exeley
Article | DOI: 10.21307/jofnem-2018-054

JOURNAL OF NEMATOLOGY
Issue 4 | Vol. 50

Effects of vermicompost water extract prepared from bamboo and kudzu against *Meloidogyne incognita* and *Rotylenchulus reniformis*

Xiaodong You,[1,2] Motoaki Tojo,[1] Shelby Ching[2] and Koon-Hui Wang[2*]

[1]Graduate School of Life and Environmental Sciences, Osaka Prefecture University, Sakai, Osaka 599-8531, Japan.

[2]Department of Plant and Environmental Protection Sciences, University of Hawaii, Honolulu, HI 96822.

*E-mail: koonhui@hawaii.edu.

This paper was edited by Maria Viketoft.

Received for publication January 2, 2018.

Abstract

A series of experiments in laboratory, greenhouse, and field were conducted to compare the nematode suppressive effect of vermicompost tea (VCT) prepared from vermicompost with moso-bamboo (*Phyllostachys edulis* (Carrière) J. Houz.) and kudzu (*Pueraria lobata* (Willd) Ohwi) as feed stock (weed VCT) to that prepared from vegetable food waste (vegetable VCT) against *Meloidogyne incognita* and *Rotylenchulus reniformis*. Two laboratory trials were conducted by incubating eggs of *M. incognita* and *R. reniformis* in weed VCT or vegetable VCT over 1 wk. These trials revealed that although both VCTs suppressed *M. incognita* egg hatching compared to water control, only weed VCT suppressed *R. reniformis* egg hatching. In addition, both VCTs suppressed the mobility of second stage juveniles (J2s) of *M. incognita* equally compared to water control though suppression from weed VCT performed inconsistently between the trials. When root penetration of *M. incognita* on cucumber drenched with VCT on one side of a split-root system in a greenhouse sterile sand-soil mix was examined, weed VCT suppressed root penetration of *M. incognita* on the other side of the root in two trials, but vegetable VCT was only effective in one trial. However, both VCTs did not suppress *R. reniformis* root penetration. When the effect of the VCTs was examined in two cowpea (*Vigna unguiculata*) field trials, drenching of VCTs did not affect cowpea growth and yield, but weed VCT reduced root-gall index compared to the water control in both trials. Although both VCTs did not reduce the number of *M. incognita* and *R. reniformis* in soil, weed VCT did increase omnivorous nematodes in the second trial, indicating a gradual improvement of soil food web structure through VCT drenching over time. Overall, performance of weed VCT was more consistent than vegetable VCT for plant-parasitic nematodes suppression.

Key words

Bacterivorous nematodes, Cowpea, Meloidogyne incognita, Rotylenchulus reniformis, Split-root experiment, Vermicompost.

Invasive plant species such as moso-bamboo (*Phyllostachys edulis* (Carrière) J. Houz.) and kudzu (*Pueraria lobata* (Willd) Ohwi) are extremely destructive to ecosystems in Japan. Researchers are finding uses for these invasive weeds to encourage their removal from the natural ecosystem (Kameyama, 1978; Isagi et al., 1997). Since the bamboo and kudzu are characterized by rich carbon and nitrogen, respectively (Wang et al., 2013; Nakhshiniev et al., 2014), their combination is ideal as a feed stock for vermicomposting. Vermicomposting is a nutrient recycling process for biodegradable solid wastes through the decomposition

© The Society of Nematologists 2018.

and digestion of earthworms and its associated microorganisms (Elvira et al., 1998; Tajbakhsh et al., 2011). Generally, a minimum of two months are needed to produce vermicompost suitable to be used as organic fertilizer (Radovich and Arancon, 2011). Various feed stock commonly used for vermicomposting include animal manure, shredded paper, vegetable or fruit scrap from kitchens or farms (Atiyeh et al., 2000; Garg et al., 2006). Vermicompost tea (VCT) is a water extract of vermicompost generally at 1:10 or 1:20 dilution ratio of vermicompost to water aerated over a certain period of time, pending on usage, for the purpose of numerous bioactive molecules as well as microbial populations of the vermicompost (Edwards et al., 2006). Applying VCT to crops is easier than applying vermicompost, which is bulky and heavier, and needs soil incorporation that makes post-plant treatment impractical in many cases. Many scientists reported that drenching VCT suppressed plant-parasitic fungi (Singh et al., 2003; Scheuerell and Mahaffee, 2004), or plant-parasitic nematodes such as *Meloidogyne* spp. in different crops (Arancon et al., 2002; Edwards et al., 2007; Mishra et al., 2017). Although the mechanisms on how VCT drench suppresses plant-parasitic fungi or plant-parasitic nematodes are not completely known, there is evidence showing its consistent effect against various diseases. For example, Mishra et al. (2018) showed that VCT could induce host-plant resistance in cucumber against *Meloidogyne* spp. through split-root experiments. Moreover, some suggested that the abundant organic acids substances such as humic acids, hormones such as N-indole-3-acetic acid (IAA), cytokinin, and gibberellins found in VCT could suppress nematode infestation (Oka, 2010; Arancon et al., 2012).

