Solarization mulch reduces weed seed bank and initial population of plant-parasitic nematodes.

Sunn hemp planted cover crop terminated using no-till provides **organic mulch** that enhanced detritivorous arthropods, nutrient cycling free-living nematodes, and increased crop yield.

Hover flies on buckwheat flower

Cowpea and buckwheat serve as 1) insectary borders attract natural enemies of insect pests, and 2) **living mulch** to mitigate weed seeds from flying in.

**Effects of Mulching on Above and Below Ground Pests and Beneficials in a Green Onion
Agroecosystem**

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ABSTRACT

In 2013 and 2014, different mulching systems were investigated for their potential to suppress above and below ground pests, and enhance beneficial arthropods and soil health in green onion (*Allium cepa*) plantings. Three types of mulch systems (organic, living and solarization mulch) were evaluated and compared. Green onions were grown in four pre-plant treatments: 1) organic mulch generated by flail mowing a sunn hemp (*Crotalaria juncea*) cover crop (SH) followed by a no-till cropping system, 2) soil solarization (Sol), 3) sunn hemp-solarization mulch in which the sunn hemp was incorporated into the soil followed by soil solarization (SHSol), and 4) bare ground with insecticides (BG). Sol, SHSol and BG were practiced in conventional tilled system. SH (in 2013 and 2014) and SHSol (in 2014) treatments included strips of buckwheat and cowpea along the crop border to serve as living mulch or insectary plants. Green onion plants in SH had lower thrips and leaf miners damage than other treatments in both study years. When insectary borders were added to SHSol in 2014, thrips and leaf miners damages were also reduced in SHSol compared to Sol and BG. Incidence of purple blotch was reduced in SH and SHSol treatments in 2014. The SH treatment contained an increased abundance and richness of detritivores, predatory arthropods, parasitoids and beneficial free-living nematodes (particularly bacterivores and fungivores). Although weeds and initial populations of plant-parasitic nematodes were lower in solarization (Sol, SHSol) than other treatments, green onion yield was greatest in SH organic mulch systems in both study years. Overall, the integration of surface organic, living and solarization mulches into a green onion agroecosystem provided multiple ecosystem services including suppression of above and below ground pest organisms.

Keywords

Insectary plants, onion thrips, organic mulch, purple blotch, soil health, solarization, weeds.

35

36 **1. Introduction**

37 In light of soil degradation problems caused by continuous tillage (Reeves, 1997) and its
 38 negative impact on soil health (Magdoff, 2001; Roger-Estrade et al., 2010), reduced tillage,
 39 cover cropping, mulching and other management tactics that reduces organic producers reliance
 40 on tillage have received greater research attention in recent years (Hartwig and Ammon, 2002;
 41 Pittelkow, et al., 2015; Roger-Estrade et al., 2010). Mulching can be the addition of inorganic or
 42 organic material such as plastic, straw, cover crop residue or live plant to the soil surface to
 43 provide one or several ecosystem services such as enriching or protecting the soil, preventing
 44 pest establishment or enhancing crop yield. Mulching in the form of cover crops and practicing
 45 reduce tillage have some ecological advantages over conventional land preparation tasks such as
 46 plowing and disking the entire field as they are generally less disrupted to the soil environment.

47 Cover crop mulch that remains on the soil surface can be used to add soil organic matter
 48 (Dabney *et al.*, 2001), prevent soil erosion (Saxton *et al.*, 2000), increase soil water retention
 49 (McIntyre, 1958; Dabney, 1998), improve soil health (Wang *et al.*, 2011a), and suppress
 50 arthropod and weed pests as well as diseases (Altieri 1999; Creamer et al., 1996; Gonzalez-
 51 Martin *et al.*, 2014). Organic mulch associated with no-till farming is well-known for its soil
 52 health benefits (Doran, 2002; Parr *et al.*, 1992). Many researchers have used nematode
 53 community indices as soil health indicators and found that no-till farming and organic mulches
 54 can enhance nematode diversity, soil food web structure of free-living nematodes and crop yields
 55 (Bongers, 1990; Ferris *et al.*, 2012; Hoyt, 1999; Sieriebriennikov *et al.*, 2014). Nematodes are
 56 good soil health indicators because they play important roles in soil nutrient cycling (Ferris et al.,
 57 2012). Organic mulches have been shown also to increase spider abundance (Sunderland and

Samu, 2000) and subsequently enhance biological control. Despite vast ecosystem services that can be provided by mulching, limited effort has been devoted to integrating different mulching practices to concurrently manage above and below ground pest complexes.

Cover crops may be used as insectary plants to enhance the activity of beneficial arthropods by providing them nectar and pollen (Cowgill *et al.*, 1993; Lavandero *et al.*, 2005; Hogg *et al.*, 2011) or augmenting their prey (Taylor and Pfannenstiel, 2008). Insectary plants have been shown to attract beneficial arthropods such as Coccinellid beetles, spiders and Chalcidoid wasps (Rodriguez-Saona *et al.*, 2012). However, insectary plants may differ in their attractiveness to beneficial arthropods. For example, buckwheat (*Fagopyrum esculentum*) is quick to flower and its floral resources can attract a diverse range of beneficial insects (Platt *et al.*, 1999; Ambrosino *et al.*, 2006, Tavares et al. 2015); whereas cowpea (*Vigna unguiculata*) has extra-floral nectaries (Pate *et al.*, 1985) which attract beneficial arthropods. However, insectary plants may need to be used in conjunction with other pest management tactics to have a perceptible impact on pests being targeted and cash crop yield.

Cover crops may be used also to prevent weed establishment. If used alone as surface residue, they may not provide satisfactory weed control unless there is sufficient biomass which allows the residue to persist for a lengthy period of time. In the U.S.A., farmers spend \$6 billion a year on herbicides, tillage, and cultivation for weed control (Chandler, 1991); and weeds are still the number one production constraint for many crop producers (Turner et al. 2007). Synthetic mulches have been studied for their ability to suppress weed establishment by acting as physical barriers, trapping solar heat or both (Stapleton, 2000). Soil solarization involves covering the soil with a transparent polyethylene film to reach temperatures detrimental to soil-borne pests (Gamliel and Katan, 2012; McGovern and McSorley, 1997). Soil solarization has

81 been used consistently to suppress weeds (Marahatta *et al.*, 2012), but its effect on plant-parasitic
82 nematodes has been variable or provided short-term suppression (Wang *et al.*, 2011b). In
83 addition, soil solarization can temporarily reduce soil health conditions (Wang *et al.*, 2006).
84 However, negative effects of soil solarization on soil health can be negated by integrating cover
85 crops into the system. For example, a combination of cover cropping and soil solarization
86 reduced plant-parasitic nematodes and weeds more effectively than either tactic alone, and soil
87 health as indicated by the abundance of free-living nematodes was enhanced significantly by the
88 combination compared to using soil solarization alone (Marahatta *et al.*, 2012).

