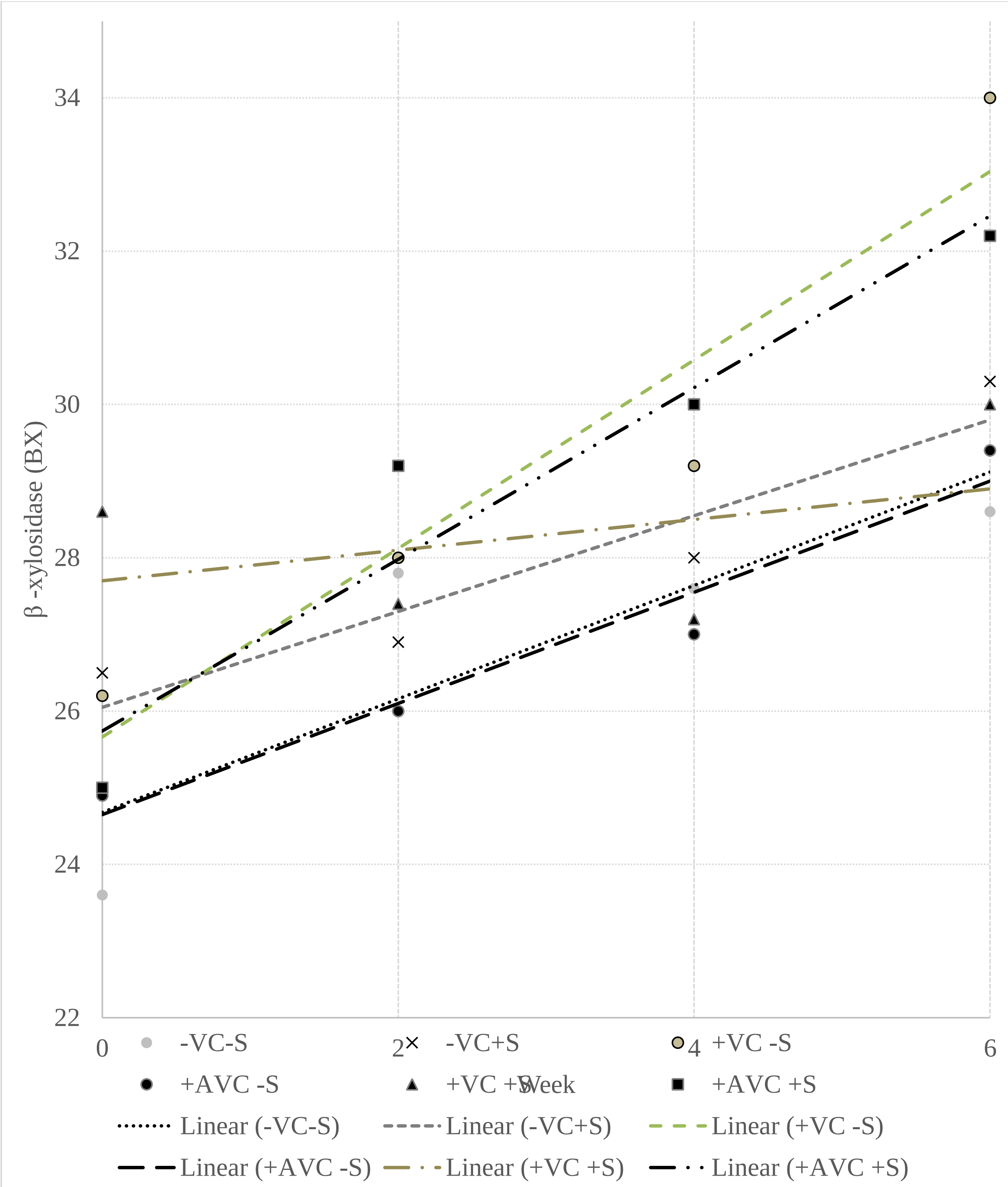
