Organic farming research project report submitted to:

Organic Farming Research Foundation
P.O. Box 440
Santa Cruz, CA 95061

Date: March 2001

Project title: *Organic Management of Garden Symphylans (Scutigerella immaculata) in Annual Cropping Systems*

Investigators:
Mark Van Horn
Student Experimental Farm
University of California-Davis
One Sheilds Avenue
Davis, CA 95616
530-752-7645
mxvanhorn@ucdavis.edu

Mario Ambrosino
Oregon State University

Jim Leap
Center for Agroecology and Sustainable Food Systems
University of California-Santa Cruz
1156 High Street
Santa Cruz, CA 95604
831-459-3375
jimleap@cats.ucsc.edu

Project budget: $6,950

Funding provided by OFRF: $6,950

Project period: 1999-2000

OFRF project number: 99-53, awarded Fall 1999

I. Summary

The garden symphylan is an increasingly common problem on organic farms. Symphylans have a diverse diet, feeding on decaying organic matter and on the roots of a very wide range of crops and other plants, including many weeds. Heavy symphylan populations can severely stunt, and even kill, most annual crops. To our knowledge, there are no organically acceptable symphylan control strategies that have been shown to work consistently and most of the information about organic control strategies for symphylans is anecdotal and often contradictory.

We conducted field and laboratory studies at the Davis and Santa Cruz campuses of the University of California to evaluate a number of symphylan management and control strategies and to develop and evaluate methods for studying symphylans and their management. In field studies we evaluated the effects of a number of cover crop and cash crop residue treatments, shrimp shell extracts and tillage effects on symphylan populations over time. In laboratory trials, we evaluated modifications of soil pH, a number of neem formulations, the commercial product Farewell, mustard seed extracts and three species of predatory nematodes for their effects on symphylans.

The results of our field studies did not indicate any simple practice or material that reduced symphylan populations by an agronomically significant amount. However, based upon our work and that of others, growers may be able to utilize information about the biology and behavior of symphylans to better manage fields with damaging symphylan populations. Knowledge of symphylan sampling methods, symphylans' vertical migrations in the soil and potential impacts of cultural practices such as tillage and irrigation may help growers use symphylan infested fields productively.

Our laboratory studies indicated some materials had a biological effect on symphylans under laboratory conditions, but how such materials could be used effectively to reduce symphylan populations under field conditions was not demonstrated. These materials are strong candidates for further study in the laboratory and field.

Information dissemination and exchange has been an integral part of this project. We have discussed this project with growers, consultants and researchers from the initial stages of our work and relied on them to help guide and focus our activities. Articles about our work have been written for the UCSC *Cultivar* and the CCOF Statewide Newsletter and we expect at least one more article in a grower-oriented publication. We also conducted a farmer-researcher workshop that focused exclusively on organic symphylan management at the 2001 Ecological Farming Conference. The purpose of this workshop was to share and exchange information and ideas with approximately 50 growers and other participants and to help refine future research and extension goals and objectives.

II. Objectives

This project had three objectives:

Objective 1. To determine the effect of different management strategies on established populations of *Scutigerella immaculata* in replicated field trials at the UC Davis Student Experimental Farm and the UC Santa Cruz Center for Agroecology and Sustainable Food Systems farms, based on results of preliminary work done at these and other sites.

Objective 2. To continue to develop effective symphylan rearing media and techniques for the amplification of stock populations to use in bench trials as an essential first step in studying the efficacy of potential biological control agents.

Objective 3. To disseminate information about the results of these studies and other practical information about organic symphylan management to the organic farming community.

III. Materials and methods

Corresponding to the objectives listed above, this project has had three *components, field studies, laboratory studies and information dissemination and exchange.*

In the field studies, after conducting preliminary studies to compare methods for monitoring field populations of symphylans, the effects of different management strategies on established symphylan populations were studied in replicated field trials on organically managed fields at UC Davis and UCSC in fall 1999 through summer 2000.

In the laboratory studies, we refined methods of maintaining and rearing symphylans and conducted preliminary laboratory tests on a number of potential control treatments, including biological control agents.

Our information dissemination efforts have included articles about our work in the UCSC publication, *The Cultivar,* and the CCOF Statewide Newsletter and a farmer-researcher workshop at the 2001 Ecological Farming Conference.

Field Studies

- *Preliminary Methodology Studies*

Preliminary trials designed to compare symphylan baiting methods were conducted in garden plots with high symphylan levels at UCSC. These trials included a comparison of different surface bait materials and an investigation of the optimal baiting time interval.

In the first trial, lettuce, beet and potato pieces were compared in randomized complete block design with nine replications. Several bait stations of one type of bait were placed in each 5 ft. x 20 ft. plot. Each bait station consisted of a 2.5 inch diameter piece of the bait material that was placed on the moist soil surface and covered with a 4 inch dark plastic pot to prevent it and the soil from drying out. Symphylans were counted by randomly choosing individual bait stations within each plot over a period of five days.

In a separate investigation of the optimal baiting interval conducted in nine replicate beds, covered beet pieces were placed on the soil and numbers of symphylans present after 24 hours or 48 hours were recorded for each station. In three of these beds, some bait stations were observed at 72 hours.

In addition to these replicated trials, several methods of directly sampling soils for quantitative assessments of symphylan populations were tested using various methods to extract and handle soil samples. From these tests, methods that optimized efficient symphylan recovery were developed which were used in other field trials.

- *UC Davis Field Trial: Effects of Various Incorporated Plants and Micronized Shrimp Shells*

This trial was conducted in a field with high symphylan pressure, as demonstrated by previous observations and sampling in 1998 and 1999. A Randomized Complete Block Design with four replications was used to compare six treatments: "Mustard" ('Martagena' mustard cover crop), "Barley" ('Micah' barley cover crop), "Vetch" (cover crop mix of 'Lana' woolypod, Common and Purple vetches), "Shrimp shells" (micronized shrimp shells applied in conjunction with two irrigations), "Brassicas" (mixed brassica crop residues), and "Control" (untreated resident vegetation minimized by winter

mowing). Plots were 18 ft. x 20 ft. The field was prepared by two uniform discings in late summer, 1999.

There was very little early fall rain and the three cover crop treatments (Mustard, Barley and Vetch) were sown November 10, 1999 with the first significant rain of the season. There was sufficient rain following this to germinate and sustain the cover crops through the winter. No further manipulations of the barley and vetch cover crop were done until flail mowing and incorporation of all treatments on April 20, 2000. On March 14, 2000, the mustard plots were manually topped to a 2 ft. height to remove flower heads to keep this early-flowering treatment in a more vegetative state.

In the Brassica plots, six week-old broccoli starts were manually transplanted planted at 32" x 18" spacing on February 26, 2000, one week after these plots had been hand weeded and flamed to control weeds. This broccoli did poorly due to heavy symphylan pressure and eight week-old cabbage starts were planted between the broccoli transplants on March 14, 2000. The cabbage also did poorly. Therefore, on April 19, 2000, one day before flail mowing all plots, fresh crop residues of organically grown brassica crops harvested from another harvested, field were then added to the Brassica plots at the following approximate rates (dry weight basis): 1950 lb/A of collards; 12 1 0 lb/A of cabbage (re-sprouts after harvest); 440 lb/A of Brussels sprouts. These plots were flail mowed, disced and tarped the following day, as described below.

Weeds growing in the Shrimp shell and Control plots were mowed on March 18, 2000. In the Shrimpsheliplots,watersuspensionsofcommercialmicronizedshrimpshells(Eco-Poly21, EcoNutrients, Crescent City, CA) were added at a label rate of 50 pounds/acre/application on March 22 and April 10. Applications were done by backpack sprayer followed immediately by sprinkler irrigation of the entire trial.

On April 20, 2000 one I m^2 samples of each cover crop was collected from each cover cropped plot for determination of aboveground biomass. On the same day all cover crop treatments were flail mowed and the entire experiment was immediately disced three times. All Mustard and Brassica plots were tarped with 4 mil clear plastic within 24 hours of incorporation. The tarps remained on these plots for 20 days. Tomato transplants (organically grown 'Heinz 8892', 50 days old) were machine transplanted in all plots on May 4, 2000 in rows spaced 30" apart and at an in-row spacing of 18" apart. All plots were sprinkler irrigated following transplanting and subsequently during the growing season.

Data were collected on symphylan surface numbers by surface baiting at monthly intervals for a total of seven dates. The first five dates were during the cover crop growing season, the last two were during the tomato growing season. On July 31, 2000 the number and general size of surviving tomato plants were counted and a qualitative assessment of weed cover was made in each plot.

