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Population Dynamics of *Meloidogyne chitwoodi* on Russet Burbank Potatoes in Relation to Degree-day Accumulation[1]

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Abstract: Population dynamics of *Meloidogyne chitwoodi* were studied for 2 years in a commercial potato field and microplots. Annual second-stage juvenile (J2) densities peaked at harvest in mid-fall, declined through the winter, and were lowest in early summer. In the field and in one microplot study, population increase displayed trimodal patterns during the 1984 and 1985 seasons. Overwintering nematodes produced egg masses on roots by 600–800 degree-days base 5 C (DD_5) after planting. Second-generation and third-generation eggs hatched by 950–1,100 DD_5 and 1,500–1,600 DD_5, respectively, and J2 densities rapidly increased in the soil. A fourth generation was observed at 2,150 DD_5 in 1985 microplot studies. Tubers were initiated by 450–500 DD_5, but J2 were not observed in the tubers until after the second generation hatched at 988–1,166 DD_5. A second period of tuber invasion was observed when third generation J2 hatched. The regional variation in *M. chitwoodi* damage on potato may be explained by degree-day accumulation in different potato production regions of the western United States.

Key words: Columbia root-knot nematode, crop loss, ecology, *Meloidogyne chitwoodi*, potato, *Solanum tuberosum*.

Solanum tuberosum L., the potato, is a major crop in the Pacific northwestern United States. During the last 10 years, the Columbia root-knot nematode, *Meloidogyne chitwoodi*, has been recognized as a serious pest on potato in this region (13,15). This nematode invades tubers and induces gall on their surface, rendering them unmarketable (17). In areas with a long, warm growing season, such as the Columbia Basin of Washington and Oregon, total crop loss can occur in infested fields unless the soil is fumigated before each potato crop.

Meloidogyne chitwoodi is well adapted to the relatively cool soil temperatures of the region (14). Embryogenic development requires 82–84 days at 10 C with 40% of the eggs hatching after 65 days (8). Second-stage juveniles (J2) penetrate wheat roots (9) and hatch at 4 C. Nematode embryogenesis and development on Russet Burbank potato proceeded at 6 C (2). Egg production is greatest at 15–25 C (14).

Meloidogyne chitwoodi overwinters primarily as eggs which hatch as soil temperatures increase in the spring. Second-stage juveniles invade roots soon after planting, and nematode maturation rate in Russet Burbank potato is regulated by temperature (2). The economic threshold for Russet Burbank potato in eastern Washington is 1 J2/250 cm^3 soil because of the high nematode fecundity and a low tolerance for nematode damage in tuber grading standards (18). Field studies of *M. chitwoodi* on Russet Burbank potato demonstrated that degree-day accumulation during the season is more important than the initial soil J2 population in determining tuber damage (6). Understanding *M. chitwoodi* population dynamics in the potato agroecosystem should aid in the development of guidelines for the selection and timing of management inputs. The purpose of this study was to determine the relationship between degree-day accumulation and population dynamics of *M. chitwoodi* in soil and potato tubers.

MATERIALS AND METHODS

Field studies: Meloidogyne chitwoodi populations were monitored in a commercial potato field under center pivot irrigation east of Pasco, Washington. In November 1983, five-row plots (4 m × 10.7 m) with six replications were established in a loamy

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sand (85.6% sand, 10.4% silt, 4.0% clay) area with a history of nematode damage. Soil temperature was recorded daily (Datapod, Omnidata International, Logan, UT) at 15 cm deep throughout the 2-year study and degree-day accumulation base 5 C (DD_5) was calculated from mean daily temperatures.

Stubble from the previous maize crop was incorporated at the time of plot establishment. The plot area was fallowed from harvest until potatoes were planted in spring each year. Russet Burbank potatoes were planted 3 May 1984 and 1 May 1985. Standard commercial irrigation, fertility, and agronomic practices were used to manage the potato crop (11). Insects were controlled with the nonsystemic insecticides fenvalerate and methamidophos. Plots were harvested 12 October 1984 and 2 October 1985.

