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Evaluation of Legumes Common to the Pacific Northwest as Hosts for the Pea Cyst Nematode, *Heterodera goettingiana*[1]

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Abstract: Seventeen leguminous species common to the Pacific Northwest were evaluated as potential hosts of the pea cyst nematode, *Heterodera goettingiana,* in both greenhouse and field experiments. In all experiments, juveniles of *H. goettingiana* penetrated roots of these 17 species with the exception of greenhouse-grown chickpea. Nematodes molted and developed into swollen third-stage or fourth-stage juveniles in many of the plants, but cyst development occurred only in the field on green pea, edible dry pea, and faba bean. More *H. goettingiana* cysts developed on fava bean than on green pea or edible dry pea. In *H. goettingiana*-infested soils, cropping sequences that include fava bean and pea should be avoided. However, certain legumes, such as winter vetch, may have the potential of serving as trap crops for *H. goettingiana* in this region.

Key words: Heterodera goettingiana, host range, nematode, *Pisum sativum, Vicia faba, Vicia villosa varia.*

The pea cyst nematode, *Heterodera goettingiana* Liebscher, has been reported on pea (*Pisum sativum* L.) and other legumes throughout Europe and the Mediterranean basin (Di Vito and Greco, 1986) since it was described by Liebscher (1892) from pea and vetch (*Vicia sativa*) in Germany in 1890. Reports of occurrence now exist from Germany, The Netherlands, France, Spain, Portugal, Great Britain, Belgium, Israel, Algeria, Malta, and the former USSR (Di Vito and Greco, 1986).

Although Thorne (1961) referred to isolated occurrences of *H. goettingiana* on greenhouse-grown sweet pea (*Lathyrus odoratus* L.) in Idaho and Illinois in 1961, this nematode was not reported in commercial pea production regions of the United States until recently (Handoo et al., 1994). In 1992, several pea fields in western Washington had obvious circular patches of stunted, chlorotic plants. Handoo et al. (1994) confirmed that *H. goettingiana* was responsible for these symptoms.

Establishment and subsequent spread of *H. goettingiana* may be influenced, in part, by the host status of crops grown in rotation with pea. Reported hosts of *H. goettingiana* include species in the family Leguminosae (De Vito, 1991), although a few females and cysts of *H. goettingiana* have been observed on the roots of *Asperula arvensis* L. (Rubiaceae) (Di Vito, 1976). Leguminous crops generally reported as hosts include garden and field pea (*P. arvense* L.), fava bean (broad and field bean) (*Vicia faba* L.), several species of vetch (*Vicia* spp.), lentil (*Lens culinaris* Medik.), and certain species of *Lathyrus* (Brown, 1958; Goodey et al., 1959, Huettel et al., 1993; Jones, 1950; Liebscher, 1892; Winslow, 1955). Huettel et al. (1993) concluded that soybean (*Glycine max* L.) most likely is not a host of *H. goettingiana.*

In the Pacific Northwest, several different leguminous crops may be grown in or near fields in which pea is included as part of a rotation. Because there have been conflicting reports of susceptibility to *H. goettingiana,* the host status of common legumes in this region needs to be evaluated. For example, fava bean has been reported as a good host (Beane and Perry, 1983; Biddle et al., 1988; Brown, 1958; Jones et al., 1965; Liebscher, 1892), but others (Jones and Moriarty, 1956; Moriarty, 1963) have found it to

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be a relatively poor host. Variable responses ranging from strong to weak hosts have also been described for certain vetches (Biddle et al., 1988; Brown, 1958; Di Vito et al., 1980; Jones and Moriarty, 1956; Liebscher, 1892; Winslow, 1954, 1955). Dennis and Green (1983) found that the *H. goettingiana* can multiply on certain wild vetches, e.g., hairy vetch (*Vicia hirsuta* (L.) S. F. Gray), but little is known about the practical importance of these weeds as hosts. Lentil and chickpea (*Cicer arietinum* L.) have been reported as resistant to the pea cyst nematode based on reactions to six Italian populations of *H. goettingiana* in the greenhouse (Di Vito et al., 1980), yet lentil is included as a host in other reports (Winslow, 1954). Thorne (1961) described *H. goettingiana* from cultures on sweet pea, but other studies have indicated that sweet pea is resistant to this nematode (Goodey et al., 1959; Jones, 1950; Winslow, 1954).