The surface baiting method consisted of placing covered fresh garden beet slices (approx. 2.5" diameter x 0.25" thick) on the soil surface, after slight disturbance to break any dry crust and covering with a 5.5" x 5.5" piece of wood to avoid beet and soil drying if necessary, and counting individual symphylans present on each beet slice 24 hours later. Typically seven subsamples were taken per plot at each sample date. To check the accuracy of this baiting method, repeated attempts were made to compare this method with replicated soil core samples. Soil cores were taken by removal of equal sized, 5" deep by 4" diameter 'cones' of soil with a curved, 6" long by 4" wide trowel. Each core was emptied onto a 12" diameter tray and sorted for 5 minutes while recording numbers of mature and immature symphylans. Useable sets of coring data were obtained only on two dates, April 8, 2000 and May 18, 2000. On May 18, an additional sampling method was tried in addition to the baiting and coring in which the poorly

developing tomato transplants were carefully pulled from the soil and the symphylans in the still discrete transplant cell soil plug were counted using the same procedure as the one described above for the soil cores.

- *UCSC Field Trial I.-Effects of Various Cover Crops and Extra Tillage*

This trial was conducted in a field with high symphylan pressure as demonstrated by previous observations and sampling from 1997 through 1999. A Randomized Complete Block Design with four replications was used to compare four treatments: "V 0 B" (a mix of vetch seeded at 40 lbs./acre, oats seeded at 7 lbs./acre and bell beans seeded at 50 lbs./acre), "V 0 B - T" (the V 0 B mix with an extra tillage event in the spring prior to cash crop planting), "Barley" ('Micah' barley, 100 lbs./acre), and "Fallow" (a weedy fallow). Plots were 20 ft. x 30 ft. A sordan cover crop was planted in the late summer of 1999 and spade-incorporated on October 26, 1999. Seed of the cover crop treatments was broadcast on November 30, 1999 and incorporated with a shallow rototilling the following day. Cover crops established quickly with subsequent rains.

The weed plots were mowed on March 16, 2000. All plots in the trial were flail mowed, mechanically spade incorporated to an 14" depth and bedded up on March 24, 2000. Light (4" deep) tillage was done on all beds for weed control on April 24, 2000. The V 0 B - T plots were rototilled to a 8" depth on April 27, 2000 when coring showed the symphylans to be near the surface. All plots were worked with a rolling cultivator to re-establish surface uniformity. Next, beds were shaped and the entire experiment was pre-irrigated by sprinkler and then flamed to control germinating weeds. 'Di Cicco' broccoli was direct seeded into all plots on June 12, 2000 and the crop was grown until September, 2000.

Regular attempts at baiting and sampling indicated symphylans to be below 6" for most of November 1999 to May 2000. A full sampling of symphylan numbers was obtained on only two sampling dates: January 7, 2000 (65 days after seeding cover crops), when five core subsamples were taken from each plot, and May 13 (16 days after extra tillage), when ten bait subsamples were taken per plot. Core samples were also taken on April 24 (3 days before extra till, I core/plot) and May 7 (10 days after extra till, 2 cores/plot) to more precisely assess the effects of the extra tillage. Following the planting of the broccoli cash crop, crop roots were examined for symphylan damage and presence periodically during the growing season and three core samples per plot were taken on August 17, 2000. The coring and baiting methods utilized in the UCSC trial were the same as those described for the UC Davis trial.

- *UCSC Field Trial II. Effects of Oats vs. Barley in a Cover Crop Mix*

A separate trial was also conducted to compare the effects of oats vs. barley, when grown in combination with vetch and bell beans, on symphylan populations and the following crop. A randomized complete block design with 22 replications was used to compare oats and barley, each grown in association with vetch and bell beans. Plots were 25 ft. long sections of 5 ft. wide beds; seeds were planted November 27-30, 1999. Although symphylan sampling by baiting and coring was attempted regularly during the winter, because the symphylans were not near the surface at this time, a full set of data was not obtained until a coring on March 26, 2000. Surface baiting data was obtained for three of the beds on different dates in April and May, 2000.

<u>*Laboratory Studies:*</u>

- *Laboratory Rearing Trials*

Early attempts with various combinations of food type, container size and type, moisture levels, temperature and media for the culturing of symphylans were used to identify the conditions which produced no mortality over 1-2 week periods. With this information, trial with four replications was

conducted in covered, 7" tall by 5" diameter plastic containers using a base substrate of coco peat to compare additives of a) grass clippings, b) vermiculite or c) 1/4" piece orchid bark. Thirty symphylans were placed in each container at the beginning of the trial in November 1999. The treatments were evaluated for their effects on symphylan numbers over a 6 month period, with final counts of live symphylans conducted in May, 2000.

- *Neem Trial*

A laboratory trial with four replications was conducted to evaluate the effects of four commercial azadirachtin (neem) based materials in March 2000. 2"x 2"x 2.5" pots were filled with fluffed SuperSoll and the following treatments applied (rates based upon pesticide label rates).

1) Agroneem: 744 ml in 200ml water added to pots (equivalent to 32 oz. a.i./acre)
2) Ecozin: 232 ml in 200ml water (10 oz. a.i./acre)
3) GWN 1535: 744 ml in 200ml water (32 oz. a.i./acre)
4) Neemix 4.5: 372 ml in 200ml water (at 16 oz. a.i./acre)
5) WFS 8.0 1/2%: (Spreader-sticker) 1 ml in 200ml water
6) Distilled water: 200ml

To test for potential anti-feedant activity of these materials, four 1 cm diameter sections ("discs") of romaine lettuce were dipped in each of the solutions described above. Then, one disc from each of the six treatments was placed on the surface of each of four different symphylan colonies living in coco peat without a food source. Each leaf disc was assessed for feeding activity at daily intervals for seven days.

- *Soil Amendments Trial*

A separate laboratory study with four replications was conducted to compare the following treatments: "Control" (coco peat slightly moistened with water in a closed I pint container); "Neem" (same as Control, but moistened with a neem solution (0.025% Azadirachtin, Neemix, W.R. Grace & Co.) "Mustard" (same as control, but moistened with supernatant solution from grinding 'Martagena' mustard seeds and soaking for IO minutes in water at v/v ratio of 2: 1), "High pI-F' (same as control, but with sufficient CaCO3 added to achieve pH of 8.2), and "Farewell" (same as control, but moistened with 5% dilution of Farewell (Organic Alternatives, Inc.). Symphylans for this study were collected from the field and maintained in coco peat in a large container for several weeks prior the start of the trial. Ten symphylans were taken from this source and placed into each container. After 13 days, each container was opened and its contents visually examined and the number of live and dead symphylans was recorded.

- *Predatory nematode trials*

Trials were conducted to evaluate three nematode species *(Heterorhabditis marelatus, Steinernema feltiae and S. carpocapsae)* as potential biological control agents.

Plastic 1/2 pint containers were filled 3/4 full with moistened coco peat. 20 symphylans were added to each pot. There were three replications of each of treatments:

a. *H. marelatus* @ 100 IJs per sq. cm
b. *H. marelatus* @ 500 IJs per sq. cm
c. *S. feltiae* @ 100 IJs per sq. cm
d. *S. carpocapsae* @ 500 IJs per sq. cm
e. Water control

Inoculum consisted of the specified nematode rate concentrated into 2.3 ml deionized water and applied to substrate surface in a circular pattern. Lettuce discs were used as a food source for the symphylans and the number of surviving symphylans was determined after seven days.

Information Dissemination and Exchange:

Information dissemination and exchange efforts were conducted via publications, a participatory workshop and through conversations with individual growers, consultants, researchers and others. These efforts are described in more detail in the Results section.

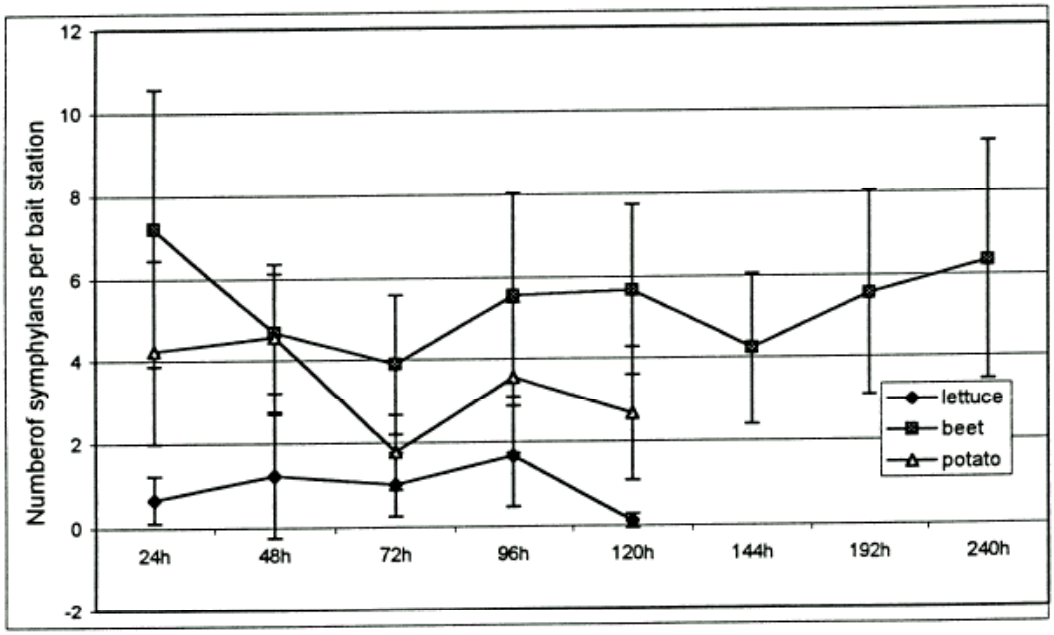
IV. Results

Field Studies

- *Preliminary Methodology Studies*

Comparison of different surface bait types:
Figure I shows the numbers of symphylans recovered from lettuce, beet and potato bait materials over several days. The lettuce and potato were removed after five days due to deterioration of the bait pieces. Lettuce bait clearly attracted fewer symphylans than beets and potatoes. In addition, beets seem generally superior to potatoes in terms of utility for long sample periods and also numbers of symphylans recovered (although statistically there was no difference between the number of symphylans recovered from beets and potatoes on any of the five sample dates).