Ten soil core samples (each 2.5 cm × 30 cm) were collected at 1-m intervals in the center row of each plot. Soil was sampled monthly during the overwintering period from harvest through planting each year. After planting in May 1984, soil samples were collected every 14 days during the growing season. In 1985, samples were collected every 14 days from planting to 30 June and then every 7 days through harvest. Root samples from two plants selected from each plot were collected and examined for egg masses on each sampling date until egg masses were detected (3). Tubers were sampled weekly from tuber initiation in mid-June until the field was harvested. Ten tubers representing various size and maturity classes were collected from two plants selected from the three inner rows of each plot on each sampling date.

Microplot studies: Sixty microplots were established in a field site at the Washington State University Irrigated Agriculture Research and Extension Center in Prosser, Washington (16). Each microplot was a 19-liter bucket filled with methyl bromide-fumigated (1984) or steam-pasteurized (1985) sandy loam soil (81% sand, 17% silt, 2% clay). *Meloidogyne chitwoodi* eggs were reared on tomato roots, collected (7), and incorporated at 150 eggs/250 cm^3 soil while filling the microplots. A single Russet Burbank potato seed piece was planted 15 cm deep in each microplot and in the rows between plots on 23 May 1984 and 30 April 1985. Microplots and interplants were fertilized and irrigated by drip irrigation. Soil temperature was recorded 15 cm deep each season and DD_5 was calculated.

In 1984, five microplots were destructively sampled on each of 11 dates after planting. Soil, roots, and tubers were carefully separated and processed to estimate nematode population densities. In 1985, a manganese toxicity developed with one batch of pasteurized soil and weekly destructive sampling was curtailed because of the reduced number of plants. In these plots, a single soil core sample (2.5 cm × 30 cm) was collected weekly from five plants in each of five replicates from planting until tuber set. After tuber set, five microplots were destructively sampled weekly until mature *M. chitwoodi* females were detected in tubers, and then soil core samples were again collected.

Nematode analysis: Second-stage juveniles were extracted from 250-cm^3 soil samples by wet sieving-centrifugation (10) and counted. Samples of field soil collected at planting and harvest each season were bioassayed with a 3-week-old Columbia tomato plant to determine nematode infectivity. Plants were harvested after 21 days, the roots were stained (1), and the nematodes in the roots were counted. Five tubers from each plot on each sampling date were carefully scrubbed with a nylon scouring pad to remove the epidermis. A series of slices (0.75–1.5 mm thick) was cut tangentially from the tuber surface through the vascular ring. Approximately 5 g tissue per tuber was collected from four surfaces of each tuber. The slices were soaked in 1.5% NaOCl for 5 minutes, rinsed in tap water for at least 30 minutes, and stained (1). The location and development stages of nematodes in each slice were recorded: filiform J2, swollen J2 through J4, females, and females with egg masses.

