

AN ABSTRACT OF THE THESIS OF

Jan-Marie Schroeder for the degree of Master of Science in  
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Title: Population Dynamics, Distribution, and Control of Nematodes  
in Highbush Blueberries.

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Fluctuations in population density of Pratylenchus sp.,  
Trichodorus sp., and Xiphinema americanum s. l. in three blueberry  
fields were determined monthly for one year. Pratylenchus densi-  
ties were greatest in August and least in October. Three distinct  
periods of population growth occurred; during January, April, and  
between June and August. Trichodorus populations were highest  
between February and April, and lowest in June. Xiphinema occur-  
red in only one of three fields sampled, with densities highest in  
May and lowest in August.

Root samples from blueberry plants, and soil samples from  
the rooting zone were taken in June of 1986 to determine hori-  
zontal and vertical distribution of Pratylenchus and Trichodorus

populations. Samples were taken at depths of 0-3, 3-9, and 9-15 inches at 6-18 and 18-30 inches from the base of the plant and within and between rows.

Pratylenchus densities at certain orientations depended on the distance from the base of the plant that the soil was sampled. Samples taken within the row were similiar at one and two feet from the base of the plant, whereas samples from between rows taken at one foot from the base of the plant were significantly less (22%,  $p < .10$ ) than those taken from two feet away. The presence of a living mulch between the rows may account for this difference.

Pratylenchus populations differed significantly with depth. There was little difference in density between 3-9 inches and 9-15 inches, but both differed significantly ( $p < 0.01$ ) from 0-3 inches. Densities were greatest below 3 inches.

Trichodorus densities depended on the distance the sample was taken from the base of the plant. At one foot from the base of the plant, the population was significantly greater ( $p < .01$ ) than at two feet.

The horizontal distribution of Pratylenchus and Trichodorus in a blueberry field was determined by sampling five rows of ten plants each, at a depth of 3-9 inches. Pratylenchus populations tended to be distributed in a clumped pattern. The mean population density of 50 samples was 270 Pratylenchus/ qt. soil and 42% of the 50 plants sampled were infested. In contrast, Trichodorus distribution was fairly uniform, with 74% of the 50

plants infested. The mean population was 253 Trichodorus /qt. soil.

Efficacy trials with fenamiphos (Nemacur 3E) indicated that the most effective rate for Pratylenchus control was 12 lbs. ai/A, which reduced populations by 95%. Fenamiphos was not an effective control for Trichodorus in this study.

Analysis of fenamiphos treated fruit from two Oregon and one Washington blueberry fields showed no detectable chemical residues for 6 or 12 ai/A rates at the spiking level of 0.1 ppm.

Population Dynamics, Distribution, and Control of Nematodes in  
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## TABLE OF CONTENTS

INTRODUCTION	1
The Blueberry Host Plant	2
Nematode Distribution	3
<u>Pratylenchus penetrans</u>	7
<u>Xiphinema americanum</u>	9
<u>Trichodorus christei</u>	14
Nematode Control in Highbush Blueberries	17
GENERAL MATERIALS AND METHODS	23
POPULATION DYNAMICS	27
Materials and Methods	27
Results and Discussion	32
DISTRIBUTION OF <u>PRATYLENCHUS</u> AND <u>TRICHODORUS</u> SP. IN BLUEBERRYFIELDS	60
Materials and Methods	60
Results and Discussion	64
CONTROL OF NEMATODES IN Highbush BLUEBERRIES WITH FENAMIPHOS	77
Materials and Methods	77
Results and Discussion	79
LITERATURE CITED	84
APPENDICES	90

## LIST OF FIGURES

### Figure

1. Mean 1985-86 bimonthly soil temperature at a depth of 8 inches from the Hyslop Farm near Corvallis, Oregon.	28
2. Average 1985-86 monthly rainfall for Corvallis, Oregon.	30
3. 1985-86 seasonal changes in <u>Pratylenchus</u> populations from three Oregon blueberry fields.	33
4. 1985-86 mean seasonal <u>Pratylenchus</u> population levels from three Oregon blueberry fields.	35
5. Affects of temperature on 1985-86 mean seasonal <u>Pratylenchus</u> population levels.	38
6. 1985-86 seasonal changes in <u>Xiphinema</u> population densities from site two.	44
7. Affects of temperature on 1985-86 mean seasonal <u>Xiphinema</u> population levels.	46
8. 1985-86 seasonal <u>Trichodorus</u> population densities from site one.	50
9. 1985-86 seasonal <u>Trichodorus</u> population densities from sites two and three.	52
10. 1985-86 mean seasonal <u>Trichodorus</u> population densities from three Oregon blueberry fields.	54
11. Affects of temperature on 1985-86 mean seasonal <u>Trichodorus</u> population densities from three Oregon blueberry fields.	57
12. Schematic representation of sampling regime for depth and distance study.	62
13. A three dimensional projection of the horizontal distribution of <u>Pratylenchus</u> in a western Oregon blueberry field.	71

14. A three dimensional projection of the horizontal distribution of <u>Trichodorus</u> in a western Oregon blueberry field.	73
15. 1985-86 mean soil moisture for a Salem, Oregon blueberry field (site one).	91
16. 1985-86 mean soil moisture for a Albany, Oregon blueberry field (site two).	93
17. 1985-86 mean soil moisture for a Peoria, Oregon blueberry field (site three).	95



## LIST OF TABLES

### Table

1. Nematodes associated with highbush blueberries.	4
2. Site Descriptions.	24
3. Mean population densities of <u>Pratylenchus</u> per quart of soil at different orientations and distances from blueberry plants.	65
4. Mean population densities of <u>Pratylenchus</u> per quart of soil at three depths.	65
5. Mean population densities of <u>Trichodorus</u> per quart of soil at different distances from the blueberry plant.	69
6. Effects of 1986 fenamiphos application on <u>Pratylenchus</u> densities (numbers per quart of soil) in a blueberry field.	80
7. Mean of post treatment <u>Pratylenchus</u> densities expressed as a percent of pretreatment densities.	80
8. Mean population densities of <u>Pratylenchus</u> /qt. soil at different depths, distances and orientations from a blueberry plant.	97
9. Mean population densities of <u>Trichodorus</u> /qt. soil at different depths, distances and orientations from the blueberry plant.	97

POPULATION DYNAMICS, DISTRIBUTION AND CONTROL OF NEMATODES IN  
HIGHBUSH BLUEBERRIES.

Jan-Marie Schroeder

INTRODUCTION

The cultivated highbush blueberry (Vaccinium corymbosum L.) occupies approximately 1200 acres in western Oregon, and 800 acres in western Washington. Commercial production of blueberries is a relatively new agricultural enterprise in the Pacific Northwest, with a high percentage of the acreage newly established and not yet in full production.

Recently, many northwest blueberry growers have indicated that they have experienced crop loss and lowered production in certain areas of commercial plantings. A 1982 study revealed that nine out of ten blueberry fields sampled in the Willamette Valley harbor plant parasitic nematodes. Similarly, nematode testing laboratories in the Pacific Northwest have received an increasing number of soil samples from blueberry fields that show relatively high populations of plant parasitic nematodes (personal communication, Gene Newcomb and Dr. Fred McElroy). Results of nematode tests in Willamette Valley fields demonstrate that Pratylenchus, Xiphinema, and Trichodorus are the most prevalent plant parasitic nematodes in the cultivated blueberry. A survey of 10 Oregon locations indicated that Pratylenchus spp. (root lesion nematodes) were most common, occurring in 6 out of 10 locations,

followed by Xiphinema americanum (Cobb) (dagger nematode), which were found in 4 out of 10 sites surveyed. Trichodorus spp. (stubby root nematodes) occurred in 3 out of 10 locations (6).

Presently, very little information on the distribution, interaction and control of nematodes in highbush blueberries exists. There is no available data from the Pacific Northwest. Furthermore, there is no registered chemical control for nematodes in established highbush blueberries. Increased awareness of high nematode populations in northwest blueberry fields has prompted grower support for research on the biology and control of nematodes.

#### THE BLUEBERRY HOST PLANT

The highbush blueberry plant is a perennial, long-lived, deciduous woody shrub, which stands 5-10 feet tall at maturity. Maturation and full production is usually reached about 6-8 years after planting. Like other plants in the family Ericaceae, blueberries thrive on an acidic soil, with optimum pH ranging between 4 and 5 (8).

The highbush blueberry is a shallow-rooted plant, characterized by a lack of root hairs and consequently a requirement for high soil moisture. The walls of the epidermal cells of the blueberry root are thick, (1.3 $\mu$  to 2.5 $\mu$ ) compared to those of root hairs which measure one-fourth to one-sixth as thick. Therefore, even though the blueberry roots are fine and numerous, the absorbtive capacity is small. A section of a blueberry rootlet

having no root hair presents about one-tenth of the absorbtive surface of an equal area of a wheat rootlet bearing root hairs. Furthermore, the blueberry root grows only about 1 mm. per day under favorable conditions, while a wheat rootlet often grows 20 times as fast (7). These factors cause blueberry plants to be greatly affected by root injury because of the reduction in water and nutrient uptake to an already needy plant and the inability to regenerate roots quickly.

The majority of Northwest blueberries are grown on organic (peat or muck) soils, and more recently, mineral soils. This recent move to mineral soils seems to be accompanied with an increase in nematode problems (Fred McElroy, personal communication). Common cultural practices by blueberry growers include incorporation of sawdust into the planting row prior to planting two to three-year-old bushes. The majority of growers use a 3 to 6 inch sawdust mulch to conserve moisture, aid in weed control and increase acidity.

#### NEMATODE DISTRIBUTION

Plant parasitic nematodes have been reported in blueberries since 1955 (15) and several species have been extracted from the roots and associated soil around wild and cultivated blueberries. (Table 1.)

The Pacific Northwest climate and soils west of the Cascades are very favorable for nematode growth and reproduction. The mild

Table 1. Nematodes Associated with Highbush Blueberries\*

<u>Name</u>	<u>Location</u>
Aphelenchoides sp.	MA, NJ, MD, RI
Aphelenchus sp.	MA, NJ, PA
Aporcelaimus sp.	MA
Atylenchus decalineatus	NJ, MA
Criconemoides sp.	NJ
Diptherophora sp.	RI, MA
Ditylenchus sp.	NJ, MD, RI, MA
Dolichodorus heterocephalus	NJ
Dolichodorus sp.	NC
Dorylaimoides sp.	MA
Dorylaimus sp.	MA
Helicotylenchus goodeyi	NJ
H. erthyrinae	NJ
H. nannus	NJ
Helicotylenchus sp.	MD, NC
Hemicycliophora gracilis	NJ
H. similis	NJ
H. uniformis	NJ, MA
Hemicycliophora sp.	MA, NJ
Heterodera trifolii	OR
Hoplolaimus tylenchiformis	NJ
Hoplolaimus sp.	MD
Meloidogyne sp.	NJ, MA, NC
Meloidodera floridensis	NJ
Paratylenchus projectus	PA
Paratylenchus sp.	RI, MA, OR
Paurodontus sp.	NJ
Pratylenchus penetrans	PA, NJ, OR
Pratylenchus pratensis	PA
Pratylenchus sp.	MA, RI, MD, NJ, OR, WA
Psilenchus	NJ
Rotylenchus robustus	NJ
Tetylenchus joctus	NJ
Tetylenchus sp.	MA, NJ, MD, NC, OR
Trichodorus aequalis	NJ
T. christei	NJ, MD
T. nanus	MD
Triplonchium sp.	MA
Tylencholaimus sp.	MA
Tylenchorhyncus claytoni	MA

Tylenchus sp.  
Xiphinema americanum

NJ, MA  
NJ, MD, MA, OR, WA

\* Primary references: 5,13,19,25.

winters accompanied with the winter weed cycle make it possible for certain nematode species to reproduce all year round (Gene Newcomb, personal communication). Thus, there is a greater potential for nematode infestation of blueberries in the Pacific Northwest than in other areas of blueberry cultivation. Therefore, results from eastern regions should be interpreted with caution when extrapolated to the west.

High populations of three nematode genera have repeatedly been reported in western Oregon and Washington blueberry fields. Pratylenchus spp. has been reported in soil and root samples from the majority of blueberry growing areas (6,21,27,42,59,60) but its pathogenicity on blueberries in the eastern states has been questioned (20,31,40). However, continuous high populations, associated with blueberry decline and decreased production in Oregon and Washington, warrant further investigation in these areas.

The role of Xiphinema americanum as a virus vector in blueberries is established, although direct damage to blueberries in absence of the virus has not been documented (6,9,19) Trichodorus spp. have been reported in association with cultivated blueberries since 1955 (21) and wild blueberries since 1961 (20). Studies by Hutchinson et al (1960) and Zuckerman (1962) confirmed that growth of hardwood blueberry cuttings may be severely stunted when set in soil infested with T. christei (21,59). In Oregon, nurseries propagating blueberries have reported infestations of T. christei.

### PRATYLENCHUS PENETRANS

Pratylenchus penetrans was first identified as a plant parasite by Cobb in 1917. Numerous reports over the next 50 years, however, are ambiguous because the species of Pratylenchus is not always clearly identified. Some species of Pratylenchus are now recognized among the most serious root parasitic nematodes (46). P. penetrans occurs as an important plant pathogen in temperate zones throughout the world. Nearly 400 hosts have been described from six continents, with widespread injury and yield losses reported for many crops. P. penetrans is considered the most economically important plant parasitic nematode in the northeastern United States (26). Yorston considered it to be the most important plant parasitic nematode in Oregon due to its abundance, wide host range of economically important plants and interaction with disease complexes (58).

Pratylenchus penetrans is primarily a parasite of the root cortex, migrating through and between parenchyma cells and causing necrotic areas (26). These brown areas are visible on washed roots as minute lesions. Cell breakdown results from mechanical thrusting of the stylet and probable secretion of cell wall degrading enzymes. The extent of the host injury is dependent on the phenolic compounds of the root cells attacked or the plant's ability to synthesize phenols after injury. Oxidation of the phenols results in formation of a brown pigment that seems to deter movement of the nematode into the vascular tissue of the host (26).



The necrotic tissue of the lesions provide an ideal environment for many bacteria and fungi. Nematode injury is nearly always accompanied by secondary invasion of microbial pathogens. The diminished root system of infected hosts is inadequate to absorb sufficient water and nutrients causing the tops of infected plants to become stunted, chlorotic, and wilt readily (26).