Such discrepancies in host status of *H. goettingiana* could be the result of testing different cultivars of the same crop or by relying exclusively on field observations and assuming that only a single and uniformly distributed cyst population is present in the field. Discrepancies could also result from basing host status on final cyst populations without regard to reproduction efficiency. Jones et al. (1965) observed that when the same initial nematode density was used, cultivars of pea that matured quickly supported smaller numbers of cysts and eggs than later-maturing cultivars, even though there was ample time for nematodes to complete their life cycle on the early-maturing cultivars.

One objective of this study was to evaluate legumes that are commonly grown in the Pacific Northwest for host status to *H. goettingiana*. A second objective was to compare root penetration, nematode development, and fecundity of selected leguminous hosts to determine if the western Washington biotype of *H. goettingiana* had the same host-parasite relationships as European populations. The third objective was to establish whether host status for *H. goettingiana* could be accurately assessed under greenhouse conditions.

Materials and Methods

Soil, nematodes, and plants: The site used for the field test and as a source of soil for greenhouse experiments was located near Mount Vernon, Washington. The soil at the site was a Puget silt loam soil consisting of 50% sand, 38% clay, 3.8% organic matter, with a pH of 6.2. Until 1992, this field had been planted (approximately two crops every 3 to 4 years) to a pea crop for the past 30 years and had developed high and relatively uniform densities of *H. goettingiana* cysts (D. A. Inglis, unpubl. data). The site was plowed to a depth of 15 cm, and 10 soil cores (2-cm-diam. × 34-cm-deep) were collected on 17 April 1995 in a zigzag pattern from each 15 × 24-m block for cyst and egg counts. The site averaged 21 ± 3 *H. goettingiana* eggs/cm^3 of soil. The field experiment was planted on 9 May 1995.

For the two greenhouse experiments, soil was collected on 17 April 1995. After mixing, soil was screened through a sieve (5-mm-diam. openings), mixed thoroughly again, and stored at field capacity in uncovered buckets in the greenhouse for less than 30 days before use. The average number of eggs per cyst was determined from 50 cysts. Potential inoculum densities were calculated by multiplying the average number of eggs per cyst by the average number of cysts extracted from soil of eight replicate Conetainers (2.5-cm diam. × 16-cm length) (Stueber and Sons, Corvallis, OR). The inoculum densities for the first and second greenhouse tests were 15 ± 1 and 20 ± 3 eggs/cm^3 soil, respectively.

Cysts were extracted from soil and counted as follows. A 4-liter bucket was placed on top of nested sieves (710-µm-pore sieve over a 180-µm-pore sieve). A 100-g sample of mixed, air-dried soil was added to the bucket, and the bucket was filled with water. The soil suspension was thoroughly mixed, and more water was added to the bucket so that cysts and debris slowly washed over the edge of the bucket onto the screens. The remaining water then was passed through the screens, leaving the soil in the bottom of the bucket. Cysts collected

on the 180-µm-pore sieve were washed with sucrose solution (254 g/l) into a glass petri dish lined with a 34-cm-long and 2-cm-wide strip of paper toweling that overlapped on the joining edges. The sucrose solution was stirred gently so that cysts floated to the outer edge of the dish and adhered to the paper strip, as floating cysts tend to cling to most objects they contact (Brodie et al., 1976). The sucrose solution was removed by aspiration, and then the paper strips were carefully removed from the dish and paced onto the upper surface of a 30-cm-long by 3-cm-wide wooden garden stake lying in a flat horizontal position. The cysts, now aligned in the center of the strip for the entire stake length and supported by the stake, were easy to handle and were counted with a dissecting microscope with reflected light.