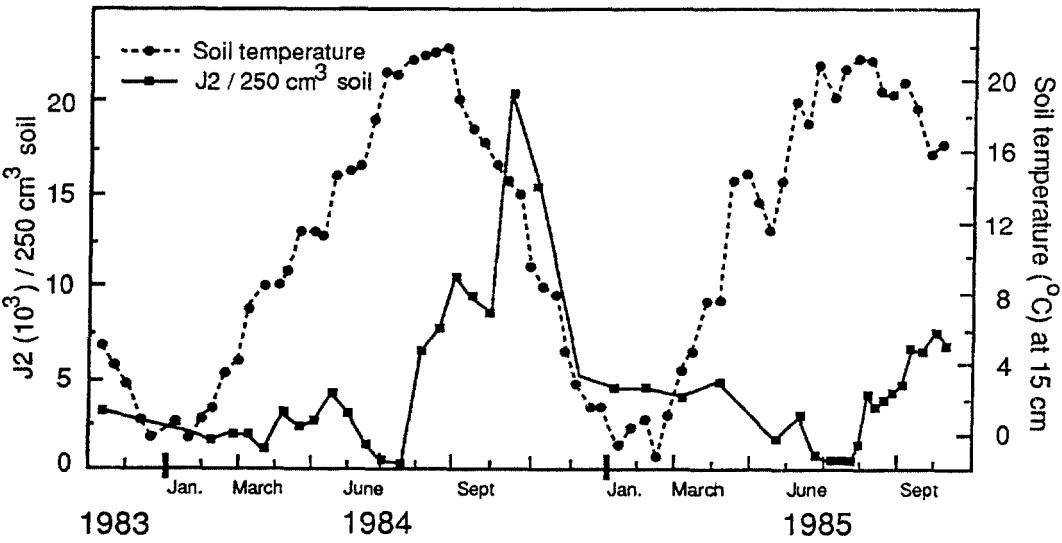

FIG. 1. Seasonal population dynamics of *Meloidogyne chitwoodi* and soil temperature 15 cm deep in an eastern Washington potato field.

RESULTS

Field studies: Population trends in the field study were similar in 1984 and 1985, with maximum densities reached after plants became senescent, 23 September and 10 September, respectively (Fig. 1). In the fall of 1983, J2 population densities following corn (3,250/250 cm³ soil) were lower than following potato (20,400 and 7,550/250 cm³ soil in 1984 and 1985, respectively). The 1985 crop displayed symptoms of early dying syndrome, a common problem with potato–potato rotations, and the crop was dead weeks before the scheduled harvest date. Second-stage juvenile densities declined through the winter and increased slightly as soil temperature increased in the spring. Population densities were high at planting, with 2,650 and 2,100 J2/250 cm³ soil in 1984 and 1985, respectively. Bioassay tests determined that at least 15 and 25% of the J2 were infective at planting in 1984 and 1985, respectively. Annual minimum densities were recorded in early summer after which densities increased rapidly until harvest. Annual maximum and minimum soil temperatures at 15 cm deep were 21 to 22 C and −1 to 0 C, respectively, during the study (Fig. 1).

Soil J2 population dynamics displayed three phases during both growing seasons (Fig. 2). Nematode densities rose slightly after planting but declined to 130 and 500/250 cm³ soil after 848 DD_5 (12 July 1984) and 873 DD_5 (8 July 1985). Soil J2 density increase was first recorded at the end of July at 1,115 DD_5 in 1984 and 1,104 DD_5 in 1985. Population densities increased until 1,541 DD_5 (23 August 1984) and 1,233 DD_5 (30 July 1985) after which J2 densities increased little during the following 28 days. A second increase in J2 densities was recorded on 23 September 1984 and 27 August 1985 after 1,877 DD_5 and 1,639 DD_5, respectively. Egg masses were first observed on roots at the end of June 1984 and 1985, after 610 DD_5 and 804 DD_5, respectively (Table 1).

Tubers were initiated by mid-June after 450–550 DD_5 each year. In 1984, J2 were first observed in tubers at 995 DD_5 (22 July), swollen juveniles at 1,115 DD_5 (29 July), females at 1,350 DD_5 (13 August), and females with egg masses at 1,541 DD_5 (26 August) (Table 1). In 1985, J2 were first observed at 988 DD_5 (15 July), swollen juveniles at 1,104 DD_5 (22 July), females at 1,428 DD_5 (13 August), and egg masses at 1,639 DD_5 (27 August). Tuber penetration by nematodes in 1985 showed a bimodal