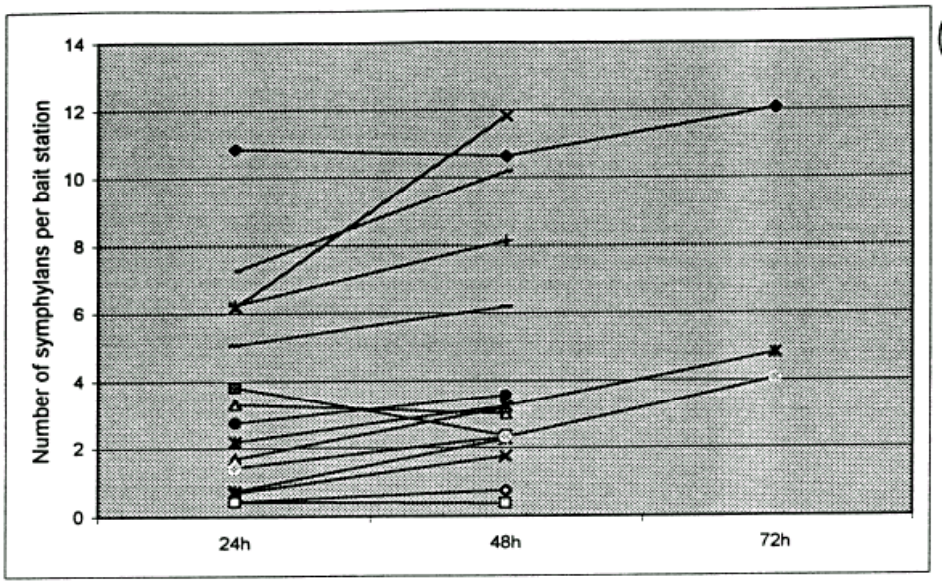
Figure 1. Number of symphylans per bait station recovered from different baits over several days.



Comparison of beet bait symphylan recoveries over time:
Figure 2 shows that the number of symphylans found on beet bait pieces was fairly consistent over time. Although there was an average tendency to increase marginally over time in this study, this increase was

generally fairly small, and was not seen in all cases in this study nor in the comparison of bait types over time (Figure 1). Thus, no clear advantage to the 24 or 48 sampling time period was demonstrated.

Figure 2. Number of symphylans recovered from beet pieces in several locations over time.



- *UC Davis Field Trial: Effects of Various Incorporated Plants and Micronized Shrimp Shells*

Table I and Figure 3 show the mean number of symphylans per surface bait sampling station for all seven sample dates. The first sampling date, 12/4/99, shows the three cover crops have significantly fewer symphylans (square root transformed data) than the three other treatments (the, 'shrimp shell' and 'brassica' treatments had not yet been applied). The second sampling date, 1/9/00 showed consistently lower numbers of symphylans, but the numbers of symphylans in the barley and mustard plots were still significantly lower than those in all three of other treatments. On the third date, 2/9/00, the three cover crop treatments again had significantly fewer symphylans than the other three treatments; the barley also had significantly fewer symphylans than the mustard and vetch. On the fourth date, 3/12/00, the symphylan counts in the brassica and barley treatments were significantly higher than the rest of the treatments. The fifth sampling date, 4/9/00, showed the barley to remain significantly higher than the other treatments. Replicated core samples of all treatments on this date did not show any significant differences (data not shown). The sixth sampling date, 5/11/00 occurred seven days after tomatoes were transplanted into all plots. At this time, symphylan numbers had increased at the surface in all treatments except for the barley, which had significantly fewer symphylans than all other treatments. At this time, the mustard treatment had significantly more symphylans than any of the other treatments. The final bait sampling conducted on 5/18/00 showed a similar increase in symphylan numbers in all the treatments, with the barley treatment still showing significantly fewer symphylans and the mustard treatment showing significantly more symphylans than the other treatments. The tomato transplant plug samples conducted on this date generally yielded fewer symphylans than the beet bait method and the results of this sampling method produced a similar, but not identical, ranking of the treatments (Figure 4).

Table 1. Mean number of symphylans per bait station on seven sample dates.

Treatment	4-Dec*	9-Jan	9-Feb	12-Mar	9-Apr	11-May	18-May
Vetch	1.714 a	0.678 a	3.750 b	0.071 a	1.071 a	14.142 b	20.964 b
Mustard	0.619 a	0.047 a	3.571 b	1.476 a	2.381 a	22.714 c	30.571 c
Weed	6.428 b	2.071 a	8.143 c	1.250 a	2.036 a	13.000 b	20.178b
Shrimp	6.036 b	1.536 b	7.714 c	2.000 b	2,821 a	10.857 b	19.321 b
Brassicas	6.850 b	2.393 b	7.214 c	7.000 b	3.607 a	11.679 b	17.964 b
Barley	1.643 a	0.000 b	1.036 a	6.321 b	13. 429 b	1.357 a	5.179 a

* Values in a column followed by the same letter are not statistically different (P=0.05) by Duncan's Multiple Range Test.

Figure 3. Number of symphylans per bait station on seven sample dates.

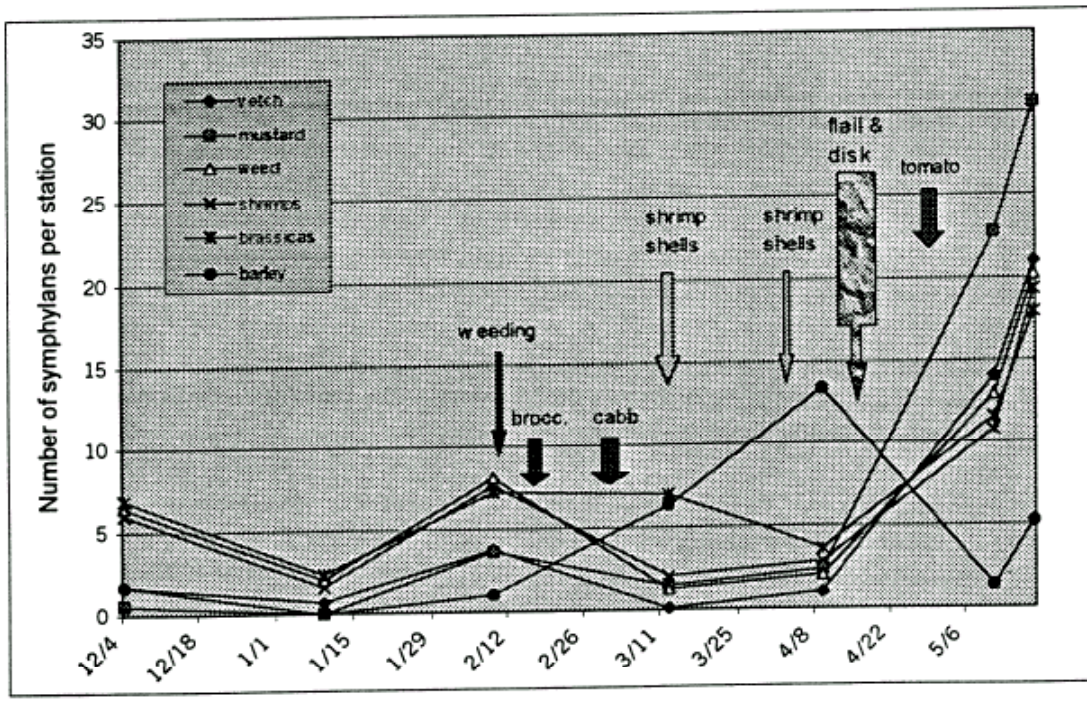
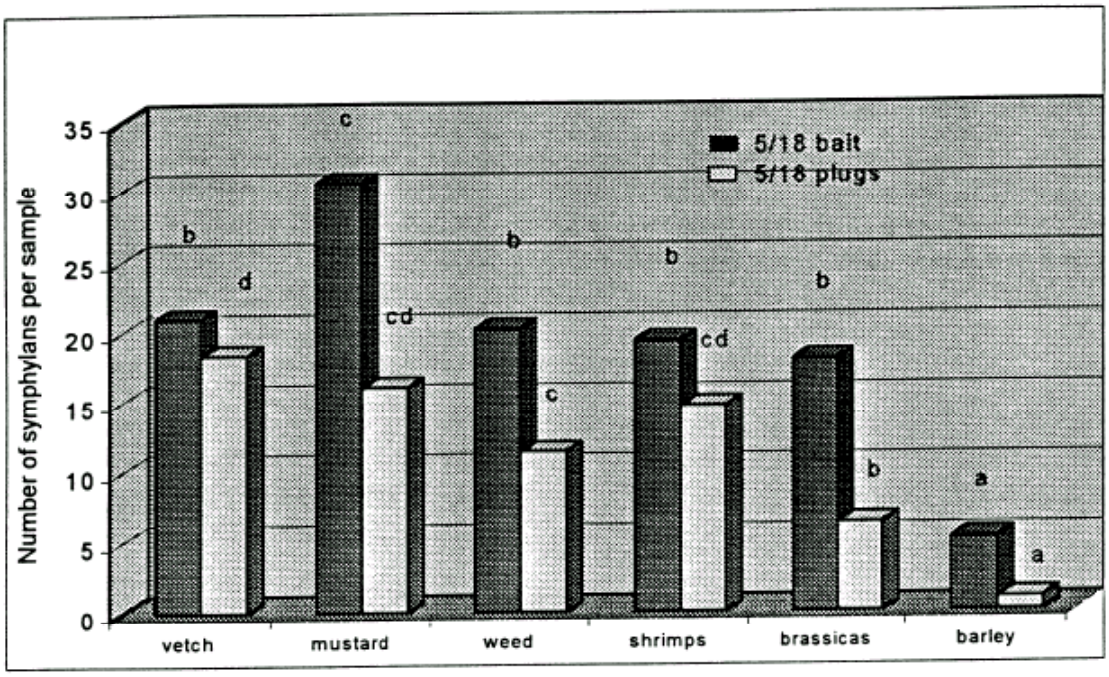