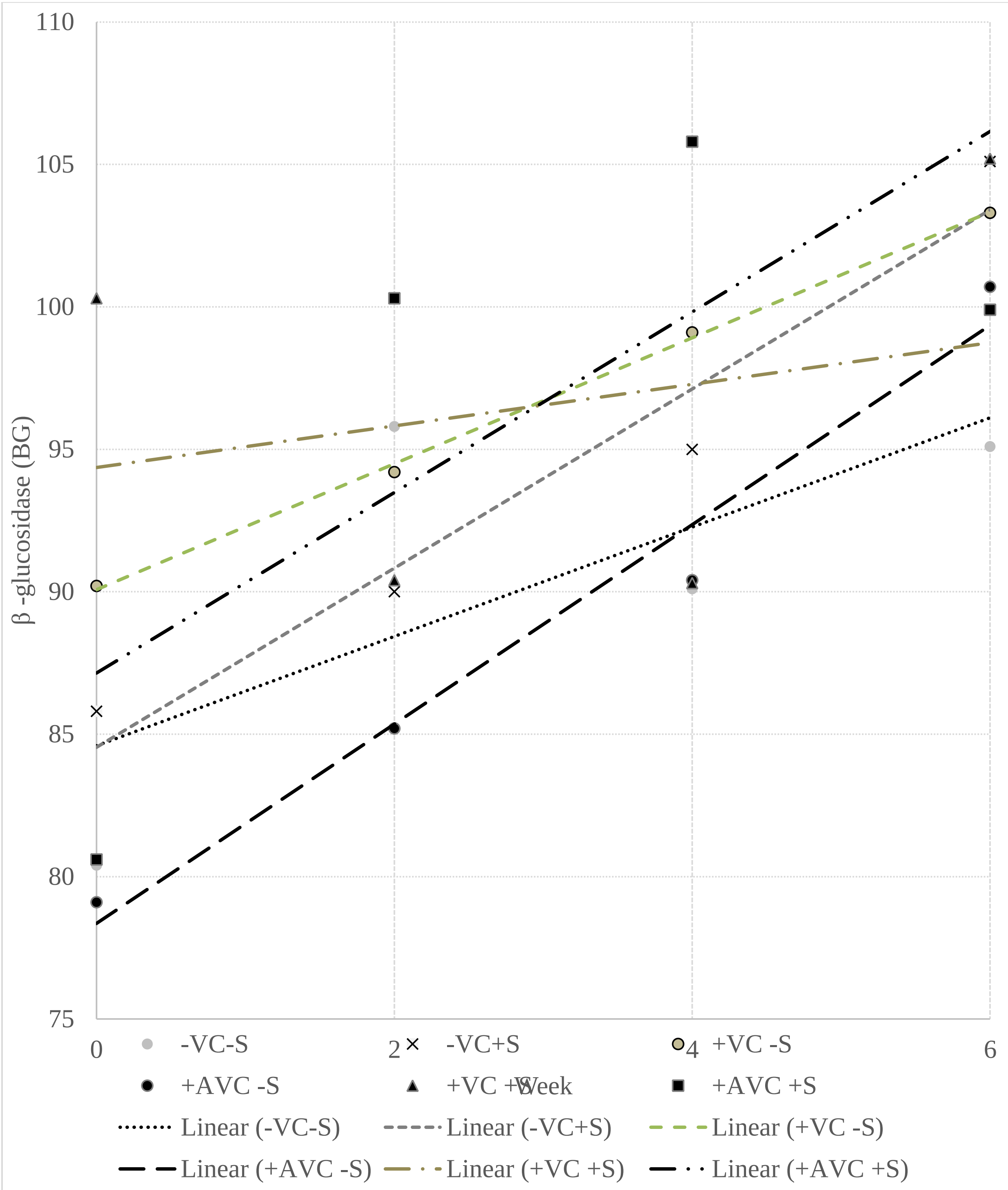