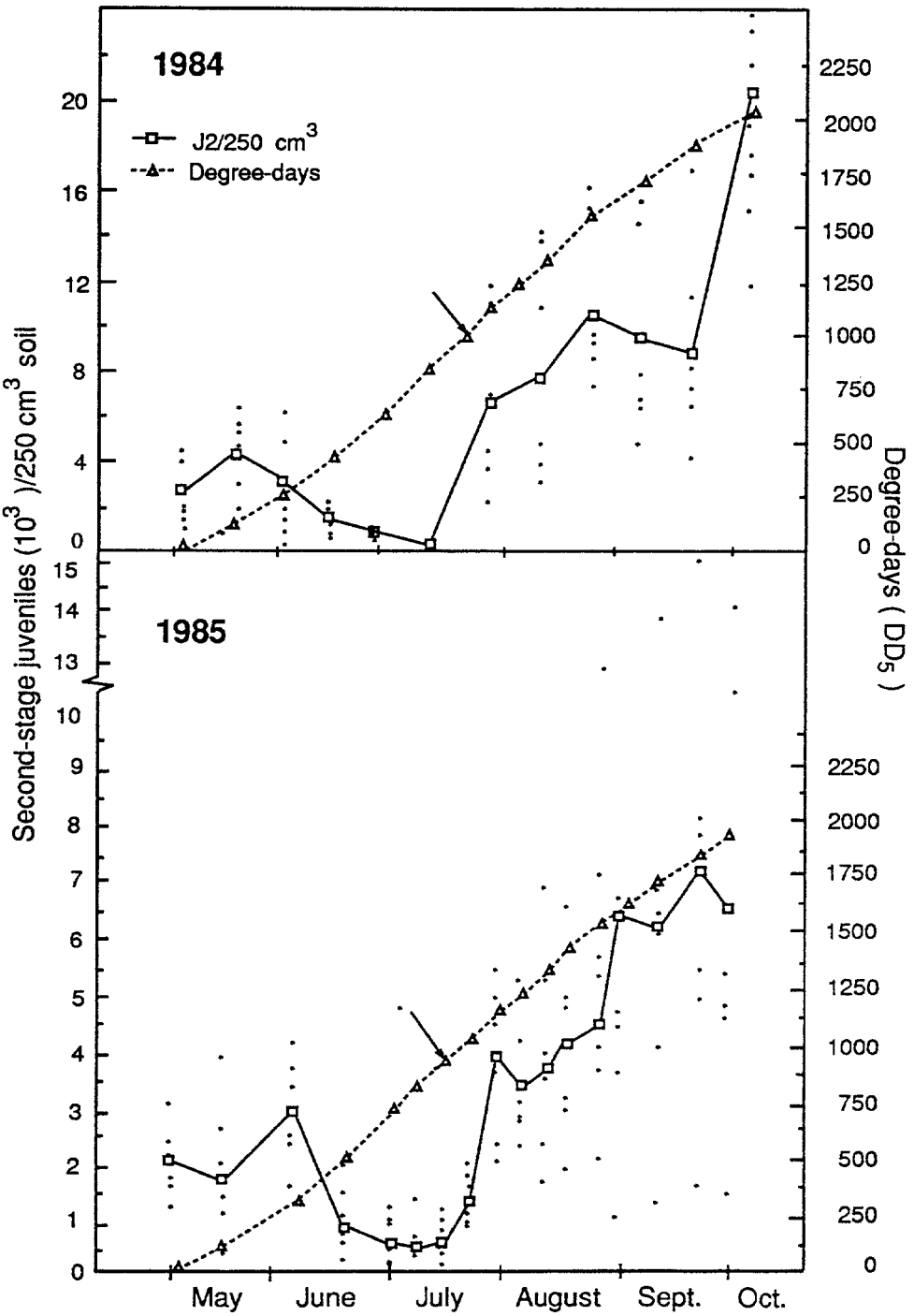

FIG. 2. Relationship between *Meloidogyne chitwoodi* population development and degree-day accumulation on field-grown Russet Burbank potatoes. Arrow indicates when J2 were first detected in tubers.

TABLE 1. Degree-days (DD_5) accumulated for *Meloidogyne chitwoodi* development on Russet Burbank potato grown in field and microplots.