Stunting of parasitized plants is often greater than would be expected from the amount of mechanical injury to roots. Growth reduction involves the entire plant so that the stem to root ratio is the same in healthy plants as in infected plants. Overall changes in the infected plant include loss of cation exchange capacity, increased water tension in stem and roots, and reduced phosphorus content (26).

Pratylenchus penetrans has been involved with a number of interactions with other plant pathogens including fungi, viruses and other nematodes. Reports demonstrate that P. penetrans does not alter resistance of tobacco to black root rot, but the pathogen Thielaviopsis basicola facilitated penetration of the roots by the nematode. Initial development of verticillium wilt in potatoes is more rapid when P. penetrans is present and there is a greater reduction in growth of celery infested with P. penetrans in natural soil than in autoclaved soil (26). In the Pacific Northwest, it is speculated that P. penetrans is a factor in the infection of blueberry roots with fungal pathogens of the *Phytophthora* root rot complex (Ralph Garren, personal communication).

Pathogenicity is often related to population fluctuations

regulated by soil and climatic factors. The size and pathogenicity of the overwintering population are of particular importance when making predictions of crop damage. There is also a direct effect of soil moisture and temperature on pathogenicity of individual populations (26).

Soil type regulates the moisture holding capacity of a soil, and therefore influences population growth and survival. P. penetrans survives best at high moisture tensions but the rate of population increase is best at moderate moisture tensions and least at very low or very high tensions. Nematodes survive tensions as high as pF 5.0 (100 bars), but death is rapid at pF 5.06. Penetration of roots is greatest at pF 1.8 to 2.5 (0.01 to 0.33 bars)(26).

Temperature has a major influence on the growth and reproduction of P. penetrans. The life cycle of P. penetrans is shortest (30 days) at 30°C, and longest (92 days) at 15°C. Individuals have survived for 120 days in culture. The exposure time necessary to kill 50% of the population is 742 days at 4°C, 1-7 days at -4°C, and less than four hours at -8°C (26).

#### XIPHINEMA AMERICANUM

The genus Xiphinema was first described by Cobb in 1913, when he suggested that it was an injurious plant parasite. Pathogenicity was not experimentally demonstrated until 1955 when White showed that root injury appeared on pine parasitized with X. americanum. Nematodes in the genus Xiphinema have long stylets, allowing penetration of many root cell layers while remaining

ectoparasitic in habit. They feed mainly on woody plants, and frequently on herbaceous perennials (22).

Xiphinema americanum is one of the most commonly found nematodes in the United States. Although it can attain very large populations in the field, it is very difficult to maintain in the greenhouse. Therefore, only minimal research has been completed on host parasite relationships. Populations of X. americanum have been reported to reach levels of 4000 per pint of soil in field conditions (22).

Very little is known about the life cycle of X. americanum. Flegg reported the period from egg to adult to be two to three years in Southeast England (13). In two separate investigations, it was found to have two distinct population peaks: one in early spring, and one in mid-late summer or in the late fall (22). From these reports it appears that X. americanum overwinters in the egg stage, while few other stages are present. The first peak appears as the rising temperature encourages maturation and hatching of overwintered eggs. There is a population decline in the warm months which may correspond with the exhaustion and senescence of the reproductive females and the growth and maturation of eggs. Decline may also be due to the presence of a gram-positive bacterium that is favored by high temperature and present in most populations of X. americanum. The second population peak corresponds with cooler temperature and the second egg hatch (22).

Conversely, Ferris reported that the population of X. americanum in a California vineyard is higher in the fall and

winter than in the spring and summer. As the soil moisture increases, the population of Xiphinema americanum also increases. Thus, he inferred that there may be a reproductive flush in the fall under field conditions. A late summer increase in population corresponding to the number of gravid females was reported by Norton in Iowa (11). Ogiga reported that nematode populations from orchard soils were highest in September, low in December, January, and February, and then increased to a peak in May. Populations decreased in June and July, but increased in August (37).

In a 1969 study of seven Xiphinema species in Israel, Cohn found no characteristic or consistent pattern to seasonal population fluctuations of any of the species studied. However, a peak in adult densities of most species occurs in May through July (4).

Vertical distribution of Xiphinema populations has been widely reported as well. Griffen and Darling recorded abundant densities above 25 cm. in summer and fall but only minor population densities occurred at depths of 25-50 cm. (61). Ponchilla reported that this nematode was most abundant in the upper 15 cm. of the soil. Ferris found the populations of X. americanum to be highest from the top 115 cm. of soil in the undisturbed area of the grape row. Vertical distribution studies of seven Xiphinema species in Israel revealed maximum population levels of all seven to be in the top 30 cm. of soil with decreasing numbers as depth increased. Proportions of adult females to juveniles for three

ubiquitous species were found to increase with increasing depth (4). Ogiga reported the highest Xiphinema populations to be at 60 cm. in October (37).

Soil type also has an effect on Xiphinema americanum populations. Cohn found a close relationship between distribution of five species of Xiphinema and soil type in Israel. Smaller species were found to inhabit heavier soils, whereas the lighter soils were occupied by nematodes with greater body volume. Cohn suggested that oxygen content and water-holding-capacity might determine the ability of a species of Xiphinema to survive (4). Thus, larger nematodes may require well aerated soils and be unable to survive in heavier clay soils. The relative decrease in surface area to volume ratio as nematodes increase in size, and the consequent reduction in cuticle area through which gases can diffuse presumably accounts for this occurrence (57). Likewise, Ponchilla found that air-filled pore space is important to the ecology of Xiphinema americanum. Nematode survival and migration was greatest in the soils having the largest amount of air-filled pore space. Nematodes migrated further and survived at a higher rate in silt loam and loamy sand soils, than in either silty clay or clay loam, presumably due to greater available pore space. He attributes the reductions in nematode movement and survival in silty clay and clay loam to the high percentage of organic matter, concluding that a naturally occurring toxin may be present in native soil organic matter (39).

Moisture also affects the survival of Xiphinema. Wide mois-

ture fluctuations are detrimental to population increase and survival while consistent, moderate moisture levels are favorable. In general, a soil moisture of 25%-80% is optimum (22).

Host nutrition may also influence population growth of Xiphinema americanum. After 90 days, the population of X. americanum is greater on alfalfa plants (Medicago sativa var. moapa) given complete fertilizer than on those to which added minerals are not supplied. However, while deficiencies of potassium, magnesium, and iron increased the number of adults, shortages of phosphorus and calcium did not (36).

The optimum pH range for X. americanum is 5.6-7.4. When soil pH is above or below optimum, oviposition ceases, and population densities are significantly lower (36). A recent nematode distribution study found X. americanum to be one of two nematodes most frequently found in soils with a pH greater than 6.0 (62).

The role of Xiphinema americanum as a virus vector has been reported for many years. Brice and Hart reported in 1959 that Xiphinema americanum transmitted Tomato Ringspot Virus (TomRSV) (62). In 1966, Teliz found that X. americanum can acquire the virus in one hour from mechanically inoculated cucumbers, and transmit the virus to healthy cucumbers within one hour after infection. There is no latent period in the vector and the virus does not pass through the egg or molt. Further, he reported that adults and three larval stages transmit TomRSV (48).

TomRSV was first reported on blueberries from Washington in 1972, and reported again from Oregon by Converse in 1982 (6).

Shoots of blueberry cultivars infected with TomRSV are usually dwarfed and plants in the field show stunting and have reduced numbers of leaves which are often small, necrotic and distorted (6).

Blueberry Necrotic Ringspot was first observed in 1955 and shown to be caused by a ringspot virus by Varney and Rainier in 1960. Subsequent work by Rainier (1963) in the United States, and Lister (1963) in Scotland determined that the tobacco ringspot virus was the causal agent (53). Converse was the first to report blueberry necrotic ringspot disease caused by Tobacco Ringspot Virus (TobRSV) in Vaccinium spp. from Oregon, although it is widespread in cultivated blueberry from the eastern United States (6).

Blueberries infected with TobRSV show stunting, twig dieback, and soon become unproductive. New leaves are chlorotic with necrotic spots, rings, and line patterns. Chlorotic areas become necrotic and drop out, giving a tattered appearance to the leaves. Severe affected leaves are often reduced in size and deformed (53). Different blueberry varieties have diverse reactions. Some show resistance or are symptomless. Susceptible varieties are underproductive, and losses due to blueberry necrotic ringspot disease may be severe in local areas.

#### TRICHODORUS CHRISTEI

The genus Trichodorus was first described by Cobb in 1913. The common name, stubby root nematode, was originally given by

Christie and Perry to the organism that stunted the roots of several Florida crops in 1951. Later that organism was found to be Trichodorus christei (22).

Although the genus Trichodorus has been reported from North America, Latin America, Europe, Africa, Asia, and the Pacific Islands, it is more commonly found in warmer tropical and subtropical regions (22).

Trichodorus christei is a polyphagous nematode. In one study it maintained populations on 42 of 46 plants tested. The plants represented 14 families including grains, legumes, ornamentals, and vegetables. A later report added 66 species to the host range (22). Ayala found that marked differences in host preference exist between isolates of T. christei. Out of 48 plant species from 16 families, one-half were considered excellent hosts of one of the isolates, eleven were good hosts, eight were poor hosts, and five species were reported to be nonhosts (1).

In trichodorids, the feeding apparatus is in the form of a solid tooth, or onchiostyle, which is used to penetrate the epidermal cells of root tips. Secretions of esophageal glands are injected into the cell by pulsations of the bulb, and within a few seconds the cell contents are ingested. The onchiostyle is withdrawn and the nematode moves on to a new cell (62). Feeding occurs at the root tip and mechanical damage appears to be slight. The parasitized roots become stunted, with little or no necrosis or galling. Stunting is the most common above ground symptom. Significant reduction in top growth has been reported in



tomatoes, alfalfa, sugarcane, cranberry, onion, and other crops (22).

Trichodorus christei has a very short generation time. There are only three juvenile stages outside the egg. Therefore, the life cycle is rapid, taking only 21-22 days at 22°C, and 16-17 days at 30°C. The life cycle is not completed at 20°C or 35°C (22).

Ayala reported that temperature is one of the most important ecological factors in nematode reproduction. He demonstrated the optimum temperature for T. christei reproduction to be between 16°C and 20°C, whereas Malek, Jenkins and Powers considered 25°C to be optimum (1).

Fertilizer applications are consistently associated with a decrease in numbers of T. christei and parasitized root tips, as well as increased root growth. Ayala reported population increases with fertilizer concentrations as high as 50% (Hoagland's nutrient solution), but higher fertilizer decreased numbers while plant vigor increased. Populations of T. christei were low on plants given 100% Hoagland's or water alone (1).

Trichodorus species have been reported to inhabit soil at greater depths than most nematodes. Brodie found T. christei at all depths sampled up to 105 cm., with the greatest population densities at 30 cm. Above and below this depth, significantly lower densities occurred. The highest population densities are found during December through March, when the soil temperature at 30 cm. is 11-17°C and the moisture is 18-23%. Further, Brodie concluded that soil temperature, texture, and moisture exert a marked in-

fluence on vertical distribution of this nematode (2). Conversely, Minton and colleagues found that rainfall and population size of T. christei were not closely related (22).

Studies on blueberries indicate that T. christei feeds readily on the roots of seedlings grown in vitro (59). It is reported to be one of the most damaging nematodes to blueberries (42) and cuttings are severely stunted when the soil is infested with T. christei. Zuckerman concluded from his work on blueberries that T. christei would probably not reduce vigor and productivity of large bushes. However, plants that have limited root systems from other factors, such as poor drainage or additional nematode infestations, may be susceptible to T. christei damage (59).

## NEMATODE CONTROL IN Highbush BLUEBERRIES

### Chemical Control

Presently there is no registered chemical control for nematodes in established highbush blueberry plantings. Preplant soil fumigants such as dichloropropene, methyl bromide, chloropicrin, and combinations of these chemicals are available, but because blueberries have a very long life span (up to 50 years), nematode populations may increase to problem levels during the lifetime of a planting. The recent registration in Oregon of dazomet (Basamid) provides spot treatment for problem areas if infected plants are removed, and roots to surrounding plants are severed.

Fenamiphos (Nemacur) was synthesized by Farbenfabriken Bayer

GmbH, Leverkusen, West Germany. It is a tan, waxy, solid with a melting point of 40°C. It has a high mammalian toxicity; the acute oral LD (rat) is 8.1-9.6 mg./kg. and the dermal LD (rat) is 72-84 mg./kg. (2). Initial screening indicated excellent activity against various species of nematodes. Mobay Corporation conducted the first tests in the United States and obtained the first registered use of Nemacur in the United States for turf in 1973 (35).

Nemacur has been tested on nematodes from several field, vegetable and fruit crops. Nematicidal activity has been reported against endoparasitic, ectoparasitic, cyst forming, and root-knot species belonging to the genera Belonolaimus, Criconemoides, Helicotylenchus, Hemicycliophora, Heterodera, Meloidogyne, Paratylenchus, Pratylenchus, Radopholus, Rotylenchus, Trichodorus, Tylenchorhynchus, Tylenchulus, and Tylenchus. Nemacur offers some advantages over other nematicides. It moves readily into the root zone with rain or irrigation, and is more effective in wet soils than fumigant nematicides because of its solubility in water. Nemacur has few reported phytotoxic affects on plants. Vegetable, field and fruit crops have not been injured by applications at several times the effective nematicidal rates (35). Nemacur is easily applied by common farm equipment and the cost of application is much lower than for most fumigant nematicides.

Raski reported that fenamiphos is degraded in all biological systems to relatively nontoxic end products that do not accumulate in the environment. The length of time it remains active in the

soil is dependent on a number of interrelated conditions including soil moisture, temperature, cultural practices, and application rates. The half-life of fenamiphos is three to six weeks, and, in general, chemical residues are very low (41).

In addition to direct nematicidal activity, fenamiphos also effects enzyme activities associated with plant growth. Pineapple roots sprayed with fenamiphos showed inhibition of peroxidase (PO) and indoleacetic acid (IAA) oxidase activity (34). When applied to citrus stems, an increase in length and weight of aerial parts, as well as an increase in root weights occurred with the reduction of nematodes (47). It has been suggested that reduced IAA oxidase activity in fenamiphos treated plants may increase the availability of IAA, resulting in growth stimulation beyond that associated with nematode control (34).