89 Green onion (*Allium cepa*) is a short-term vegetable crop that has low tolerance to weeds
90 (Smith *et al.*, 2010). In addition, green onion production in Hawaii is challenging due to thrips
91 (Thysanoptera: Thripidae) which can transmit Iris yellow spot virus (IYSV, *Toposvirus*:
92 Bunyaviridae) (Bag *et al.*, 2015), leaf miners (*Liriomyza spp.*) (Diptera: Agromyzidae) (Herr and
93 Johnson, 1992), and purple blotch caused by foliar infection of *Alternaria porri* (Ellis). Incidence
94 of purple blotch can be intensified by thrips damage (Diaz-Montano *et al.*, 2011; Thind and
95 Jhooty, 1982), causing up to 59% yield reduction in bulb onions (Gupta & Pathak, 1988).
96 Covering the soil with organic mulch has been reported to reduce thrips infestations on onions
97 and other crops (Larentzaki *et al.*, 2008; Diaz-Montano *et al.*, 2011). Thus, green onion
98 production can benefit from a mulching system that provides multiple ecosystem services
99 including pest suppression.

100 The overall goal of this study was to evaluate the effect of integrating multiple mulching
101 tactics on above and below ground pests and beneficial organisms, weed suppression and
102 marketable yield within a green onion cropping system. It is hypothesized that an organic mulch
103 will enhance above and below ground beneficial organisms and subsequently improve soil

health; living mulch (insectary borders) will attract natural enemies of arthropod pests; and a solarization mulch will reduce weed establishment and abundance of plant-parasitic nematodes within the upper soil layer prior to crop planting. As such, it is postulated that integrating several mulching practices within the same field will provide greater ecosystem services including the suppression of multiple pest complexes.

2. Materials and methods

2.1. Field Experimental Layout

A field experiment was conducted at the University of Hawaii at Manoa Poamoho Experiment Station (21°53' N, 158°8' W) on Oahu, HI in 2013 and 2014. The soil type at the site is Wahiawa silty clay in the Oxisol order with Tropptic Eutrustox, clayey, kaolinitic, isohyperthermic properties, containing 18.6% sand, 37.7% silt, and 43.7% clay in the top 25-cm soil. Soil organic matter was approximately 2% with pH of 6.5. The experiment consisted of four treatments: 1) organic mulch generated by flail mowing a sunn hemp (*Crotalaria juncea* 'Tropic Sun') cover crop (SH) followed by a no-till cropping system, 2) soil solarization (Sol), 3) SH green manure (soil incorporation) followed by soil solarization (SHSol), and 4) bare ground (BG) with insecticide sprays. SH (in 2013 and 2014) and SHSol (in 2014) treatments included strips of buckwheat and cowpea along the crop border. SH treatment plots were managed without tillage (No-till), whereas SHSol, Sol, and BG plots were tilled prior to green onion planting. Each treatment was replicated four times in $9.2 \times 2.4\text{-m}^2$ plots, and arranged in a randomized complete block design. Individual plots were separated by a minimum 6-m of bare-ground. The experiment was repeated in the same field and treatment plots to evaluate the cumulative effect over two field plantings.

Sunn hemp was seeded at a rate of 33 kg/ha and grown for 3.5 months in the SH treatment, the soil was solarized for 3.5 months in the Sol treatment, and sunn hemp was grown for two months prior to soil incorporation and afterwards the soil was solarized for six weeks in the SHSol treatment. A flail mower was used to terminate the SH, leaving SH residues as an organic surface mulch in SH plots. Solarization involved covering the soil after tillage with 1.2-m wide, 25- μ m thick, uv stabilized, low density transparent polyethylene mulch (ISO Poly Firms, Inc., Gary Court, SC). Temperature probes (WatchDog B-series button data logger, Spectrum[®] Technologies, Aurora, IL) were placed at 5- and 15-cm soil depth in Sol and SHSol plots to monitor soil temperature hourly. BG treatment was initially tilled, left fallow with weeds during SH growing or soil solarization period, and tilled again prior to crop planting. Strips of buckwheat (60 cm $\times$ 2.4 m) and cowpea (60 cm $\times$ 9.2 m) were seeded at rates of 63.8 kg/ha and 55 kg/ha, respectively along the borders of SH plots 30 cm away from the onion crop in 2013, and SH and SHSol in 2014 to serve as insectary plants.

In 2013, green onions were planted on July 1, and harvested on October 4 from 100 randomly selected plants per plot. In 2014, green onions were planted on July 3, and harvested on two dates (September 9 and December 4) from 50 randomly selected plants per plot on each harvest date. Green onion vegetative propagules were planted in eight rows within each plot at 30-cm intra- and inter- row spacing. Plants were drip irrigated and fertilized with turkey manure fertilizer (Sustane 5-2-4, Sustane Naturally Fertilizer Inc., Cannon Falls, MN) at 66 kg N/ha over two applications. Green onion in the control plots (BG) received insecticides spray of spinosad (Entrust[®], Dow Agrosiences, Indianapolis, IN) and pyrethrins (Pyganic[®] EC 5.0II, MGK, Minneapolis, MN) applied in rotation every two weeks or as needed to manage thrips. Weeds

were managed manually or sprayed with herbicides (Roundup[®], Monsanto, St. Louis, MO, or Fusilade[®], Syngenta, Greensboro, NC) in all plots as required.

2.2. Foliar pests and beneficial monitoring

Thrips and leaf miner damage on green onion was monitored biweekly from July 25 (a total of 5 sampling dates) in 2013 and July 17 (a total of 8 sampling dates) in 2014 following planting. A total of nine green onion plants were examined from three systematically selected areas per plot for the number of leaves with thrips or leaf miners damage, and total number of leaves per plant were recorded. Percent of leaves displaying thrips or leaf miners damage was calculated for each plant. In 2014, additional data were taken on incidence of purple blotch when symptoms became apparent near the end of the cropping cycle on November 6 and 20, 2014 using the same sampling units for thrips and leaf miners.

Yellow sticky cards (13×7.5 cm²) were positioned 50 cm above ground and placed systematically in three areas (front, center and rear) within each plot. Cards were collected after one week of exposure and new cards were placed out every two weeks. All herbivorous arthropods (thrips, whitefly, and aphids) found on cards were identified and counted using a dissecting microscope (Leica[®] M125, Buffalo Grove, IL). In 2014, all arthropods were identified to the lowest taxon possible.

2.3. Pitfall traps

Pitfall traps were established at three random locations throughout each plot from July 25 to September 26 in 2013 and from July 24 to November 25 in 2014. Pitfall traps consisted of a 740-ml small square Ziploc container (SC Johnson, Racine, WI) filled with soapy water and

buried so that the top of the container was located just below the soil surface. Traps were placed next to green onion plants. Ground dwelling arthropods mainly detritivores and predatory arthropods found in each trap were identified to order, counted and recorded. Traps were emptied and refilled with soapy water weekly.

Arthropod counts from the yellow sticky traps and pitfall traps were calculated for richness = number of taxa and Simpsons index of diversity $1/\lambda = \sum (p_i)^2$, where p_i is the proportion of each of the i taxon present (Simpson, 1949).