Fig. 6 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by β - xylosidase (BX) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite

(75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.



110
105
100
95
90
85
80
75
β -glucosidase (BG)
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 7 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by β - glucosidase (BG) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

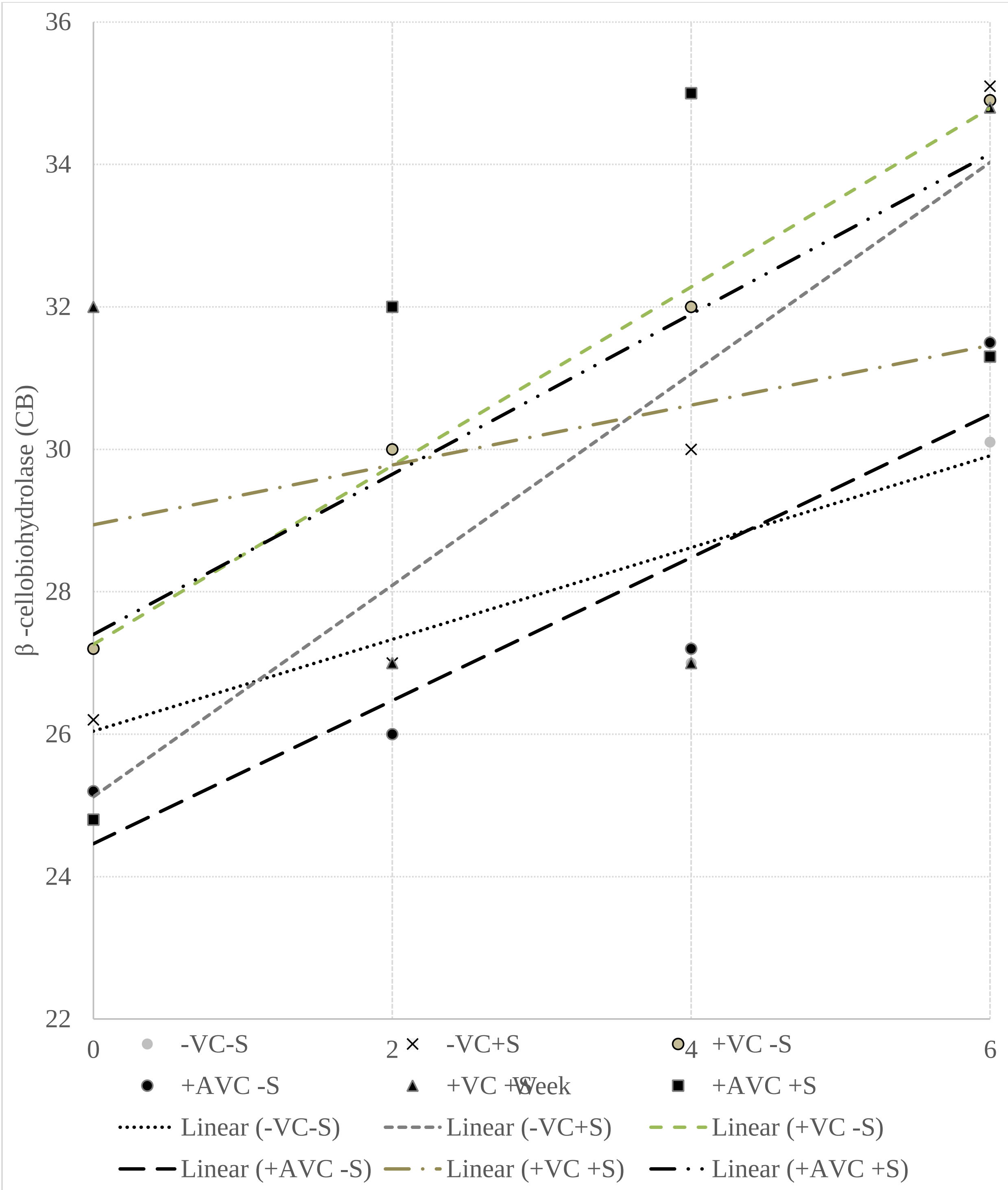
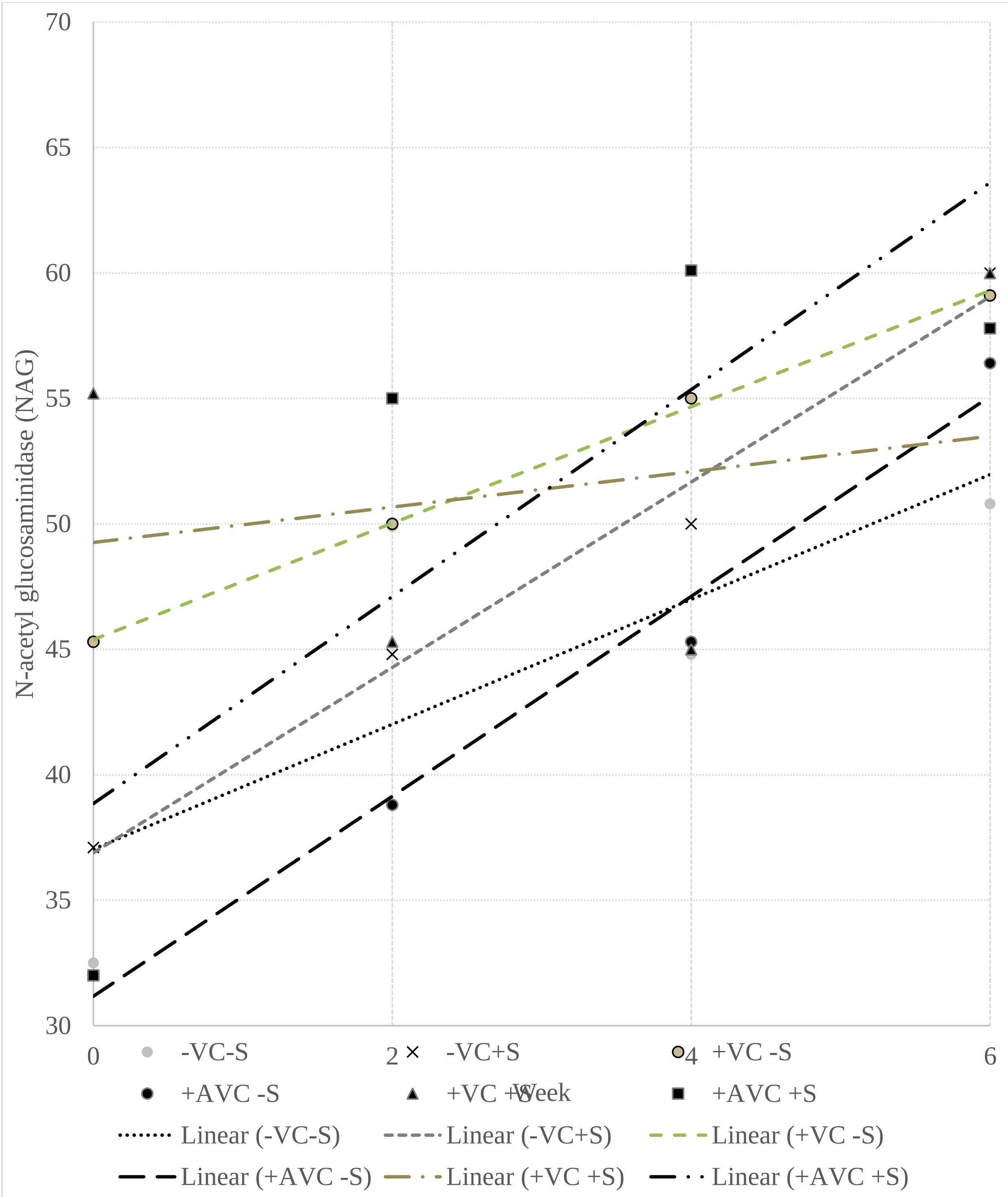
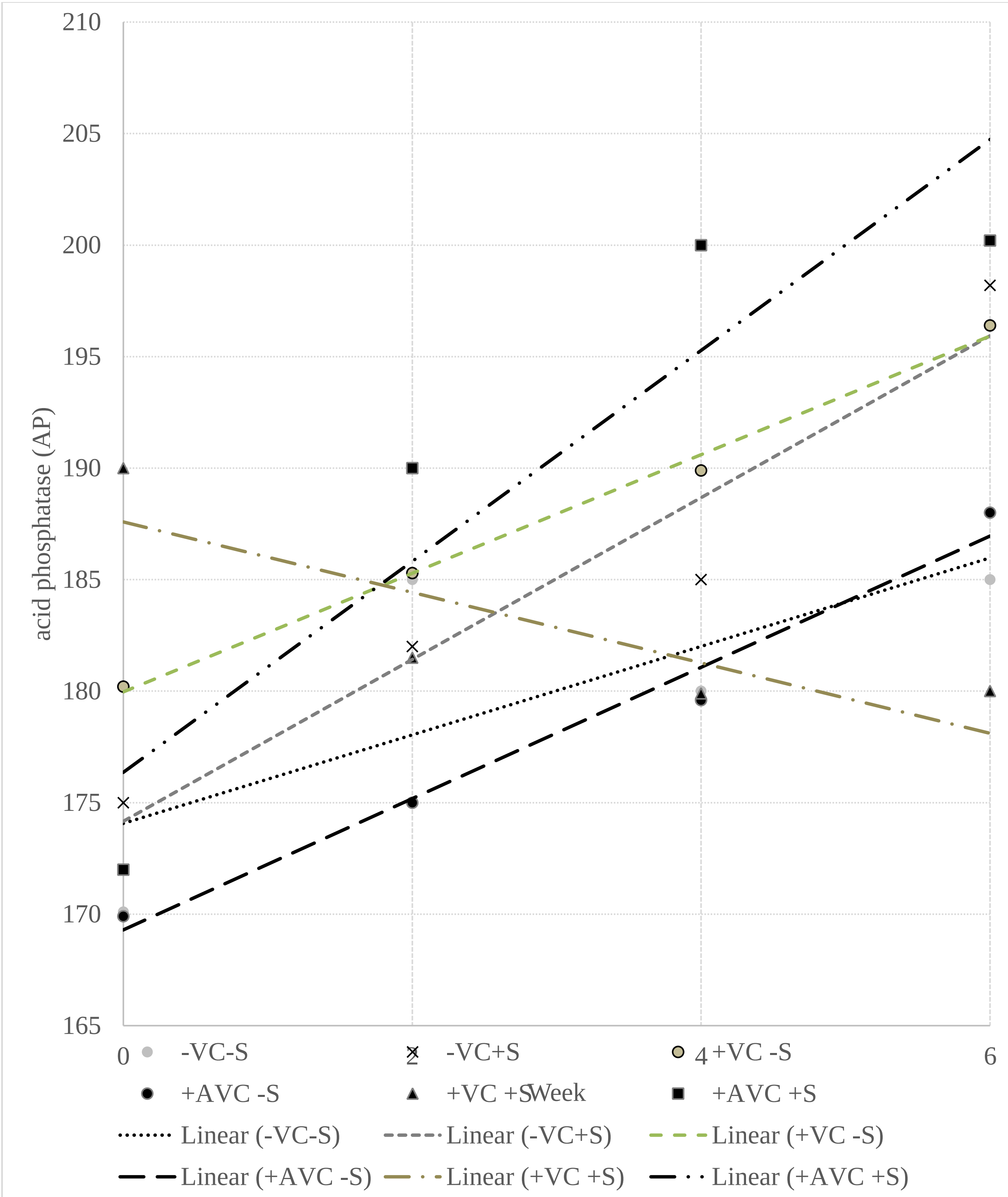