#### Cultural Control

The use of a living mulch between the rows of blueberries has become a common cultural practice in many Oregon fields. It helps to control erosion and increases accessibility to the fields during the winter months when the soil is wet and muddy. Living mulch can also be an excellent barrier for controlling nematodes if a poor host or nonhost species is used. A vigorously growing cover crop can become the dominant cover species, excluding weeds that become reservoirs of high nematode populations (25). The living mulch is commonly planted in the area between the blueberry rows and chemical suppression is used within the row to avoid compe-

tition between the cover crop and the blueberry plant. The use of a nonhost or poor host species would suppress nematode populations between plant rows and provide the crop plant more root area.

Marks et al found (29) that the most important factor in controlling Pratylenchus penetrans in orchard soils is the duration of weed control, rather than the weed control per se. Furthermore, they observed that clean cultivation actually increased P. penetrans populations in orchard soils. In general, practices that allow a temporary re-establishment of weed covers do not decrease Pratylenchus penetrans. Cultivation is usually too infrequent and the regrowth of weeds continues to maintain the nematode population. Herbicides which provide short term control, such as paraquat and glyphosate, are not as good as combinations that provide complete control. The greatest reduction in P. penetrans populations in peaches was obtained with a cover crop of red fescue (which is a poor host and a good ground cover for weed exclusion) between the rows, and an herbicide combination such as paraquat and linuron within the row.

Weed control should be paramount in fields that have an infestation of Pratylenchus penetrans. Townshend and Davidson found P. penetrans in the roots of 55 weeds and 7 cultivated plants from 52 genera and 23 families. Sixty-three percent of the weeds belonged to the families Compositae and Cruciferae (51). Yorston found that most plants are susceptible to P. penetrans infection. Common weed species in Oregon blueberries such as clovers, wild carrot, lambsquarter, and pigweed are excellent host plants for

P. penetrans (58).

McDonald and Mai (1963) found that Sudan grass (Sorghum vulgare var. sudanese) was a poor host for P. penetrans and grew vigorously enough to compete with weeds. However, Marks and Townshend (1973) observed that Sudan grass was a good host of P. penetrans and inferred that the race of the nematode and/or cultivar of the Sudan grass may have been a factor in the differences found. They suggested that creeping red fescue or perennial rye should be effective cover crops to reduce P. penetrans in orchard soils. Further, they concluded that perennial covers are better than annuals because large numbers of nematodes migrate to the crop plant after the annuals mature (30).

Townshend et al (1984) screened 18 turfgrasses for repression of Pratylenchus penetrans. Eight weeks after inoculating 500 nematodes per pot, populations varied from 230 nematodes per pot on Agrostis alba L., to 1800 per pot on Poa trivialis L.. In cover crop trials with selected grasses in the field tall fescue and creeping red fescue, Festuca rubra L., were more effective at suppressing nematodes than Kentucky bluegrass, Poa pratensis L., and orchardgrass, Dactylis glomerata L.. Over a five year period, tall fescue, Festuca arundinacea (Schreb.), as a grass cover had the lowest average nematode populations (50).

Another common cultural practice that may affect nematode infestation is the addition of sawdust to blueberry plantings. A 3-6 inch layer of sawdust mulch is commonly applied to blueberry plants for moisture retention and weed control. Addition of

certain organic amendments to the soil may reduce populations of P. penetrans (26,44). Szygiel demonstrated that addition of organic matter to pots containing P. penetrans was harmful to the nematodes under certain conditions, and reduced their pathogenicity (44). Additions to the soil of leaves or leaf extracts of pachysandra, geranium, sunflower, black oak, dogwood, or bean decreased numbers of P. penetrans (26).

The cultural practices implemented by the blueberry grower strongly affect the nematode environment. Various management systems such as drip versus overhead irrigation, weed control programs, soil and crop fertility procedures and use of living mulches need to be considered in an effort to design more effective control strategies. In addition, the distribution and population dynamics of nematode pathogens of blueberry must be better understood to optimize placement and timing of sampling and chemical application.

## GENERAL MATERIALS AND METHODS

### Introduction

Site characteristics are summarized in Table 2. Sites were chosen from a subset of blueberry fields known to be infested with plant parasitic nematodes from prior sampling. Selection of sites was based on the genera and density of nematodes present and the grower's willingness to participate in the study. Sampling areas within a given site were randomly sampled in a preliminary survey to locate areas of high nematode density. Blueberry plants sampled in the study ranged in age and variety, and cultural practices differed between sampling sites (Table 2).

### Estimation of Soil Populations

From each experimental plot consisting of one blueberry plant, four one inch diameter soil cores were taken to a depth of nine inches. Two cores were removed from within the row (one on each side of the plant), and two cores from between the rows (one on each side of the plant). All cores were taken at a distance of one foot from the base of the blueberry plant. The uppermost 3 inches from each nine inch core was discarded and the sample was then taken from the subsequent six inches of soil. If a sawdust mulch greater than 3 inches was present, the entire mulch was discarded, and the soil sample was taken from the adjacent six



Table 2. Site Descriptions

## I. Population Dynamics Sites

## A. Site One

Location: Approximately 5 miles north of Salem, Oregon  
 Soil Type: Woodburn silt loam  
 Acreage: >5 acres  
 Irrigation Method: Overhead sprinklers  
 Sawdust: None  
 Living Mulch: Between rows  
 Variety: Rubel (>7 years)

## B. Site Two

Location: Near Albany, Oregon  
 Soil Type: Coburg/Wapato silty clay loam  
 Acreage: <5 acres  
 Irrigation Method: Overhead sprinklers  
 Sawdust: 2-4" within row only  
 Living Mulch: None  
 Variety: Berkeley (>7 years)

## C. Site Three

Location: One mile east of Peoria, Oregon  
 Soil Type: Willamette silt loam  
 Acreage: >5 acres  
 Irrigation Method: Overhead sprinklers  
 Sawdust: 4-6" over entire field  
 Living Mulch: None  
 Variety: Herbert (> 7years)

## II. Residue Trial Sites

Site one and two above were used for residue trials. In addition, chemical applications were made at one Washington site.

## D. Site Four

Location: Near Battleground, Washington  
 Soil Type: Hesson clay loam  
 Acreage: >5 acres  
 Irrigation Method: Drip  
 Sawdust: None  
 Living Mulch: Between rows  
 Variety: Bluecrop (<7 years)

#### IV. Efficacy Trial Site

##### E. Site Five

Location: Near Cottage Grove, Oregon  
Soil Type: Unknown  
Acreage: <5 acres  
Irrigation Method: Drip  
Sawdust: 2-4" within row  
Living Mulch: None  
Variety: Olympia and Bluecrop (<7 years)

inches of soil. The four soil cores from each plot were bulked into one sample and sifted through a 5 mm. mesh screen to remove stones, large woody roots and debris. Fine, fibrous roots and soil were mixed thoroughly. A random subsample of 100 grams of wet soil and roots was processed from each sample by the Baermann funnel method 7 days to extract nematodes. Insufficient root biomass was obtained to extract soil and roots separately. Population estimates were determined by counting nematodes within half the area of a calibrated counting dish. Soil moisture was determined gravimetrically by weighing soil before and after drying at 100 C. Extraction efficiency was determined from the number of living nematodes that remained in the soil after Baermann funnel extraction by sucrose centrifugation with a pre-determined extraction efficiency of 66%. Each nematode sample was corrected for extraction efficiency and soil moisture and densities were adjusted to numbers per quart of soil as done routinely by the Oregon State University Plant Clinic Nematode Testing Service.

## POPULATION DYNAMICS

Seasonal population trends are an important first step in determining economic loss, optimum sampling procedures, and timing for control measures. In this study population dynamics of three plant parasitic nematodes were monitored monthly in three Willamette Valley blueberry fields. Data were utilized for predicting appropriate sampling times to maximize detection.

## MATERIALS AND METHODS

Two Linn county and one Marion county sites (sites one, two and three) were sampled between the 12th and the 20th of every month for one year. Ten plants were arbitrarily chosen in each field based on areas of the field that were known to have nematode populations from previous sampling. Soil and root populations were determined as described earlier.

Soil temperature and precipitation data were obtained from the Climatic Research Institute, Corvallis Oregon, as individual sites were not instrumented. Readings were taken at the Hyslop farm, five miles southeast of Corvallis, a relatively central location to all three sites. Mean semi-monthly soil temperature (at 8 inches) and monthly rainfall accumulation interpolated from daily measurements are presented in Figures 1 and 2.

The relationship between mean seasonal population densities and soil temperature was analyzed by multiple regression and

Figure 1. Mean 1985-86 bimonthly soil temperature at a depth of 8 inches from the Hyslop Farm near Corvallis, Oregon.

Figure 1.

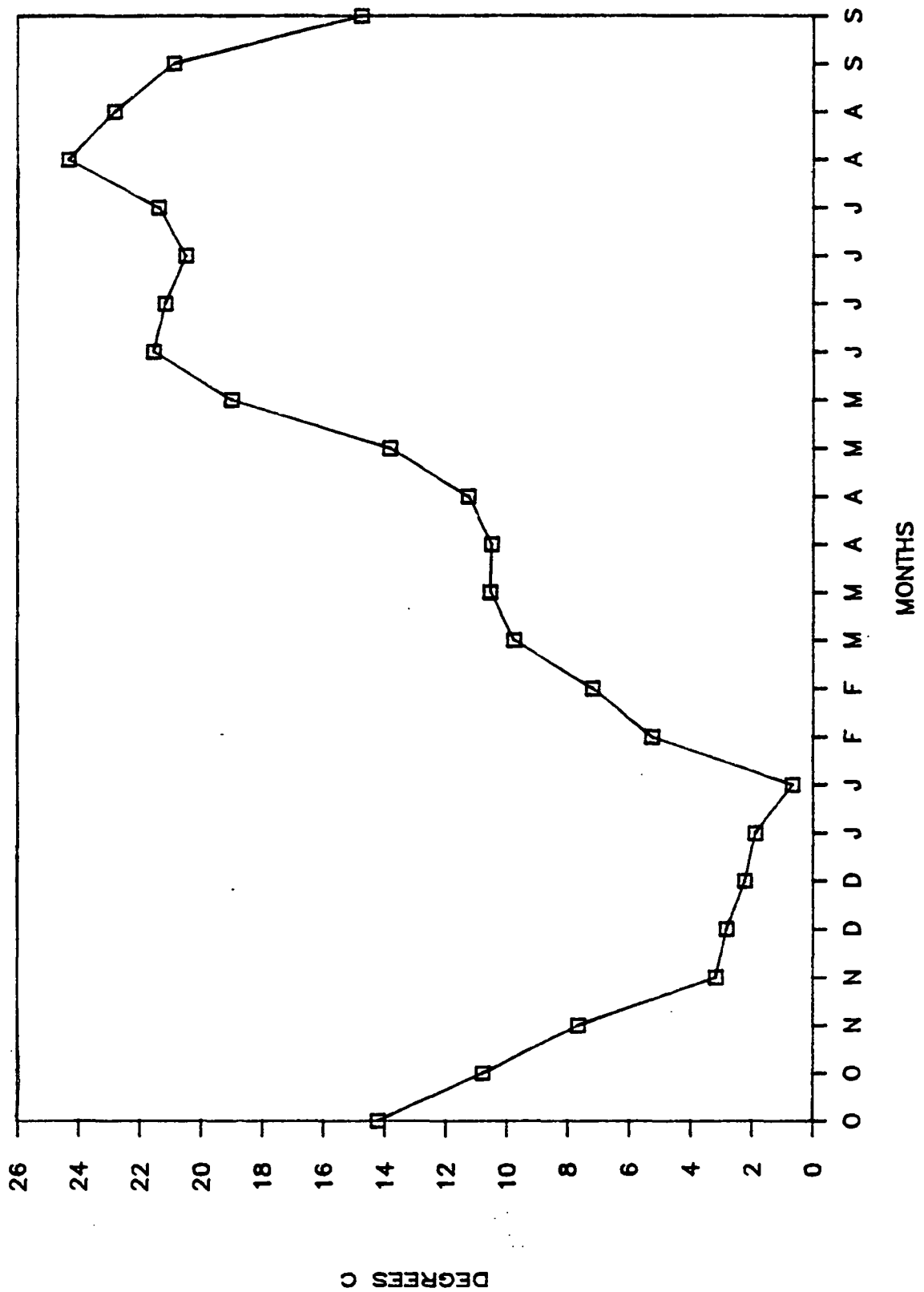


Figure 2. Average 1985-86 monthly rainfall for Corvallis, Oregon.

