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Effect of Organic Fertilizer Source and Rate on Growth and Nutrient Leachate Profile of Greenhouse-grown Cucumber

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ADDITIONAL INDEX WORDS. compost, *Cucumis sativus*, nutrient leaching, substrate, vermicompost

SUMMARY. Fertility management of seedlings and transplants is considered a key challenge in organic greenhouse production. This study was conducted to determine response of greenhouse-grown cucumber (*Cucumis sativus*) and nutrient release profile to two organic fertilizers and their combinations applied at three different concentrations in organic substrate. The organic fertilizers used were a turkey litter-based compost (TC) and a dairy manure vermicompost (VC). In addition, two control treatments [no fertilization (CK), conventional liquid fertilizer (CF)] were included. For TC, substrate leachate pH decreased for the first 17 days after addition and then increased, whereas electrical conductivity (EC), and calcium (Ca) and nitrate-nitrogen (NO_3^- -N) concentrations increased and then declined. For VC, EC decreased continuously over time from days 0 to 52, whereas pH increased. The Ca and NO_3^- -N concentrations decreased over time to 24 days and then did not change further. For TC/VC combinations, EC was stable for the first 17 days and then declined. For all organic fertilizer applications, potassium concentration was stable for the first 17 days and then decreased, whereas most of the sodium, ammonium-nitrogen, and chloride were no longer leached by 24 days. The VC and TC/VC combinations did not affect cucumber seed germination rate, seedling survival rate, seedling height, and leaf greenness (SPAD) as compared with CF. The stem length, leaf number, dry weight (DW), root index, and SPAD readings of cucumber transplants increased with increasing TC and VC fertilizer applications. The TC/VC combinations increased the biomass of cucumber transplants compared with CK, and did not differ from CF. The results of this study indicated that the 28.32 lb/yard³ of VC (high rate) or the 9.44 lb/yard³ of VC combined with 4 lb/yard³ of TC (medium rate) can be substituted for CF for the cultivation of cucumber seedlings. Based on DW, the 12 lb/yard³ of TC (high rate) or the 4 lb/yard³ of TC combined with 9.44 lb/yard³ of VC (medium rate) fertilizers were suitable replacements for CF for the cultivation of cucumber transplants.

The increase in consumer demand for fresh organic fruits and vegetables has been recognized by many greenhouse producers throughout the world, including China and the United States (Burnett et al., 2016; Meng et al., 2017; Olczyk et al., 2007; Treadwell et al., 2007). Among organic greenhouse

production practices, fertility management of seedlings and transplants is considered a key challenge (Brace, 2017). Unlike inorganic fertilizers, organic nutrients from plant- and animal-based residues are often not immediately available to plants after application. One of their main difficulties is the timing of microbially mediated nutrient release in

relationship to plant growth (Bi et al., 2010; Burnett et al., 2016). In addition, the feedstocks and methods for producing organic fertilizers are extremely variable, which results in different components and physiochemical properties among different organic fertilizers. Many traditional organic fertilizers are produced as composts or other formulated byproducts of livestock, fish, and food and other processing industries, including feather meal, blood meal, meat and bone meal, and manure-based materials (Bi et al., 2010; Gaskell and Smith, 2007).

Vermicomposts, produced using the fragmentation of organic wastes by earthworms, have a fine particulate structure and contain nutrients in forms that are more readily taken up by the plants, such as NO_3^- -N, available phosphorus, potassium (K), Ca, and magnesium (Arancon et al., 2006; Atiyeh et al., 2000; Brace, 2017; Yang et al., 2015). Arancon et al. (2006) reported that food waste and paper waste vermicomposts can increase the amount of ammonium-nitrogen (NH_4 -N), NO_3 -N, and orthophosphates in soil on the harvest date. Vermicompost amendment has been shown to increase the growth, yield, or quality of some greenhouse crops, such as tomato (*Solanum lycopersicum*), pepper (*Capsicum annuum*), and cucumber (Arancon et al., 2004; Atiyeh et al., 2000; Zhao et al., 2010). Atiyeh et al. (2000) reported that incorporation of 10% or 20% pig solid vermicomposts into a standard commercial horticultural potting substrate (Metro-Mix 360; Sun Gro Horticulture, Agawam, MA) increased the growth of marigold (*Calendula officinalis*) and tomato seedlings as compared with the standard commercial horticultural potting substrate alone, even when all required mineral nutrients were supplied.