2.4. Nematode assay

Soil samples were taken at green onion planting and harvest in 2013, and at planting, and first and second harvest in 2014. During each sampling occasion, six soil cores were taken at a depth of 15-cm deep in close proximity to onion rows in each plot and composited into one sampling bag. Nematodes were extracted from a subsample of 250 cm³ of soil per sample by elutriation and centrifugal flotation method (Jenkins, 1964). Nematodes were identified to the genus level wherever possible, counted and assigned to trophic groups: algivores, bacterivores, fungivores, herbivores, omnivores, or predators mostly based on categorization by Yeates *et al.* (1993). *Filenchus* and *Tylenchus* were classified as fungivores (Okada and Kadota, 2003), *Prismatolaimus* was classified as a bacterivore rather than a substrate ingester (Yeates *et al.*, 1993). Nematode richness are the total number of taxa recorded. Simpsons index of dominance was calculated as $\lambda = \sum (p_i)^2$, where p_i is the proportion of each of the i taxon present (Simpson, 1949), whereas diversity was calculated as $1/\lambda$. The fungivore to bacterivore (F/B) ratio was calculated to characterize the dominant decomposition pathways (Freckman and Ettema, 1993). Taxonomic families were assigned a colonizer-persister (c-p) rating of taxon i according to the

1–5 c-p scale of Fargues and Bongers (1998). Free-living nematode maturity index (MI) was calculated as $\sum (p_i c_i)$, where c_i is the c-p value (Yeates, 1994). In addition, enrichment index (EI) was calculated as $100 \times [e/(e + b)]$ to assess soil food web responses to available nutrient resources, structure index (SI) was calculated as $100 \times [s/(s + b)]$ to reflect the complexity of trophic connection in soil food webs, and channel index (CI) was calculated as $CI = 100 \times [0.8 F2/e]$ to determine if a soil food web was dominated by fungal or bacteria decomposition where e, s, and b are enrichment, structure, and basal food web components, and F2 is fungivores with c-p value of 2 as described by Ferris *et al.* (2001). The EI assesses food web responses to available resources, and SI reflects the degree of trophic connection in food webs of increasing complexity as the system matures. Whereas the CI represents the decomposition pathway in the soil food web. In general, higher EI and lower CI suggest greater bacterial activity, more nutrient enriched soil food web, whereas higher SI indicates a less disturbed soil food web.

2.5. Weed management monitoring

Weeds were managed by herbicide spot treatment and by hand weeding. Average time per person to weed each plot was recorded and used to compare the impact of treatment differences on weed pressure. To reduce heavy weed pressure, herbicides were applied after the first and second weed surveys in 2013. Spot treatment of herbicide was conducted much like precision herbicide treatment that is highly correlated with weed distribution (Gerhards et al., 2003). Thus, in 2014, the time required for hand weeding and herbicide spot treatment in each plot were recorded to help assess weed pressure.

2.6. Statistical analysis

All data were checked for normality using Proc Univariate (SAS Institute, Cary, NC). Parameters that were not normally distributed were subjected to transformation such as log transformation ($\log_{10} [x + 1]$) or square root transformation ($\sqrt{[x + 1]}$) as recommended in Steel and Torrie (1980). Percent of leaves damaged by pests and disease (thrips, leaf miner, and purple blotch), and abundance of arthropods on yellow sticky traps and pitfall traps were subjected to repeated measures analysis over time using Proc Mix (SAS Institute, Cary, NC). Due to significant interaction between sampling time and treatment effects based on a two-way (sampling time $\times$ mulching treatment) analysis of variance (ANOVA) for nematode abundance and indices data in 2013, nematode data were analyzed by sampling date. However, no interaction between sampling date and treatment effects occurred for the free-living nematodes parameters in 2014, thus nematode data in 2014 were subjected to repeated measure analysis. All parameters listed above along with weed management time and green onion yield for each harvest were subjected to orthogonal contrast analysis to compare SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH) using Proc GLM in SAS (SAS Institute Inc., Cary, NC).

3. Results

3.1. Effects of mulching on foliar pests and pathogens

In 2013, fresh biomass of sunn hemp in SH and SHSol reached 41.0 and 23.5 Mgha⁻¹, respectively, prior to termination. During the solarization period, soil in Sol treatment achieved maximum temperatures of 55° and 41°C at 5- and 15-cm soil depth, respectively; whereas soil in SHSol achieved maximum temperatures of 53° and 44°C at 5- and 15-cm soil depth, respectively. Although there was no significant treatment effect on thrips damage, leaf miners

damage were reduced significantly in no-till (SH) compared to tilled (Sol, SHSol, BG) plots (df = 1, $F = 6.0$, $P < 0.05$).

In 2014, fresh biomass of sunn hemp in SH and SHSol reached 48.5 and 27.7 Mgha^{-1} , respectively. Soil in Sol reached maximum temperatures of 47° and 42°C at 5- and 15-cm depth, respectively; whereas soil in SHSol reached a maximum temperatures of 48° and 40°C at 5- and 15-cm depth, respectively. Thrips damage was significantly less in sunn hemp (SH, SHSol) compared to no sunn hemp (Sol, BG) plots (df = 1, $F = 31.8$, $P < 0.01$) and in no-till (SH) compared to tilled (Sol, SHSol, BG) plots (df = 1, $F = 38.5$, $P < 0.01$), whereas solarization did not impact thrips damage. Leaf miner damage was significantly reduced in no-till compared with tilled plots (df = 1, $F = 6.2$, $P < 0.05$) and no differences existed among the other contrast analysis. Incidence of purple blotch was reduced in green onion planted in no-till compared to tilled treatments (Table 1, df = 1, $F = 9.5$, $P < 0.05$).

Whiteflies (*Bemisia argentifolii*), onion thrips (*Thrips tabaci*) and western flower thrips (*Frankliniella occidentalis*), onion aphids (*Neotoxoptera formosana* Takahashi) and cowpea aphids (*Aphis craccivora* Koch) were found most commonly on yellow sticky card traps (Table 2). Whiteflies and cowpea aphids were the most dominant herbivores encountered, but are not considered green onion pests. Their total abundance was grouped under the herbivores category. Total abundance of herbivorous insects found on yellow sticky cards was reduced in solarized (Sol, SHSol) compared to non-solarized treatments (SH, BG) (df = 1, $F = 8.8$, $P < 0.05$) in 2013, but was greater in no-till (SH) than tilled (Sol, SHSol, BG) treatments (df = 1, $F = 10.9$, $P < 0.01$) and greater in sunn hemp (SH, SHSol) vs no sunn hemp (Sol, BG) treatments (df = 1, $F = 16.1$, $P < 0.01$) in 2014 (Table 2).