Seeds of 17 leguminous species common to the Pacific Northwest were obtained from various sources (Table 1) and treated with captan (2 g a.i./454 g of seed) prior to planting.

Greenhouse experiments: Approximately 50 cm^3 of soil was added to each of 170 plastic Cone-tainers (2.5-cm-diam. × 16-cm-length) so that 10 replicate samples of all 17 species could be evaluated. For plants with large seeds (chickpea, fava bean, lentil, lima bean, lupine, pea, snap bean, sweetpea, and winter vetch), one seed was planted per replicate Cone-tainer. For plants with small seeds (alfalfa, alsike clover, birdsfoot trefoil, black medic, red clover, sweet clover, white Dutch clover, and yellow blossom sweet clover), 10 seeds were planted to ensure at least 1 or 2 plants per Cone-tainer. The experiment was repeated once (trials 1 and 2).

Cone-tainers were placed in racks suspended above water in a temperature-controlled water path to maintain a soil temperature of 18 °C. Plants were watered daily, as needed, and harvested 14 days after planting. Roots were stained (Byrd et al., 1983) and nematodes within roots were quantified. To determine if nematodes had developed following root invasion, nematodes in roots were categorized as either vermiform second-stage juveniles (J2) or swollen juveniles. Cysts were not quantified in the greenhouse experiments due to insufficient incubation time for females to develop in the Cone-tainers.

Field experiment: A 26 × 20-m field plot was established so that six replications arranged in randomized complete blocks containing 3-m-long single-row plots of each of the 17 species could be planted. There was a 1.2-m

TABLE 1. Source of leguminous plants tested as potential hosts of the pea cyst nematode, *Heterodera goettingiana,* in greenhouse and field tests.

Common name	Scientific name	Source
Alfalfa cv. Fortress	*Medicago sariva* L.	Skagit Farmers Supply, Mount Vernon, WA
Alsike clover	*Trifolium hybridum* L.	Skagit Farmers Supply, Mount Vernon, WA
Birdsfoot trefoil	*Lotus corniculatus* L.	F. Muehlbauer, Pullman, WA
Black medic	*Medicago lupulina* L.	Valley Seed Service, Fresno, CA
Chickpea cv. Dwelley	*Cicer arietinum* L.	F. Muehlbauer, Pullman, WA
Fava bean cv. Dianna	*Vicia faba* L.	C. Lataber, Mount Vernon, WA
Lentil cv. Brewer	*Lens culinaris* Medik.	F. Muehlbauer, Pullman, WA
Lima bean cv. Maffei 15	*Phaseolus lunatus* L.	Sacramento Valley Milling Seed Service, Ordbend, CA
Lupine cv. Russell's Mixture	*Lupinus* spp.	Ed Hume Seed Co., Kent, WA
Pea (green) cv. Charo	*Pisum sativum* L.	Crites Moscow Growers Inc., Moscow, ID
Pea (dry) cv. Latah	*Pisum sativum* L.	F. Muehlbauer, Pullman, WA
Red clover	*Trifolium pratense* L.	Skagit Farmers Supply, Mount Vernon, WA
Snap bean cv. Labradore	*Phaseolus vulgaris* L.	Asgrow Seed Co., LaConner, WA
Sweet pea cv. Knee-hi Semi-dwarf	*Lathyrus odoratus* L.	Chas. H. Lilly Co., Portland, OR
Yellow-blossom sweet clover	*Melilotus officinalis* (L.) Lam.	Skagit Farmers Supply, Mount Vernon, WA
White clover	*Trifolium pratense* L.	Skagit Farmers Supply, Mount Vernon, WA
Winter vetch	*Vicia villosa* Roth ssp. *varia* (Host) Corb.	Valley Seed Service, Fresno, CA

spacing between rows and 1.5-m spacing between replicate blocks. Seeds were planted on 9 May 1995 with an Almaco One Row Belt Push Planter (Almaco, Nevada, IA). The number of seeds planted per row was either 75 (for large seeds) or 150 (for small seeds). Granular fertilizer 0-45-0 (3.9 g/m) was side-dressed to each row at planting. The field plot was hand-weeded as needed throughout the study. To prevent insect damage, 0.037 kg a.i./ha of esfenvalerate was applied on 25 May 1995.