Composting is generally defined as the biological aerobic transformation of an organic byproduct into a different organic product that can be added to the soil without detrimental effects on crop growth (Atiyeh et al., 2000; Baca et al., 1992). The application of composted manure is a common practice in organic culture (Hartz and Johnstone, 2006). Hartz and Johnstone (2006) reported on the effect of temperature on nitrogen (N) availability from feather meal, seabird guano, fish powder, and blood meal in soil. For blood

meal after 1 week, 18% of N had mineralized at 10 °C, and 51% had mineralized at 25 °C. By 2 weeks, across materials, approximately half or more of all N had mineralized at 25 °C. Burnett et al. (2016) suggests that substrate-incorporated organic fertilizers are typically used as the sole fertilizer source only for short-term crops because a large proportion of organic nutrients are mineralized within the first few weeks and can leach out of container mixes. Therefore, a difficulty with using organic fertilizers is matching the rate of nutrient release to the plant's nutrient demands (Burnett et al., 2016; Treadwell et al., 2007).

Cucumber is an important greenhouse vegetable crop and one of the most popular members of the cucurbit (Cucurbitaceae) family (Alsadon et al., 2016). In 2017, world production of cucumbers and gherkins was 84 million tonnes, led by China with 77% of the total (Food and Agriculture Organization of the United Nations, 2019). The objective of this study was to evaluate the effects of organic fertilizer source and rate of application on nutrient leaching over time and to determine the growth response of greenhouse-grown cucumber to two different organic fertilizers.

Materials and methods

EXPERIMENTAL DESIGN. The substrate used in this experiment was a commercially available organic peat/perlite substrate (Sunshine #4 Natural and Organic; Sun Gro Horticulture). The plant material consisted of 'Salad Bush F1' cucumber (Harris Seeds, Rochester, NY). The experiment was performed in a controlled greenhouse at Cornell University, Ithaca, NY (lat. 42°N). Two commercial organic fertilizers were

selected: 1) TC 8N-1.8P-3.3K (Sustane Natural Fertilizer; Cannon Falls, MN), and 2) VC 3.4N-1.5P-3.1K (Worm Power, Avon, NY). Nine organic fertilizer treatments (11 pots per treatment) were designed with three different fertilizers [TC, VC, and the combinations of TC and VC (1:1 N by weight)] and three N application levels [0.32 (low), 0.64 (medium), and 0.96 (high) lb/yard³] of each fertilizer. Namely, TC was actually applied at three rates of 4, 8, and 12 lb/yard³. The VC was actually applied at three rates of 9.44, 18.88, and 28.32 lb/yard³. The TC/VC combination was actually applied at three rates of 2/4.72, 4/9.44, and 6/14.16 lb/yard³. In addition, two control treatments [no fertilization (CK), CF 150 mg·L⁻¹ N from 21N-2.2P-16.6K (Jack's Professional LX 21-5-20 All Purpose Water-Soluble Fertilizer; J.R. Peters, Allentown, PA)] were included. The organic fertilizers were completely incorporated into the substrate before seeding. One seed of cucumber was sown into each 6-inch-diameter round pot (1.7 L volume) containing the aforementioned substrates (≈1 inch deep). After 52 d, the cucumber seedlings without root rot from each treatment were transplanted into 10-L pots, again containing the 11 aforementioned substrates. All pots were arranged in a completely randomized design on raised benches. Pots were watered as needed according to treatment with either clear water (CK and organic fertilizer treatments) or in the case of the CF treatment fertigated on weekdays and clear water on weekends. All treatments were watered until substrate reached saturation (i.e., until a small fraction of water leached from the bottom of the pot). During the experimental period, greenhouse temperature was set to a constant 19 °C, and plants were grown under natural lighting from 28 Oct. 2012 to 18 Jan. 2013.