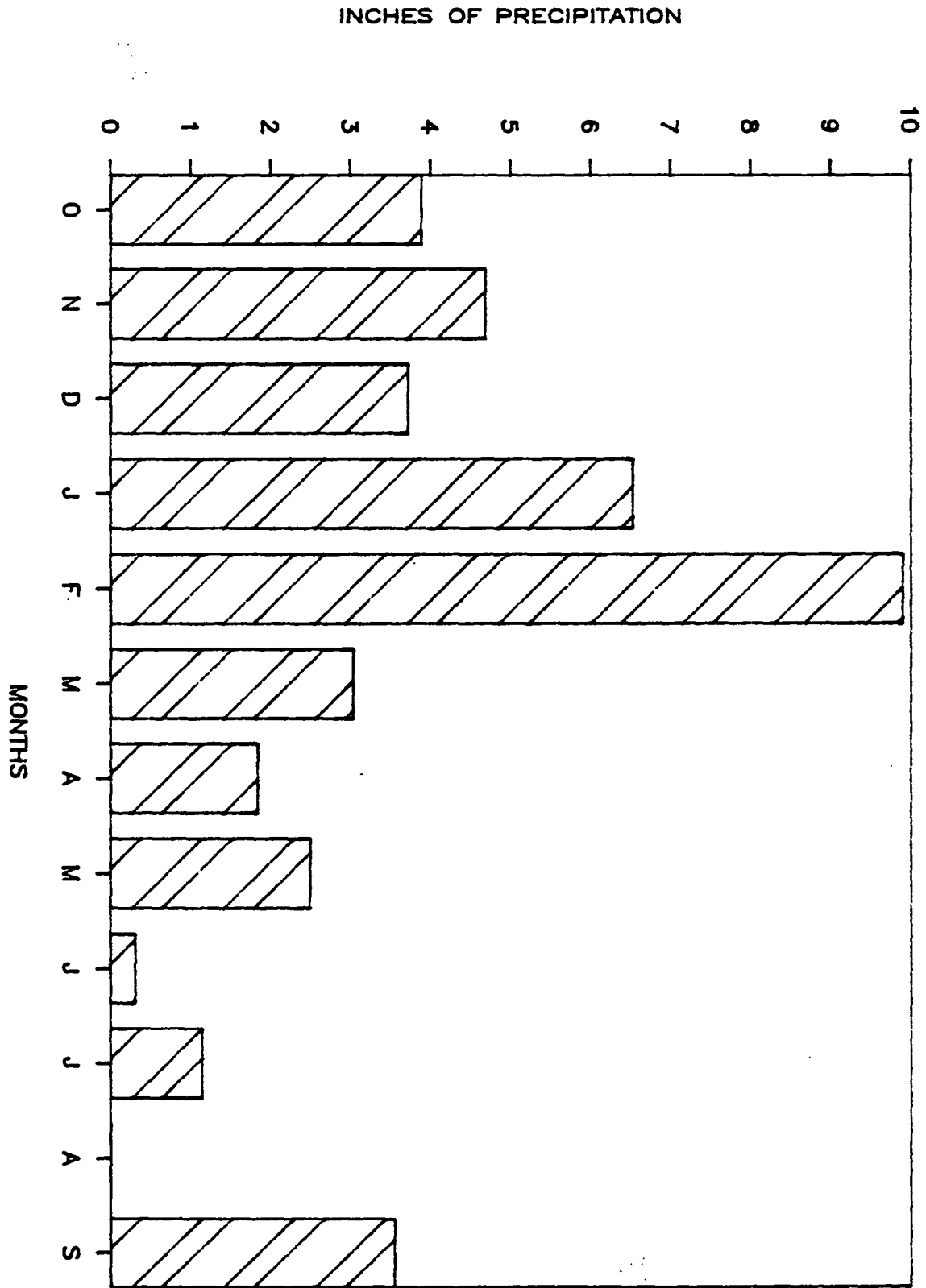


Figure 2.



ANOVA. No apparent relationship existed between rainfall and nematode population density.

## RESULTS AND DISCUSSION

### Pratylenchus

Two Pratylenchus species were identified from the three fields sampled. P. penetrans was present at site two, and P. crenatus was identified from sites one and three. Because of the difficulty of identifying Pratylenchus to species, only a limited number of individuals could be identified from each site. Therefore, it is possible that each site may harbor mixed cultures of both of these nematodes.

Pratylenchus population dynamics are shown in Figure 3. Three Oregon sites sampled were similar in their seasonal population fluctuations. The lowest population densities occurred from October through December at all sites followed by slight increases in densities during January. No great increase in population occurred until April. Site one tended to increase slowly from December to June, increase greatly in July and drop sharply in August. Site two populations increased moderately in April and July, but exhibited little change during the rest of the year. Pratylenchus in site three increased sharply in April and between June and July but populations dropped from 7900/qt. soil in August to near 2000/qt. soil in September. Mean population densities from 30 monthly samples taken from three sites are given in Figure 4. Overall there were three periods of population growth: during

Figure 3. 1985-6 seasonal changes in Pratylenchus populations from three Oregon blueberry fields.

□ = Site one

+ = Site two

◇ = Site three

# NEMATODE PER QUART SOIL (Thousands)

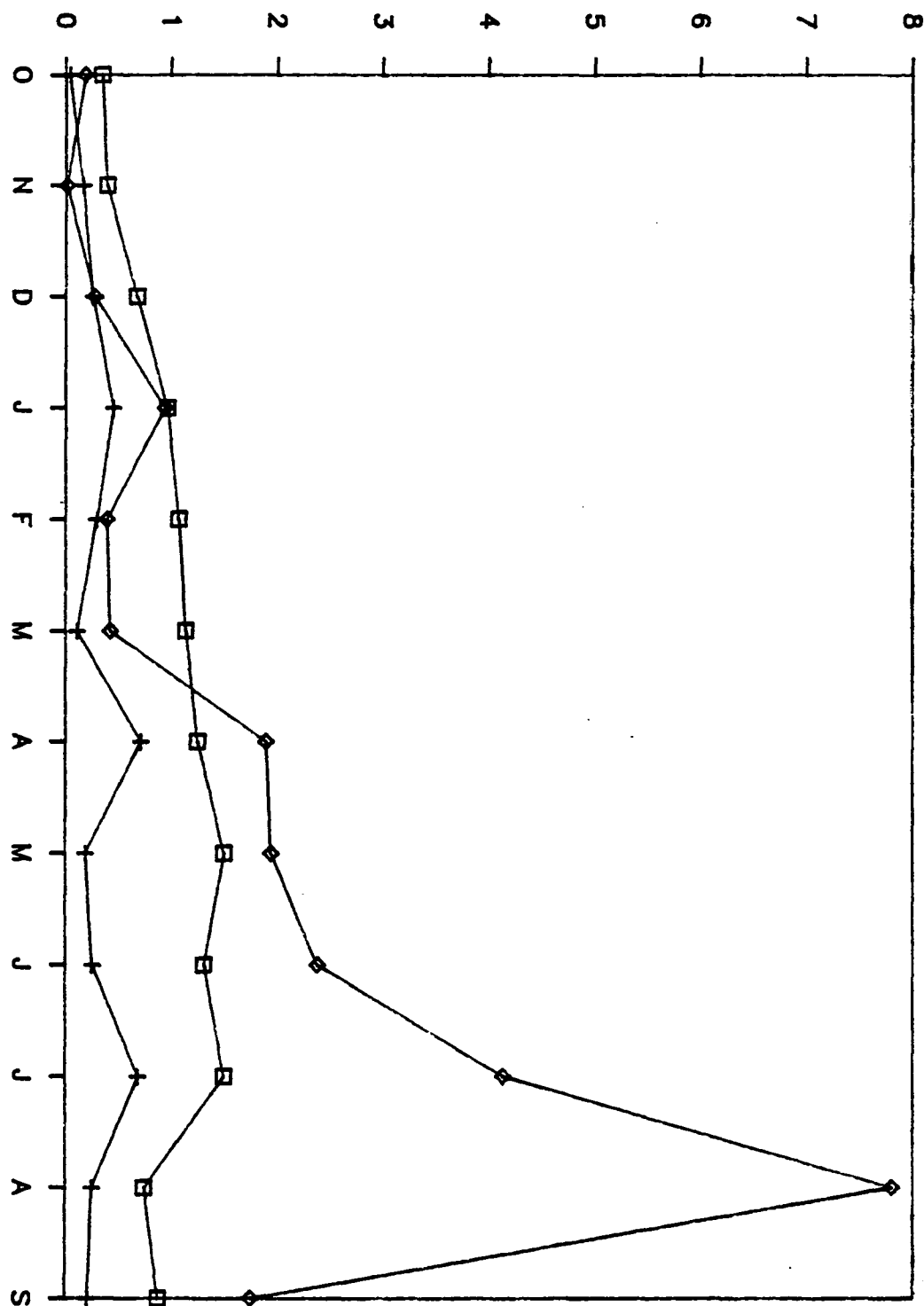


Figure 3.

Figure 4. 1985-86 mean seasonal Pratylenchus population levels from three Oregon blueberry fields.

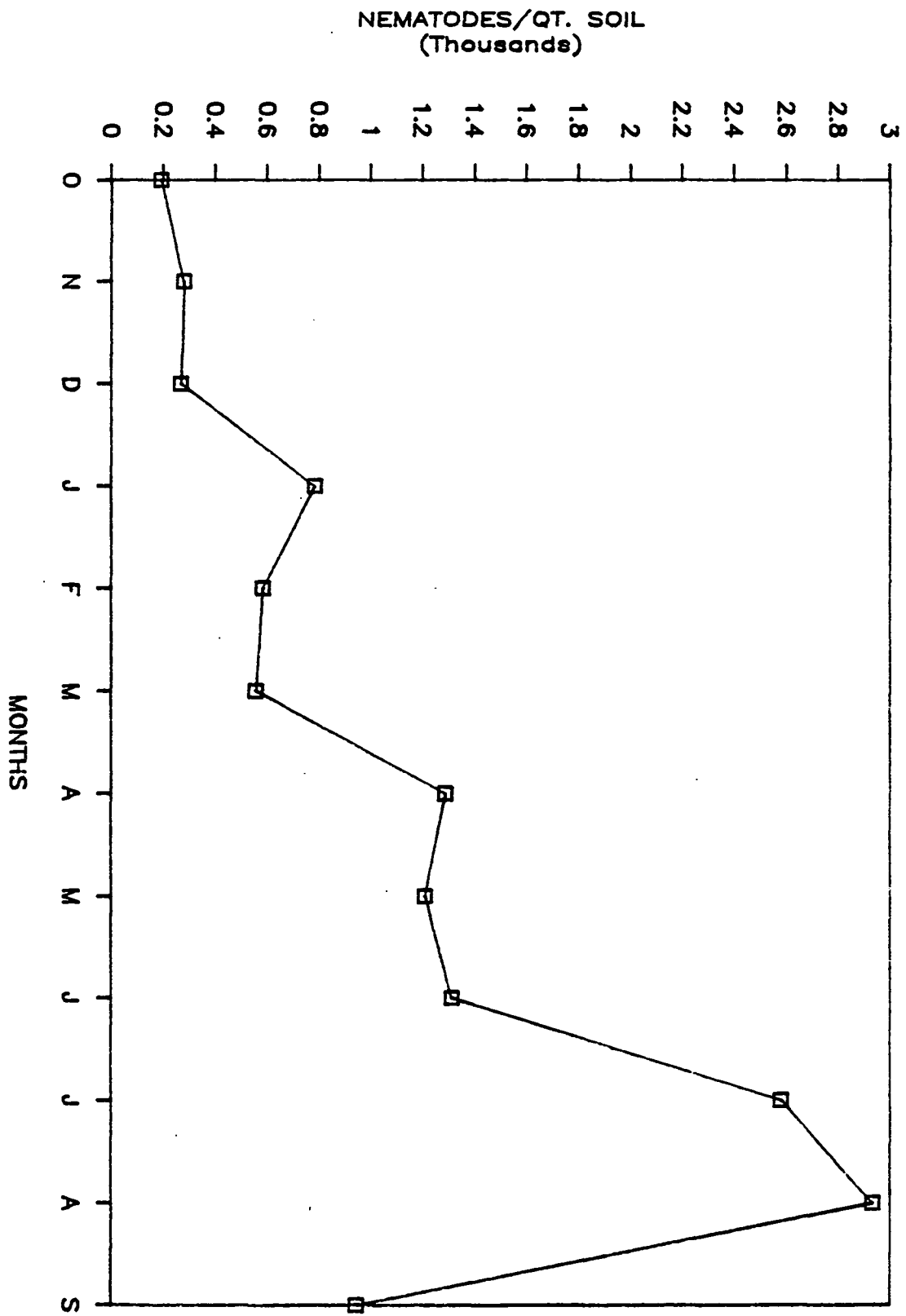


Figure 4.

January, April and between June and August. Maximum Pratylenchus population densities in July reached 2839 nematodes/qt. soil. Minimum densities of 200 nematodes /qt. soil were observed in October.

The relationship between nematode densities and soil temperature is presented in Figure 5. Regression analysis and ANOVA showed a significant positive correlation ( $p < 0.01$ ,  $R = .57$ ) between temperature and Pratylenchus densities.

Results of the present Pratylenchus population dynamics study are similar with those on other crops. Graham found that density of Pratylenchus in tobacco increases in the spring and summer to peak in August, followed by a sharp decline. In corn roots, a peak population occurs in September, while in cotton and crabgrass, the populations tend to increase until October (16).

Little is known about the fluctuations of Pratylenchus in perennial crops. Goheen and Williams found the maximum root population in bramblefruits to be the first of June, which they correlated with maximum root growth. During the summer there was a marked decline, with levels remaining low during fall and winter. A rapid increase in spring Pratylenchus densities correlated with plant growth (16). P. coffea densities in strawberries peaked in April and May followed by a decline in midsummer which continued to a low in the winter (38).

Populations of P. vulnus on peach were highest in the roots from November to May, but highest in the soil during April and May. P. zeae reached peak densities during April and May and

Figure 5. Affects of temperature on 1985-86 mean seasonal  
Pratylenchus population levels.