Developmental stage	Field plots†		Microplots†	
	1984	1985	1984	1985
Egg masses on roots	610	804	684	782
Vermiform juveniles in tubers	995	998	940	1,003
Swollen juveniles in tubers	1,115	1,104	1,119	1,270
Females in tubers	1,350	1,428	1,376	1,383
Females with egg masses in tubers	1,541	1,639	1,492	1,481

† Average DD_5 accumulated at tuber initiation in field and microplots were 492 and 526, respectively.

pattern with peaks at 1,104 and 1,845 DD_5 (Fig. 3). The second peak started at 1,639 DD_5 and followed the increasing J2 densities observed in the soil.

Microplot studies: Soil J2 population dynamics in microplots displayed three phases in 1984 and four in 1985 (Fig. 4). Densities were below 13 J2/250 cm^3 soil after planting and declined to less than 1/250 cm^3 until 943 DD_5 (23 July) in 1984 and 1,003 DD_5 (1 July) in 1985 when densities increased. Soil J2 densities then rose until 1,390 DD_5 (20 August) in 1984 and 1,405 DD_5 (4 August) in 1985 after which J2 densities stabilized. In 1984, J2 densities increased after 1,736 DD_5 and peaked at harvest, 1,917 DD_5 (3 October). In 1985, J2 densities increased after 1,714 DD_5 and two additional peaks were recorded at 2,047 DD_5 (1 September) and 2,393 DD_5 (1 October). Date of appearance of nematode life stages and accumulated degree-days for their development in roots and tubers are reported in Table 1.

DISCUSSION

Soil J2 population densities in the field declined through the winter. However, nematode inocula at planting, measured by J2 soil densities and bioassays, were similar in both years. This may indicate a density-dependent mortality as reported for *M. arenaria* and *M. incognita* (19). In both years, J2 densities remained stable through the

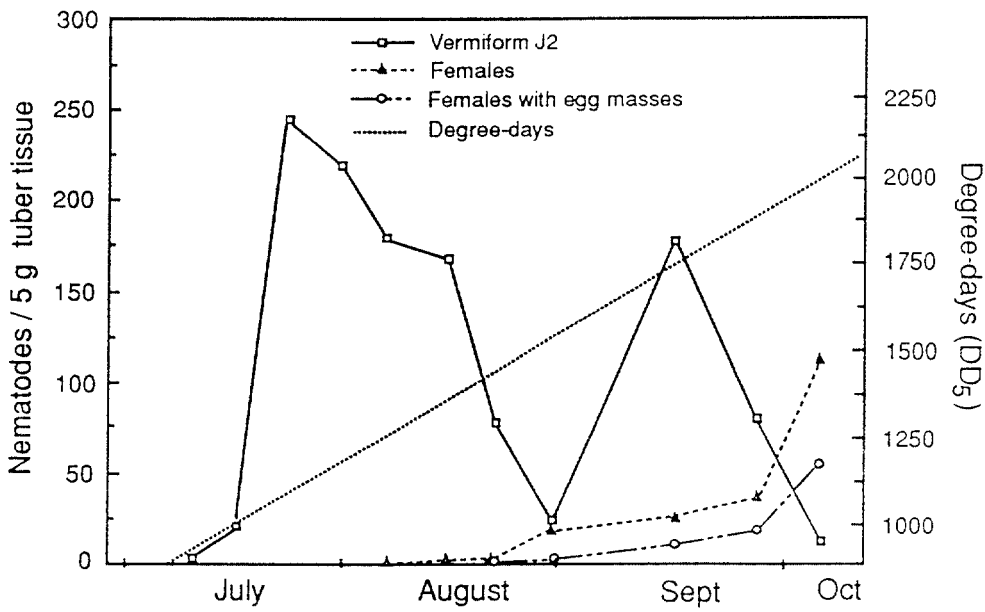

FIG. 3. Penetration and population development of *Meloidogyne chitwoodi* in field-grown Russet Burbank potato tubers during 1985.