DATA COLLECTION. During the experimental period, substrate leachate was collected weekly using the nondestructive PourThru extraction method (Wright, 1986). Substrate leachate pH was measured using a pH meter (pHTestr 20; Oakton Instruments, Vernon Hills, IL), and EC using an EC meter (ECTestr 11, Oakton Instruments). During the seedling stage, element concentration in substrate leachate [Ca, NO₃⁻-N, K, sodium (Na), NH₄⁺-N, and chloride (Cl)] was measured using a multi-ion meter (CG001; CleanGrow, Vacaville, CA). The meter was calibrated before use and after every 10 samples. At the end of seedling stage, plant heights, leaf number, and SPAD were measured. At the end of posttransplanted stage, stem length (from soil to the apical meristem), fresh weight (FW), DW, root index (RI), and SPAD readings were measured. The SPAD readings were quantified using a nondestructive dual-wavelength chlorophyll meter (Minolta SPAD-502 chlorophyll meter; Spectrum Technologies, Plainfield, IL) and the average reading of three recently mature leaves per plant was taken. At harvest, the plant stem was cut at the soil line and shoot FW was recorded. Shoots were then oven dried at 70 °C for 72 h to determine shoot DW. The RI was evaluated using a 0 to 5 scale according to visible root density at the substrate surfaces, with 0 indicating no visible roots at the substrate/container wall interface and 5 indicating visible roots were matted on the substrate/container wall interface (Bi et al., 2009; Li and Mattson, 2016). For each treatment, four replicates were carried out.

STATISTICAL ANALYSIS. Analysis of variance was conducted using the general linear model program of SAS (version 9.3; SAS Institute, Cary, NC). Means were separated using the least significant difference test at $P < 0.05$.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.5933	lb/yard ³	kg·m ⁻³	1.6856
1	mmho/cm	mS·cm ⁻¹	1
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
0.9072	ton(s)	tonne(s)	1.1023
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Fig. 1. Effect of organic fertilizer source and rate on substrate leachate pH and electrical conductivity (EC). The pH and EC values were measured by the pour-through method weekly after organic fertilizer treatments ($n = 4$): CK = control (no fertilization), CF = fertigation using $150 \text{ mg} \cdot \text{L}^{-1}$ nitrogen (N) from conventional liquid fertilizer 21N-2.2P-16.6K (Jack's Professional LX 21-5-20 All Purpose Water-Soluble Fertilizer; J.R. Peters, Allentown, PA). TL, TM, and TH represent the applications of 0.32, 0.64, and $0.96 \text{ lb} \cdot \text{yard}^{-3}$ N of turkey litter-based compost 8N-1.8P-3.3K (Sustane Natural Fertilizer, Cannon Falls, MN) to substrate, respectively. VL, VM, and VH represent the application of 0.32, 0.64, and $0.96 \text{ lb} \cdot \text{yard}^{-3}$ N of dairy manure vermicompost 3.4N-1.5P-3.1K (Worm Power, Avon, NY) to substrate, respectively. TVL, TVM, and TVH represent the applications of 0.32, 0.64, and $0.96 \text{ lb} \cdot \text{yard}^{-3}$ N of the combination of aforementioned two organic fertilizers (1:1 N by weight); $1 \text{ mg} \cdot \text{L}^{-1} = 1 \text{ ppm}$, $1 \text{ lb} \cdot \text{yard}^{-3} = 0.5933 \text{ kg} \cdot \text{m}^{-3}$, $1 \text{ mS} \cdot \text{cm}^{-1} = 1 \text{ mmho} \cdot \text{cm}^{-1}$.

Results

SUBSTRATE LEACHATE pH AND EC. Organic fertilizer source and rate affected the substrate leachate pH values (Fig. 1). For the TC treatments, substrate leachate pH decreased for the first 17 d after seeding and then increased; whereas for VC, pH increased continuously over time from days 0 to 52. In general, substrate leachate pH for the TC treatment varied between 6.0 and 7.5. Substrate leachate pH for

the VC treatment varied between 6.9 and 8.1. When the two organic fertilizers were combined, substrate leachate pH exhibited an initial decline in pH, which then increased to day 52. Overall, pH varied between 6.3 and 7.4. During the seedling or posttransplanted stages, substrate leachate pH values in the control treatment significantly increased over time. Meanwhile, CF application decreased substrate leachate pH compared with CK. In general, the changes of

substrate leachate pH during the posttransplanted stage had similar trends with seedling stage. However, substrate leachate pH during the posttransplanted stage was somewhat higher compared with the seedling stage, which was probably because of the effects of a larger posttransplanted root zone substrate and larger plant size, which required greater volume of irrigation with moderate-alkalinity water.

The EC differed greatly among fertilizer treatments (Fig. 1). During seedling or posttransplanted stages, both TC and VC treatments and their combinations resulted in increased substrate leachate EC values compared with the controls. In addition, substrate leachate EC increased with increasing TC, VC, and TC/VC application. For TC, the EC increased for the first 2 weeks after addition, then declined over time; whereas for VC, the EC declined following addition, and for TC/VC combinations, EC was stable for ≈ 2 weeks and then declined. During the experimental period, CF treatment resulted in increased substrate leachate EC compared with CK.