Owing to the effective disease suppression, VCT has become a potential alternative to chemical pesticides in agriculture. Previous research by the authors has demonstrated that VCT prepared from vermicompost produced from using invasive weeds, bamboo and kudzu, as feed stock (here by referred to as weed VCT) showed promising suppressive effects on several soil-borne plant pathogens including *Pythium aphanidermatum* (Edson) Fitzp., *P. ultimum* Trow var. *ultimum*, and *Rhizoctonia solani* J.G. Kühn AG1-IB (You et al., 2018), but its potential effects against plant-parasitic nematodes has not been examined. A comparison of weed VCT versus a conventional VCT prepared from vermicompost using vegetable food waste as feed stock (here by referred to as vegetable VCT) was conducted to examine for their nematode suppressive effects against two common plant-parasitic nematodes in the tropics, the southern root-knot nematode (*Meloidogyne incognita*) and the reniform nematode (*Rotylenchulus reniformis*). Previously, vegetable VCT has been demonstrated to suppress root penetration and egg hatching, but not the reproduction, of *M. incognita*.

Besides suppressing plant-parasitic nematodes, another advantage of drenching VCT to plant rhizosphere is to improve soil and plant health. Free-living nematodes have been used as soil health bioindicators as they can be used to determine dominant nutrient decomposition pathways, soil food web structure and ecosystem functions in soil (Ingham et al., 1985; Bongers and Ferris, 1999; Wang and McSorley, 2005). A healthy soil food web should sustain nematodes with different life strategies and feeding behaviors ranging from fast growing and reproducing bacteria-feeding nematodes (colonizers) at the bottom of the soil food web to slow reproducing but longer living predaceous nematodes at the top of the soil food web (Bongers, 1990). This research project aimed to also evaluate the soil health benefits of drenching roots with weed VCT vs vegetable VCT.

Specific objectives of this project were to compare the ability of weed VCT and vegetable VCT on mitigating (i) egg hatching, (ii) vermiform stages mobility, (iii) root penetration, and (iv) damage of *M. incognita* and *R. reniformis* on cowpea, as well as their ability to improve soil health.

Materials and methods

Vermicompost tea preparation

Weed vermicompost made from moso-bamboo (*Phyllostachys edulis* (Carrière) J. Houz.) and Kudzu (*Pueraria lobata* (Willd) Ohwi) and vegetable vermicompost made from vegetable food waste were prepared as described by You et al. (2018) and Mishra et al. (2017), respectively. Weed vermicompost was prepared from 10 kg of the bamboo shoots powder mixed with 100 g of air dried kudzu vine pieces (< 10 cm in length) and 20 g of a commercial horse manure/wheat straw compost (Iris Ohyama Inc., Sendai, Japan) and adding 100 g of red wiggler (*Eisenia fetida* Savigny) (Commercial name 'Kumataro-futomushi,' Yokomizo-shokai Inc., Mito, Japan) in a closed container to conduct vermicomposting for 2 mon. Vegetable vermicompost was initiated 3 yr prior to this experiment with approximately 100 g of commercial mix of red wiggler (*E. fetida*) and blue worms (*Perionyx excavatus* Perrier) (Waikiki Worms Co., Honolulu, HI). The worms were fed weekly with vegetable food waste such as lettuce, kale, papaya, and banana peel. All earthworms were removed from the vermicompost right before VCT preparation.

The VCTs were prepared fresh for each experiments, and were prepared by mixing each type of vermicompost in water at 1:10 (v/v) ratio, and aerated for 24 hr using 2.5 W Elite 800 air pumps (Rolf C. Hagen Inc., Montreal, Canada) at room temperature (24). The VCT was filtered using a kitchen strainer to separate the solid from the liquid prior to application. Samples of weed VCT and vegetable VCT were submitted to the Agriculture Diagnostic Services Center (ADSC) at the University of Hawaii at Manoa to assay for concentrations of macro-nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and boron) and micro-nutrients (Fe, Mn, Zn, and Cu).

Hatching experiment

A laboratory assay was conducted to examine the effects of weed VCT and vegetable VCT on the hatching of *M. incognita* and *R. reniformis* compared to that of water control. *Meloidogyne incognita* eggs were extracted from coleus (*Plectranthus scutellarioides* (L.) R. Br.) roots and *R. reniformis* eggs were extracted from pineapple (*Ananas comosus* (L.) Merr.) roots using NaOCl and centrifugal flotation methods (Hussey and Barker 1973). Water, weed VCT or vegetable VCT were contained in 60-ml plastic cups at 15 ml/cup. The experiment was arranged in complete randomized design with four replications. Each plastic cup served as a hatching chamber where approximately 200 freshly extracted *M. incognita* eggs or *R. reniformis* eggs were suspended in 200 µl of water over a 60.33-µm pore size screen (Fig. 1). This mesh size kept nematode eggs on the screen but allowed second stage juveniles (J2s) to pass through. To avoid bacterial growth, VCT or water was replaced every day with fresh VCT or water. Hatched J2s were collected every day for 7 d and total hatching was counted under an inverted microscope (Leica DMIL LED, Wetzlar, Germany). The egg hatching experiment was repeated once.

