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

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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...
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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; Scheuerrl 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. *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 ent 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 ‘Kumatoro-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 experiment, and were prepared by mixing each type of vermicompost in water at 1:10 (v/v) ratio, and aerated for 24 hr using 2.5W 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.

**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*
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**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 cm³ 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 m² 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

**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.**

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

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.

**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.**
(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-cm³ 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-
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Table 2. Effect of vermicompost tea on plant-parasitic nematodes and percent trophic groups of free-living nematodes in a cowpea agroecosystem.

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

5/25/17

6/21/17

Figure 6: Abundance of (A) bacterivorous and (B) omnivorous nematodes in water or vermicompost teas prepared from 30 cm³ 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-ratio (k = 100) t-test.

*Nematode abundance (numbers/250 cm³ soil) was log transformed, log(x + 1) prior to analysis of variance; 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.*
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* ≤ 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* ≤ 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* ≤ 0.05), both VCTs suppress the J2s mobility equally in Trial II compared to the water control (*P* ≤ 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* ≤ 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* ≤ 0.05, Fig. 6A), but more omnivorous nematodes were found in weed vermicompost than vegetable vermicompost in Trial II (*P* ≤ 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* ≤ 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 bacterioves 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* ≤ 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 (Rodríguez-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.

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