Plants were sampled 6 and 8 weeks after planting (21 June and 7 July 1995) by carefully digging one randomly selected plant of each of the 17 species from all six replicate blocks. Roots were weighed and then stained (Byrd et al., 1983), and nematodes in roots were quantified as follows: Roots were comminuted for 1 minute at high speed in a blender containing 100 ml of water, contents from the blender were washed through stacked 833 and 20-µm-pore sieves, and nematodes and debris from the 20-µm-pore sieve were collected on the surface of a Whatman #4 filter paper with vacuum filtration. Nematodes were counted and assigned to developmental stage (J2, swollen, or cyst).

Fecundity was evaluated on crop species (green pea, edible dry pea, and fava bean) that supported cyst development by the 21 June sample date. One cyst was added to 1 ml of 2.1% NaOCl in a 1.5-ml microfuge tube and left in the NaOCl solution for 5 minutes to dissolve the cyst wall and liberate the eggs from the cyst. One milliliter of water was then added to each tube, and eggs were counted immediately afterward. A minimum of 10 cysts were evaluated for each replicate sample of each plant species. Reproductive potential (potential number of eggs per host) was calculated by multiplying the average number of cysts per plant on 7 July by the number of eggs per cyst. Plants that had roots in which *H. goettingiana* penetrated but failed to develop (lentil, winter vetch, lima bean, red clover, sweet pea, chickpea) on the 7 July sample date were sampled and re-evaluated for cysts 4 weeks later (9 August) to ensure that the absence of cysts on the 7 July sampling date was not due to slow nematode development in those plant species.

Data analysis: Greenhouse and field data were analyzed with the SAS General Linear Model procedure (SAS Institute, Cary, NC). Due to a significant trial effect, the data for the two greenhouse trials were analyzed separately.

Results

Greenhouse: The number of nematodes that penetrated roots was lower in greenhouse trial 2 than in trial 1, regardless of host species (Fig. 1). However, the trends were similar between these two trials. More nematodes penetrated roots of fava bean, lentil, green pea, edible dry pea, and winter vetch and molted to the swollen stage than penetrated roots of other plants. Very few or no nematodes penetrated roots of chickpea, lima bean, or snap bean. Nematodes penetrated but developed little in roots of alfalfa, alsike clover, birdsfoot trefoil, black medic, lupine, sweet pea, red clover, white clover, and yellow-blossom clover, although the effect was not as pronounced in trial 2 (Fig. 1).

Field: Regardless of sampling date, juveniles were detected in roots of all 17 species evaluated in the field (Fig. 2). Nematodes penetrated roots, molted, and developed into swollen J3 or J4 in all species except birdsfoot trefoil. However, cyst development was detected only on fava bean, green and dry edible peas, and lentil (Fig. 2), but the number on lentil was negligible. Cysts were present on pea roots at both 6 and 8 weeks after planting, but there were more ($P < 0.05$) present on the second sampling date than on the first. Also, on the first sampling date, with the exception of pea and fava bean, substantially more *H. goettingiana* were detected in the roots of sweet pea and winter vetch than in the roots of the other plants. However, cysts were not detected on either of these species on this date. On the second sampling date, there were more nematodes in the roots of lentil, lima bean, lupine, and