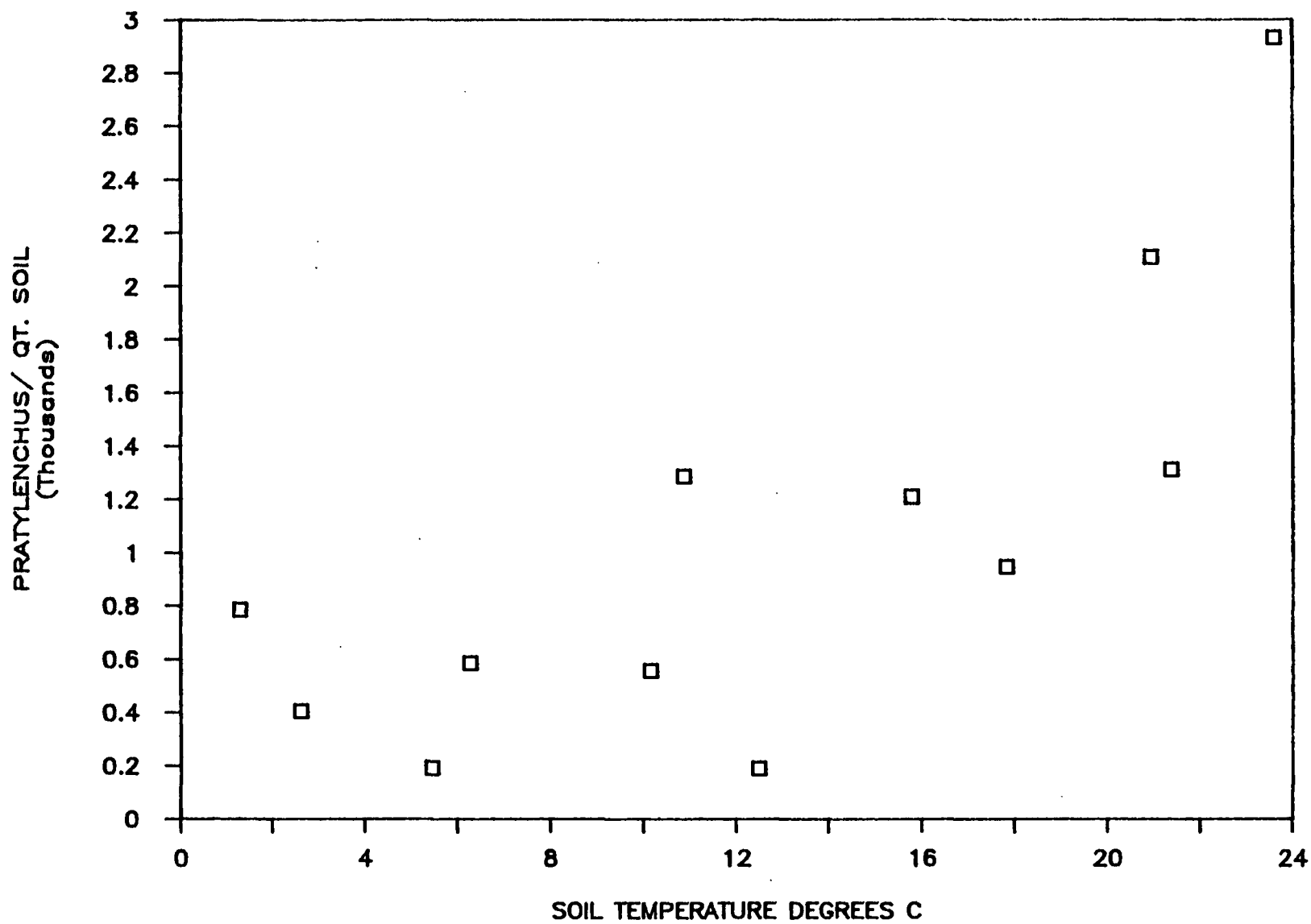


Figure 5.



again in August in the roots, but the highest soil densities occurred in April. Populations of soil P. vulnus often varied inversely with that of the roots (14). In apple orchard soils, the peak Pratylenchus populations occurred in June, followed by a sharp decline during July and a second peak in October (37). These earlier population peaks in other perennial crops are probably related to soil moisture availability and plant maturity. The current study on blueberries indicates that there was no correlation between Pratylenchus density and moisture. However, moisture levels in blueberries in the Pacific Northwest are kept relatively constant throughout the growing season from either overhead or drip irrigation. A general recommendation is two inches of water a week when natural rainfall is unavailable, usually June through October. Most blueberry growers continue to supply moisture after harvest until fall rains begin. Growers are encouraged to apply moisture more frequently than once a week, using small emitters to reduce the amount of water applied at one time. The result is a fairly constant supply of moisture, often with a 3-6 inch layer of sawdust mulch on the soil surface to reduce evaporation. Thus, soil moisture remains optimum in blueberries during the period of high soil temperature, allowing for maximum population growth of nematodes. Conversely, in other non-irrigated or occasionally irrigated crops there is a lack of soil moisture during the period when the soil temperature is most favorable for reproduction. Therefore, the highest population densities are found in the spring when moisture is available, but before temperature is

optimal.

Oostenick stated that although there is a linear relationship between the log of the initial population of P. penetrans and growth reduction in a crop host, the relationship varies greatly with crop, soil, year and other factors affecting the growth of the plant (58). Pinkerton stated that seasonal trends are the result of a complex interaction between soil moisture, temperature and host factors (38). Maniya reported that the life cycle of P. penetrans on seedling Cryptomeria is temperature dependent. A complete egg to egg cycle ranged from 80 days at 18°C to 30-31 days at 30°C (38). The present results on blueberries suggest that temperature affects population density of Pratylenchus (Figure 5), but it is also an important factor in the physiological condition of the blueberry. Density fluctuations of Pratylenchus coincide with seasonal temperature fluctuations which also regulate physiological events occurring in the blueberry plant. The first elevation in population began in late January when the soil temperature began to rise and the initial flush of root growth was probably occurring. A second population increase in April coincided with another rise in temperature during late April and May, and the period of bloom. The peak nematode population occurred when the plants were fruiting and the soil temperature was at the highest level in July. There was a sharp decline in nematode population and soil temperature in September which coincided with dormancy and a decline in root growth.

Differences in population density at individual sites was

probably the result of different cultural practices and site characteristics. The early increase in density at site one, compared to lower densities and stability at sites two and three in the early spring may have been related to the lack of sawdust at site one. Organic mulches tend to keep soil temperatures cool longer into the spring than exposed soil which will heat up earlier. Thus, sites two and three probably had less root development and lower soil temperatures until later in the spring. This would tend to slow plant growth causing flowering and fruitset to be later than plants without mulch.

Soil type exerts considerable influence on species distribution and population levels since nematode activity is restricted to soil water within soil pore spaces. Therefore, air-water relationships are important to nematode reproduction, mobility and survival. Several species of Pratylenchus are reported to reach higher densities in light sandy soils, yet other surveys find no correlation between distribution of Pratylenchus and soil type (22). Blueberries are often grown on heavier mineral soils. Results of this study indicate that the highest mean density of Pratylenchus occurred on the lightest silt loam soil (Willamette silt loam), followed by relatively high densities on Woodburn silt loam. The lowest densities occurred at site two on Wapato silty clay loam. This site often reached field saturation during winter rains.

Weed control practices seem to have very little effect on the population of nematodes at these three sites. Sites one and three

were extremely clean fields, with few weeds present. Site two had an abundance of weeds present in the field but had the lowest nematode population of the sites sampled.

The presence of a grass cover between the rows at site one is probably influencing the population of nematodes in the blueberry rows. Samples taken in the sod cover had high populations of P. crenatus which is known to be a grass parasite. The lack of any grass or weed species in site two indicates that this nematode may be a blueberry parasite as well. There is little known about the host range of P. crenatus in the Pacific Northwest. Future research on its pathogenicity and plant injury to the blueberry would be of great value.

### Xiphinema

Xiphinema americanum s. l. occurred only at site two. Seasonal sampling indicated that the highest Xiphinema densities occurred in May followed by a sharp decline from June to August (Figure 6). The lowest densities occurred in August followed by a small increase in September. Densities probably continued to increase slowly through the fall, although lack of sampling data during that time makes it difficult to know for certain. No linear relationship was found to exist between temperature and population density of Xiphinema in this study (Figure 7).

The results of the current study are most consistent with those reported in Southeast England which showed an initial peak in the early spring which was attributed to the maturation and

Figure 6. 1985-86 seasonal changes in Xiphinema population densities from site two.

Figure 6.

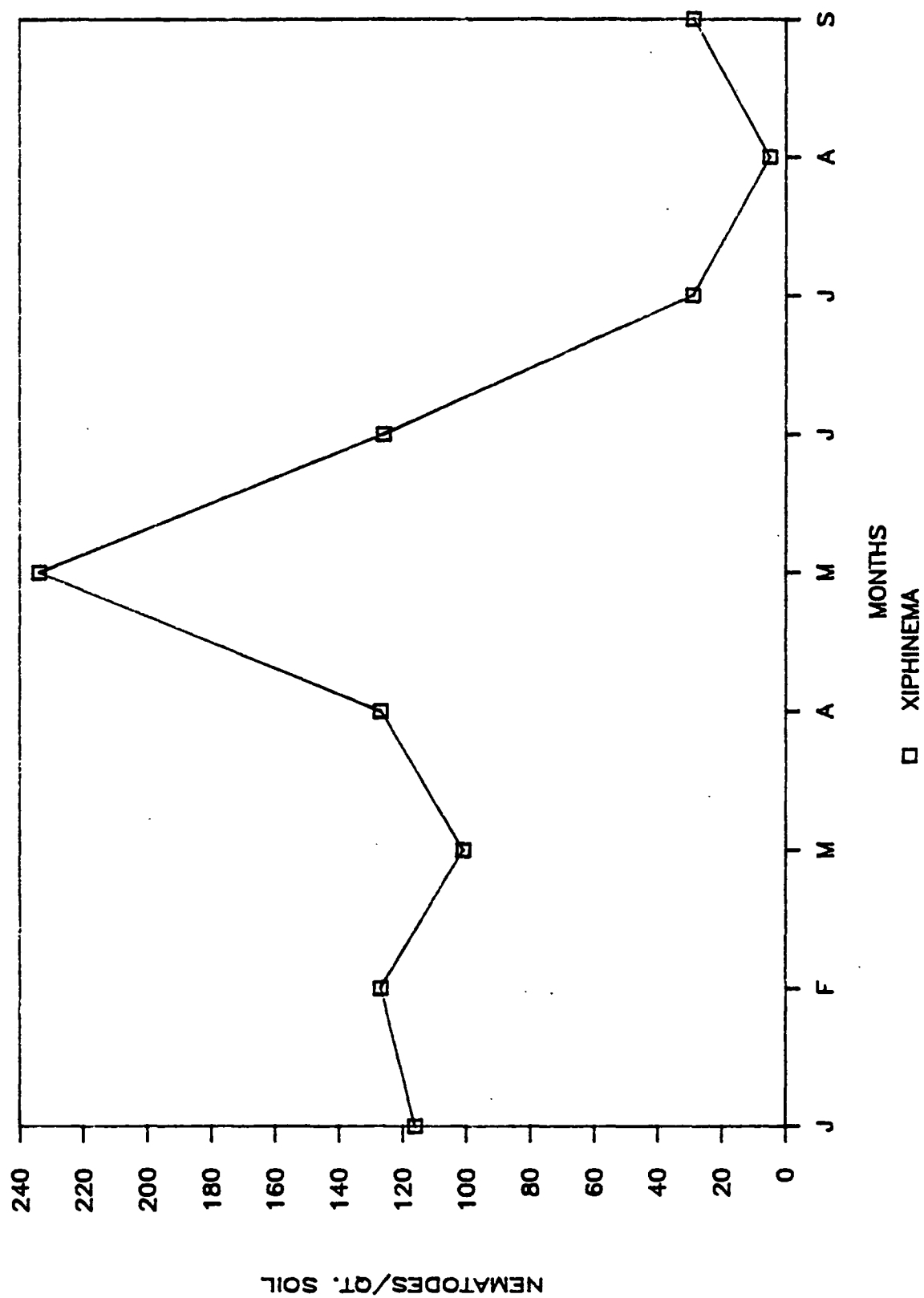


Figure 7. Affects of temperature on 1985-86 mean seasonal  
Xiphinema population levels.

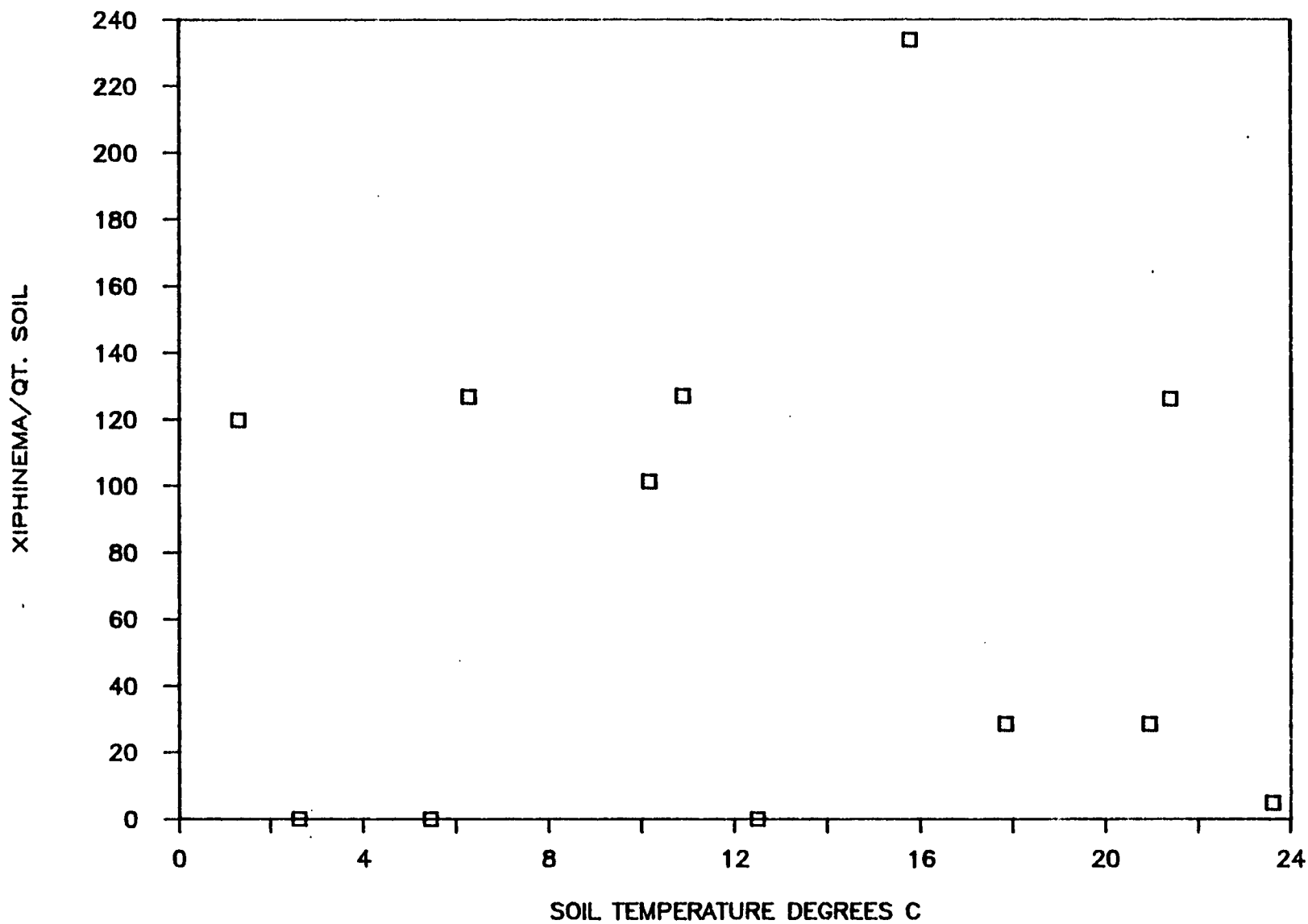


Figure 7.



hatching of the overwintered eggs. This was followed by a population decline in the warm months reportedly coinciding with the exhaustion and senescence of reproductive females. A second peak occurred in the late summer or late fall, and was attributed to the cooler temperatures and egg hatch (13). Similarly, the density of Xiphinema in blueberries declined in the warm months and began to rise again as temperatures cooled. The lack of data during the months of October through January makes it impossible to determine if and when a second population peak may have occurred in the fall or early winter.