β -cellobiohydrolase (CB)
36
34
32
30
28
26
24
22
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 8 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by β -cellobiohydrolase (CB) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.



N-acetyl glucosaminidase (NAG)
70
65
60
55
50
45
40
35
30
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 9 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by N-acetyl glucosaminidase (NAG) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.



acid phosphatase (AP)
210
205
200
195
190
185
180
175
170
165
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 10 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by acid phosphatase (AP) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

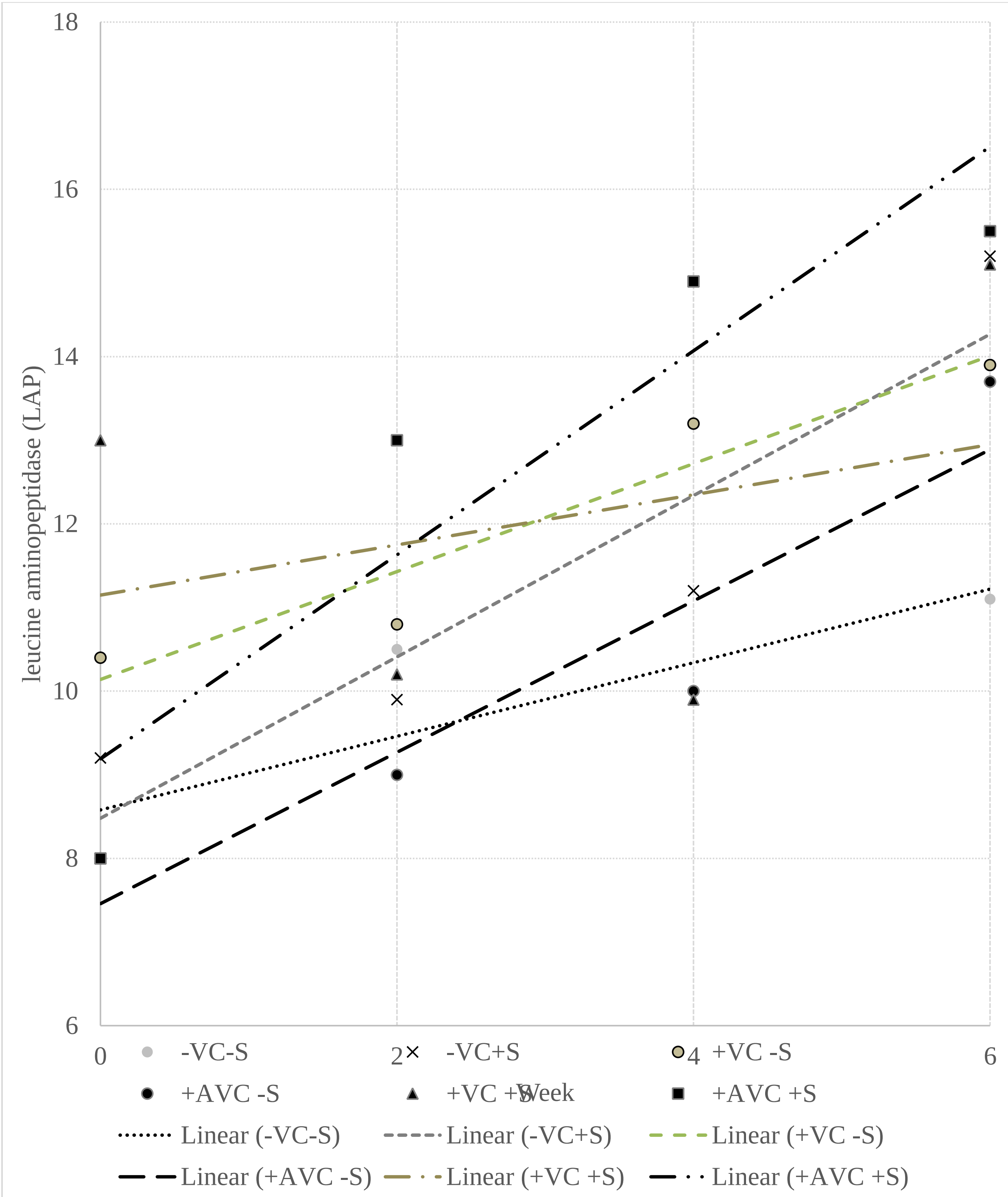
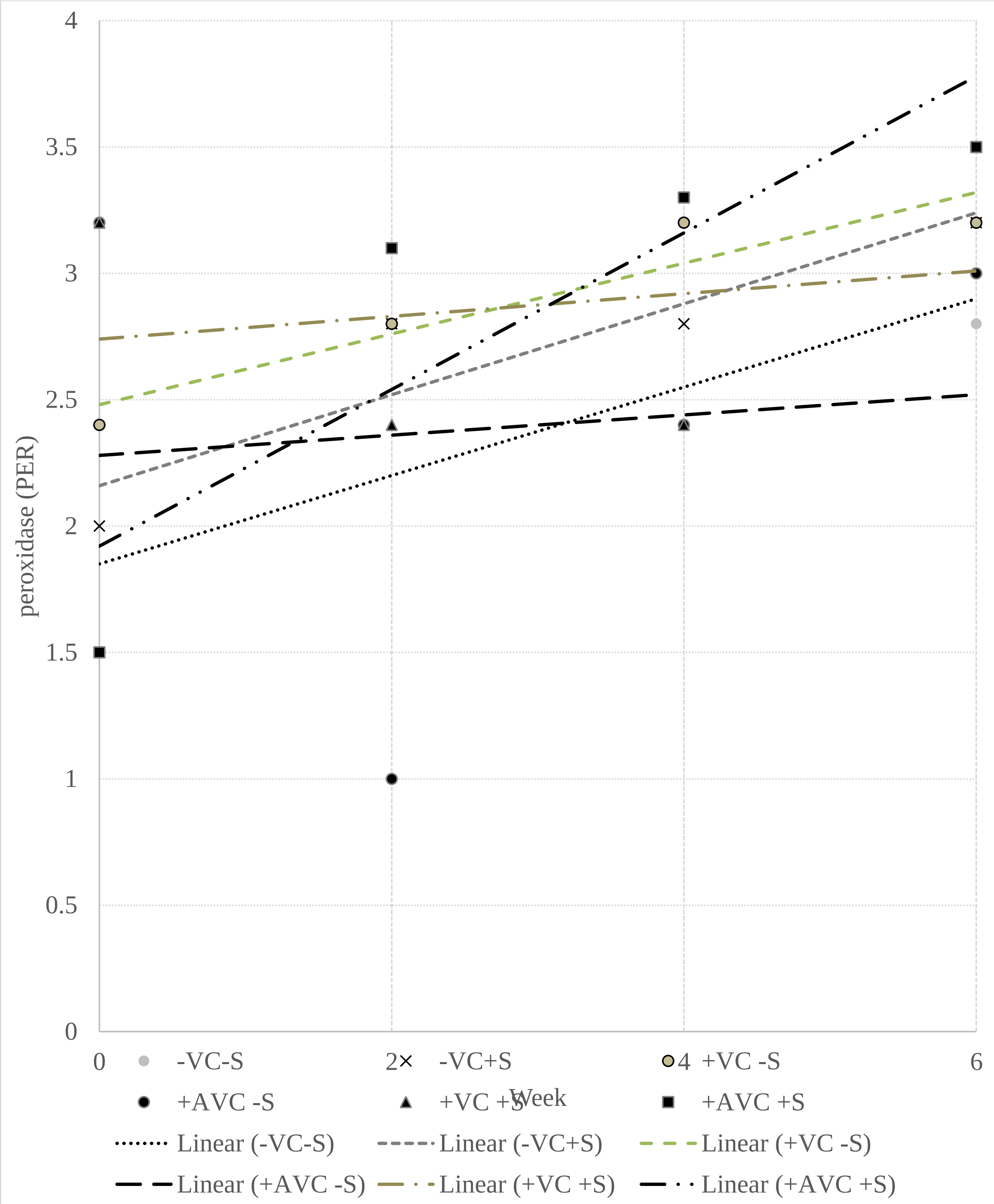