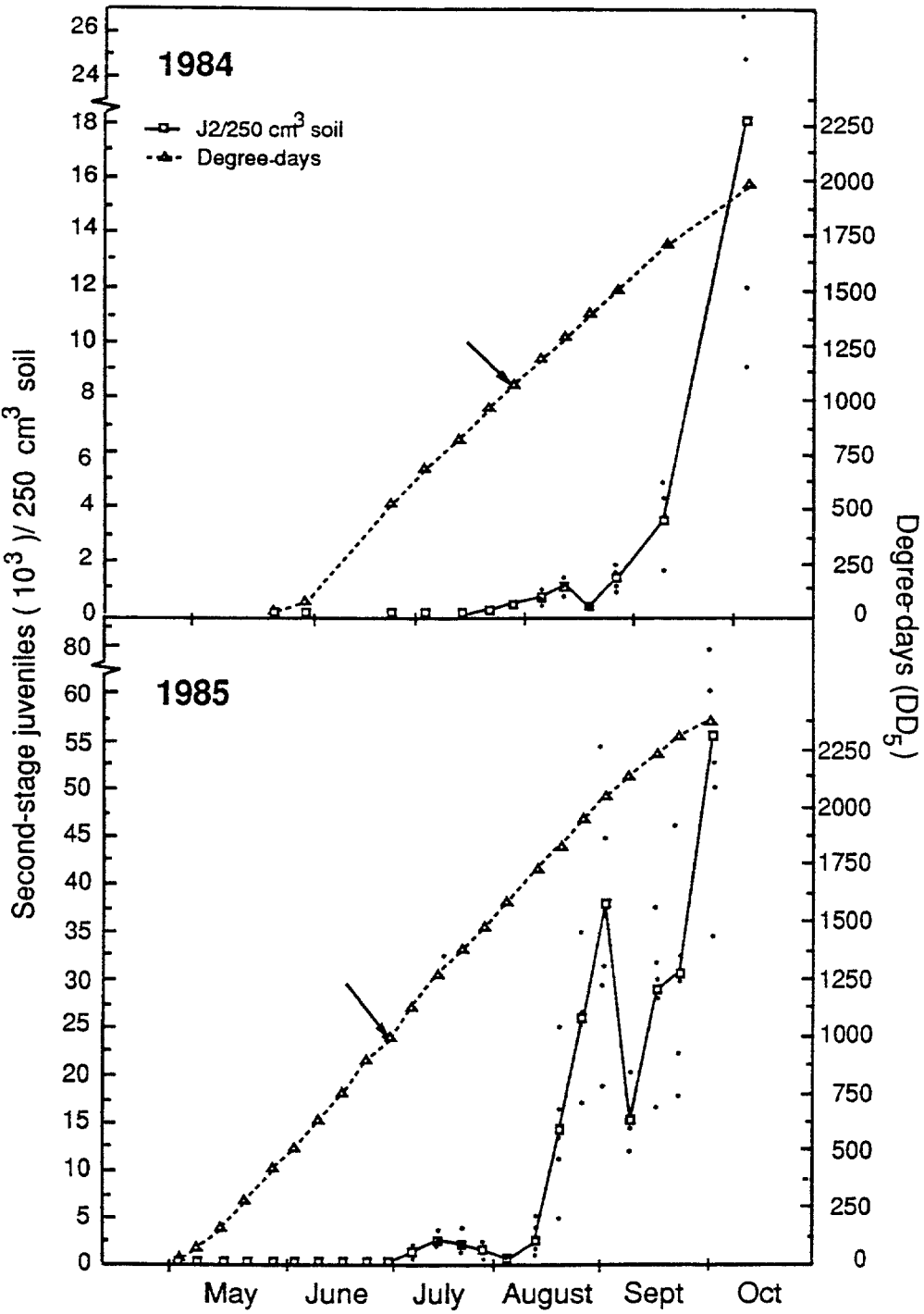

FIG. 4. Relationship between *Meloidogyne chitwoodi* population development and degree-day accumulation in Russet Burbank potatoes grown in microplots. Arrow indicates when J2 were first detected in tubers.

period when soil profiles were frozen 20–40 cm deep. Gradual cooling temperatures appear to acclimate *M. chitwoodi* to temperatures below 0 C, as observed with *M. incognita* and *M. hapla* (20).