3.2. *Effects of mulching on above ground beneficials*

Non-herbivorous arthropods trapped on sticky cards were classified as predators, parasitoids and detritivores. Predators included hoverflies (Diptera: Syrphidae), lady beetles (Coleoptera: Coccinellidae), long legged flies (Diptera: Dolichopodidae: Condyllostylus), minute pirate bugs (Hemiptera: Anthocoridae), short-winged mold beetles (Coleoptera: Staphylinidae: Pselaphinae), spiders (Arachnida: Araneae), spider wasps (Hymenoptera: Pompilidae), thread-waisted wasps (Hymenoptera: Sphecidae), *Paederus* rove beetles (Coleoptera: Staphylinidae: Paederinae), and vespid wasps (Hymenoptera: Vespidae). Parasitoids encountered were: aphidius wasps (Hymenoptera: Braconidae: Aphidiinae), Ichneumon wasp (Hymenoptera: Ichneumonidae), and multiple taxa within the Chalcidoidea (Aphelinidae, Chalcididae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Mymaridae, Signiphoridae, Pteromalidae: Spalanginae, Tanaostigmatidae, and Trichogrammatidae). Whereas, detritivores included barklice (Psocoptera), larva stages of click beetles (Coleoptera: Elateridae), roaches (Blattodea: Blattidae), dermestid beetles (Coleoptera: Dermestidae), minute fungus beetles (Coleoptera: Corylophidae), and springtails (Collembola).

Greater numbers of predators ($df = 1$, $F = 11.9$, $P < 0.01$), parasitoids ($df = 1$, $F = 13.3$, $P < 0.01$) and detritivores ($df = 1$, $F = 18.2$, $P < 0.01$) were found on card traps in sunn hemp plots with insectary borders (SH, SHSol) compared to non sunn hemp (Sol, BG) treatments (Table 2). Subsequently, arthropod richness was greater in sun hemp than non sunn hemp treatments ($df = 1$, $F = 22.4$, $P < 0.01$), but diversity was similar ($P > 0.05$). There was no effect of solarization on the abundance, richness or diversity of beneficial arthropods (Table 2). There was a greater number of detritivores ($df = 1$, $F = 9.8$, $P < 0.05$) in no-till (SH) compared to till (Sol, SHSol,

BG) treatments, which contributed to a greater arthropod richness ($df = 1$, $F = 9.8$, $P < 0.05$) in no-till compared to tilled treatments.

3.3. Effects of mulching on soil dwelling arthropods

Spiders (Arachnida: Araneae) ($df = 1$, $F = 17.6$), carabid beetles (Coleoptera: Carabidae) ($df = 1$, $F = 7.7$), earwig (Dermaptera) ($df = 1$, $F = 22.2$) and pillbugs (Isopoda) ($df = 1$, $F = 20.1$) were greater in sunn hemp (SH, SHSol) compared to non sunn hemp (Sol, BG) treatments in 2013 ($P < 0.05$). In 2014, there was only an increase in spiders ($df = 1$, $F = 12.8$, $P < 0.01$) in sunn hemp compared to non sunn hemp treatments (Table 3). Fewer spiders were found in solarized (Sol, SHSol) compared to non-solarized (SH, BG) treatments in 2013 ($df = 1$, $F = 13.0$, $P < 0.01$) but no differences were detected in 2014. More spiders ($df = 1$, $F = 19.9$, $P < 0.05$) and pillbugs ($df = 1$, $F = 5.93$, $P < 0.05$) were found in no-till (SH) during both years and earwig ($df = 1$, $F = 5.2$, $P < 0.05$) in 2013 compared to tilled (Sol, SHSol, BG) treatments (Table 3).

3.4. Effects of mulching on below ground nematode pests and beneficials

Different mulching effects were observed on plant-parasitic nematodes between July 1 (at green onion planting) and October 3 (after green onion harvest) in 2013. At green onion planting, fewer root-knot (*Meloidogyne* sp.) ($df = 1$, $F = 26.5$), reniform (*Rotylenchulus reniformis*) ($df = 1$, $F = 9.3$) and total herbivorous nematodes ($df = 1$, $F = 21.1$) were found in solarized (Sol, SHSol) compared to non-solarized (SH, BG) treatments ($P < 0.05$, Table 4). However, by green onion harvest, no differences were detected between solarized and non-solarized treatments (Table 4). Effects of mulching tactic on the total abundance of herbivorous nematodes varied also over time in 2014. Plant-parasitic nematode numbers were reduced in solarized prior to green onion

planting compared with non-solarized treatments ($df = 1$, $F = 7.2$, $P < 0.01$), but no differences were detected during the 1st and 2nd green onion harvest period (Table 5). Similarly, fewer herbivorous nematodes were found in tilled (Sol, SHSol, BG) compared to no-till (SH) treatments at green onion planting ($df = 1$, $F = 6.0$, $P < 0.05$), but no differences were detected during harvest in both years (Tables 4 and 5).

Effects of mulching on the abundance of beneficial nematodes varied among sampling periods in 2013. Abundances of bacterivorous ($df = 1$, $F = 42.3$) and omnivorous nematodes ($df = 1$, $F = 16.8$) were greater in sunn hemp (SH, SHSol) compared to non sunn hemp (Sol, BG) treatments ($P < 0.01$), but predatory nematode abundance ($df = 1$, $F = 8.7$) was less in sunn hemp compared to non sunn hemp treatments at green onion planting in 2013 ($P < 0.05$, Table 4). At green onion harvest, abundance of fungivorous nematode was greater ($P < 0.01$) in sunn hemp than non sunn hemp treatment in 2013 (Table 4). No interaction was detected between sampling time and mulching treatment on the abundance of beneficial nematodes in 2014, repeated measure of nematodes abundance showed no difference between sunn hemp and non sunn hemp treatments in 2014 ($P > 0.05$, Table 5).

Solarization had no effect on the abundance of free-living nematodes prior to green onion planting in 2013 ($P > 0.05$). However, fungivores were lower in solarized (Sol, SHSol) than non-solarized (SH, BG) plots at green onion harvest in 2013 ($df = 1$, $F = 13.1$, $P < 0.05$, Table 4) and in 2014 ($df = 1$, $F = 10.0$, $P < 0.01$, Table 5). Abundances of bacterivores ($df = 1$, $F = 24.9$, $P < 0.01$) and omnivores ($df = 1$, $F = 7.8$, $P < 0.05$) were greater in no-till (SH) than tilled (Sol, SHSol, BG) plots at green onion planting in 2013, but fungivorous nematode counts were greater ($df = 1$, $F = 8.5$, $P < 0.05$) in no-till compared to till treatments at green onion harvest in 2013. In

2014, only the abundance of fungivores were greater ($df = 1$, $F = 7.0$, $P < 0.05$) in no-till compared to till treatment.

Effects of sunn hemp planting on other nematode community indices were more apparent at the termination of preplant treatments (just prior to green onion planting) than at the green onion harvest in 2013 (Table 4). There was an increase in nematode richness and EI ($df = 1$, $F = 10.6$ and 39.8 , respectively, $P < 0.01$), and decrease in diversity, MI and CI ($df = 1$, $F = 13.0$, 25.6 and 15.4 , respectively) in sunn hemp (SH, SHSol) than non sunn hemp (Sol, BG) plots on July 1, 2013 ($P < 0.01$, Table 4). In addition, more enchytreid worms were found in sunn hemp than non sunn hemp plots ($df = 1$, $F = 21.4$, $P < 0.01$). On October 3, 2013 (green onion harvest), nematode richness ($df = 1$, $F = 10.8$, $P < 0.01$) and EI ($df = 1$, $F = 6.3$, $P < 0.05$) were greater in sunn hemp than non sunn hemp plots. These indices did not differ between sunn hemp and non sunn hemp treatments in 2014.