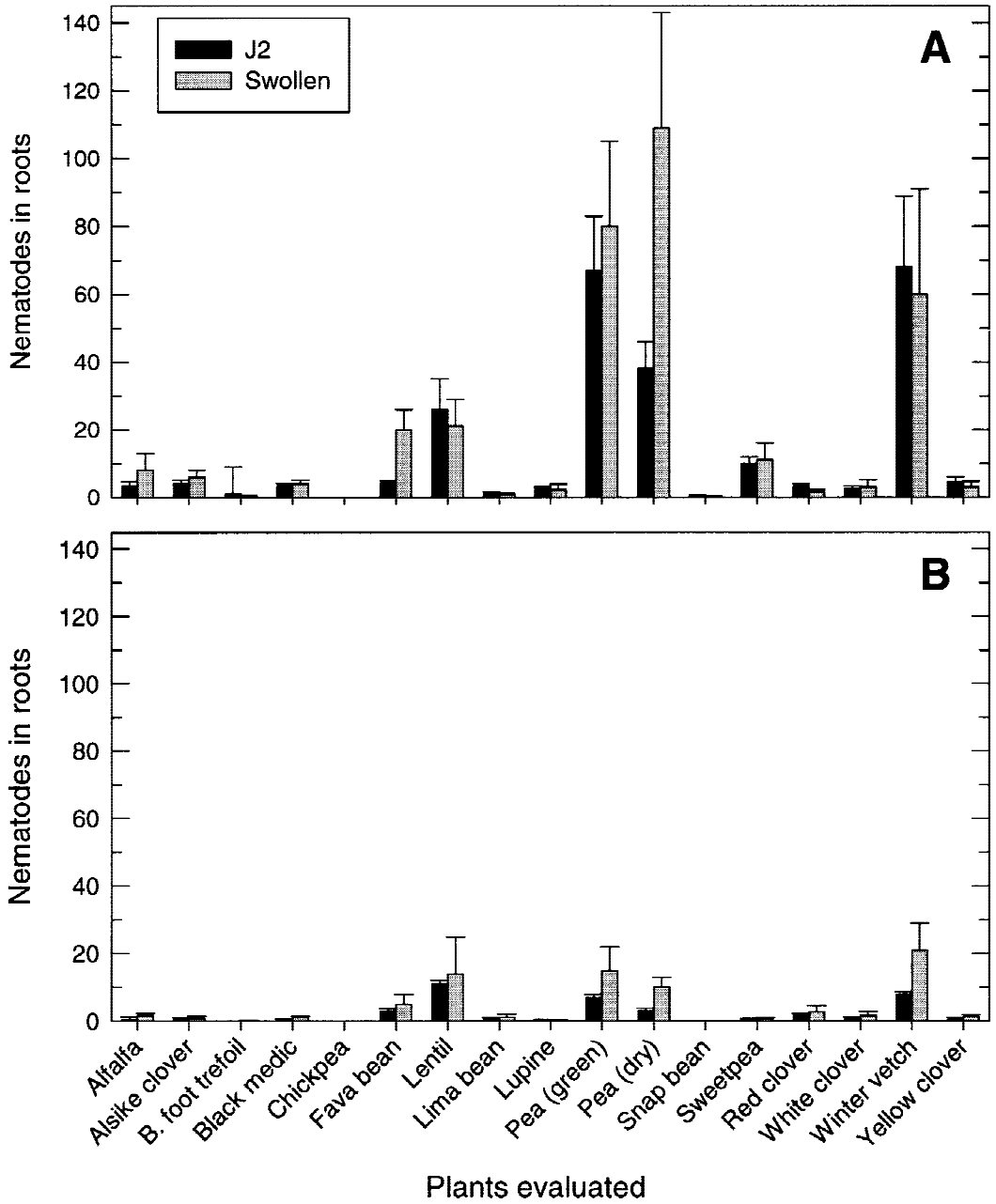

FIG. 1. Number of second-stage juveniles (J2) or swollen juveniles (J3-J4) of *Heterodera goettingiana* within roots of 17 leguminous plants. Root invasion and nematode development were quantified 14 days after planting, with 10 replicates/plant species. A) Greenhouse trial 1. B) Greenhouse trial 2. Bars represent standard errors.

red clover than in the roots of other plants, except for peas, fava bean, sweet pea, and winter vetch. Cysts developed only on fava bean, sweet pea, and dry pea. To determine if nematode development was delayed in these plants compared to pea or fava bean, the chickpea, lentil, red clover, sweet pea, and winter vetch plots were evaluated again 4 weeks later (2 August). Cysts still were not detected in any of these plants at this time.