Figure 4. Comparison of surface baiting and transplant plug sampling methods.



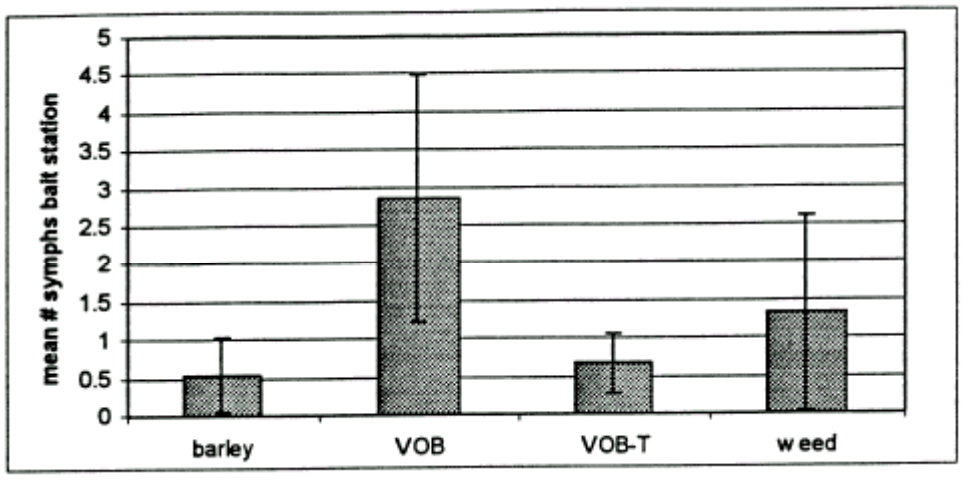
By 7/31/00 over eighty percent of the tomato transplants had died (This was caused by symphylan damage coupled with an irrigation regime designed to lead to high mortality of symphylan damaged plants.). Comparison of the number and size of surviving tomato plants showed no significant differences between treatments (data not shown). Comparing these data and the evaluation of weed cover on this date with similar evaluations done on these plots in previous seasons showed a very similar spatial pattern of symphylan damage in 2000 as in previous years.

- *UCSC Field Trial I: Effects of Various Cover Crops and Extra Tillage*

There were no significant differences in the number of symphylans found per core sample between treatments on January 7, 2000 (data not shown).

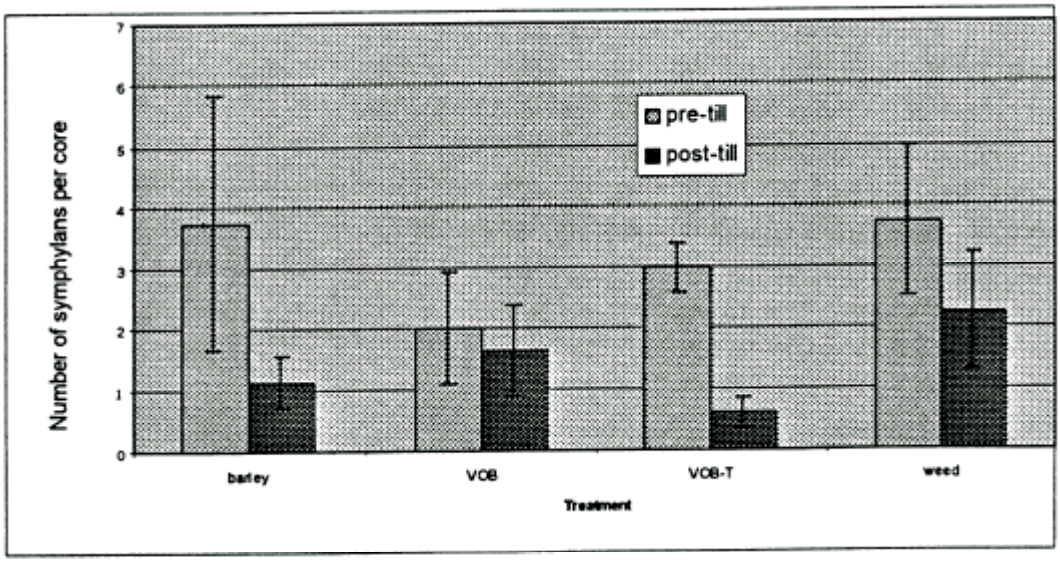
As indicated in Figure 5, the 5/13/00 baiting (48 day after cover crop incorporation and 16 days after the extra till in the V O B-T plots), the V O plots and the barley plots had significantly fewer symphylans per core (square root transformed data) than the V O B plots, but not significantly less than the weed fallow plots.

Figure 5. Number of symphylans per bait station after incorporation and extra till of various cover crop treatments.



The core sampling done three days before and ten days after extra tillage (Fig. 6) showed apparent reductions in symphylan numbers in all treatments, but this was most dramatic in the plots which received the extra tillage (VOB-T). The reduction in the barley plots was also substantial. While direct comparisons can not, be made between the counts in Fig. l0 (bait samples, 16 days after extra till) and Fig. 11 (core samples, 3 days before and 10 days after extra tillage), the data from Fig. 10 corroborate data from Fig.11 in that the VOB-T treatment had symphylan counts that were significantly lower than the VOB treatment at that time.

Figure 6. Number of symphylans per 6" core sample before and after extra-till.



No symphylans or symphylan damage were observed in these plots, either in the broccoli root examinations that were performed periodically during the growing season, nor in the core samples that were taken, following the planting of the broccoli on June 12.

- *UCSC Field Trial II.- Effects of Oats vs. Barley in a Cover Crop Mix*

In the experiment comparing the effects of adding barley versus adding oats to the Fall-Winter cover crop on symphylan numbers in the subsequent Spring, no significant differences were noticed in either the 145 days after seeding cover crop coring, nor in the spring crop bait sampling (data not shown).

Laboratory Studies:

- *Laboratory Rearing Trials*

Early attempts with various combinations of food type, container size and type, moisture levels, temperature and media for the culturing of symphylans allowed us to identify those media and conditions which produced no mortality over 1-2 week periods. Light, relatively non-compacting media with moderate moisture and in a moderate temperature environment were most conducive to symphylans. Additionally, in certain media, specific components of certain media apparently contributed to symphylan mortality (e.g. ammonium nitrate in one of the commercial shredded bark materials).

In the six month long evaluation of media for population amplification, grass clippings, wonder bark and vermiculite showed 5.2-, 5.3- and 3.8-fold increases in population numbers, respectively. Although the differences between treatments were not statistically significant, the main result of this trial is that symphylan population increases were achieved.

- *Neem Trial*

In the laboratory trial comparing several neem-based materials, all 6 treatments appeared to have the same general level of mortality (around 75%), including the distilled water and spreadersticker only controls (data not shown).

- *Soil Amendments Trial*

In contrast to the above trial, in the laboratory trial that compared one neem product with various other chemical and plant extract treatments, the neem had a significant effect on the symphylans (Table 2). In this trial, the Farewell treatment also had a significant effect on the symphylans and the mustard seed extract also appeared to cause symphylan mortality, although not as dramatically.

Table 2. Mean number of symphylans recovered live and dead and unrecovered.

Treatment	Number Alive	Number Dead	Number Unrecovered
Farewell	0	5.0	5.0
Neem	0	4.5	5.5
Mustard	5.25	0.75	4.0
High pH	8.25	0.5	1.25
Control	9.25	0.0	0.75

- *Predatory nematode trials:*

There were no reductions in symphylan numbers following exposure to any of the predatory nematode species utilized in the trials.