Solarization did not affect any nematode community indices ($P > 0.05$) in 2013, but richness ($df = 1$, $F = 11.3$, $P < 0.01$) and EI ($df = 1$, $F = 4.5$, $P < 0.05$) were lower in solarized than non-solarized treatments in 2014 (Table 4). Nematode richness ($df = 1$, $F = 6.9$) and EI ($df = 1$, $F = 3.9$) were increased, and MI ($df = 1$, $F = 15.3$) and CI ($df = 1$, $F = 5.7$) were decreased ($P < 0.05$) in no-till compared to tilled plots on July 1, 2013. However, at green onion harvest in 2013, only EI was greater in no-till compared to tilled treatments ($df = 1$, $F = 9.4$, $P < 0.05$). In 2014, only nematode richness was higher in no-till than tilled treatments ($df = 1$, $F = 6.9$, $P < 0.05$).

3.5. Weed management time

Time required for manual weed removal was less in solarized (Sol, SHSol) than non-solarized (SH, BG) treatments in 2013 ($df = 1$, $F = 19.5$, $P < 0.01$) and 2014 ($df = 1$, $F = 50.4$, $P <$

0.01; Fig. 1 A, B). Time required for herbicide spray was not monitored in 2013. However, in 2014, less time was required for herbicide spot treatment in solarized compared to non-solarized treatments ($df = 1$, $F = 28.4$, $P < 0.01$; Fig. 1 C). In 2013, no-till (SH) required more time for weed management than tilled (Sol, SHSol, BG) treatments early in the season but weeding time in no-till was similar to tilled treatments by the final sampling date, resulting in no differences between no-till and tilled treatments (Fig. 1A). However, more time was required for hand weeding ($df = 1$, $F = 11.7$) and herbicide spot treatment ($df = 1$, $F = 9.4$) in no-till than tilled treatments in 2014 ($P < 0.01$; Fig. 1 B, C). Overall weed pressure in 2014 was higher than that in 2013.

3.6. Green onion yield

Green onion yields were higher in sunn hemp (SH, SHSol) than non sunn hemp (Sol, BG) treatments ($df = 1$, $F = 64.2$, $P < 0.01$), and no-till (SH) yielded higher than tilled (Sol, SHSol, BG) treatments in 2013 ($df = 1$, $F = 25.2$, $P < 0.01$; Fig. 2). Green onion was harvested on two dates in 2014 and a significant interaction was detected between harvest date and treatment ($P < 0.01$). No treatment differences were detected during the initial harvest on September 24 in 2014 ($P > 0.05$), but green onion yields were higher in sunn hemp (SH, SHSol) than non sunn hemp (Sol, BG) ($df = 1$, $F = 26.2$), and no-till (SH) than tilled (Sol, SHSol, BG) treatments ($df = 1$, $F = 45.9$), but lower in solarized (Sol, SHSol) compared with non-solarized (SH, BG) treatments ($df = 1$, $F = 11.4$) at the second harvest on Dec 4, 2014 ($P < 0.01$, Fig. 2).

4. Discussion

4.1. Effects of mulching on above ground pests

Results obtained from this study support the supposition that no-till organic mulch or planting living mulch insectary borders can help reduce numbers of foliar pests and pathogens such as thrips and leaf miner and *A. porri* and lower the incidence of purple blotch. Results were more apparent in 2014, provisionally due to the longer monitoring period and less frequent insecticide spray (3-week interval in 2014 compared to 2-week interval in 2013) in BG. The cumulative effect of no-till cover cropping and using insectary plants in the same green onion plots from 2013 to 2014 may have contributed also to the outcome.

Lower thrips damage in no-till plots in this study is similar to findings from Toews *et al.* (2010) where they found that strip-till planting of cotton (*Gossypium hirsutum*) into crimson clover (*Trifolium incarnatum*), wheat (*Triticum aestivum*) or rye (*Secale cereal*) winter cover crops reduced thrips damage. A negative correlation was found between ground coverage and thrips densities on cotton plants (Toews *et al.* 2010). Reductions of insect pests encountered in vegetative diverse cropping systems are often accredited to increased natural enemy abundance (Tahvanainen and Root, 1972; Sunderland and Samu, 2000). The increase in natural enemy populations such as spiders and parasitoids detected in pitfall and yellow sticky card traps are believed to have contributed to greater pest suppression in no-till treatments. The strategy of using sunn hemp solely as an organic mulch produced similar results as using sunn hemp as an organic and living mulch intercropping in zucchini with respect to suppression of herbivorous arthropods (Manandhar *et al.*, 2009; Hinds and Hooks, 2013). Manandhar *et al.* (2009) found that using sunn hemp as an interplanted living mulch between zucchini rows reduced silverleaf whitefly and aphid numbers and their associated plant impairments.

Larentzaki *et al.* (2008) suggested that straw mulch hampered pupation or emergence of thrips on onion plants. Thrips suppression observed in SH plots after the first harvest in 2014

was similar to the reduction of thrips (*Scirtothrips perseae*) observed in avocado orchards mulched with yard waste compost compared to unmulched sites reported by Hoddle *et al.* (2002). Entomopathogenic fungi and nematodes found on the leaf duff of the organic mulch may have been antagonistic to thrips (Hoddle *et al.*, 2002). Later De Ley *et al.* (2004) confirmed that entomopathogenic nematodes including *Steinernema feltiae*, were associated with thrips in mulched soil from this avocado orchard. Organic mulch has been shown to increase entomopathogenic fungi such as *Beauveria bassiana*, *Metarhizium anisopliae* and *Paecilomyces* spp. (Sosa-Gomez and Moscardi, 1994). In addition, intense UV light created during solarization might have been destructive to the beneficial flora and fauna in the soil, thus contributing to higher thrips counts in the Sol treatment.

Leaf miner damage was reduced only in no-till SH treatment. Predators and parasitoids are known to effectively suppress *Liriomyza* leaf miners in Hawaii (Johnson and Hara, 1987; Johnson and Mau, 1986; Nakao and Funasaki, 1979). In addition to an enhancement of predators and parasitoids in no-till plots with the insectary border, another potential contributor to leaf miner reductions in no-till plots is greater soil humidity and lower soil temperatures. This, could have enhanced fungal infection of *Liriomyza* leaf miner pupa (Keularts and Lindquist, 1989). Conversely, entomopathogenic fungi could have been inactivated by UV-components during solarization (Fargues et al., 1996; 1997), resulting in higher leaf miner damage in solarized than non-solarized treatments in 2013.