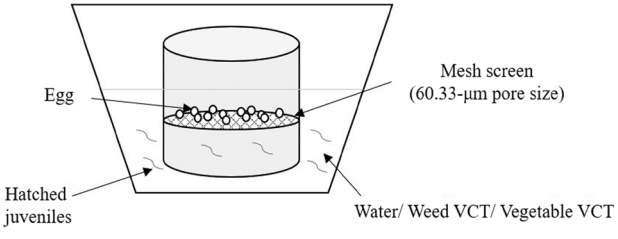


Figure 1: Hatching chamber used to allow harvesting of hatch juveniles over a 7-d period.

Mobility experiment

A laboratory assay was established to examine the effects of weed VCT and vegetable VCT on the mobility of *M. incognita* J2s. After adding 10 ml of water, weed VCT or vegetable VCT into individual 60-mm diameter petri plates, 0.5 ml of water suspension containing approximately 100 freshly hatched *M. incognita* J2s were added to each plate. Treatments were replicated four times and the experiments were repeated once. Mobility of *M. incognita* J2s was examined by probing with a dental probe after 24 hr incubation of the nematodes in the solutions. Percentile of immobilized nematodes was calculated for each petri dish.

Root penetration experiment using split-root assay

Two greenhouse trials were conducted in the Gilmore Greenhouse at the University of Hawaii at Manoa, Honolulu, HI from April to July 2017 to examine the effects of the VCTs on root penetration of *M. incognita* on 'Bush Champion' cucumber (*Cucumis sativus* L.), and that of *R. reniformis* on 'Blackeye #5' cowpea (*Vigna unguiculata* (L.) Walp.) by inducing host-plant resistance against nematodes. Roots of cucumber or cowpea seedlings were split into two parts and transplanted into two conjoined pots (Fig. 2). The purpose of using split-root assay was to avoid direct contact of VCTs on the tested nematodes that would lead to parasitism or immobilization of the nematodes by the chemical compounds or microbes in the VCTs. One side of the root system was drenched with weed VCT, vegetable VCT, or water 3 d prior to inoculation of the targeted nematode (Fig. 2). Two hundred J2s of *M. incognita* or 100 J2s of *R. reniformis* were introduced into the untreated conjoined pot. One week after *M. incognita* inoculation, or 3 wk after *R. reniformis*

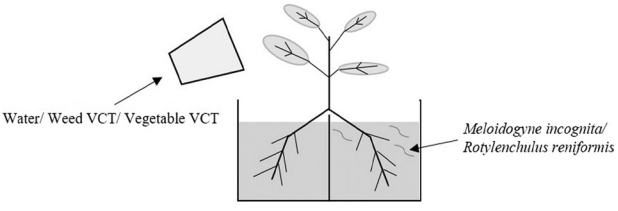


Figure 2: Split-root experiment constructed by two conjoint pots where one side of the roots will be drenched with vermicompost tea (VCT) and the other side of the roots will be inoculated with the designated plant-parasitic nematodes.

Table 1. Macro- and micro-nutrients content of weed VCT prepared from vermicompost with moso-bamboo and kudzu as feed stock and vegetable VCT prepared from vermicompost with vegetable waste as feed stock.

Content (mg/l)	Weed VCT	Vegetable VCT
Nitrogen	27.60 b	280.00 a
Phosphorus	0.80 b	5.62 a
Potassium	53.59 b	213.24 a
Calcium	20.86 a	25.74 a
Magnesium	17.21 a	18.89 a
Boron	0.06 b	0.47 a
Fe	0.03 b	0.27 a
Mn	0.01 a	0.02 a
Zn	0.03 a	0.03 a
Cu	0.01 b	0.02 a

Means (n = 3) with same letters within a row were not different ($P > 0.05$) based on Student's t-test.

inoculation, roots from the nematode inoculated side were stained with Acid Fuchsin (Daykin and Hussey, 1985) and quantified for nematode penetration under the microscope.

Bioindicators of biological activities of vermicompost

To examine biological activities of weed vermicompost or vegetable vermicompost, free-living nematodes were used as bioindicators. Nematodes were extracted from 30 cm^3 weed vermicompost or vegetable vermicompost by immersing the vermicompost into 300 ml water using Baermann trays for 24 hr (Southey, 1986). Each treatment was replicated three times. Bacterivorous and omnivorous nematodes, the two most dominant nematode trophic groups present, were counted under an inverted microscope (Leica DMIL LED, Wetzlar, Germany).