Information Dissemination and Exchange:

Information dissemination and exchange has been an integral part of this project. We have discussed this project with growers, consultants and other researchers from the initial stages of our work and relied on them to help guide and focus our activities. We have disseminated information about symphylans, their biology and management and our research efforts through several means. Articles about our work include those in the UCSC *Cultivar* (reprint of one article enclosed and a second article expected some time later this year) and the CCOF Statewide Newsletter (reprint enclosed).

We also conducted a farmer-researcher workshop that focused exclusively on organic symphylan management at the 2001 Ecological Farming Conference. The purpose of this work shop was to share and exchange information and ideas with the approximately 50 growers and other participants and to help refine future research and extension goals and objectives. We conducted this workshop with Jon Umble, graduate student from Oregon State University. It included an overview of symphylan biology, damage and sampling and a facilitated discussion of the participants' experiences and attempts to manage and control symphylans. In addition, a several page literature review for growers was prepared and distributed at the workshop (enclosed). Several participants indicated they learned useful information about symphylans during the workshop that helped them better understand observations that they had made. Participants discussed several management strategies but there were no strategies for organically reducing symphylan populations that work consistently that were identified during the workshop.

Lastly, we continue to communicate directly with farmers who have had problems and experience with symphylans whenever possible and we make available to all interested parties our research findings and general recommendations for managing symphylans.

V. Discussion:

The results of our field studies did not indicate any single practice or material that reduced symphylan populations by an agronomically significant amount. Our laboratory studies indicated some materials had a biological effect on symphylans under laboratory conditions, but whether and how such materials could be used effectively to reduce symphylan populations under field conditions could not be explored within this work. Our choices of practices and materials to study were based upon input from organic growers, consultants and other researchers and we chose those treatments which we thought held the greatest potential for influencing symphylan population numbers. Based primarily on our own studies, but also influenced by the experiences of others, we have drawn the following conclusions:

1. It is very difficult to study the effects of management practices on symphylans because:
- **a.** Their unpredictable vertical movement in the soil profile means they commonly disappear from the soil surface layers for several months and then return.
- **b.** Their fragility makes direct sampling difficult at the surface and very time consuming and difficult from depths below a few inches; baiting methods allow more rapid assessments of symphylan numbers, but are only developed for the soil surface and only attract symphylans during the actively feeding stages.
- **c.** Since they can move up to one foot/day laterally in the soil, plot sizes may need to be quite large. On the other hand, symphylan spatial distribution is typically very non-uniform, so large plots are very difficult to use.

2. In our field studies, none of the management practices that we tried proved to be successful in reducing symphylan numbers in an agronomically meaningful way. This may be because:
- **a.** The practices truly did not have a significant biological effect, or

b. There may have been some small effect, but it may take more than one season of treatment for any effect to be agronomically meaningful, or c. there may have been effects, but symphylan movement between plots did not allow us to measure the effects.

3. In the Davis trial, while the barley cover crop resulted in significantly lower symphylan numbers shortly after transplanting of the subsequent tomato cash crop (shown consistently by direct core, plant plug and beet bait methods), barley also showed the highest numbers of symphylans in the last sampling before mowing and discing the cover crops. In addition, barley did not seem to help the tomatoes as the season progressed. One possible explanation for this is that somehow the barley stimulated the symphylans to move closer to the soil surface than the other treatments late in the cover crop season and, therefore, the tillage that occurred at this time was more damaging to the symphylan population in the barely plots. Thus, there was a temporary reduction in the surface population of symphylans following spring tillage, but either this reduction was insufficient to reduce damage to the subsequent tomato crop or migration of symphylans from deeper in the soil or ad . acent plots eliminated surface population reduction over course of the tomato growing season.

4. The Santa Cruz trial was hindered by a general lack of symphylan activity in the surface layers of the soil (where sampling is possible) for the almost 12 month duration of the trial, despite the fact that relatively high numbers of symphylans were seen in this soil both before and after the trial. In this trial, there were few statistically significant differences between treatments. However, there was some indication that, compared to a vetch/oat/bell bean mix cover crop with "regular" tillage, the same cover crop mix with an extra tillage (conducted when symphylans were observed near the surface) resulted in fewer symphylans at the soil surface, as did a barley cover crop with only "regular" tillage.

5. Taken together, the results of these two trials lead, first and foremost, to the conclusion stated in #2, above. However, they also indicate that the practice of timing pre-plant tillage to coincide with periods of symphylan presence near the soil surface, may, at least temporarily, reduce symphylan populations to some extent. This appeared to happen in both the barley plots at Davis and the VOB-T plots at Santa Cruz.

6. Our laboratory studies indicated that some organically acceptable materials may have biological activity on symphylans. However, we did not demonstrate any such activity in the field. There are several factors that may cause a material that is effective under certain laboratory conditions to be ineffective in the field. In the case of symphylans, one of these factors is the symphylans' ability to move a number of feet deep in the soil. From our results, neem extracts and products such as Farewell, seem to warrant further study in this area. The mustard seed extract also appeared to have potential although it's effects were not as great as with the other two materials. While it was not demonstrated in this study, the mode of action of the mustard seed extracts might be similar to the demonstrated mode of action of decomposing Brassica crops on various soil bome organisms, which we were not able to demonstrate on symphylans in our "Brassica" treatment in the Davis field study.

7. The workshop we conducted at the Ecological Farming Conference reconfirmed that symphylans are a significant problem for a number of organic growers. Similarly, it reconfirmed that there are many seemingly contradictory growers' experiences with symphylans. During our discussion there were a number of examples of management strategies that appeared to be successful for one individual but not for one or more of the other participants.

8. Lacking a clear organic method for achieving large reductions in symphylan populations, what strategies might be suggested for farming fields with significant symphylan populations? We can make the following suggestions:

a. From our own work as well as the experience of others, we know that it is conu-non for symphylan populations to move vertically in the soil in what appears to be an annual cycle. The seasonality of this cycle is generally consistent, but significant annual variation may occur. For example, in some locations with hot summers, surface symphylan numbers are typically high in the spring, but decrease dramatically in early summer. However, it is important to note that the timing of the decrease can vary by several weeks from one year to the next. Since symphylans are most damaging when feeding on roots of young plants near the surface of the soil, planting crops after the symphylans have left the surface layers of the soil can allow successful crop production in fields with significant symphylan populations. However, it is not possible to predict precisely when the symphylans will leave the soil surface for deeper layers.

b. For a number of reasons (e.g., see above paragraph), it is useful for growers to be able to sample their soil for symphylans. Baiting seems to be a relatively simple and accurate method, at least for detecting populations of feeding symphylans near the soil surface, if done correctly. A reliable method uses 1/4" to 1/2" thick slices of beets or potatoes that are placed on the soil surface. Typically, it may be necessary to remove a dry or crusty layer of the soil to get the beet piece in good contact with moist, intact, non-crusty soil and/or to cover the beet piece with something (e.g., a piece of wood approximately 6" x 6" or a 6" diameter PVC plastic cap) to prevent desiccation of the beet piece and the soil immediately around it. Bait pieces are checked in one or two days by picking up each piece and looking quickly at the soil where the piece had been to see symphylans rapidly moving into the soil voids arid then immediately examining the bait piece itself for symphylans crawling on its surface. To sample for symphylans deeper in the soil, the most reliable method that we have found involves carefully looking through shovels-full of soil. This method can be very time consuming and care must be taken not to destroy the small and fragile symphylans in the process. However, if the goal of sampling is not quantitative, but rather to detect the presence of any symphylans in the soil, this method may produce satisfactory results with less careful sample handling, especially if the symphylan population is relatively large.

c. Aggressive soil tillage when there are symphylans near the soil surface may sometimes reduce surface symphylan numbers by either directly killing some of them and/or hastening their movement down into the soil. However, because symphylans can migrate quite rapidly in the soil, recolonization of the soil surface by individuals from below the tillage zone may limit the effectiveness of this technique in many situations.

d. Because symphylans feed heavily on plants' small feeder roots, using healthy transplants with large, vigorous root systems and keeping young plants well watered can sometimes help a crop survive symphylan feeding early in the season until the symphylans migrate deeper in the soil. However, irrigation may also make the surface environment more favorable to symphylans and, with prolonged feeding by heavy symphylan populations, these strategies are usually not sufficient to allow the crop to survive and grow well.

e. Since our observations confirm that symphylans are attracted to and feed on beets and carrots, and because it has been shown elsewhere that symphylans very successfully reproduce on

fresh plant material, it is advisable to remove as completely as possible all unharvested beets and carrots (or similar root crops) prior at the end of the season. This may help minimize food sources that have the potential to increase symphylan populations. However, it should also be noted that established symphylan populations can persist for long periods with very little, or no, input of fresh plant material.