SUBSTRATE LEACHATE NUTRIENTS. In the seedling stage, substrate leachate nutrient concentrations were affected by organic fertilizer source and rate (Fig. 2). Data were not taken after transplant. For Ca and $\text{NO}_3^- \cdot \text{N}$, TC exhibited greater concentrations than the corresponding VC treatments as well as CF and CK. For TC, Ca, and $\text{NO}_3^- \cdot \text{N}$ concentration in leachate increased to 17 d and then decreased. For VC treatments, there was very low Ca and $\text{NO}_3^- \cdot \text{N}$ in leachate by 24 d, suggesting most had been taken up by the plant or leached. Substrate leachate Ca/ $\text{NO}_3^- \cdot \text{N}$ concentrations for TC/VC treatments exhibited a pattern in-between the TC and VC treatments with relatively stable/slightly declining concentration to 17 d, a fairly dramatic decline between 17 and 24 d, and a more gradual decline thereafter.

Organic fertilizer application (and increasing rate of application) increased substrate leachate K concentration compared with CK and CF. For TC and TC/VC combination, K concentration in leachate was stable for the first 17 d after addition and then declined. For VC, K concentration in leachate was

Fig. 2. Effect of organic fertilizer source and rate on the concentrations of calcium (Ca), nitrate-nitrogen (NO_3^- -N), potassium (K), sodium (Na), ammonium-nitrogen (NH_4^+ -N), and chloride (Cl) in substrate leachate. Data were determined weekly using a multi-ion meter (CG001; CleanGrow, Vacaville, CA) by pour-through method. CK = control (no fertilization), CF = fertigation using $150 \text{ mg}\cdot\text{L}^{-1}$ nitrogen (N) from conventional liquid fertilizer 21N-2.2P-16.6K (Jack's Professional LX 21-5-20 All Purpose Water-Soluble Fertilizer; J.R. Peters, Allentown, PA). TL, TM, and TH represent the applications of 0.32, 0.64, and $0.96 \text{ lb}/\text{yard}^3$ N of turkey litter-based compost 8N-1.8P-3.3K (Sustane Natural Fertilizer, Cannon Falls, MN) to substrate, respectively. VL, VM, and VH represent the applications of 0.32, 0.64, and $0.96 \text{ lb}/\text{yard}^3$ N of dairy manure vermicompost 3.4N-1.5P-3.1K (Worm Power, Avon, NY) to substrate, respectively. TVL, TVM, and TVH represent the applications of 0.32, 0.64, and $0.96 \text{ lb}/\text{yard}^3$ N of the combination of aforementioned two organic fertilizers (1:1 N by weight). The vertical bars represent the standard errors ($n = 4$); $1 \text{ lb}/\text{yard}^3 = 0.5933 \text{ kg}\cdot\text{m}^{-3}$, $1 \text{ mg}\cdot\text{L}^{-1} = 1 \text{ ppm}$.

stable for the first 10 d following addition and then declined. Similar trends for Na concentration in leachate were observed with K.

The NH_4^+ -N concentration in leachate of TC was quite high compared with VC, CK, or CF. For all organic fertilizer treatments, NH_4^+ -N

concentration in leachate decreased for the first 24 d following application and was minimal thereafter. Similar trends for Cl concentration in leachate were

observed with $\text{NH}_4^+\text{-N}$. The low substrate leachate concentration suggested that most of the Na , $\text{NH}_4^+\text{-N}$, and Cl was no longer leached by 24 d.

SEED GERMINATION AND SEEDLING GROWTH. Cucumber seed germination under two organic fertilizer treatments was more than 80% (Table 1); however, for TC, seedling survival rate ranged from 44% to 60%. In this experiment, it was observed that the treatments containing TC fertilizers exhibited occurrence of root rot of seedlings. The two organic fertilizer treatments significantly increased seedling height and leaf number compared with CK. Cucumber seedling height and leaf number under the two

organic fertilizer treatments did not differ with CF. The TC or TC/VC combinations increased seedling SPAD readings compared with the controls; however, VC treatment did not affect seedling SPAD readings compared with the controls.