Cowpea field experiment

Two field trials were conducted at the Poamoho Research Station in Waialua, Oahu, HI to compare the mitigation of nematode damage on 'Black Eye #5' cowpea by weed VCT or vegetable VCT compared to water control using cowpea as a bioassay crop in field naturally infested with *M. incognita* and *R. reniformis*. Cowpea plants were drenched with weed VCT or vegetable VCT, or water weekly at 50 ml per plant during the first 2 wk, followed by 250 ml per plant for the rest of the crop over a three-month growing period from 27 April to 12 July, 2017. Each experimental plot had eight cowpea plants in a 1 × 3 m^2 -area. The three treatments were arranged in randomized complete block design with four replications. Soil nematode population densities were monitored at pre-plant, and at 1 and 2 mon after planting. Shoot and root weights, and root-gall index

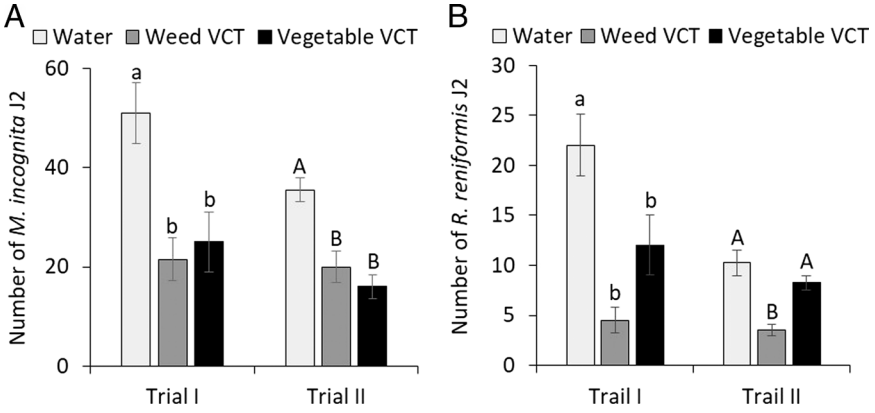


Figure 3: Numbers of juveniles of (A) *Meloidogyne incognita* and (B) *Rotylenchulus reniformis* hatched after incubating their eggs in vermicompost teas prepared from vermicompost composed of bamboo and kudzu (weed VCT) and vegetable food waste (vegetable VCT), and water control for 7 d. Columns (n = 4) with same letter(s) are not different according to Waller–Duncan k-ration (k = 100) t-test.

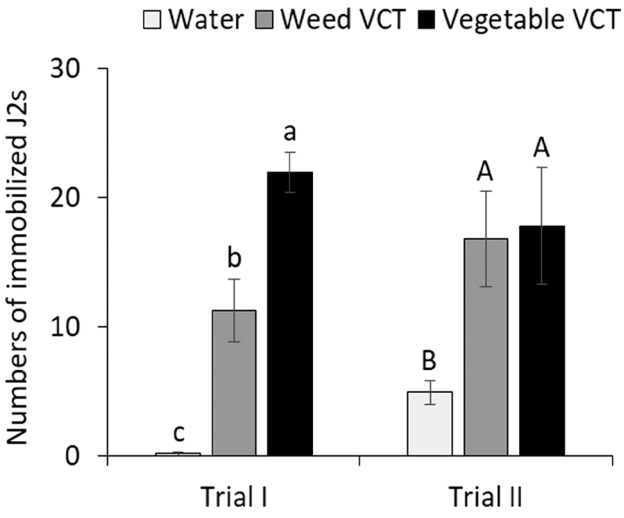


Figure 4: Numbers of *Meloidogyne incognita* J2 immobilized after incubating in vermicompost teas prepared from vermicompost composed of bamboo and kudzu (weed VCT), vegetable food waste (vegetable VCT) and water for 24 hr. Columns (n = 4) followed by the same letter(s) are not different according to Waller–Duncan k-ration (k = 100) t-test.

(RGI) were measured from three plants randomly selected in each plot at 2 mon after planting. Root galling was rated using a root-gall index based on a scale of 0 to 5, where 0 = 0, 1 = 1–2, 2 = 3–10, 3 = 11–30, 4 = 31–100, and 5 ≥ 100 galls (Taylor and Sasser, 1978). Cowpea pods from five plants per plot were harvested and weighted weekly from 21 June to 12 July, 2017.

Nematode assay

Soil samples were collected 1 and 2 mon after cowpea planting in both trials. Four 20-cm deep soil samples were collected from each plot and combined into one bag. Nematodes were extracted from 250-cm^3 soil by elutriation and centrifugal floatation (Jenkins, 1964; Byrd et al., 1976). All nematodes extracted were identified and assigned to a trophic group of bacterivores, fungivores, omnivores, or predators (Yeates et al., 1993), but herbivores were identified to the genus level with the aid of the inverted microscope described above.

Statistical analysis

Differences in macro- and micro-nutrient content between the weed VCT and vegetable VCT were analyzed by Student's t-test. The other data were checked for normality, nematode data were log transformed [$\log_{10}$(x+1)] if needed and subjected to one-way analysis of variance (ANOVA) using SAS (SAS Inc., Cary, NC). Repeated measures of nematode abundance from the cowpea field experiment were subjected to homogeneity of variance test over time. If there was no significant interaction between sampling date and treatment effect, data were subjected to repeat-