APPENDIX

Garden Symphylans *(Scutigerelia immaculata, Newport):* Ecology, Distribution and Management - A Brief Literature Review for Growers

Prepared by:
Jon Umble, Graduate Student, Department of Entomology, Oregon State Mark Van Horn, Student Experimental Farm, Pomology Department, UC Davis Jim Leap, Center for Agroecology & Sustainable Food Systems, UC Santa Cruz (Ecological Farming Conference 2001**,** workshop session F)

Intended to provide a basic background to the garden symphylan literature including references to selected relevant publications

Introduction:
The garden symphylan (symphylid), *Scutigerella immaculata* (Newport), is a serious pest of many vegetables, fruits and several specialty crops in the Pacific Northwest and Northern California. Garden symphylans are small, white, soft-bodied "centipede-like" animals which are not insects, but members of the class Symphyla. Several symphylan species are present in the Pacific Northwest and Northern California, and not all are pests. However, garden symphylans are the most widespread pest species present in agricultural soils.

2. Geographic distribution and pest status:

Following an initial report of *S. immaculata* as a pest in 1905 near Sacramento, CA (Woodworth 1905) *S. immaculata* was additionally identified as a pest in several other states, including Indiana, Michigan, New Jersey, New York, Ohio and Oregon. Since these early reports, *S. immaculata* has been identified as a pest worldwide. The greatest number of published reports of *S. immaculata* as a pest in the United States have been in California, Oregon, Washington, Connecticut, eastern Pennsylvania, Massachusetts, New Jersey, and Vermont (Waterhouse 1970). Most of the research concerning *S. immaculata* in the past 30 years has been in the Pacific Northwest and Northern California.

3. Description of lifestages:

Eggs of *S. immaculata* are commonly deposited in clusters of 7 to 11, but single eggs and clusters of over 25 eggs have also been observed (Waterhouse 1963). Young eggs are pearly white and spherical with hexagonal shaped ridges (Michelbacher 1938). Egg incubation period is 39.8d at 10 degrees C, 24.9d at 20 degrees C and 12.8d at 25 degrees C (Berry 1972).

First instars emerge from the egg with 6 pairs of legs and 6 complete antennae segments, their bodies are covered with fine hairs (Michelbacher 1938). With a swollen posterior and slow movements, first instars superficially appear more like a collembolan than an adult *S. immaculata* (Waterhouse 1963). First instars molt in about 2d at 20 degrees C; the resultant second instars are more similar morphologically to adults (Michelbacher 1949; Berry and Robinson 1974). Each of the six subsequent molts results in the addition of a pair of legs and variable numbers of scuta and antennal segments (Waterhouse 1963). Total time from egg to sexually mature adult (seventh instar) is 159.9d at 10 degrees C, 86.6d at 20 degrees C and 53.2d at 25 degrees C (Berry 1972).

Adults are cream colored with 12 pairs of legs, 15 dorsal scuta and 23 to 27 antennal segments. The alimentary canal is clearly visible through the integument; and the color of the canal depends on what was consumed (Michelbacher 1938). Depending on environmental and genetic factors, adults may molt up to 43 times (Michelbacher 1938). During molts, adults may add antennal segments and increase in size. Most of the growth occurs before the thirteenth instar, and the maximum length is generally 6-7mm (Waterhouse 1963).

At constant temperatures in the laboratory, *S. immaculata* exhibits periods of regular oviposition lasting about two months that alternate with periods of low oviposition of three to four months (Berry 1972). The number of eggs deposited decreases during sequential oviposition periods (Berry 1972).

In the field, environmental factors modify the cycle that is observed in the laboratory, and periods of increased oviposition are only observed in the spring and fall (Berry 1972). Berry (1972) found that field-collected *S. immaculata* oviposited after an average of 5.2d when soil temperatures were below 10 degrees C, and after an average of 23.5d when soil temperatures were above 10 degrees C, suggesting that temperature plays a key role in regulating oviposition. The highest rate of oviposition was observed when the average soil temperature in the field during the proceeding month was below approximately 10 degrees C.

4. Feeding habits and damage to plants

From the first observance of *S. immaculata* feeding on asparagus roots (Woodworth 1905), research has focused on its feeding habits. Early observations demonstrated that S. *immaculata* could survive for several years in cultures without live plant materials and led to the hypothesis that it fed significantly on microflora, microfauna and decaying organic matter. Support for this hypothesis was provided by Waterhouse (1969), who demonstrated that S. *immaculata* survived for only 37.2d when maintained in a sterile environment, and by the observation that *S. immaculata* is most commonly found in soils with high organic matter, and that populations seemed to intensify with addition of manure.

Although *S. immaculata* do feed on organic matter and microbes, addition of organic matter has not been demonstrated to provide a direct or indirect food source that will attract S. *immaculata* away from the roots of crops. Under suitable conditions for population growth, garden symphylans feed substantially on plant roots. Shanks (1966) demonstrated that S. *immaculata* is not able to reproduce significantly without live plant material, and numbers of *S. immaculata* within a field have been shown to be greater in regions of soil containing root systems than in bare soils (Michelbacher 1938; Edwards 1961). Plants transplanted into bare soil also develop higher populations of *S. immaculata* than in the surrounding soil in about 5d (Edwards 1961). Non-phytophagous species symphylans do not aggregate near root systems (Edwards 1961).

Garden symphylans are general feeders that attack germinating seeds, plant root systems, and above-ground plant parts in contact with the soil surface (Waterhouse 1963). High *S. immaculata* populations may reduce the stand of direct-seeded crops, and transplants may be killed or fail to establish well. Plants surviving initial feeding may be stunted and produce poorly in yield and quality. In general, if plants can become established and make it through the periods of most intense symphylan feeding, they may be able to recover from symphylan feeding to some degree (Waterhouse 1963).

S. immaculata feeding is reportedly noticeable in some crops, such as sugar beets and broccoli, than in other crops such as small grains. However, it is unknown whether these differences are due to the variable attractiveness or tolerance of specific host crops. Levels of tolerance, likely due to root system vigor, have been observed in broccoli (Simigrai and Berry 1974) and in strawberries (Morrison 1957), but differences in attractiveness have also been reported (Howitt et al. 1959). Additionally, variation in food quality can have a strong influence on population growth in the laboratory (Shanks 1966) and may partially explain the lower seasonal *S. immaculata* numbers following cover crops of barley or oats than following a *brassica* or legumes (Peachey et al. 2000).

5. Seasonal life history:

Eggs, nymphs and adults can be found in any month of the year. Nymphs and adults become active in the spring and can be found in increasing numbers in the upper 15 cm of soil during the spring (Berry and Robinson 1974). Surface numbers decrease in mid-summer with warming and drying of the soil. Two distinct peaks of egg production have been observed in the field in Oregon, one in April and early May and another smaller peak in late August and early September (Savos 1968).

6. Factors influencing occurrence and vertical distribution:

6.1 Soil: Garden symphylans are unable to burrow through the soil, but use pores, seasonal cracks and burrows made by other soil animals, such as earthworms, to travel through the soil (Filinger 1931). As a result, high populations of garden symphylans are more commonly found in fine-textured heavier soils with moderate or better structure and many macropores, than in sandy soils (Edwards 1958). The abrasive nature of sand may also limit *S. immaculata* populations in sandy soils (Edwards 1958). In the Pacific Northwest and Northern California garden symphylans are commonly found in silty alluvial soils (Michelbacher 1938; Waterhouse 1967).

Soil conditions other than structure, such as moisture holding capacity and soil chemistry, also may influence *S. immaculata* occurrence (Shanks 1966). High populations of garden symphylans are often

associated with soils high in organic matter; this is likely due to improvement of soil structure and moisture holding capacity, not because the garden symphylans are directly responding to a food source (Shanks 1966). Though symphyla species are found in widely variable habitats including podzols with a pH of 3.65 (Hagvar 1997), in general, the optimal conditions for garden symphylans are a well aerated, neutral, cultivated loam soil high in organic matter and strong structure (Edwards 1958).

Within a favorable soil habitat garden symphylans may migrate from the soil surface to a depth of over a meter (Michelbacher 1949). Garden symphylans may spend a large amount of time in lower soil strata, demonstrated by the large number of molted skim that are observed in these strata (Michelbacher 1949).

The soil profile, which may include compacted or sandy horizons and high water tables that may impede movement, determines the depth to which garden symphylans may migrate (Martin 1948). However, the vertical migrations are primarily due to the interaction of moisture, temperature and feeding cycles.

6.2 Moisture: Moisture gradients have been clearly shown to influence *S. immaculata* movement when other factors have been experimentally controlled (Edwards 1961). The use of irrigation has been observed to increase the number of *S. immaculata* in the surface soil. However, *S. immaculata* will enter surface horizons to feed, to a lesser extent, even in dry soils (Waterhouse 1959). Additionally, seasonal migrations are also observed in irrigated agriculture, thus moisture alone does not appear to account for the seasonal migrations of *S. immaculata* (Howitt 1959a).