TRANSPLANT GROWTH. The growth of cucumber transplants was affected by organic fertilizer sources and rate (Table 2). The stem length, leaf number, DW, RI, and SPAD readings increased with increasing TC and VC fertilizer applications. Compared with CK, TC/VC combinations increased the growth of cucumber transplants. The stem length, leaf number, DW, RI, and SPAD readings under CF

were 4.1, 2.4, 14.5, 2.7, and 1.8 times that of CK. In general, the growth of cucumber transplants in 12 lb/yard³ of TC, 28.32 lb/yard³ of VC, and TC/VC combinations was the same or close to CF, which indicated that these organic fertilizers or their combinations were suitable for the cultivation of cucumber transplants. The RI of TC at the high level or medium and high level of the TC/VC blend was greater than control plants.

Discussion and conclusions

Substrate pH is an important chemical property that strongly influences nutrient availability in substrates (Ao et al., 2008; Li and

Table 1. Effect of organic fertilizer sources and rate on cucumber seed germination rate, seedling survival rate, and seedling related indices.

Treatment ^a	Germination rate (%)	Seedling survival rate (%)	Seedling ht (cm) ^y	Leaves (no./plant)	SPAD ^x
CK	91	100	17.1 c ^w	2.6 d	33.1 def
CF	100	100	20.9 a	4.6 a	35.0 cde
TL	91	50	18.0 bc	3.2 cd	35.9 bcde
TM	82	44	19.6 ab	4.0 abc	41.8 a
TH	91	60	19.7 ab	4.0 abc	36.8 bcd
VL	82	100	20.8 a	3.8 abc	32.7 ef
VM	82	100	19.7 ab	4.0 abc	30.1 f
VH	91	100	21.4 a	3.8 abc	32.2 ef
TVL	82	67	20.0 ab	4.2 ab	34.2 cde
TVM	82	100	19.9 ab	3.6 bc	39.0 ab
TVH	100	91	18.6 bc	3.8 abc	37.6 bc

^aCK = control (no fertilization); CF = fertigation using 150 mg·L⁻¹ nitrogen (N) from conventional liquid fertilizer 21N-2.2P-16.6K (Jack's Professional LX 21-5-20 All Purpose Water-Soluble Fertilizer; J.R. Peters, Allentown, PA). TL, TM, and TH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of turkey litter-based compost 8N-1.8P-3.3K (Sustane Natural Fertilizer, Cannon Falls, MN) to substrate, respectively. VL, VM, and VH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of dairy manure vermicompost 3.4N-1.5P-3.1K (Worm Power, Avon, NY) to substrate, respectively. TVL, TVM, and TVH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of the combination of aforementioned two organic fertilizers (1:1 N by weight); 1 mg·L⁻¹ = 1 ppm, 1 lb/yard³ = 0.5933 kg·m⁻³.

^y1 cm = 2.54 inch.

^xSPAD = leaf greenness, which was quantified for all plants using a nondestructive dual-wavelength chlorophyll meter (Minolta SPAD-502 chlorophyll meter; Spectrum Technologies, Plainfield, IL) and taking the average reading of three recent mature leaves per plant.

^wMeans (n = 4) in each column followed by the same letters are not significantly different according to least significant difference test at $P < 0.05$.

Table 2. Effects of organic fertilizer sources and rate on the growth of cucumber transplants.

Treatment ^a	Stem length (cm) ^y	Leaves (no./plant)	Dry wt (g/plant) ^y	RI (0-5 scale) ^x	SPAD ^x
CK	16.4 c ^w	4.8 d	0.78 f	1.3 g	20.7 e
CF	66.6 a	11.6 a	11.34 a	3.5 cde	36.9 a
TL	39.2 d	8.4 c	4.15 e	2.4 f	31.8 c
TM	53.0 bc	9.6 bc	8.72 cd	3.3 de	33.9 bc
TH	67.4 a	11.8 a	10.80 ab	4.4 a	34.9 ab
VL	46.6 cd	9.6 bc	5.26 e	3.1 e	26.7 d
VM	50.0 cd	9.6 bc	5.36 e	3.4 de	26.6 d
VH	65.0 a	11.8 a	8.98 bcd	3.8 bcd	32.5 bc
TVL	62.4 ab	11.0 ab	8.12 d	3.7 bcd	32.4 bc
TVM	64.8 a	12.0 a	10.81 ab	4.1 ab	32.5 bc
TVH	62.2 ab	12.0 a	10.17 abc	4.0 abc	34.7 ab