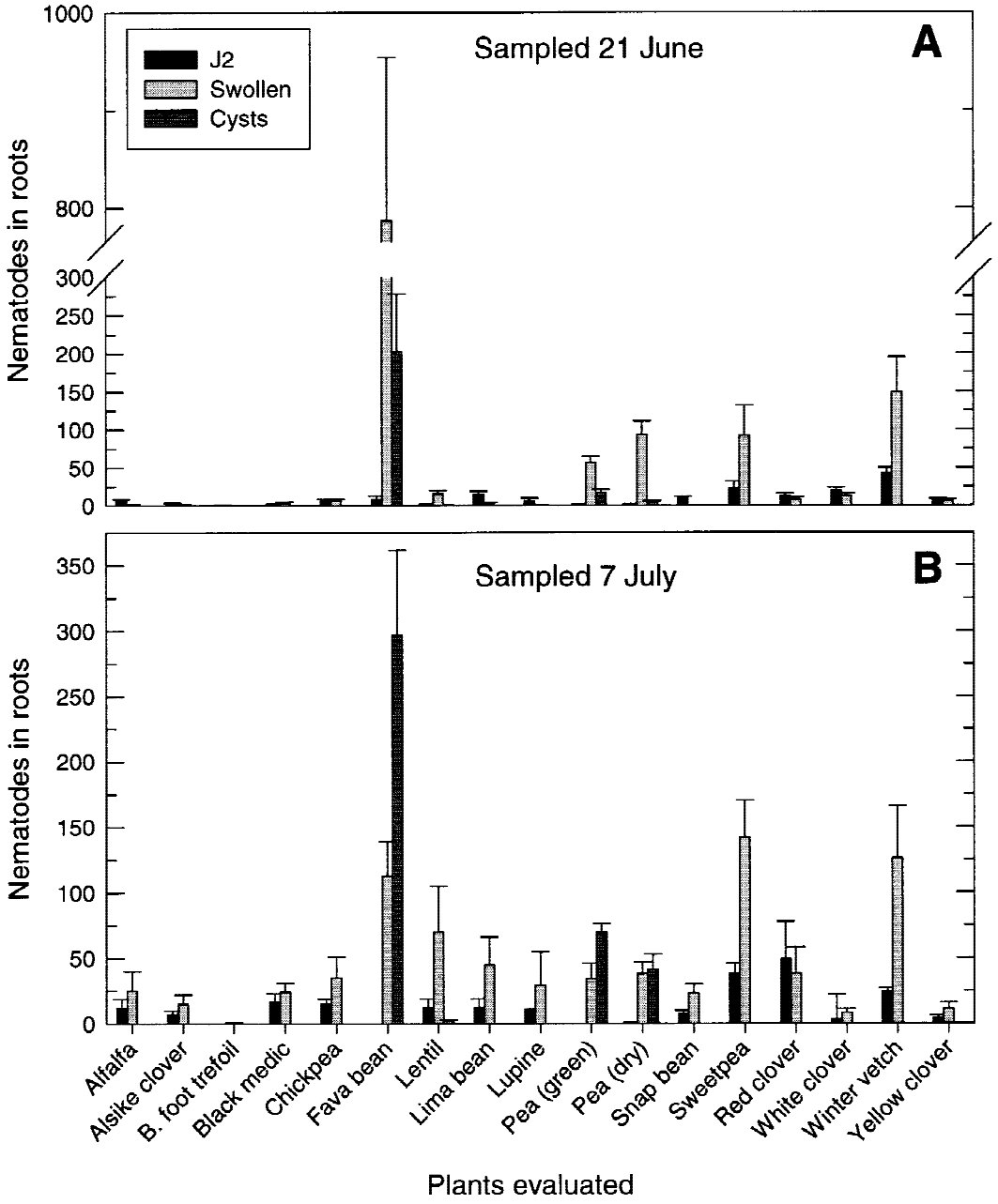

FIG. 2. Number of second-stage juveniles (J2), swollen juveniles (J3-J4), or cysts of *Heterodera goettingiana* within roots of 17 leguminous plants in field plantings with 6 replicates/plant species. A) 43 days after planting. B) 60 days after planting. Bars represent standard errors.