Our studies showed that overwintering populations of *M. chitwoodi* penetrated roots shortly after planting and produced eggs at 600–800 DD_5. Second generation J2 hatched at 950–1,100 DD_5 and third generation J2 hatched at 1,500–1,600 DD_5. In the 1985 microplots, the fourth generation hatched after 2,150 DD_5. Given that roots must develop from the seed pieces before overwintering J2 can begin to mature, approximately 1,000 DD_5 are required to complete the first generation, whereas subsequent generations require 500–600 DD_5. These data support other laboratory (2) and field (6) studies. The consistent potato tuber damage each year in eastern Washington commercial fields can be explained by the annual accumulation of 2,000 or more DD_5, compared to that recorded in cooler regions in southern Idaho (6) and Colorado (15) where *M. chitwoodi* is less damaging. Approximately 2,700–2,900 DD_5 were accumulated in eastern Washington during the 1987 growing season, which resulted in at least four generations and greater nematode damage (Santo, unpubl.).

In our study, the population increase was not continuous, but showed bimodal or trimodal patterns. If the majority of overwintering eggs hatched by early spring as reported with other *Meloidogyne* spp. (19), a uniform-aged cohort would develop in the plant roots. Overwintering J2 unable to penetrate the roots would die and nematode densities in the soil would decline after planting as observed in our studies. The rapid increase in J2 densities in the soil corresponded to the hatch of eggs from the previous generation. The intervening periods of stable J2 densities suggest reduced oviposition or egg hatch. In a study with *M. arenaria* on six grape cultivars, Ferris et al. (4) proposed that the general relationship between cumulative egg production and elapsed DD_{10} was linear between 100 and 500 DD_{10}, after which egg production ceases. They hypothesized that individual females have fixed reproductive potentials and that eggs are produced more rapidly on good hosts. Although fecundity was not directly measured in our study, the discontinuous population pattern suggests that the *M. chitwoodi* fecundity period on Russet Burbank potato, an excellent host, was shorter than the generation period or that fecundity declined as females aged.

Overwintering J2 present in the soil from planting until mid-season did not penetrate the developing tubers and fewer than 25% were able to infect bioassay plants at planting. These J2 may have been active in the soil for months before planting, depleting their energy reserves and becoming noninfective. We have also observed that J2 of *M. chitwoodi* do not penetrate young tubers unless wounds are present or lenticles are fully developed (Mojtahedi, unpubl.). In this study, J2 were recovered from tuber tissues upon hatch of the second-generation eggs at 1,000 DD_5. The pattern of tuber penetration by J2 corresponded with the flush of J2 from each generation's egg hatch. As observed by Finley (5), tuber penetration in our study continued to increase into the third generation until the tuber epidermis suberized after which few J2 penetrated.

Several strategies based on degree-days accumulated may be used to mitigate crop loss. Nonfumigant nematicide applied at 900–1,000 DD_5 would prevent second-generation J2 penetration of the roots and tubers, thus reducing tuber damage and restricting third-generation inocula production. Field trials have demonstrated that in-season applications of ethoprop can significantly reduce nematode damage of tubers (12). A second approach would be to reduce the number of degree-days the crop is in the ground by harvesting early, before nematode inoculum density increases to damaging levels. In eastern Washington State, early potato varieties, which are harvested before 1 August, are generally not seriously damaged by *M. chitwoodi*. How-

ever, in years with an unusually warm spring, such as observed in 1987, severe damage still could occur. Degree-day monitoring and in-season nematode sampling should be valuable tools for developing either of these strategies.

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