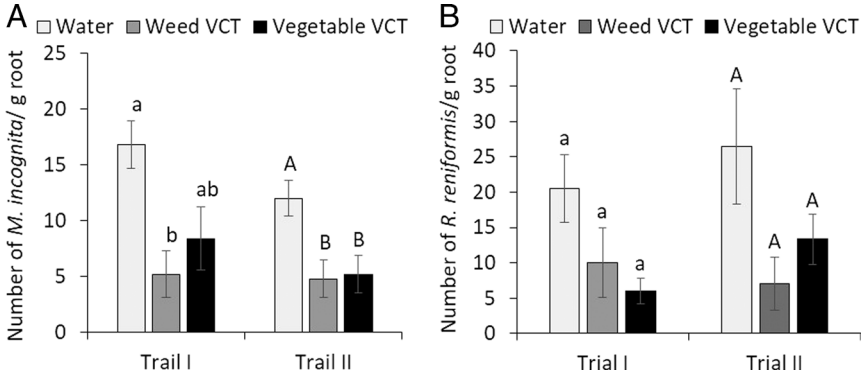


Figure 5: Effect of vermicompost teas prepared from vermicompost composed of bamboo and kudzu (weed VCT), vegetable food waste (vegetable VCT) compared to water control on root penetration of (A) *Meloidogyne incognita* in cucumber, and (B) *Rotylenchulus reniformis* in cowpea using split-root assays. Means are average of five and four replications for *M. incognita* and *R. reniformis*, respectively. Column followed by same letter(s) are not different according to Waller-Duncan k-ration (k = 100) t-test based on log transformed values, log (x+1).

Table 2. Effect of vermicompost tea on plant-parasitic nematodes and percent trophic groups of free-living nematodes in a cowpea agroecosystem.

	Trial I			Trial II		
Nematodes	**Water**	**Weed VCT**	**Vegetable VCT**	**Water**	**Weed VCT**	**Vegetable VCT**
			5/25/17			
M. incognita	62 a	90 a	120 a	155 A	132 A	35 A
R. reniformis	312 a	465 a	435 a	728 A	450 A	402 A
% Bacterivores	40.45 a	27.11 a	27.12 a	20.82 A	21.18 A	25.00 A
% Fungivores	22.22 a	15.77 a	12.19 a	17.53 A	17.91 A	12.37 A
% Omnivores	0.28 a	0.35 a	0.00 a	0.39 A	0.10 A	0.61 A
			6/21/17			
M. incognita[z]	25 a	95 a	60 a	28 B	195 A	30 B
R. reniformis	402 a	285 a	495 a	338 A	385 A	502 A
% Bacterivores[y]	18.89 a	17.84 a	12.21 a	17.99 A	12.68 A	13.38 A
% Fungivores	10.62 a	10.92 a	6.53 a	9.82 A	10.76 A	6.89 A
% Omnivores	3.62 a	1.42 a	0.96 a	0.45 B	2.90 A	1.75 AB

[z]Nematode abundance (numbers/250 cm^3 soil) was log transformed, log(x + 1) prior to analysis of variance; [y]Percent nematode in trophic groups was square-root transformed Ö(x + 0.1) whenever needed to normalize the data prior to analysis of variance; Means (n = 4) followed by the same letter (s) are not different according to Waller–Duncan k-ratio (k = 100) t-test.

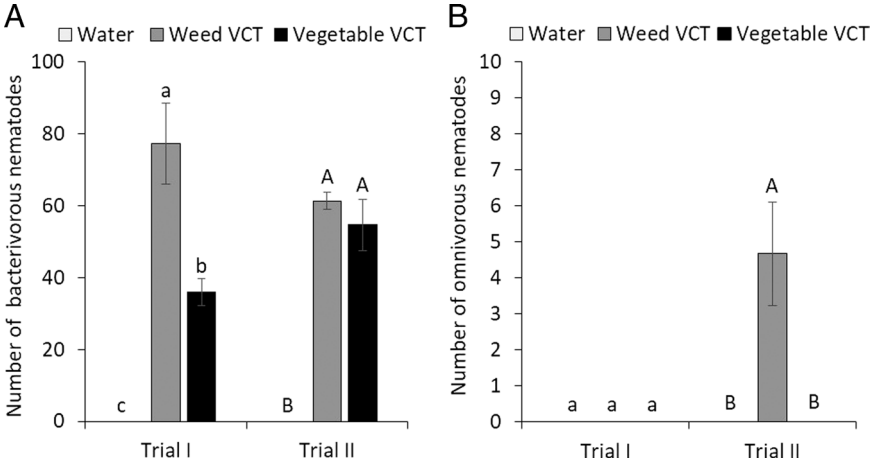


Figure 6: Abundance of (A) bacterivorous and (B) omnivorous nematodes in water or vermicompost teas prepared from 30 cm^3 of vermicompost composed of bamboo and kudzu (weed VCT) or vegetable food waste (vegetable VCT) incubated in Baermann trays. Columns (n = 3) followed by the same letter(s) are not different according to Waller–Duncan k-ration (k = 100) t-test.

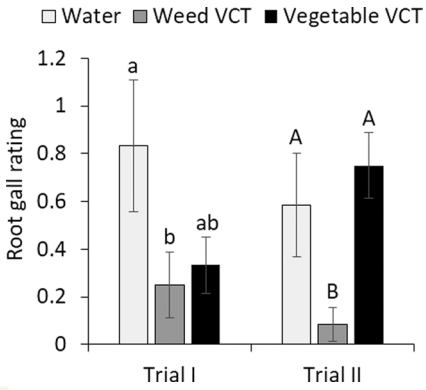


Figure 7: Effect of vermicompost teas prepared from vermicompost composed of bamboo and kudzu (weed VCT), vegetable food waste (vegetable VCT) compared to water control on root-gall index (in a scale of 0-5) of cowpea in two field trials. Columns (n = 4) followed by same letter(s) are not different according to Waller–Duncan k-ration (k = 100) t-test.

ed measures analysis. Means were separated using Waller–Duncan k-ration (k=100) t-test. Only true means were presented.