Very few or no J2 were found in the roots of green pea, dry edible pea, or fava bean after 8 weeks; instead, most or all of the nematodes in the roots were either swollen juveniles or cysts.

More ($P < 0.05$) cysts developed on fava bean than on green pea or edible dry pea (297 ± 65 vs. 70 ± 6 and 41 ± 12 cysts/plant, respectively) (Fig. 3A). Average root weight also was greater for fava bean than for green pea and dry pea (16.7 ± 6.8 vs. 0.9 ± 0.3 and 1.2 ± 0.5 g/plant, respectively). The number

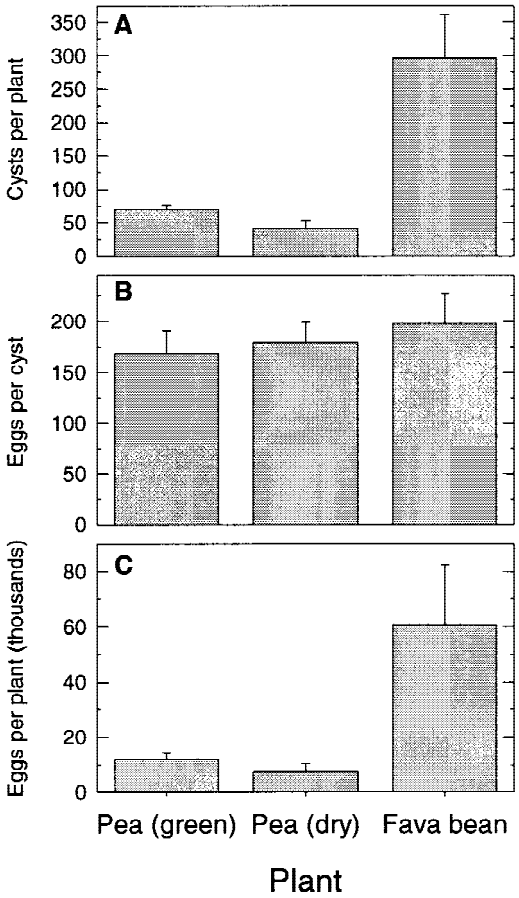

FIG. 3. Numbers of cysts per plant, eggs per cyst, and eggs per plant for *Heterodera goettingiana* on green pea, edible dry pea, and fava bean grown in the field. A) Cysts per plant. B) Eggs per cyst. C) Eggs per plant. Bars represent standard errors.

of eggs per cyst did not differ with host plant (Fig. 3B). Cysts from green pea, dry pea, and fava bean contained 168 ± 23, 179 ± 20, and 198 ± 29 eggs, respectively. Thus, the reproductive potential was higher for fava bean than for either green pea or edible dry pea, which did not differ from each other (Fig. 3C).

DISCUSSION

Similar to reports from studies in Europe (Di Vito, 1991), pea and fava bean in this study were the most important hosts of *H. goettingiana* in both greenhouse and field studies involving a western Washington biotype of this nematode. Of the other hosts of particular economic interest to the region, both chickpea and lentil were resistant to *H. goettingiana* while sweet pea and winter vetch supported substantial root invasion by juveniles but not cyst development.