6.3 Temperature: Temperature is a second key factor in determining vertical distributions of *S.* immaculata; both low and high temperatures are physiologically limiting (Michelbacher 1938). Experiments in the field have demonstrated that lower soil temperatures during the winter months retard egg production and slow the developmental rate of immature stages (Berry 1972). When soil temperature increases in the spring, a large number of mature garden symphylans are present and are stimulated to deposit eggs. Summer surface soil temperatures range well above the optimal range for *S. immaculata* development, which may cause migrations deeper in the soil (Filinger 1928).

6.4 Feeding cycles: Environmental conditions such as soil temperature and moisture provide general constraints for the vertical migrations of *S. immaculata,* and are likely most influential in the surface soil (Edwards 1961). Within favorable conditions, however, garden symphylans exhibit endogenous feeding cycles; feeding decreases substantially before a molt, and increases dramatically afterwards. Garden symphylans likely leave the root system for deeper strata when not feeding (Edwards 1961).

7. Spatial distributions

Garden symphylans may be found across an entire landscape but tend to reach high numbers only in localized "target areas" or "hotspots" of a few hundred meters to over a third of a hectare (Howitt and Bullock 1955). The great spatial heterogeneity of the alluvial soils in which garden symphylans are often found in the Pacific Northwest may contribute to its commonly observed patchy distribution.

Target areas often remain consistent from year to year with little changes in populations and only minor lateral spread possibly due to physical characteristics of the site such as soil type (Edwards 1958). However, horizontal spread of garden symphylans is not well understood, and seemingly sudden occurrence and disappearance of hotspots has been observed (Morrison 1954; Howitt 1959a). Spread may occur with movement of sediment in flooding events (Wymore 1931; Berry and Robinson 1974), which may be significant considering *S. immaculata* often occur in alluvial soils. In cultivated row crop agroecosystems infestations have been observed to spread in the direction of rows (Wymore 1931). This spread may be due to direct movement by equipment such as cultivators as well as from natural movement through regions of contiguous roots and reduced compaction, which may provide least resistance to spread.

8. Assessing populations:

Estimating the occurrence of *S. immaculata* populations across a landscape is difficult because of their clustered distributions and vertical migrations. As a result, large numbers of samples may be required to obtain an accurate estimate of *S. immaculata* populations (Howitt 1959a). For a given effort, therefore, a larger number of small informative samples will give a more accurate assessment of the distribution than a limited number of large samples.

A number of methods have been used to sample for garden symphylans, depending on sampling objectives. Soil sampling areas have varied from cores as small as 6.35 cm in diameter, to 30 cm square samples. Depth of soil sampling has varied from only a few centimeters to over a meter. Edwards and Dennis (1962) provide a summary of soil sampling methods for symphyla prior to 1962.

The two most extensive efforts to sample *S. immaculata* populations were by Edwards (Edwards 1958) and Michelbacher (Michelbacher 1938). Edwards (1958) used core samples of 6.35 cm in diameter and found population estimates derived from 20 random samples taken over an area of 418 square meters usually did not vary significantly. Additionally, he suggested that samples should be taken when the soil surface was uniformly covered or bare. Michelbacher (1938) suggested that 10 to 12 samples seemed to give a reliable estimate of *S. immaculata* populations, but did not specify the area sampled.

Workers in agroecosystems have had difficulty in relating crop response to estimates of *S. immaculata* populations. Measures of crop and weed growth have been used to indirectly assess *S. immaculata* numbers and distributions (Morrison 1954; Howitt 1959a; Sechriest 1972 Michelbacher, 1938 #141), especially in identifying hotspots. However, weak spots in crop and weed growth may be due to many factors in addition to *S. immaculata,* and indirect measures should not be used without some direct sampling (Howift and Bullock 1955; Howitt 1959a; Berry and Robinson 1974). It is additionally valuable to note that *S. immaculata* occur across a landscape and that the identification of *S. immaculata* alone may not signify a problem. The combination of a weak spot and the presence of *S. immaculata* provide strong evidence for causation.

Before planting highly susceptible crops, such as asparagus, mint, hops, strawberries, rhubarb, caneberries, or snap beans, fields are often surveyed in April, May or June for garden symphylans (Berry and Robinson 1974). The current general recommendation for soil sampling for agricultural purposes in Oregon is to take in the spring at least 3 samples per hectare of ordinary shovelfuls of soil to a depth of 15 to 20 cm (Berry and Robinson 1974). In general, the later in the spring that sampling is done, the more garden symphylans will be found in the samples. Soil samples that include crop and weed roots will contain more root feeding symphylans, including *S. immaculata,* than those taken in bare soil (Edwards 1961). Inspecting weed roots for garden symphylans in the spring may additionally aid in assessing *S. immaculata* distributions (Illingworth 1928). Because of the time and resources required to process soil samples, enough samples can rarely be taken for proper statistical analysis, leading to questionable practices such as excluding samples with zero garden symphylans (Howitt 1959a).

In addition to soil sampling, a surface baiting method has been used experimentally for the past several years (Peachey et al. 2000). To bait sample for garden symphylans, half a potato or red beet is placed on the soil surface (sliced side down) and covered with a PVC cap or a white flowerpot with the holes covered. Baits may be checked from 1 to 5 days after they are set up, by carefully picking up the bait and counting the number of garden symphylans on both the surface of the soil and the bait. The number of garden symphylans on the baits is similar for 24, 48 and 72 hour sampling time (Van Horn et al. 2001).

Baiting allows a greater number of samples to be taken for a given amount of time and effort. Additionally, bait counts are probably more consistent between different scouts because this method requires much less training than sorting through soil samples. Baiting samples only feeding garden symphylans, which is advantageous in relating *S. immaculata* feeding to plant growth. It may, however, be inconvenient in some cases to set up baits and return to check them. Additionally, because baiting

only measures the garden symphylans in the surface soil, this method is more sensitive to changes in temperature and moisture. Baits sampled on a warm spring afternoon may have much lower numbers of garden symphylans than those sampled in the morning of the same day.

9. Estimating thresholds

Economic thresholds are not well established for garden symphylans, owing to the difficulty in estimating their numbers, and the variability due to their feeding cycles. Starved animals may consume as much as fifteen times their weight in a day (Edwards 1961), and nonfeeding individuals may cause no damage. *S. immaculata* numbers as low as 1 0 in 6.4 x 25.4cm pots have been shown to influence plant physiology of snap beans in the laboratory (Eltoum and Berry 1985). However, sweet corn seed has been observed to survive and develop in laboratory populations of several thousand garden symphylans in 10 liter buckets (personal observation).

There are no well-established methods of evaluating management thresholds in the field concerning numbers, timing and distances between samples. Oregon extension recommendations in 1974 stated that "a definite problem exists" if an average of 10 or more symphylans per shovelful are found after taking 30 samples, although no sampling area or sampling time was provided (Berry and Robinson 1974). More recent recommendations have stated that "problems are usually encountered" if more than an average of 5 garden symphylans per shovelful of soil are found out of 30 or more representative soil samples taken (at least 3 per hectare) (Anonymous 2000). Bait counts have not been calibrated with soil samples.

10. Management:

Early attempts at management of *S. immaculata* in the field involved cultural methods such as tillage and flooding (Michelbacher 1938) as well as chemical control. While greenhouse management tactics included steam sterilization, chemical control and cultural methods such as using raised beds to break contact with the soil (Filinger 1931; Kearns and Walton 1932). Current *S. immaculata* management tactics may involve tillage, flooding, drying, natural enemy conservation, crop rotation, cover crop management, organic matter management, crop timing, use of toxic compounds such as botanicals, products of *brassica* incorporation and synthetic pesticides.

Thorough cultivation may crush some garden symphylans if done at a time when they are in the plow layer. Cultivation may additionally physically disrupt *S. immaculata* activity by destroying their runways. Howitt (1959) suggested that cultivation might prevent garden symphylans from reaching the surface soil in large numbers for 2 weeks. Even with well timed spring cultivation, however, garden symphylans may be found at the surface only a few days following cultivation. The effect of tillage probably varies greatly with soil type, and the method and timing of cultivation. Compacted surface soil also provides some protection from garden symphylans by physically blocking them from the establishing plants, demonstrated by the observation that plants in a compacted zone from a tractor tire may establish better than plants nearby in non-compacted soil (Michelbacher 1949).

Little quantitative *S. immaculata* research has been done with naturally occurring toxic compounds such as botanicals. However, issues concerning their use and effectiveness are similar to those concerning the use pesticides used in conventional systems.

When used effectively, toxic compounds may protect crops sufficiently for the production of an annual crop (Gessell and Hower 1973; Berry and Robinson 1974). Some protection may come from direct control, but because of the ability of garden symphylans to retreat deep into the soil, some compounds may largely provide a repellency effect, thus protecting plants during sensitive stages. Evidence of repellency was provided by Martin (1948) who reported that garden symphylans vacated soil that had been treated with Chloropicrin in the field and in the laboratory. Howitt (Howitt 1959b) observed that garden symphylans avoid treated soil in the laboratory. However, Shanks and Gans (1964) did not observe *S. immaculata* avoidance of soil treated with Zinophos and suggested that Howitt's

observed avoidance may actually have been due to a moisture gradient. Additionally, corn soaked in bichloride of mercury was used successfully as a toxic bait in 1926, suggesting that the effect of repellency and.toxicity a compound may exhibit may vary greatly (Report 1926).