Incidence of purple blotch was 47.7% lower in no-till SH than BG plots. Organic mulch (sunn hemp residue) in no-till plots may have prevented soil splash and spore dispersal of *A. porri* as purple blotch spores are dispersed by wind and water (Meredith, 1965). Additionally, insectary borders may have served as barriers to the spread of *A. porri* resulting in lower

incidences of purple blotch in SH and SHSol plots. It is also plausible that tillage activity reduced beneficial fungi in the soil that are antagonistic to *A. porri*. Tyagi *et al.* (1990) reported a combination of *Penicillium* sp., *Aureobasidium pullulans*, *Sporobolomyces roseus* and *Cryptococcus luteolus* could reduce purple blotch infection on onion by 79%.

Overall, it is unclear which factors contributed to thrips, leaf miner, and purple blotch suppression in the no-till system. A meta-analysis of 43 published studies reporting 62 independent taxa on the density response of natural enemies (invertebrate predators and parasitoids) to increases and decreases in habitat complexities concluded that mechanisms underlying responses of natural enemies to complex habitats are still unclear. However, the addition of alternative prey, more effective prey capture and greater access to pollen and nectar sources are possible mechanisms (Langelloto and Denno, 2004).

4.2. Effects of mulching on fauna diversity

Increase abundance and richness of parasitoids and detritivores in no-till or plots with insectary borders (SH and SHSol) in this study are in agreement with findings of several review articles (Meyling & Eilenberg, 2007; Altieri, 1999). It is possible that cowpea and buckwheat insectary borders attracted high number of herbivores despite having the lowest level of herbivore caused damage on the green onion planted in this treatment. Larger populations of herbivores in insectary borders can be beneficial as they may attract greater numbers of natural enemy (Agnew and Smith, 1989) and lure pests away from the cash crop (Hooks and Johnson, 2003; Cook *et al.*, 2007). Higher spider numbers have frequently been reported in no-till systems (Hendrix, 1986; Kladviko, 2001). Maintaining arthropod diversity in agroecosystems vulnerable

to thrips could be beneficial if it leads to greater pest management as insecticide resistance is a common occurrence among thrips populations (Shelton *et al.*, 2003; 2006).

Most soil dwelling arthropods monitored by pitfall traps such as dermapterans and isopodans were also enhanced in the no-till and insectary plant border systems, similar to that reported by Altieri (1999) and Brevault *et al.* (2007). Although some dermapterans (e.g. earwigs) may be crop pests or natural enemies of pests, these soil dwelling detritivores play an important role in soil nutrient cycling.

4.3. *Effects of mulching on plant-parasitic nematodes*

Although solarization did not contribute to a reduction in arthropod pests, it suppressed plant-parasitic nematodes by the first sampling date in both study years. Soil solarization is known for its nematode suppressive effects (Oka *et al.*, 2007; McSorley *et al.*, 2009). A combination of sunn hemp cover cropping and solarization suppressed plant-parasitic-nematode more effectively than solarization alone (Marahatta *et al.*, 2012). In the 2013 and 2014 trials, abundance of herbivorous nematode were reduced by 55% and 63%, respectively early in the growing cycle in SHSol compared to Sol. However, plant-parasitic nematode numbers in solarization treatments recovered over time, and resulted in higher or equivalent counts to non-solarized treatments by onion harvest in both years. Although root-knot nematode infestation can cause stunting, uneven plant stands and substantial yield loss in onion (Westerdahl and Becker, 2008), the temporary reduction of plant-parasitic nematodes by solarization early in the green onion growing season did not contribute to green onion yield improvement.

Sunn hemp is known to suppress plant-parasitic nematodes when soil incorporated (Wang *et al.*, 2014; Wang and McSorley, 2004). However, it does not suppress herbivorous nematodes

when used as a surface mulch (Hinds *et al.*, 2013). Therefore, it was not unforeseen that plant-parasitic nematode numbers were highest in SH treatment during initial sampling dates. Thomas (1978) documented that no-till systems often resulted in highest levels of plant-parasitic nematodes. However, by the end of the green onion harvest in both years, the results were similar to Quintanilla-Tornel (2009) who demonstrated no differences in the abundance of plant-parasitic nematodes between no-till and conventional till systems.

4.4. Effects of mulching on beneficial soil fauna (nematodes)

Sunn hemp and no-till cover cropping enhanced bacterial and fungal decomposition as indicated by higher abundance of bacterivorous and fungivorous nematodes in these treatments compared to non sunn hemp treatments (Sol, BG). SH and SHSol had a higher nematode richness than the BG treatment on multiple dates which is an indication of healthier soil. Overall, soils in no-till plots were nutrient enriched as indicated by higher EI in 2013 and 2014 and lower CI in 2013, and a more structured soil food web as indicated by more omnivorous nematodes in 2013. Previously, Hinds *et al.* (2013) reported higher nematode richness in sunn hemp cover cropping compared to bare ground control. Wang *et al.* (2011, 2014) found that sunn hemp enriched and improved soil food web structure in conservation tillage systems. Higher abundance of fungivorous nematodes in SH at the end of 2013 and throughout the season of 2014 are common occurrences in no-till farming (Hendrix *et al.*, 1986; Kladvko, 2001). This higher abundance of fungivorous nematodes supports our supposition that the no-till organic mulch system may have enhanced entomopathogenic fungi leading to lower thrips and leaf miner damage, or enhanced antagonistic fungi that resulted in a reduction of purple blotch on green onions. In contrary, solarization alone often caused reductions in bacterivorous or fungivorous

nematodes, but integration of sunn hemp with soil solarization (SHSol) showed no negative impact of solarization on soil health. These results were consistent with findings of Marahatta *et al.* (2012) which showed that integrating sunn hemp with solarization reduced the negative impact of solarization on free-living nematodes.

Identifying mulching treatments that can enhance soil health has great implication in the development of production practices that can improve crop yield. Ferris and Matute (2003) verified that amounts of N mineralized in the soil were directly related to EI which was based on the abundance of opportunistic bacterivorous and fungivorous nematodes, and inversely related to CI which indicated whether the decomposition was dominated by fungal or bacterial pathways. Greater abundances of bacterivorous, fungivorous or omnivorous nematodes in SH and SHSol were most likely responsible for better soil nutrient cycling, which led to higher green onion yields in both years.

4.5. Weed management time

Findings from this study supported others that showed solarization mulch is a viable weed management tool (Chase *et al.*, 1998; Gamliel and Katan 2012; Locascio *et al.*, 2000; McSorley *et al.*, 2009; Marahatta *et al.*, 2012; Wang *et al.*, 2011b). Initially, weed pressure in no-till was higher than in conventional till systems similar to that reported by Kettler *et al.* (2000). However, as the season progressed, weed pressure in the no-till system was at par to solarized systems in 2013. Clement *et al.* (1996) demonstrated that reduction of weed seed bank in no-till or ridge-till system over time is due to shallower weed seed distribution in the soil profile or greater weed seed predation, and that adequate aboveground weed control (without deep tillage) may cause seeds present in the upper soil layer to diminish over time.