Heterodera goettingiana penetrated roots of all 17 leguminous species in this study under both greenhouse and field conditions. We had expected to find some of the legume species with nematodes in their roots, and several without any, but did not expect all species to be infected, for several reasons. First, some of the plants that we tested had previously been described by others as ''poor hosts'' or ''non-hosts'' of *H. goettingiana* (Biddle et al., 1988; Di Vito, 1991; Di Vito et al., 1980; Jones and Moriarty, 1956; Lamberti and Dandria, 1979). Second, inoculum was in the form of soil naturally infested with cysts and eggs of *H. goettingiana;* therefore, J2 would have had to first hatch from eggs prior to root invasion. Eggs of *H. goettingiana* do not hatch readily in the absence of specific root exudates from plants that are generally good hosts (Beane and Perry, 1983; Di Vito and Greco, 1986; Perry et al., 1980; Shepherd, 1963). It would have been desirable to use J2 as the form of inoculum in the greenhouse to remove the process of hatching as a confounding factor in this evaluation of host status. However, it is extremely difficult to induce *H. goettingiana* to hatch in vitro (Shepherd, 1963).

Most host range studies for *H. goettingiana* have been conducted at infested field sites, in microplots with infested soil, or in soil with introduced cysts. In many of these studies it may have been assumed that only one species of cyst nematode was present in the soil, that the populations of cysts were uniformly distributed, or that host symptoms were not influenced by initial nematode density. Even though field conditions may have been less than ideal, they still have allowed researchers to evaluate a variety of plant species as potential hosts. It is more difficult to evaluate *H. goettingiana* in the greenhouse than in the field as these nematodes are extremely sensitive to temperature (Beane and Perry, 1983; Di Vito, 1991; Greco et al., 1986) and juveniles may not

hatch readily. Temperature sensitivity could explain the reduction in root penetration between the two greenhouse trials in this study (see Fig. 1) since the same batch of soil and cysts was used for both trials. The only difference between trials was that the soil was stored in the greenhouse for an additional 14 days in greenhouse trial 2 and that greenhouse trial 1 was run when outside maximum temperatures reached 27.5 °C, compared to 29.5 °C for greenhouse trial 2. Although fewer nematodes penetrated roots in the second trial, data from both greenhouse trials supported the field results with the exception of fava bean. This similarity between greenhouse and field results suggests that evaluation of plants in the greenhouse may be a useful way to screen many plants for host status to *H. goettingiana*. An important consideration for greenhouse screening is collection and storage of the nematode and maintaining the appropriate temperatures for pea root infection. Furthermore, this greenhouse screening method eliminates the need for an infested field site, minimizes the probability of nonuniform cyst densities in the soil, and reduces the chances of misinterpreting results due to the presence of multiple cyst species in the field.

It is not surprising that green pea, dry edible pea, and fava bean were all good hosts of *H. goettingiana*. There is no known resistance to *H. goettingiana* in the genus *Pisum* (Inglis et al., 1995). The results from this study support earlier reports. Brown (1958) found that fava bean increases field population of *H. goettingiana* and is important in maintaining nematode populations that are damaging to peas. Beane and Perry (1983) demonstrated that fava bean supports greater numbers of *H. goettingiana* than pea because it is more tolerant to damage. In this field study, cyst populations on roots of fava bean were greater than on roots of pea, possibly because fava bean had greater root mass and was healthier. Cyst populations might have been greater on pea if the peas could have tolerated the high nematode densities in the field. However, peas were stunted, yellow, and died prematurely compared to fava beans, which were larger and remained relatively healthy and vigorous. Field observations (D.A. Inglis, unpubl.) suggest that pea roots affected by root rot pathogens may not support as high a number of *H. goettingiana* as do healthy pea roots.

Winter vetch could possibly be considered as a trap crop for *H. goettingiana* in western Washington. In this study many juveniles penetrated roots of the vetch plants but failed to develop into cysts. Greco et al. (1991) also demonstrated that *H. goettingiana* was very damaging to pea and broad bean while vetch was more tolerant. However, the mechanism of this possible resistant response and the reaction of different species of *Vicia* to *H. goettingiana* is unclear. Cultivar, seasonal fluctuations, and nematode densities may also affect this outcome. Although the potential exists for using these plants as trap crops or cover crops in a pea cyst nematode management program, further evaluations of several species and cultivars over time and with several populations of the *H. goettingiana* are needed before recommendations can be made.

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