In California vineyards, Ferris (11) found Xiphinema populations to be highest in the fall and winter when soil moisture is more optimum. Winter soil temperatures in Oregon blueberry fields are lower than in California. Therefore, population growth in Oregon is probably temperature limited in the late fall and early winter even though sufficient moisture is available. In Iowa, Norton found population peaks to be in late summer (11), while Ogiga reported that highest densities in orchard soils occurred in September followed by a decline during December through February, and an increase until May (37). Thus, results of this study on blueberries agree with results from other crops. However, since data are limited to one site they need to be interpreted with caution.

Contrary to Ponchilla's report on the importance of air-filled pore space to the ecology of X. americanum (39), site two consisted of a very dense clay soil. Of the area sampled,

Xiphinema density was greatest in the portion of the field which had the heaviest soil and was commonly water-saturated during the winter.

The moisture conditions of a blueberry field are favorable for supporting Xiphinema populations. Wide moisture fluctuations are detrimental to population increase and survival (22), therefore, the frequently irrigated blueberry field is a propitious environment. Likewise, the pH in Oregon blueberry fields (4.5-6.0) is often within the optimum range for Xiphinema (5.6-7.4), although it may fall lower. Thus, pH may be an important factor in Xiphinema density in a blueberry field.

#### Trichodorus

Trichodorus was present in all three Oregon blueberry fields sampled monthly for seasonal nematode populations, but only site two had sufficient densities to adequately study seasonal population dynamics. There was an increase in Trichodorus densities in all fields during the early spring and again in the early fall (Figures 8 and 9). A sharp increase in April at site two is inconsistent with data from the other two sites (Figure 9). Trichodorus densities were lowest at all three sites during June and November.

Mean population densities determined from averaging the monthly samples for all three sites, indicate two distinct peaks (Figure 10). The greatest population densities occurred between January and March, followed by a dramatic decline in densities

Figure 8. 1985-86 seasonal Trichodorus population densities from site one.

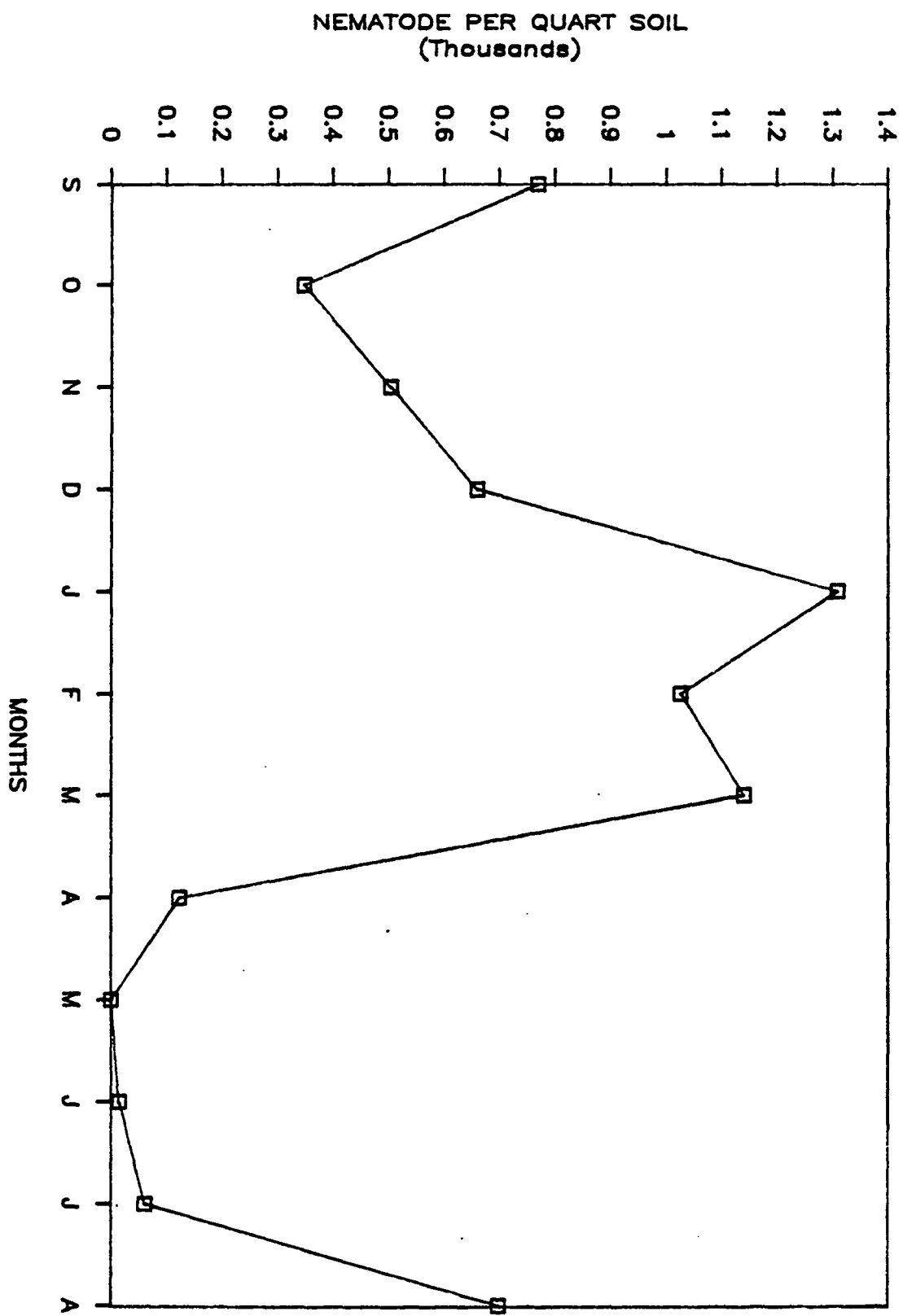


Figure 8.

Figure 9. 1985-86 seasonal Trichodorus population densities from sites two and three.

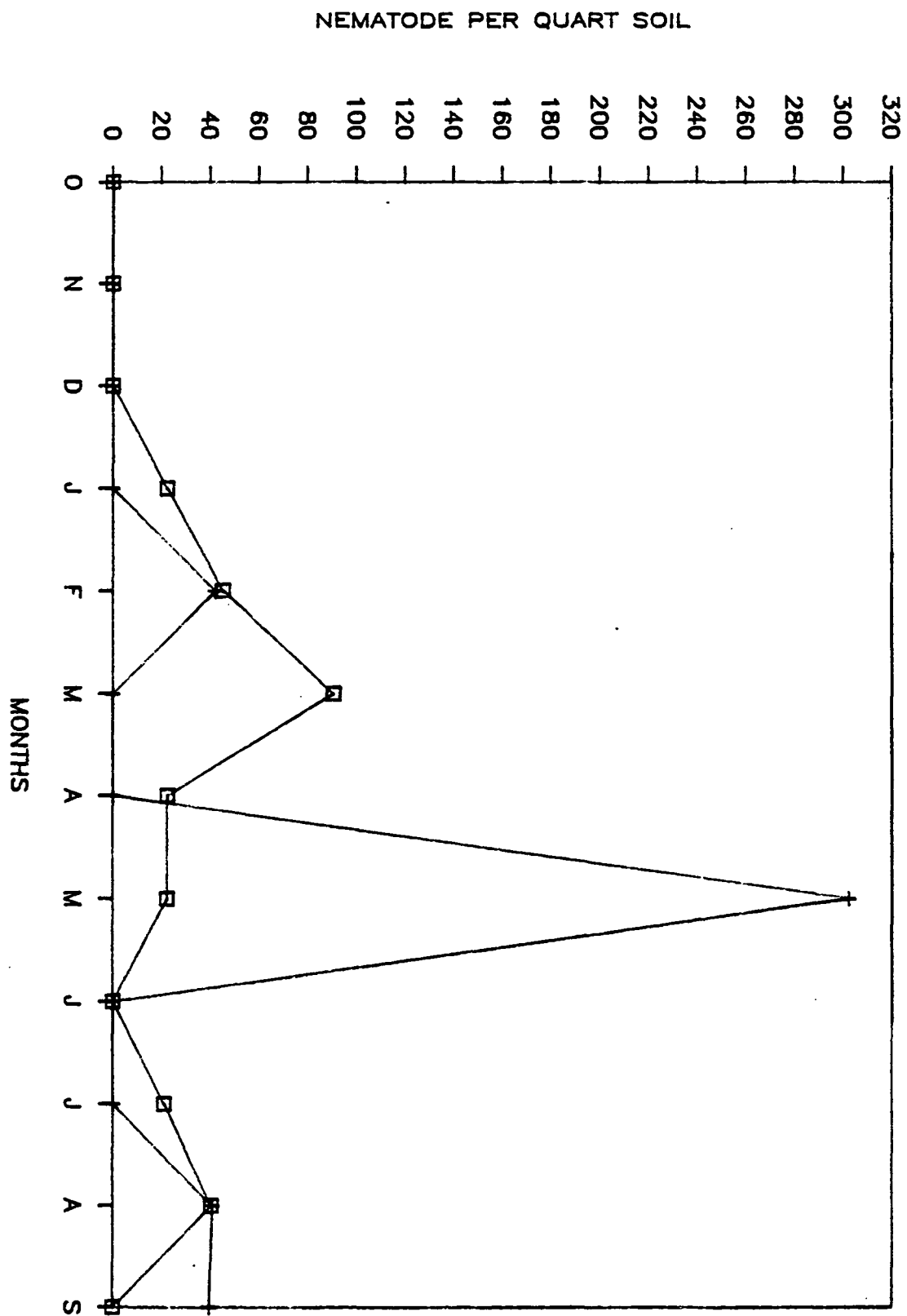


Figure 9.

Figure 10. 1985-86 mean seasonal Trichodorus population densities from three Oregon blueberry fields.

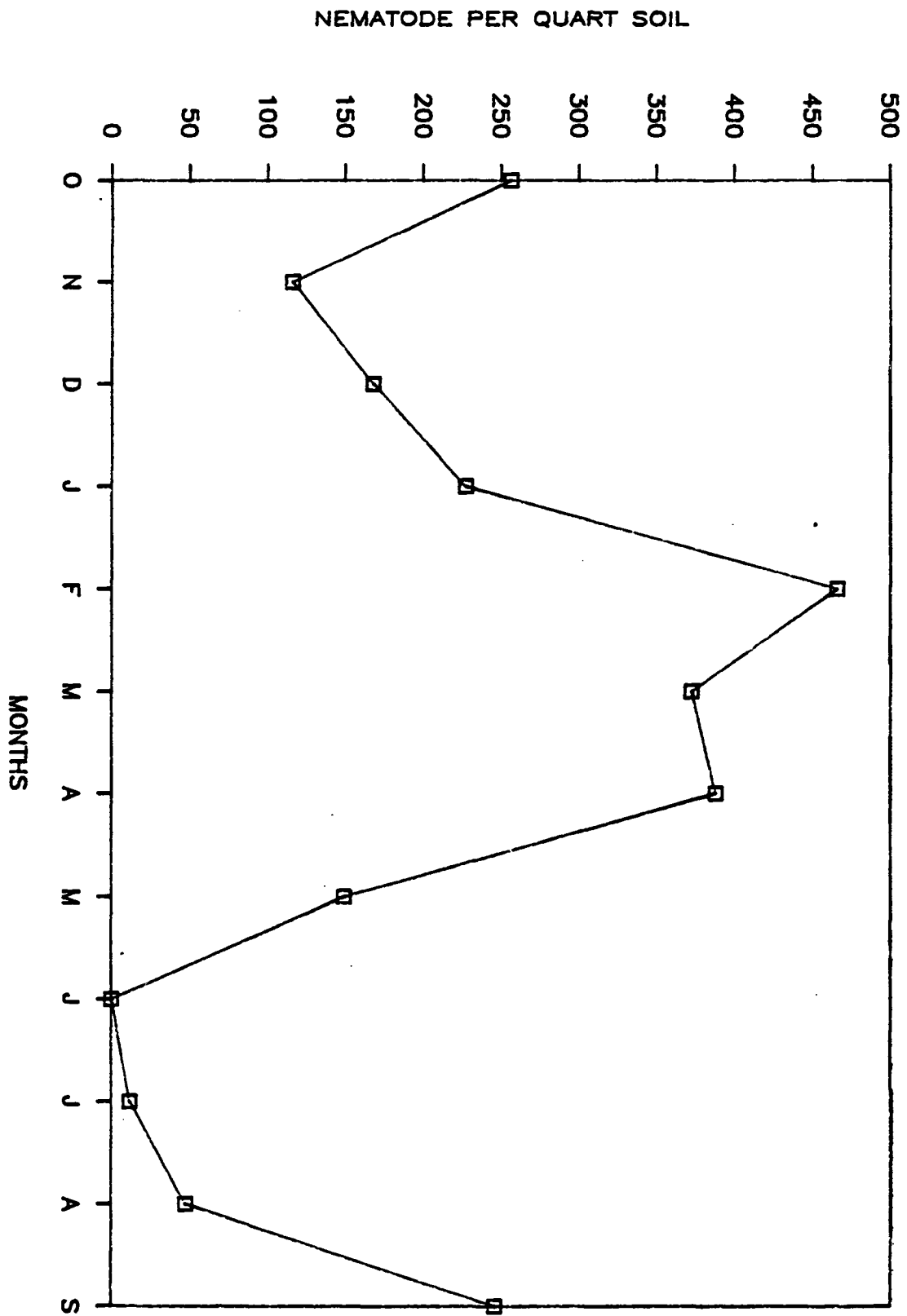


Figure 10.



between April and June. No nematodes were found from any of the three sites in June at the depth sampled. Population densities increased slowly from July to September with the greatest increase occurring between August and September. A reduction in numbers in November was followed by a slow increase until a February peak.