18
16
14
12
10
8
6
leucine aminopeptidase (LAP)
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 11 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by leucine aminopeptidase (LAP) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.



peroxidase (PER)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
Week
-VC-S
-VC+S
+VC -S
+AVC -S
+VC +S
+AVC +S
Linear (-VC-S)
Linear (-VC+S)
Linear (+VC -S)
Linear (+AVC -S)
Linear (+VC +S)
Linear (+AVC +S)

Fig. 12 Vermicompost (VC) and Sustane (S) effect on microbial activity as measured by peroxidase (PER) enzyme assay in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 $g \cdot L^{-1}$ pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

Table 3. Analysis of graphs 1-12 for significance. Vermicompost (VC) and Sustane (S) effect on nutrient leaching and microbial activity measurements in 10 cm containers with tomato transplants. The VC and S were incorporated at 6 different combinations. Four week old seedlings were transplanted into the containers filled with base substrate amended with VC. The base substrate was a peat:perlite (75:25) blend amended with 2.95 g·L-1 pulverized dolomitic limestone (Oldcastle Industrial Minerals, Thomasville, PA) added to adjust the substrate pH.to 6.0.

Fertilizer	**R^2**	**Slope**	**Intercept**	**R^2**	**Slope**	**Intercept**	**R^2**	**Slope**	**Intercept**	**R^2**	**Slope**	**Intercept**
	Figure 1. Microbial Respiration			*Figure 2. Microbial C*			*Figure 3. Total N*			*Figure 4. PMN*		
-VC-S	0.458	54.6	545.7	0.386	74.7	619.7	0.610	-9.0	41.9	0.609	-0.1	0.7
-VC+S	0.748	100.6	10746.4	0.129	46.2	1357.3	0.633	-46.7	220.2	0.662	-3.0	14.1
+VC -S	0.900	186.9	444.3	0.951	287.9	335.1	0.460	-21.2	126.9	0.653	-9.2	43.5
+AVC -S	0.719	226.1	279.5	0.167	92.2	1350.9	0.069	-9.3	76.1	0.119	-0.2	1.2
+VC +S	0.786	217.9	474.2	0.667	244.7	873.4	0.795	-126.7	625.3	0.367	-3.2	19.9
+AVC +S	0.727	261.4	637.7	0.424	130.1	1532.9	0.765	-144.4	706.7	0.799	-6.1	33.7
	Figure 5. α -glucosidase (AG)			*Figure 6. β -xylosidase (BX)*			*Figure 7. β -glucosidase (BG)*			*Figure 8. β -cellobiohydrolase (CB)*		
-VC-S	0.9795	4.67	93.69	0.7263	0.74	24.68	0.4872	1.92	84.59	0.4235	0.645	26.04
-VC+S	0.4895	3.015	85.23	0.8952	0.625	26.1	0.9536	3.145	84.54	0.905	1.485	25.12
+VC -S	0.09795	4.67	93.69	0.906	1.23	25.66	0.9986	2.21	90.07	0.9753	3.5	78.35
+AVC -S	0.8694	5.52	76.84	0.952	0.725	24.65	0.9753	3.5	78.35	0.855	1.005	24.46
+VC +S	0	0.05	105.8	0.16	0.2	27.7	0.064	0.73	94.36	0.0786	0.42	28.94
+AVC +S	0.5545	5.03	92.41	0.921	1.12	25.74	0.5503	3.17	87.14	0.4575	1.125	27.4
	Figure 9. N-acetyl glucosaminidase (NAG)			*Figure 10. acid phosphatase (AP*			*Figure 11. leucine aminopeptidase (LAP)*			*Figure 12. peroxidase*		
-VC-S	0.5923	2.49	37.03	0.5324	2.0	174.1	0.7144	0.44	8.6	0.5432	0.2	1.9