^aCK = control (no fertilization); CF = fertigation using 150 mg·L⁻¹ nitrogen (N) from conventional liquid fertilizer 21N-2.2P-16.6K (Jack's Professional LX 21-5-20 All Purpose Water-Soluble Fertilizer; J.R. Peters, Allentown, PA). TL, TM, and TH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of turkey litter-based compost 8N-1.8P-3.3K (Sustane Natural Fertilizer, Cannon Falls, MN) to substrate, respectively. VL, VM, and VH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of dairy manure vermicompost 3.4N-1.5P-3.1K (Worm Power, Avon, NY) to substrate, respectively. TVL, TVM, and TVH represent the applications of 0.32, 0.64, and 0.96 lb/yard³ N of the combination of aforementioned two organic fertilizers (1:1 N by weight); 1 mg·L⁻¹ = 1 ppm, 1 lb/yard³ = 0.5933 kg·m⁻³.

^y1 cm = 2.54 inch, 1 g = 0.0353 oz.

^xRoot index, where 0 = no visible roots at the substrate surfaces and 5 = visible roots were matted on the surface of the substrate. SPAD = leaf greenness measured using a chlorophyll meter (Minolta SPAD-502 chlorophyll meter, Spectrum Technologies, Plainfield, IL).

^wMeans (n = 4) in each column followed by the same letters are not significantly different according to least significant difference test at $P < 0.05$.

Mattson, 2016; Yeager et al., 1983). Substrate EC values reflect changes in nutrient and non-nutrient ion release (Li et al., 2013). For cucumber, optimal pH and EC values are in the intervals 5.5 to 6.2 and 2.0 to 3.0 mS·cm⁻¹, respectively (Rur, 2016; Valenzuela et al., 1994). Bi et al. (2010) reported that organic fertilizers may contribute to high substrate pH and EC. Substrate pH increased with addition of the amendment based on alfalfa (*Medicago sativa*) but remained within the acceptable range of 5.5 to 7.0 (Nair et al., 2011). In this experiment, the TC application decreased substrate leachate pH values, whereas VC increased pH values. Substrate leachate pH values of the control treatments significantly increased over time during the seedling stage and after transplant, which is likely because the tap water used in this study had moderate alkalinity [120 mg·L⁻¹ calcium carbonate (CaCO₃)], similar to findings by Camberato et al. (2013). Compared with CK, CF application resulted in decreased substrate leachate pH, which is because the water-soluble fertilizer used is moderately acidic (potential acidity 390 lb/ton CaCO₃ equivalent). Substrate leachate EC differed greatly among fertilizer treatments over time. The TC treatments led to increased substrate leachate EC values for approximately the first 2 weeks and then decreased significantly over time. Substrate leachate EC for VC applications decreased over time beginning at experiment initiation; however, substrate leachate EC for TC/VC combinations remained stable for 17 d, due to the combined effects of the two components, and then decreased thereafter. Substrate leachate EC differed slightly between the seedling stage and posttransplanted stage, especially under VC treatments, which was possibly due to substrate volumes, plant water/nutrient use and the irrigation amounts. In addition, cucumber flowers and fruit are physically and hormonally significant organs in nutrient and water movement. At the end of the posttransplanted stage, cucumber flowers and fruit were observed in fertilizer treatments.

In organic greenhouse production, fertilizer sources are often assessed based on the timing of N release relative to crop demand

because N is often the most limiting factor among all the nutrients required for plant growth and development (Treadwell et al., 2007). The study of Williams and Nelson (1992) indicated that seven organic sources, including bacteria (*Brevibacterium lactofermentum*) in a nonviable state, a mixture of bacteria (*Bacillus licheniformis* and *Bacillus subtilis*) and fungi (*Aspergillus niger*) in a nonviable state, an activated microbial sludge from wastewater treatment, sludge from a poultry manure methane generator, unsteamed bonemeal, aged pine (*Pinus* sp.) needles, and poultry feathers released N most rapidly during the first 2 weeks, followed by a decline, which ended at 6 to 7 weeks. In this experiment, substrate leachate NO₃⁻-N concentrations for VC treatments decreased over time. However, substrate leachate Ca concentration for VC treatments decreased over time to 24 d and then did not further change. The NO₃⁻-N and Ca concentrations in substrate leachate for TC treatments increased over time to 17 d and then decreased. The changes of substrate leachate NO₃⁻-N and Ca concentrations for TC/VC combinations had similar trend with TC treatment. Results of this study showed that strong linear relations were found between EC and Ca ($R^2 = 0.69$, $n = 77$, $P < 0.0001$), and between EC and NO₃⁻-N ($R^2 = 0.81$, $n = 77$, $P < 0.0001$) (data not shown). This linear relationship indicates that under our experimental conditions, substrate leachate NO₃⁻-N and Ca concentrations could be estimated by measuring substrate leachate EC values. Such relations are useful for growers who wish to estimate substrate NO₃⁻-N and Ca concentrations from EC readings when using the pour-through method.