The results of this study indicate that temperature is an important factor in Trichodorus reproduction. Optimum temperature for reproduction is reported to be between 16° and 20°C by Ayala (1). Still other reports indicate that the life cycle is not completed at 20°C or 35°C, but is rapid at 22°C, and 30°C (22). In blueberries the lowest density of Trichodorus occurred during the period when the soil temperature was the warmest, while the highest density occurred during February when soil temperatures were still cool. Although no linear relationship was evident between temperature and population density, in this study (Figure 11) temperature has been shown to be an important factor in Trichodorus reproduction. Ayala states that optimum soil temperatures for T. christei is 16° to 20°C. Soil temperatures reached these levels between May and September, when the Trichodorus densities were lowest.

Results on blueberries agree with those reported by Brodie who found the highest densities in cultivated fields to be during December through March when the soil temperature at 30 cm. (12 inches) is 11-17°C ( 52°-63° F) and the soil moisture is 18- 23 % (3). During February through April the soil moisture at site one was between 18 and 25%, and soil temperatures ranged between 6°C and

Figure 11. Affects of temperature on 1985-86 mean seasonal Trichodorus population densities from three Oregon blueberry fields.

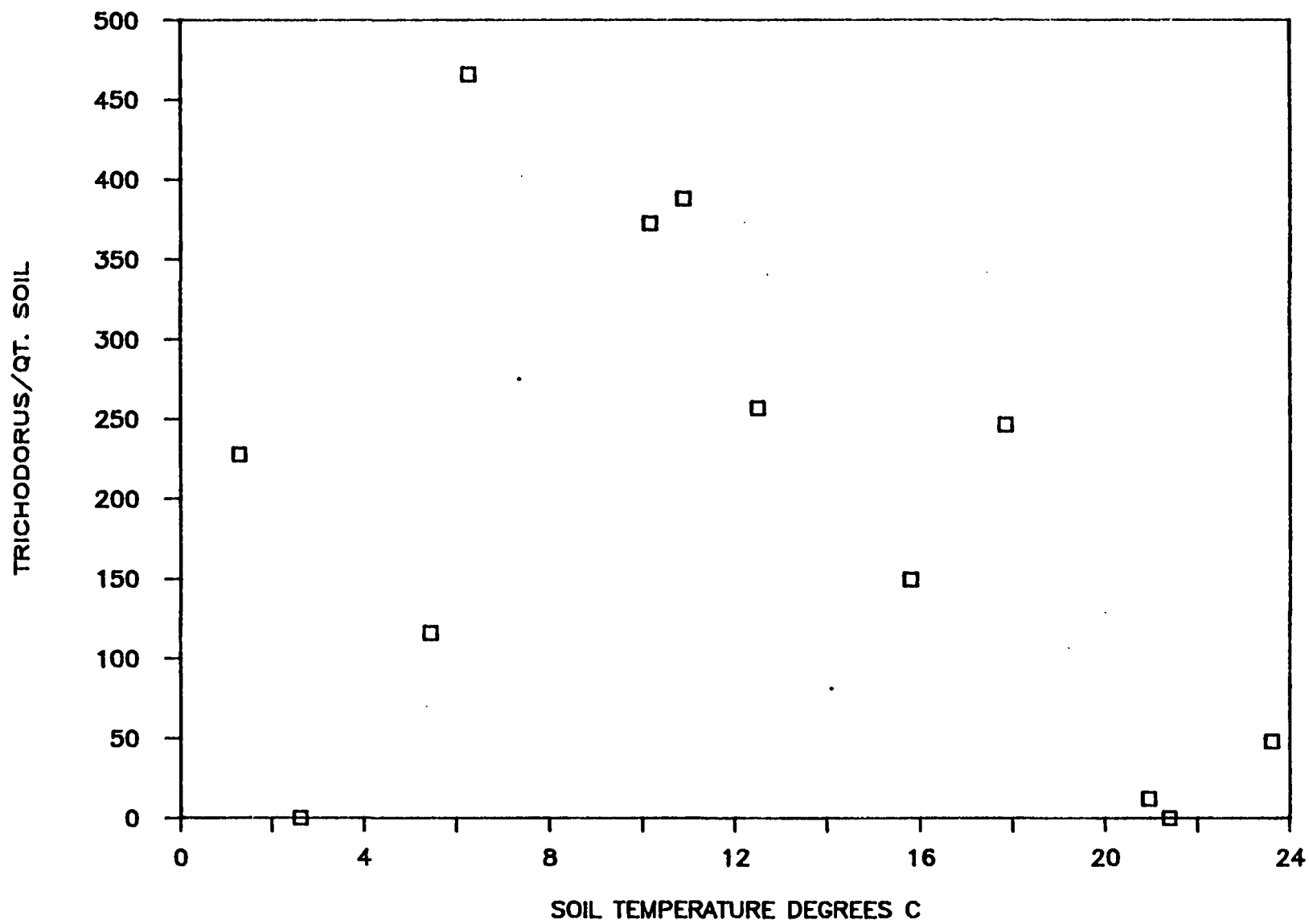


Figure 11.

12°C (42°C and 53°F) (Figure 1 and Appendix).

Trichodorus feeds primarily at the root tips (22) so high populations would likely occur during the period of greatest root generation, which would most likely be in the spring of the year in blueberries. There would probably be very little root regeneration during the late summer when allocation of the plant resources is directed to fruit production. Heavy fertilizer application in the late spring may be a factor in the reduction of nematode numbers at that time (1).

A competitive relationship may exist between Trichodorus and Pratylenchus species in blueberries. As is evident from figures 4 and 8, Trichodorus densities are lowest when Pratylenchus densities are highest. Similarly, Pratylenchus densities are still relatively low when Trichodrus densities are at a peak. While it seems likely that temperature, moisture, and host plant physiology are key interacting factors which affect plant parasitic nematode population dynamics, it is possible that competition between species may also occur.

DISTRIBUTION OF PRATYLENCHUS AND TRICHODORUS  
SP. IN BLUEBERRY FIELDS.

Sampling nematode populations is necessary to develop threshold levels and to estimate the potential risk of a crop to nematode damage. Designing an optimum sampling strategy to provide reliable estimates requires information on the vertical and horizontal distribution of nematodes within a field. In perennial plants such as blueberry, it is also important to understand the distribution of nematodes around the roots of an individual plant. Location of the samples within the areas, and times of maximum density insures the greatest probability of detection. Standardization of sampling procedures , i.e. sample location, increases the predictive power of sampling. The current study describes the horizontal distribution of Pratylenchus and Trichodorus in a blueberry field and the horizontal and vertical distribution of nematodes around individual blueberry plants.

MATERIALS AND METHODS

Depth and Distance Study

Samples were taken for the depth and distance trials in June of 1986. Each plot consisted of one blueberry plant (site one) and the surrounding soil divided into 24 sections. Sections consisted of three depth tiers which were 0-3 inches, 3-9 inches and 9-15 inches from the soil surface. Each tier was further partitioned into four equal directional quadrants oriented north,

south, east and west. The north-south orientation was within the blueberry rows, while the east-west orientation was between the rows. Within each quadrant further divisions delineated two concentric one foot wide rings; one encompassing the area of 6-18 inches, the other 18-30 inches from the base of the plant. It was impractical to sample within 6 inches from the base of the plant. Samples from like depths and distances from one direction were combined with those of the opposite direction to give a total of 12 sections. A representative sample from each of the 12 sections surrounding the blueberry plant consisted of three soil cores from the center of each section (12 and 24 inches from the base of the plant) combined with the three soil cores from the opposite directional quadrant at the same depth and distance from the plant (Figure 12).

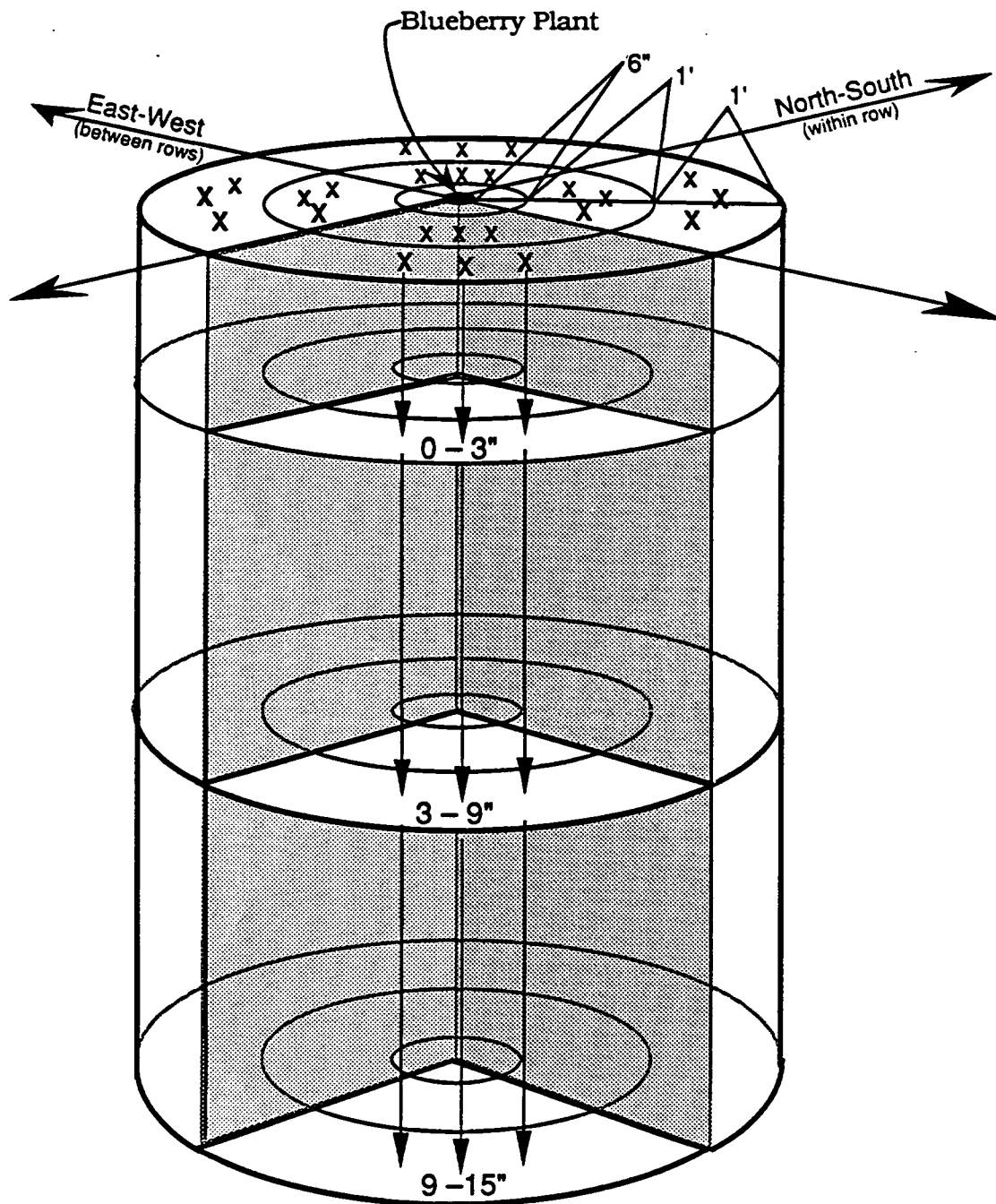
Soil population data were normalized by log (n+1) transformation for statistical analysis, but actual numbers are also presented as they are likely to be more meaningful to the reader. Differences in population densities were analyzed by ANOVA and the standard error of the treatment was calculated and used as a mean separation test.

#### Distribution Study

The horizontal distribution of Pratylenchus and Trichodorus within the blueberry field was examined from a field (site five) predetermined to be populated by these nematodes. Ten adjacent

Figure 12. Schematic representation of sampling regime for depth and distance study.

Figure 12.





rows in an area of the field with stunted plants and substandard production were chosen. The first five plants in each of the 10 rows were sampled to assess nematode populations on April 10, 1986.

## RESULTS AND DISCUSSION

### Depth and Distance

#### Pratylenchus

The significant results of the 1986 study of Pratylenchus distribution are summarized in Tables 3 and 4. Table 3 indicates that the density of Pratylenchus at a certain orientation depends on the distance from the base of the plant that the soil is sampled. Densities from samples taken north and south (within the row) of the plant were similar at one and two feet from the base of the plant, whereas those in samples taken one foot from the plant were significantly less (22%) ( $p < 0.10$ ) than those taken from two feet at the east-west (between rows) orientation.

The presence of a living mulch between the rows of the blueberry plants may account for the increase in density with distance at the east-west (between rows) orientation. The nematode was identified as P. crenatus which is known to be a grass parasite and has been extracted in high numbers from samples taken in the grass sod between the blueberry rows. Therefore, while these nematodes are present in the blueberries, it is likely that the grass is a better host. This would account for the gradual in-

Table 3. Mean population densities of Pratylenchus/qt. soil at different orientations and distances from blueberry plants.

Orientation	One Foot		Two Feet		Standard Error
	[log (n+1)]	actual	[log (n+1)]	actual	
North-South (within row)	1.506	310	.685	345	.289
East-West (between rows)	1.443	349	1.692	427	

Table 4. Mean population densities of Pratylenchus/qt. soil at three soil depth intervals.

Depth	0 - 3"		3 - 9"		9 - 15"		Standard Error
	[log (n+1)]	actual	[log (n+1)]	actual	[log (n+1)]	actual	
Mean Population	.289	84	1.890	445	1.815	545	.253

crease in nematode numbers between the blueberry rows and the living mulch.

There were no significant differences in populations numbers between the between-row one foot sample and the within-row one foot sample. Therefore, Pratylenchus feeding on blueberry roots are seemingly not influenced by the between or within row orientation. Blueberry root growth at one foot from the base of the plant is probably very similar at either orientation.

Pratylenchus populations were significantly different with depth, but there was no depth by orientation or distance interaction. Therefore, the results presented in Table 3 are based on all samples from a given depth, regardless of orientation or distance. There was little difference in nematode density between the 3-9 inch level and the 9-15 inch level, but both of these are significantly different from the 0-3 inch level.