Results

Nutrient analysis

Weed VCT contained lower concentrations of nitrogen, phosphorus, potassium, boron, Fe, and Cu than vegetable VCT, but both VCTs contained similar concentration of calcium, magnesium, Mn, and Zn levels (Table 1).

Hatching experiment

Both weed VCT and vegetable VCT suppressed *M. incognita* egg hatching compared to the water control ($P \leq 0.05$, Fig. 3A). In the first trial of *R. reniformis* egg hatching test, both weed VCT and vegetable VCT reduced *R. reniformis* hatching compared to the water control. However, in the second trial, only weed VCT ($P \leq 0.05$) reduced the hatching of *R. reniformis* compared to the water control (Fig. 3B).

Mobility experiment

Although vegetable VCT immobilized *M. incognita* J2s more effectively than weed VCT in Trial I ($P \leq 0.05$), both VCTs suppress the J2s mobility equally in Trial II compared to the water control ($P \leq 0.05$, Fig. 4).

Root penetration experiment using split-root assay

Weed VCT suppressed root penetration of *M. incognita* consistently in both split-root trials ($P \leq 0.05$), but vegetable VCT was only effective in Trial II (Fig. 5A). However, neither VCTs suppressed *R. reniformis* root penetration ($P > 0.05$, Fig. 5B) despite showing a trend of suppression compared to the water control.

Bioindicators of biological activities of vermicompost

No nematodes were found in the water control. There were more bacterivorous nematodes in weed vermicompost than vegetable vermicompost in Trial I ($P \leq 0.05$, Fig. 6A), but more omnivorous nematodes were found in weed vermicompost than vegetable vermicompost in Trial II ($P \leq 0.05$, Fig. 6B). No fungivorous, herbivorous or predatory nematodes were detected in either vermicompost examined.

Cowpea field experiment

Drenching of both types of VCT did not affect shoot, root, and pod weights of cowpea ($P > 0.05$, data not presented). However, weed VCT reduced root-gall index compared to the water control in both trials ($P \leq 0.05$, Fig. 7). Both VCTs did not reduce the number of *M. incognita* and *R. reniformis* in the soil in neither of the trials (Table 2). In fact, the weed VCT treatment increased the abundance of *Meloidogyne* spp. in Trial II compared to the water control at the end of the experiment. Although abundance of bacterivores and fungivores were not affected by VCT drenching compared to the water control on all sampling dates in both field trials ($P > 0.05$), weed VCT increased omnivorous nematodes in Trial II by >5-fold at two months after cowpea planting ($P \leq 0.05$, Table 2).

Discussion

Both VCTs showed promising results in reducing mobility and root penetration of *M. incognita* J2s, and egg hatching of both nematodes in the laboratory and greenhouse experiments. These results were consistent with the findings of Mishra et al. (2017) on vegetable VCT against *M. incognita*, and that of Wang et al. (2014) on VCT prepared from chicken manure against *R. reniformis*. Performance of weed VCT was more consistent in suppressing *M. incognita* compared to vegetable VCT, possibly due to higher carbon content that supported more abundant beneficial bacteria growth, as suggested by higher abundance of

bacterivorous in the laboratory study and omnivorous nematodes in the Field Trial II. In addition, red wiggler earthworm was the sole earthworm used in the weed vermicompost. Red wiggler earthworm may have stimulated more bacteria and actinomycetes growth as demonstrated by Pattnaik and Reddy (2012) compared to a mix of blue worms and red wigglers in the vegetable vermicompost.

Suppression of root penetration of *M. incognita* by both VCTs in the cucumber split-root assays indicated that this suppression is not due to direct antagonistic effects or nematicidal effects imposed by VCTs but rather a host-plant response. Mishra et al. (2018) reported that cucumber plants drenched with vegetable VCT showed an up-regulation of defense related genes such as CHIT-1, PAL-1 and LOX-1 encoding for chitinase, phenylalanine ammonia-lyase, and lipoxygenase protein 1, respectively. This result is supporting the hypothesis that VCT stimulated Induced Systemic Resistance (ISR) in cucumber. Similar induction of host-plant resistance (ISR) by VCT against plant-parasitic nematode has also been suggested by Xiao et al. (2016). It is encouraging to see weed VCT reduced root-gall index on cowpea compared to the water control in both cowpea field trials. However, due to the partial resistance possessed by 'Black Eye #5' cowpea against *M. incognita*, only minimal *Meloidogyne* spp. were recovered in both cowpea field trials.