514

515 4.6. *Green onion yield*

516 Green onion yields in SH no-till were 1.5 and 1.6 times greater than in bare-ground treatment
 517 plots in 2013 and by the second harvest in 2014, respectively. These findings are consistent with
 518 Larentzaki et al. (2008) who found higher yields of jumbo grade bulb onions in plots with straw
 519 mulch compared to bare-ground plots. Similarly, Wang et al. (2008) found that no-till planting of
 520 onions after a *Brassica* cover crop increased onion yields in Michigan. Higher green onion yield
 521 in the SH no-till treatment is most likely attributable to lower above ground pests and pathogens
 522 and enhanced soil health. Lack of treatment effect in the first harvest of green onion in 2014 is
 523 likely due to the heavy weed pressure encountered as indicated by the longer weeding time
 524 required prior to the first harvest compared to 2013. It is believed that the intense weed removal
 525 efforts that occurred after the first harvest in 2014 allowed green onion to be influenced by SH. It
 526 is anticipated that higher green onion yield differences would have occurred between solarized
 527 and non-solarized plots if weeds were not intensely managed in non-solarized plots.

528

529 5. Conclusion

530 Over the two year study, the integration of surface organic, living and solarization mulches
 531 into a green onion agroecosystem provide multiple ecosystem services including some
 532 suppression of above and below ground pests. Ultimately, an increase in green onion yield and/or
 533 profits would be the most important factors to convince farmers to adopt mulching practices.
 534 Results of this study showed that a no-till organic mulch system with an insectary border can be
 535 used to increase detritivores, parasitoids, predatory arthropods, and free-living nematodes.
 536 However, the significant contribution of soil solarization for weed suppression could further

benefit organic farmers as weeds are among their most challenging production constraint. Thus, periodically rotating a field site with a sunn hemp cover crop solarization system and including an insectary plant border might provide organic farmers a means for managing the weed seed bank, natural enemies and plant-parasitic nematodes while permanently transitioning into a no-till organic mulching system. In the long term, growing onion in a no-till organic mulching system could provide green onion crop producers multiple benefits including reductions in herbivorous arthropods and associated damage, and plant disease.

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Table Captions

Table 1. Percent damage of green onion plants caused by insect and disease when grown under different mulching tactics in 2013 and 2014.

% damage	Treatments ^z				Contrast analysis ^y		
	BG	SH	SHSol	Sol	SH vs no SH	Sol vs no Sol	Till vs no Till
			2013		-----	F values (df = 1)	-----
Thrips	45.47 ^x	41.76	48.38	54.31	1.7	4.5	3.3
Leaf miner	7.13	5.38	10.52	9.27	0.0	1.0*	6.0*
			2014				
Thrips	50.80	18.29	36.62	44.50	31.8**	2.8	38.5**
Leaf miner	14.31	11.05	14.62	15.35	2.7	3.4	6.2*
Purple blotch	39.56	20.69	33.54	38.27	6.5*	1.6	9.4*

^z BG = bare ground/till/insecticides spray; SH = sunn hemp cover cropping/no-till/insectary borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization (with insectary borders only in 2014).

^y Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). Leaf miner data was $\sqrt{(x+1)}$ transformed for normality prior to contrast analysis. * and ** represent significant differences detected by contrast analysis at $P \leq 0.05$, and 0.01, respectively.

^x % damage = number of leaves with damage / total number of leaves per plant. Thrips and leaf miner values are least square means (n=36) repeated measured biweekly (8 and 5 times in 2013

792 and 2014, respectively). Purple blotch value is collected only on the last two sampling dates in
793 2014 when the symptom becomes apparent.

794

Table 2. Number of arthropods by trophic group and arthropod diversity and richness on yellow sticky traps in green onion grown under different mulching tactics in 2013 and 2014.

	Treatments ^z				Contrast analysis ^y		
	BG	SH	SHSol	Sol	SH vs no SH	Sol vs no Sol	Till vs no Till
Arthropods							
	2013				-----	F values (df = 1)	-----
Herbivores	28.22 ^x	29.13	20.57	24.33	0.2	8.8*	4.0
	2014						
Herbivores	17.37	28.35	24.16	20.72	16.1**	0.0	10.8**
Predators	0.47	0.95	0.99	0.52	11.9**	0.1	2.9
Parasitoids	8.46	11.33	11.99	9.03	13.2**	0.0	4.5
Detritivores	0.98	2.37	2.62	1.28	18.2**	1.1	7.3*
Richness ^w	11.02	12.62	12.38	10.58	22.4**	0.9	9.8**
Diversity ^w	5.88	5.93	6.35	5.14	4.2	0.3	0.2

^z BG = bare ground/till/insecticides spray; SH = sunn hemp cover cropping/no-till/insectary borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization (with insectary borders only in 2014).

^y Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). NS = Not Significant. * and ** represent significant differences detected by contrast analysis at $P \leq 0.05$, and 0.01, respectively. Herbivores, predators, parasitoids, and detritivores data was $\log_{10}(x+1)$ transformed prior to

804 contrast analysis. * and ** represent significant differences detected by contrast analysis at $P \leq$
805 0.05, and 0.01, respectively.

806 ^xLeast square means (n = 12) repeated measured biweekly (8 and 5 times in 2013 and 2014,
807 respectively).

808 ^w Richness = number of taxa; diversity = Simpson index of diversity (Simpson, 1949).

809

Table 3. Number of arthropods captured in pitfall traps within green onion grown under different mulching tactics in 2013 and 2014.

Arthropods	Treatments ^z				Contrast analysis ^y		
	BG	SH	SHSol	Sol	SH vs no SH	Sol vs no Sol	Till vs no Till
	2013				-----	F values (df = 1)	-----
Spiders	1.73 ^x	2.52	1.80	1.03	17.6**	13.0**	19.9**
Carabid beetles	0.22	0.20	0.61	0.14	7.7*	3.4	0.8
Earwigs	0.18	0.44	0.48	0.03	22.2**	1.6	5.2*
Pillbugs	19.61	43.31	37.14	11.35	20.0**	1.5	5.9*
	2014						
Spiders	0.28	0.82	1.10	0.31	12.8**	0.2	7.3*
Carabid beetles	0.06	0.05	0.07	0.01	1.6	0.2	0.0
Earwigs	0.05	0.13	0.06	0.01	3.1	2.5	4.9
Pillbugs	0.34	5.47	1.19	0.35	3.6	1.5	6.6*

^zBG = bare ground/till/insecticides spray; SH = sunn hemp cover cropping/no-till/insectary borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization (with insectary borders only in 2014).

^y Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). All data were log₁₀(x+1) transformed prior to the contrast analysis. * and ** represent significant differences detected by contrast analysis at $P \leq 0.05$, and 0.01, respectively.

819 ^xLeast square means ($n = 12$) repeated measured biweekly (8 and 5 times in 2013 and 2014,
820 respectively).

821

822 **Table 4.** Number of nematodes per 250 cm³ soil and nematode community indices in green
 823 onion grown under different mulching tactics in 2013.