-VC+S	0.9856	3.695	36.89	0.9305	3.6	174.2	0.8635	1.0	8.5	0.8526	0.2	2.2
+VC -S	0.9985	2.23	45.39	0.9945	2.7	180.0	0.9217	0.6	10.1	0.8909	0.1	2.5
+AVC -S	0.982	3.985	31.17	0.9794	2.9	169.3	0.8822	0.9	7.5	0.0108	0.0	2.3
+VC +S	0.0597	0.705	49.26	0.7156	-1.6	187.6	0.0986	0.3	11.2	0.0427	0.0	2.7
+AVC +S	0.6728	4.125	38.85	0.8493	4.7	176.4	0.856	1.2	9.2	0.7657	0.3	1.9

1987) while our substrates tended to have higher quantities of microbial C, up to 2742.6 ug g^{-1} substrate for trt 5.

Our results for microbial biomass indicate that the addition of VC had a greater effect on the amount of microbes present in the substrate. AVC had a faster change in microbe biomass than the unfertilized trt or Sustane alone, but was still lower than that of the unautoclaved VC. Combined with respiration rates there was evidence that the VC additions lead to an increase in the amount and activity of the microbial community over 6 weeks

The Total N results show that N is lost rapidly in substrates amended with combinations of VC (even when autoclaved) and S. When an additional fertilizer was not added to the VC then the break down and loss of N was much slower and there was still some N left in substrate samples at the end of 6 weeks

PMN is closely tied to the total N in the substrates. The trts with higher levels of Total N had faster initial rates of PMN and greater rates of decline for both measurements. The results of the unfertilized trt having almost no N or PMN the entire period was expected and reasonable. A similar pattern as the unfertilized trt was also found for the AVC trt without Sustane, which was unexpected. William-Linera (1984) found no significant difference in the N levels of soils that had been autoclaved and as such we would expect to see similar results from AVC trts as the VC trt in regards to N and PMN.

Enzyme activity generally increased over time and for all trts. There were a few exceptions though such as VC and S for AP. The general increases showed that microbial activity for the specific extracellular enzymes increased as the experiment proceeded as a plants grew larger.

A study conducted on grasses grown in pots, indicated that the additional levels of N did not increase microbial activity, in fact they lowered the activity for BX, CB, NAG, LAP and PER (Zhu et al., 2016). The trts with VC and S had slower growth of activity over the trt period but did exhitied increased enzme activity as compared to the unfertilized control. AVC had the fastest increase of activity especially when combined with S. It is possible that the AVC had such high microbial activity because it had been sterilized and was the perfect substrate for rapid growth of any microbes that may have come into contact with the substrate such as through roots of the tomatoes (Zhu et al., 2016).

Conclusions

The combined usage of VC (whether autoclaved or not) and S increased the amount of N available to plants and microbes. The plants were the largest and the respiration rates and biomass were highest for the substrate with VC/AVC and S. PMN and Total N decreased sharply through the experimental period. The extracellular enzyme activity of VC and S increased over time but not as rapidly as other combinations such as the AVC and S combination. The AVC seemed to be a suitable host for reinoculation of microbes leading to rapid increases in enzyme activity, respiration and biomass over time. The unfertilized trt had the lowest plant growth and generally the lowest rate of microbial growth most likely due to the lack of nutrients to support the microbial and plant growth. More studies will need to be conducted to test if other methods of excluding microbes from the VC elucidate clear patterns in synergistic microbial activity.

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