Rotylenchulus reniformis was more abundant than *Meloidogyne* spp. in the cowpea field trials. Lack of induction of host-plant resistance against *R. reniformis* in cowpea in both the greenhouse split-root experiment as well as the field experiment could be due to the cowpea lack of response to ISR compared to the cucumber. In addition, interference from multiple pests or pathogens attacking cowpea plants in the field could also have disrupted the induction of ISR as suggested by Pangesti et al. (2013). Aphids and whiteflies were abundant pests on cowpea in these cowpea trials (especially toward harvesting), but no attempt was taken to take these data as it was not originally expected to interfere with VCT root drenching treatments. However, antagonistic crosstalk between jasmonic acid (JA) induced ISR and salicylic acid (SA) induced SAR can occur when sucking insects (aphids and whiteflies) are attacking a plant that was expressing ISR (Rodriguez-Saona et al., 2010). As suggested by Spoel and Dong (2012), crosstalk between plant defense hormone signaling pathways and pathogen invasion is at the expense of energy used for plant growth. It is possible that crosstalk-induced ISR may be the reason that VCT did not improve the growth and yield of cowpea, nor reduce the number of plant-parasitic nematodes in the field experiment.

Overall, drenching plant roots with weed VCT introduced high biological activities leading to high abundance of bacterivorous and omnivorous nematodes, suppression of egg hatch and mobility of *M. incognita* and *R. reniformis*, and induction of ISR that reduced root penetration of *M. incognita*. Although neither VCT examined reduced population densities of plant-parasitic nematodes in the cowpea field, or improved cowpea growth and yield, drenching weed VCT increased the abundance of omnivorous nematodes in one of the field trial toward the end of the second month of cowpea growth, indicating a gradual improvement of soil food web structure and thus soil health. Wang et al. (2014) also reported that continuous drenching of VCT prepared from chicken manure-based vermicompost increased abundance of predatory nematodes toward the end of a second zucchini crop. Nico et al. (2004) showed that vermicompost could contain nematicidal compounds, depending on the feed stocks used. Future research should examine if potential nematicidal compounds such as tannins or phenolic compounds are associated with nematode suppressive effects of VCT prepared from moso-bamboo and kudzu, and whether the use of this VCT can be improved by integrating with other nematode management practices.

Acknowledgments

This project is in parts supported by University of Hawaii Hatch Projects 9022H and 9034H, NIFA Project 1002569, and JA Bank Osaka Industry-University Cooperation Project and Geol Cosmetics Co. Ltd. The authors thank Raymond Uchida and Russell Yost for assistance in shipping vermicompost; Janice Uchida, Donna Meyer, and Basith Cader for technical assistance and advice; Yukihiro Shimogami of Kawachinagano City Office and Eboshi-yama Satoyama Conservation Club for bamboo powder.

References

Arancon, N. Q., Edwards, C. A., Yardim, F., and Lee, S. 2002. Management of plant parasitic nematodes by use of vermicomposts. Proceedings of Brighton Crop Protection Conference – Pests and Disease 8B-2:705–10.

Arancon, N. Q., Pant, A., Radovich, T., Hue, N. V., Potter, J. K., and Converse, C. E. 2012. Seed germination and seedling growth of tomato and lettuce as affected by vermicompost water extracts (teas). HortScience 47:1722–8.

Atiyeh, R. M., Domínguez, J., Subler, S., and Edwards, C. A. 2000. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei*, Bouché) and the effects on seedling growth. Pedobiologia 44:709–24.

Bongers, T. 1990. The maturity index: an ecological measure of environmental disturbance based on nematode species composition. Oecologia 83:14–19.

Bongers, T., and Ferris, H. 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends in Ecology & Evolution 14:224–8.

Byrd, D. W., Barker, K. R., Ferris, H., Nusbaum, C. J., Griffin, W. E., Small, R. H., and Stone, C. A. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. Journal of Nematology 8:206–12.

Daykin, M. E., and Hussey, R. S. 1985. Staining and histopathological techniques in nematology. in Barker, K. R., Carter, C. C., and Sasser, J. N. (Eds), An advanced treatise on Meloidogyne II. methology, North Carolina State University Graphics, Raleigh, NC: 39–48.

Edwards, C. A., Arancon, N. Q., and Greytak, S. 2006. Effects of vermicompost teas on plant growth and disease. Biocycle 47:28–31.

Edwards, C. A., Arancon, N. Q., Emerson, E., and Pulliman, R. 2007. Suppression of plant-parasitic nematodes and arthropod pests with vermicompost tea. Biocycle 48:38–9.

Elvira, C., Sampedro, L., Benítez, E., and Nogales, R. 1998. Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot-scale study. Bioresource Technology 63:205–11.

Garg, P., Gupta, A., and Satya, S. 2006. Vermicomposting of different types of waste using *Eisentia foetida*: a comparative study. Bioresource Technology 97:391–5.

Hussey, R. S., and Barker, K. R. 1973. A comparison of methods of collecting eggs of *Meloidogyne* spp., including a new technique. The Plant Disease Reporter 57:1025–8.

Ingham, R. E., Trofymow, J. A., Ingham, E. R., and Coleman, D. C. 1985. Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. Ecological Monographs 55:119–40.