Wymore (1931) found that lime refuse, air slaked lime, hydrated lime, fertilizer and tobacco dust had no noticeable repellency effect and others have reported similar effects (Report 1928). Shanks (1966) found that limestone, calcium oxide and sulfur did not affect garden symphylans reproduction.

Both use of toxic compounds and cultivation are more efficacious if garden symphylans are in the surface soil. Therefore an understanding of vertical migrations and sampling methods may aid significantly in controlling garden symphylans. In greenhouses, control has been obtained by cooling the surface soil with irrigation, then planting lettuce seeds or tomatoes to attract garden symphylans to the surface where they could be killed with steam sterilization (Filinger 1931; Kearns and Walton 1932).

Several natural enemies of garden symphylans have been reported including staphylinid and cucujid beetle adults and larvae (Illingworth 1927), centipedes (Filinger 1928; Waterhouse 1969) and predaceous mites (Berry 1973). Carabid beetle larvae occur in similar habitat, but have not been observed to feed on garden symphylans (Wymore 1931). Berry (1973) observed the predaceous mite, *Pergamasus quisquiliaum,* feeding on garden symphylans in the field, and used laboratory studies to show that *Pquisquiliaum* may help to regulate garden symphylans in the field. Waterhouse (1969) showed that centipedes could protect cabbage roots from garden symphylans feeding in the laboratory, but did not believe that centipede populations could provide sufficient control in the field. Unusually large centipede populations were noted by Flinger (1928), who suggested that their large numbers may have been due to high *S. immaculata* populations.

Reducing tillage has been shown to increase the numbers of important *S. immaculata* predators such as centipedes, spiders and predaceous mites. -However, the increase in predator numbers has not been great enough to maintain *S. immaculata* populations at acceptable levels (Peachey et al. 2000).

11. References

Anonymous 2000. Biology and control of the garden symphylan. Pacific Northwest insect management handbook, Oregon State University, Corvallis, OR, 350-353.

Berry, R. E. 1972. Garden symphlan: reproduction and development in the laboratory. *(Scutigerella immaculata).* J. Econ. Entomol. 65: 1628-1632.

Berry, R. E. 1973. Biology of the predaceous mite, *Pergamasus quisquiliarum,* on the garden symphylan, *Scutigerella immaculata,* in the laboratory. Ann. Entomol. Soc. Am. 66:13541356.

Berry, R. E., and Robinson, R. R. 1974. Biology and control of the garden symphylan. Oregon State University. Extension Service. Extension Circular 845: 9.

Edwards, C. A. 1957. Bionomics of symphyla.PhD., University of Wisconsin, Madison.

Edwards, C. A. 1958. The ecology of symphyla: Part 1. Populations. Ent. Exp. Appl. 1: 308-319.

Edwards, C. A. 1959. The ecology of symphyla: Part 11. seasonal soil migrations. Ent. Exp. Appl. 2: 257-267.

Edwards, C. A. 1961. The ecology of symphyla: part 111. factors controlling soil distributions. Ent. Exp. Appl. 4: 239-256.

Eltoum, E. M. A., and Berry, R. E. 1985. Influence of garden symphylan (Symphyla: Scutigerellidae) root injury on physiological processes in snap beans. Environ. Entomol. 14: 408-412.

Filinger, G. A. 1928. Observations on the habits and control of the garden centipede, *Scutigerella immaculata,* Newport, a pest in greenhouses. J. Econ. Entomol. 2: 357-360.

Filinger, G. A. 1931. The Garden Symphylid. Bulletin / Ohio Agricultural Experiment Station ; no. 486: 33.

Gessell, S. G., and Hower, A. A. 1973. Garden symphylan: comparison of row and broadcast application of granular Insecticides for control. J. Econ. Entomol. 66: 822-823.

Hagvar, S. 1997. Protura, pauropoda and symphyla in Norwegian coniferous forest soils: abundance and vertical distribution. Pedobiologia 41: 56-61.

Howitt, A. J. 1959a. Control of *Scutigerella immaculata* (Newport) in the pacific northwest with soil fumigants. J. Econ. Entomol. 52: 678-683.

Howitt, A. J. 1959b. Laboratory and greenhouse tests for evaluating compounds in control of the garden symphylid, *Scutigerella immaculata* (Newport). J. Econ. Entomol. 52: 672-677.

Howitt, A. J., and Bullock, R. M. 1955. Control of the garden centipede. J. Econ. Entomol. 48: 246-250.

Howitt, A. J., Waterhouse, J. S., and Bullock, R. M. **1959.** The utility of field tests for evaluating insecticides against the garden symphylid. J. Econ. Entomol. 52: 666-671.

Illingworth, J. F. 1927. Symphylids destructive to the roots of pineapple. Pineapple news MarDec: 88-91.

Illingworth, J. F. 1928. Biological notes on the Scolopendrellidae, destructive to the roots of pineapple in Hawaii. Proc. Haw. Ent. Soc. VII: 37-41.

Japeau, L. 1959. Biologie. Sur une modalite novelle de prise des spermatophores et sur l' existence de poches spermatiques gnathales chez les Scutigerellidae (Symphyles, Myriapodes). Compt. Fiend. Acad. Sci. 248: 862-865.

Kearns, H. G. H., and Walton, C. L. 1932. Experiments on the control of,;he greenhouse centipede *(Scutigerelia immaculata).* Ann. Rept. Univ. Bristol. Ag. Hort. Res. Sta.: 97-101.

Martin, C. H. 1948. Movement and seasonal populations of the garden centipede in greenhouse soil. J. Econ. Entomol. 41: 707-715.

Michelbacher, A. E. 1932. Chemical control of the garden centipede, *Scutigerella immaculata,* Agricultural Experiment Station,, Berkeley, Cal.

Michelbacher, **A. E. 1938.** The biology of the garden centipede *Scutigerella immaculata.* Hilgardia 11: 55-148.

Michelbacher, A. E. 1949. The ecology of symphyla. The Pan-Pacific Entomol. XXV: 1-12.

Morrison, H. E. 1957. Controlling symphylids. Ore. Sta. Col. Agr. Exp. Sta. Cir. of Inf. 574.

Morrison, H. E. 1965. Controlling the garden symphylan. Ore. Sta. Univ. Ext. Bul. 816.

Peachey, E., Moldenke, A., William, R. D., Berry, R., Ingham, E., and Groth, E. 2000. Effect of cover crops and tillage system on symphylans (Symphyla: *Scutigerelia immaculata)* and other soil biota in agricultural soils. Soil Ecology (in press).

Ramsey, H. L. 1971. Garden Symphylan Populations in Laboratory Cultures. J. Econ. Entomol. 64: 657-660.

Report. 1926. Symphylids. Ore. Agr. Ext. Sta. Dir. Bien. Rept. 1924-1926: 104-105. Report. 1928. Symphylids. Ore. Agr. Ext. Sta. Dir. Bien. Rept. 1926-1928: 108-109.

Savos, M. E. 1968. The bionomics of the garden symphylid. Ph.D. Thesis, Oregon State University, Corvallis.

Sechriest, R. E. 1972. Control of the garden symphylan in Illinois cornfields. J. Econ. Entomol.65: 599-600.

Shanks, C. H. 1966. Factors that affect reproduction of the garden symphylan, *Scutigerella immaculata.* J. Econ. Entomol. 59:1403-1406.

Simigral, M., and Berry, R. E. 1974. Resistance in broccoli to the garden symphylan. J. Econ. Entomol. 67: 371-373.

Thomas, C. A. 1949. The symphilid or garden centipede *(Scutigerella immaculata* Newport) and other Pennsylvania greenhouse soil pests. Penn. Sta. Col. Agr. Exp. Sta. Bul. 508. Van Horn, M., Leap, **J., and Ambrosino,** M. **2001.** Organic management of garden symphylans *(Scutigerella immaculata)* in annual cropping systems. Report to the Organic Farming Research Foundation (in press).

Waterhouse, J. S. 1959. A method for evaluating toxicity of insecticides. J. Econ. Entomol. 52:892-895.

Waterhouse, J. S. 1963. Biology of the garden symphylid, *Scutigerella immaculata* Newport.PhD., Washington State University, Pullman.

Waterhouse, J. S. 1967. Population studies of the garden symphylan, *Scutigerella immaculata* (Symphyla: scutigerellidae). Can. Entomol. 99: 696-702.

Waterhouse, J. S. 1969. An Evaluation of a new predaceous centipede Lamyctes Sp., On the garden symphylan *Scutigerella immaculata.* Can. Entomol. 101: 1081-1083.

Waterhouse, J. S. 1970. Distribution of the garden symphylan, *Scutigerella immaculata,* in the United States; a 15-Year survey. J.Econ.Entomol. 63: 390-394.

Woodworth, C. W. 1905. A new centipede of economic importance. California J. Technol. 6: 3842.

Wymore, F. H. 1931. The garden centipede. Cal. Exp. Sta. Bul. 518: 1-22.