Different organic fertilizers had differently affected substrate leachate K and Na concentrations. Substrate leachate K and Na concentrations for TC and TC/VC blend treatments increased over time to 17 d and then decreased. For VC, K and Na did not change over time to 10 d and then declined. Meanwhile, TC/VC combinations resulted in increased K concentrations compared with TC or VC treatment, indicating that there was a potential synergistic impact of TC/VC combinations on K and Na

release. In addition, substrate leachate NH₄⁺-N and Cl concentrations were differently affected by different organic fertilizers. Hawkins (2010) reported NH₄⁺-N varied for 4.8 (composted yard waste) to 19.25 mg·L⁻¹ (shellfish-based compost). In this experiment, NH₄⁺-N concentrations for TC and TC/VC blend were higher than VC treatments.

Seed germination and plant growth was affected by organic fertilizer source and rates. Nair et al. (2011) reported that an alfalfa-based substrate-incorporated fertilizer was suitable for producing commercially acceptable 6-week-old tomato transplants if a 1- to 3-week incubation period was used before seeding. Germination percentages were less than 50% in amended substrate that was either not incubated or incubated for 4 weeks. Germination was greater than 75% if amended substrates were incubated for 1, 2, or 3 weeks. Seeds grown in peat-compost without any amendments had the highest germination rates; however, severe nutrient deficiency suppressed seedling growth. Relative to growth in substrate with no amendments, plants growing in the amended substrate had increased stem diameter, height, leaf chlorophyll content, and plant DW, provided the amended substrate was incubated for at least 1 week. Mattson (2014) reported that performance of bedding plants grown with substrate-incorporated organic fertilizers compared with CF and controlled-release fertilizer (CRF). Liquid fertilized plants were the largest in all cases; however, for coleus (*Plectranthus scutellarioides*), fibrous begonia (*Begonia fibrosa*), and pansy (*Viola tricolor*), the organic fertilized plants were, in general, of similar size to CRF plants and considered commercially marketable. Bi et al. (2010) evaluated the growth and flowering responses of greenhouse-grown 'Janie Deep Orange' French marigold (*Tagetes patula*) with two noncomposted broiler chicken litter-based organic fertilizers, 4N-0.9P-1.7K (applied at 1% to 8% by volume) and 3N-1.3P-2.5K (applied at 1.3% to 8.0% by volume). Low to intermediate rates of 4N-0.9P-1.7K and 3N-1.3P-2.5K fertilizers in general produced the highest plant growth index, shoot DW, number of flowers per plant, total flower DW, and root rating.

Plants grown at high rates of 4N–0.9P–1.7K and 3N–1.3P–2.5K fertilizers showed symptoms associated with excessive fertilization. In addition, Eo and Park (2013) reported that the application of manure composts may accelerate root rot disease by promoting pathogenic fungi. In practice, growers need to be cautious with organic fertilizer application rates. Because different crops may respond differently to these natural fertilizers, it is important for growers to test any new fertilizers before incorporating them into their production practices (Bi et al., 2010). In our experiment, it was observed that the treatments containing TC fertilizers resulted in the occurrence of root rot of seedlings. This suggests care may need to be taken with fertilization application rate, especially for sensitive seedlings. Cucumber seedling growth indices for high rate of VC treatment increased compared with CK, but did not differ with CF. The stem length, leaf number, DW, RI, and SPAD of cucumber transplants increased with increasing TC and VC applications, respectively. The TC/VC combinations did not affect the growth of cucumber transplants compared with CF. The results of this study indicated that the high rate of VC or the medium rate of VC combined with TC can be substituted for CF for the cultivation of cucumber seedlings. Based on DW, the high rate of TC or the medium rate of TC combined with VC fertilizers was a suitable replacement for CF for the cultivation of cucumber transplants.

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