Isagi, Y., Kawahara, T., Kamo, K., and Ito, H. 1997. Net production and carbon cycling in a bamboo *Phyllostachys pubescens* Stand. Plant Ecology 130:41–52.

Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48 p. 692.

Kameyama, A. 1978. Characterization of the kudzu colonies in vegetation successions on the highway slopes. Journal of the Japanese Society of Revegetation Technology 5:36–42.

Mishra, S., Wang, K.-H., Sipes, B. S., and Tian, M. Y. 2017. Suppression of root-knot nematode by vermicompost tea prepared from different curing ages of vermicompost. Plant disease 101:1–4.

Mishra, S., Wang, K.-H., Sipes, B. S., and Tian, M. Y. 2018. Induction of host-plant resistance in cucumber by vermicompost tea against root-knot nematode. Nematropica 48 (in press).

Nakhshiniev, B., Perera, C., Biddinika, M. K., Gonzales, H. B., Sumida, H., and Yoshikawa, K. 2014. Reducing ammonia volatilization during composting of organic waste through addition of hydrothermally treated lignocellulose. International Biodeterioration & Biodegradation 94:58–62.

Nico, A. I., Jiménez-Díaz, R. M., and Castillo, P. 2004. Control of root-knot nematodes by composted agro-industrial wasters in potting mixtures. Crop Protection 23:581–7.

Oka, Y. 2010. Mechanisms of nematode suppression by organic amendments – a review. Applied Soil Ecology 44:101–15.

Pangesti, N., Pineda, A., Pieterse, C. M. J., Dicke, M., and van Loon, J. J. A. 2013. Two-way plant-mediated interactions between root-associated microbes and insects: from ecology to mechanisms. Frontier of Plant Science 4:414 (11 pp), available at: https://doi.org/10.3389/fpls.2013.00414.

Pattnaik, S., and Reddy, M. V. 2012. Microbial characterisation of vermicompost and compost of urban waste processed by three earthworm species – *Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavates*. International Journal of Environmental Technology and Management 15:466–500.

Radovich, T. J. K., and Arancon, N. 2011. Tea time in the tropics: a handbook for compost tea production and use. College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI, p. 70, ISBN: 978-1-929325-24-5.

Rodriguez-Saona, C., Musser, R. O., Vogel, H., Hum-Musser, S. M., and Thaler, J. S. 2010. Molecular, biochemical, and organismal analyses of tomato plants simultaneously attacked by herbivores from two feeding guilds. Journal of Chemical Ecology 36:1043–57.

Scheuerell, S. J., and Mahaffee, W. F. 2004. Compost tea as a container medium drench for suppressing seedling damping-off caused by *Pythium ultimum*. Phytopathology 94:1156–63.

Singh, U. P., Maurya, S., and Singh, D. P. 2003. Antifungal activity and induced resistance in pea by aqueous extract of vermicompost and for control of powdery mildew of pea and balsam. Journal of Plant Diseases and Protection 110:544–53.

Southey, J. F. 1986. Laboratory methods for work with plant and soil nematodes, Ministry of Agriculture, Fisheries and Food, London.

Spoel, S. H., and Dong, X. 2012. How do plants achieve immunity? Defense without specialized immune cells. Nature Reviews Immunology 12:89–100.

Tajbakhsh, J., Goltapeh, E. M., and Varma, A. 2011. Vermicompost as a biological soil amendment. in Karaca,

A. (Ed.), Soil biology: biology of earthworms, Springer, Berlin and Heidelberg: 215–28.

Taylor, A. L., and Sasser, J. N. 1978. Biology, identification and control of root-knot nematodes (Meloidogyne species). North Carolina State University Graphics, Raleigh, NC.

Wang, B., Wei, W. J., Liu, C. J., You, W. Z., Niu, X., and Man, R. Z. 2013. Biomass and carbon stock in moso bamboo forests in subtropical China: characteristics and implications. Journal of Tropical Forest Science 25:137–48.

Wang, K.-H., and McSorley, R. 2005. Effects of soil ecosystem management on nematode pests, nutrient cycling, and plant health. APSnet Feature Story January 2005, doi: 10.1094/APSnetFeatures/2005-0105.

Wang, K.-H., Radovich, T., Pant, A., and Cheng, Z. Q. 2014. Integration of cover crops and vermicompost tea for soil and plant health management in a short-term vegetable cropping system. Applied Soil Ecology 82:26–37.

Xiao, Z., Liu, M., Jiang, L., Chen, X., Griffiths, B. S., Li, H., and Hu, F. 2016. Vermicompost increases defense against root-knot nematode (*Meloidogyne incognita*) in tomato plants. Applied Soil Ecology 105:177–86.

Yeates, G. W., Bongers, T., De Goede, R. G. M., Freckman, D. W., and Georgieva, S. S. 1993. Feeding habits in soil nematode families and genera – an outline for soil ecologists. Journal of Nematology 25:315–31.

You, X.-D., Kimura, N., Okura, T., Murakami, S., Okano, R., Shimogami, Y., Matsumura, A., Tokumoto, H., Ogata, Y., and Tojo, M. 2018. Suppressive effects of vermicomposted-bamboo powder on cucumber damping-off. JARQ 53(1): (in press).