Nematode	Treatments ^z				Contrast analysis ^y		
	BG	SH	SHSol	Sol	SH <i>vs</i> no SH	Sol <i>vs</i> no Sol	Till <i>vs</i> no Till
7/1/2013 (termination of pre-plant treatment)					-----	F values (df = 1)	-----
<i>Meloidogyne</i>	158	163	0	30	4.4	26.5**	10.0*
<i>Rotylenchulus</i>	188	528	65	150	0.7	9.3*	7.9*
Bacterivores	400	3243	1510	218	42.3**	4.7	24.9**
Fungivores	110	330	265	165	2.4	0.2	1.1
Herbivores	405	743	85	190	0.9	21.1**	12.7**
Omnivores	0	32	28	5	16.8**	0.0	7.8*
Predators	10	0	0	2	8.7*	2.5	2.9
Richness	12	16	14	10	10.6**	4.4	9.5*
Diversity	6.06	3.52	3.61	5.21	13.0**	0.4	4.7
Maturity Index	2.00	1.43	1.58	1.89	25.6**	0.0	15.3**
Enrichment Index	28.90	86.34	78.90	46.30	39.8**	0.5	18.0**
Structure Index	8.21	13.64	16.02	6.27	4.2	0.0	0.6
Channel Index	51.00	4.23	7.11	68.10	15.4**	0.5	5.7*
Enchytraeidae	2	28	32	2	21.3**	0.2	4.8
10/3/2013 (at green onion harvest)							
<i>Meloidogyne</i>	665	1300	978	4388	2.1	0.4	0.0
<i>Rotylenchulus</i>	510	1558	408	448	0.1	0.2	1.1

Bacterivores	288	543	548	413	4.0	0.4	1.3
Fungivores	115	190	150	22	13.1**	5.6*	8.5*
Herbivores	1178	2865	1410	4843	2.0	0.2	0.2
Omnivores	18	58	5	37	0.2	3.1	3.9
Predators	0	0	0	0	-	-	-
Richness ^x	13	14	16	11	10.8**	0.0	0.4
Diversity	3.42	3.33	5.75	2.23	4.5	0.6	0.2
Maturity Index	2.08	1.87	1.89	2.10	2.3	0.0	0.9
Enrichment Index	44.67	73.79	47.29	28.50	6.3*	5.0	9.4*
Structure Index	29.39	39.50	9.86	22.80	0.0	3.1	2.5
Channel Index	45.43	14.80	34.50	42.00	2.4	0.2	3.6
Enchytraeidae	0	2	0	0	1.0	1.0	3.0

^z BG = bare ground/till/insecticides spray; SH = sunn hemp cover cropping/no-till/insectary

borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization.

^y Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). Means are average of 4 replications. Nematode abundance data are $\log_{10}(x+1)$ transformed, channel index data was $\sqrt{x+1}$ transformed prior to contrast analysis. * and ** represent significant differences at $P \leq 0.1$, 0.05, and 0.01, respectively.

^x Richness = number of taxa; diversity is based on Simpson index of diversity (Simpson, 1949); maturity index = weight abundance of nematode guilds as a measure of the state of soil food web in a scale of 1-5 affected by soil disturbance; enrichment index (%) = weight abundance of opportunistic bacterivorous and fungivorous nematodes to indicate soil nutrient enrichment;

835 structure index (%) = weight abundance of nematode guild to reflect the complexity of nematode
836 trophic connection in soil food webs; and channel index (%) = a measure of nematode
837 communities to determine if a soil food web was dominated by fungal or bacteria decomposition.

Table 5. Number of nematodes per 250 cm³ soil and nematode community indices in green onion grown under different mulching tactics in 2014.

Nematodes	Treatments ^z				Contrast analysis ^y		
	BG	SH	SHSol	Sol	SH vs no SH	Sol vs no Sol	Till vs no Till
					---- F values (df = 1) ----		
Herbivores (5/27)	292 ^x	1060	80	218	0.1	7.2*	6.0*
Herbivores (10/8)	1085	1975	640	855	0.3	2.7	4.1
Herbivores (12/4)	950	1030	1410	2550	0.3	3.7	0.5
<i>Repeated measure of 5/27, 10/8, and 12/4</i>							
Bacterivores	358 ^x	558	438	358	0.6	2.5	3.4
Fungivores	79	167	68	52	3.7	10.0**	7.0*
Omnivores	41	58	34	38	0.8	2.1	2.0
Predators	0	0	1	1	0.0	2.0	0.6
Richness ^w	12	13	10	9	0.7	11.3**	6.9*
Diversity	4.43	3.26	3.52	3.24	1.0	1.0	0.7
Maturity Index	2.08	1.93	2.20	2.07	0.0	1.3	2.0
Enrichment Index	46.8	56.14	35.55	37.17	0.3	4.5*	3.9
Structure Index	30.19	30.39	38.28	24.16	1.2	0.0	0.9
Channel Index	39.18	28.51	58.80	46.00	0.0	3.2	2.7

^z BG = bare ground/till/insecticides spray; SH = sunn hemp cover cropping/no-till/insectary

borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization/insectary.

^y Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). All nematode abundance data are $\log_{10}(x+1)$ transformed, whereas channel index was square root ($\sqrt{x+1}$) transformed prior to contrast analysis. * and ** represent significant differences at $P \leq 0.05$, and 0.01, respectively.

^x Means are average of 4 replications. Herbivore data is presented by sampling date due to significant interaction between sampling date and treatment in the analysis of variance. All other data were repeated measure over 3 sampling dates.

^w Richness = number of taxa; diversity is based on Simpson index of diversity (Simpson, 1949); maturity index = weight abundance of nematode guilds as a measure of the state of soil food web in a scale of 1-5 affected by soil disturbance; enrichment index (%) = weight abundance of opportunistic bacterivorous and fungivorous nematodes to indicate soil nutrient enrichment; structure index (%) = weight abundance of nematode guild to reflect the complexity of nematode trophic connection in soil food webs; and channel index (%) = a measure of nematode communities to determine if a soil food web was dominated by fungal or bacteria decomposition.

Figure caption

Fig. 1. Effect of mulching tactic on time required for one person to manually remove weeds in A) 2013 and B) 2014, and to spot spray weeds with herbicides in C) 2014. Means are average of four replications for each sampling date. Data are subjected to contrast analysis where * and ** represent significant difference at $P \leq 0.05$, and 0.01, respectively. SH = sunn hemp cover cropping/no-till/insectary borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization. Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH).

Fig. 2. Effect of mulching tactic on green onion yields in 2013 and 2014. Means are average of four replications subjected to contrast analysis where * and ** represent significant difference at $P \leq 0.05$ and 0.01, respectively. SH = sunn hemp cover cropping/no-till/insectary borders; Sol = till/solarization; SHSol = sunn hemp cover cropping/till/solarization. Contrast analysis performed are SH (SH + SHSol) vs no SH (Sol + BG), Sol (Sol + SHSol) vs no-Sol (SH+BG), and till (SH + SHSol + BG) vs no-till (SH). Bar on each column is standard error bar.

Figure 1

Fig 1.

Figure 2

1 Fig. 2.