A 1980 study on the root distribution of 7- and 12-year-old highbush blueberry plants reported that in no case were roots found in the upper 10 cm. of undecomposed sawdust (17). This is consistent with visual assessment of blueberry roots in the Pacific Northwest. Similarly, no pathogenic nematodes were ever extracted from preliminary samples of the sawdust mulch alone. Results of the current study indicate that there were very few nematodes in the upper three inches of soil at site one which had no sawdust mulch present. Therefore, we can assume that the upper three inches of substrate, either soil or sawdust should be discarded when sampling for nematodes in blueberries to avoid di-

luting the sample.

Blueberry roots were found to extend up to 1.83 meters (6 feet) from the perimeter of the crown of the blueberry, and to 80 cm. (31 inches) deep from a 13-year-old 'Coville' plant. However, 84 percent of the roots were within 61 cm (24 inches) of the crown. Similarly, 100 percent of the roots of a 7-year-old 'Lateblue' blueberry were found within the dripline (61 cm) and the crown perimeter. Most (88-100%) were within the upper 36 cm. (14 inches) of soil (17). Therefore, the highest densities of nematodes were recovered from the areas occupied by the majority of blueberry roots. Unfortunately, there were no samples taken beyond the perimeters of the blueberry roots to assess nematode density. Future studies comparing nematode density in sites with and without a living mulch between blueberry rows, and with and without sawdust mulch would be valuable, especially if samples were taken at greater soil depths and farther from the base of the plant to assess the nematode density in areas where there are few or no blueberry roots. Further, the blueberry root distribution study cited above was from an unirrigated field in Rhode Island. It is unlikely that the results of that study would extrapolate sufficiently to the irrigated conditions of blueberry fields in the Pacific Northwest. Thus, local root distribution information is also needed.

A general study of nematodes in apple orchard soils found the highest numbers of plant parasitic nematodes to be located at a depth of 20-40 cm. (approximately 8-16 inches) between May and

September. Therefore, the authors recommend that a sample at 20-40 cm. would be a good indication of plant parasitic nematodes present. However, they reported the greatest density of Pratylenchus to be present at 40 cm. (16 inches), followed by 60 cm. (24 inches). The lowest densities were found at 20 and 80 cm. (8 and 31 inches) (37). Therefore, sampling at the recommended sample depth of 20-40 cm. may indicate plant parasitic nematodes in general, but not give a good estimation of the Pratylenchus population.

### Trichodorus

The results of a 1986 distribution study of Trichodorus in blueberries indicated there were no significant differences in densities between the depths sampled or between directional orientations. Thus, the analyses summarized in Table 5 are based on samples from all depths and all orientations. The results of this study indicate that the distance the sample is taken from the blueberry plant is highly significant, while the other factors had no effect. The mean population of nematodes was greater at one foot from the base of the plant, than at two feet.

The increase in Trichodorus populations at one foot from the base of the plant compared to two feet is difficult to explain. Trichodorus nematodes tend to feed at the newly growing root tips, yet a large number of the roots on established blueberry plants within one foot of the plant base are large, older

Table 5. Mean population densities of Trichodorus/qt. soil at different distances from the blueberry plant.

Distance	One Foot		Two Feet		Standard Error
	[log n + 1]	actual	[log n + 1]	actual	
Mean Population	.639	48.5	.128	6.5	.130

woody roots. The presence of a sod culture between the rows may reduce Trichodorus populations if it is an inefficient or nonhost. This could explain a reduction in density at the between-rows two foot sampling sites, but does not explain a reduction in population at the within-row two foot sites. Similarly, there may be competition between Pratylenchus and Trichodorus, and the increase in Pratylenchus densities near the sod culture may reduce Trichodorus numbers. Again, this would not explain reduced densities at the north-south (between row) two foot site.

It is possible that the results of Trichodorus study may not be representative because the initial experiment was designed to monitor Pratylenchus populations and therefore samples were taken in May when Pratylenchus populations are relatively high. May densities of Trichodorus are relatively low and there was a high degree of variability in densities. Furthermore, Trichodorus was not present in 82 percent of the plots. More representative results would likely be obtained if samples were taken in February when Trichodorus populations in blueberries are high.

#### Distribution Study

The horizontal distribution of Pratylenchus and Trichodorus on blueberries (site five) are shown in Figures 13 and 14. Field populations of Pratylenchus tend to be distributed in a clumped pattern (Figure 13). The mean population density of 50 samples was 270 nematodes per quart of soil. Of the 50 blueberry

Figure 13. A three dimensional projection of the horizontal distribution of Pratylenchus in a western Oregon blueberry field.



Figure 13.

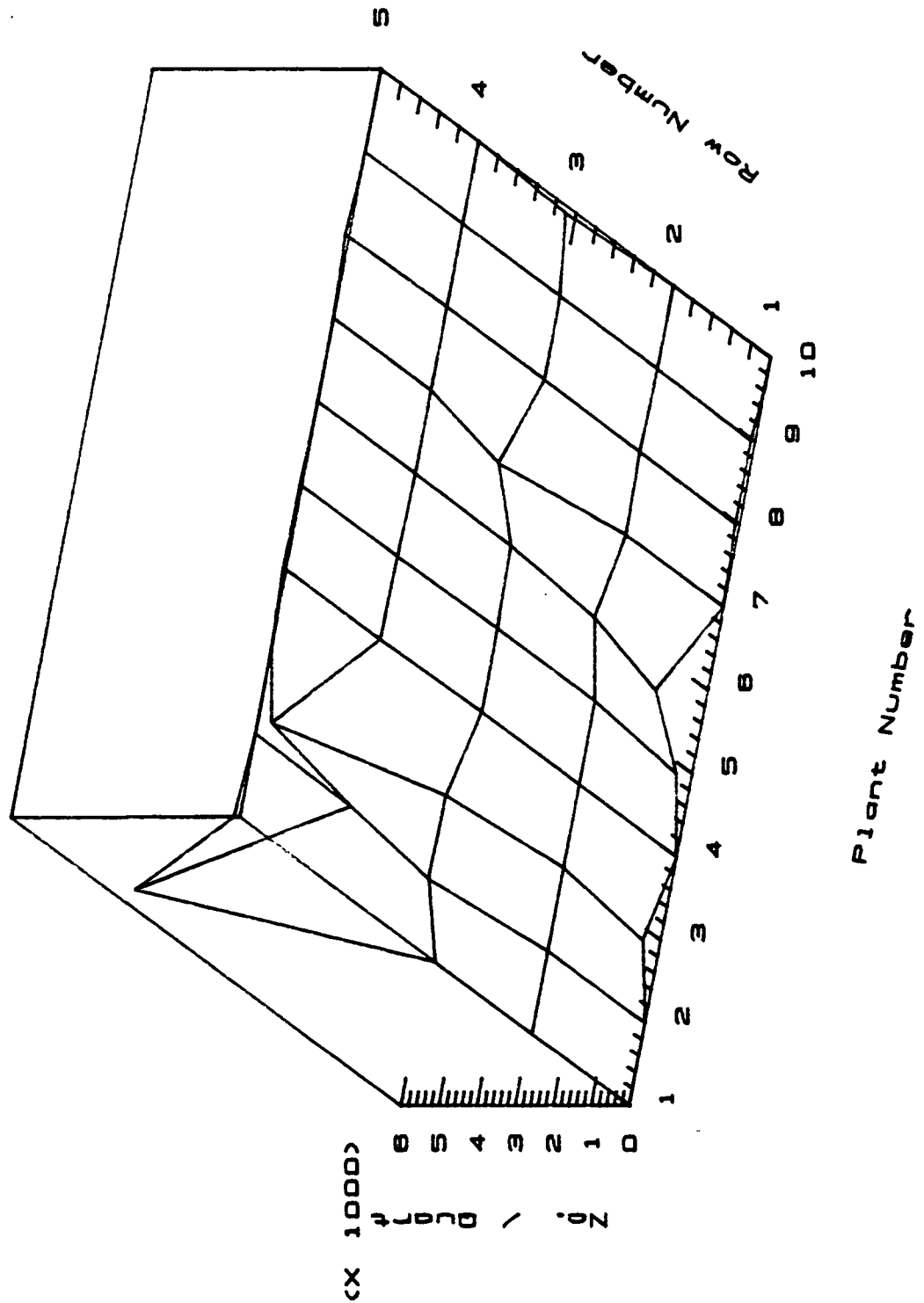
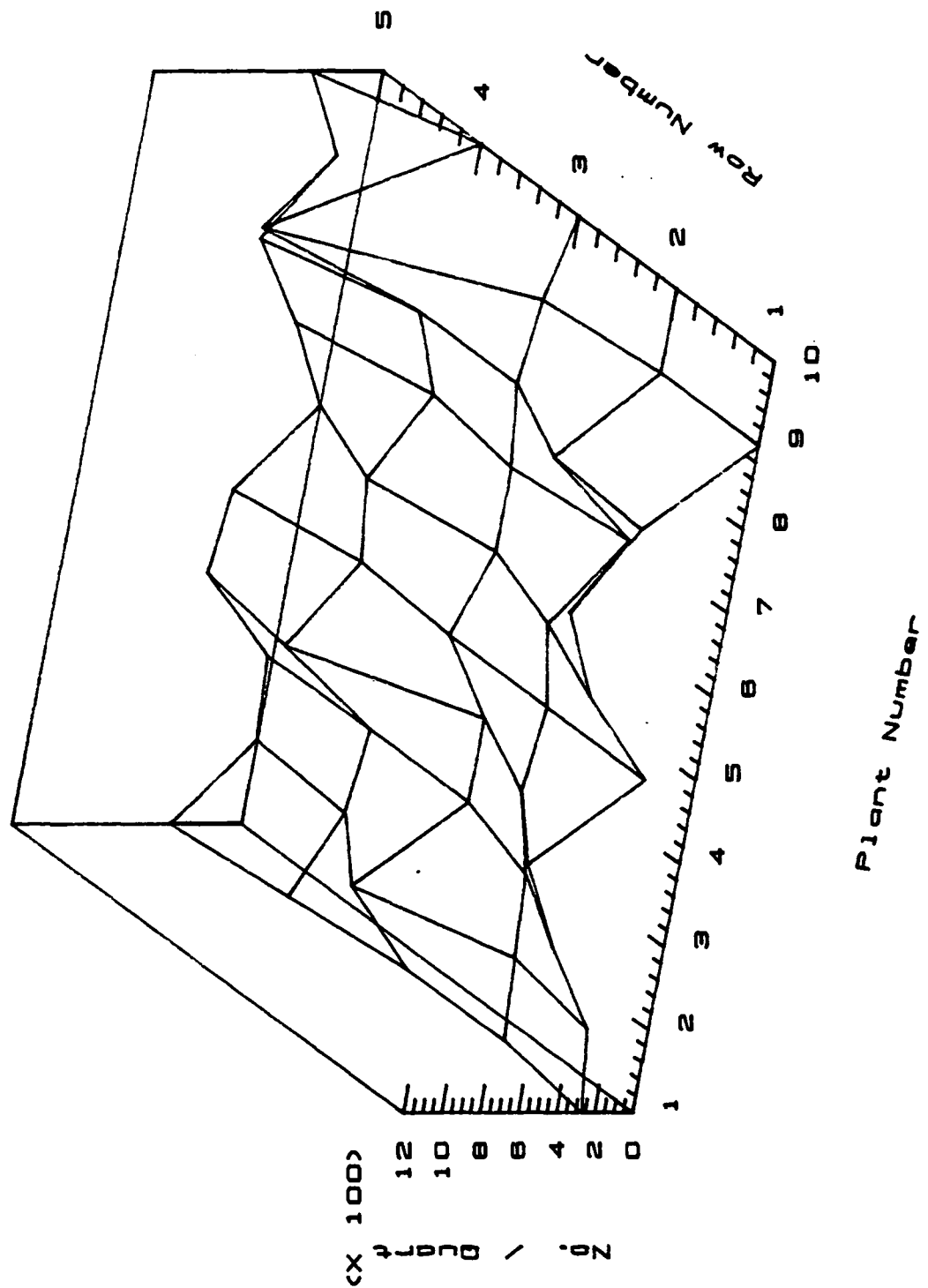


Figure 14. A three dimensional projection of the horizontal distribution of Trichodorus in a western Oregon blueberry field.

Figure 14.



plants sampled, only 42 percent were infested with Pratylenchus.

In contrast, that the distribution of Trichodorus is fairly uniform (Figure 14). The mean population density of 50 samples was 253 Trichodorus per quart of soil. Trichodorus occurred in 74 percent of the samples.

The distribution of these two nematodes emphasizes the difficulty of sampling field populations for effective population estimates. While the mean density of Pratylenchus was greater than that of Trichodorus, there were fewer individual blueberry plants which were infested. A random sample for nematode infestation would likely show fairly low densities in this area of the field, yet densities in some individual plants are relatively high. Although these data are from only one field, it indicates the difficulty of predicting field densities of Pratylenchus and therefore the accuracy of recommendations for control.

From the results of the current study, it is recommended that samples for Pratylenchus in blueberries be taken between one and two feet from the base of the plant in the direction between the rows. If sampling specifically for Trichodorus populations, a distance of one foot from the base of the plant is recommended. If a living mulch is located between the rows, it is important to sample this area separately to determine whether the sod is a source of inoculant. A deep soil core, 12 to 15 inches if possible, should be drawn and the upper 3 inches of soil or all of the sawdust mulch should be discarded before adding the core to the sample bag. For sampling an individual plant, four soil cores

are bulked to provide sufficient soil for one sample.

When a blueberry field is being tested for the presence of nematodes, it is necessary to identify areas of the field where production is low and plants are stunted. Within these areas, plants that are extremely stunted, underproductive or dying should be flagged, and soil cores should be drawn from the healthy plants adjacent to the unhealthy ones. Nematode sampling in blueberries has consistently shown nematode density to be low on very unhealthy plants, while adjacent healthy plants support high densities (Fred McElroy, personal communication). Tseh-An-Chen and Rich suggested that secondary invaders may displace the primary parasites from the original invasion. They reported that as fungi grew close to Pratylenchus-infested lesions on strawberries, most of the nematodes moved away (52). Fungi usually infected roots with necrotic lesions more readily than healthy tissues. Therefore, it is possible that the nematodes have left the infected blueberry plants for healthier sites. In addition, stunted plants may have insufficient root biomass to support high nematode populations.

## CONTROL OF NEMATODES IN Highbush blueberries with fenamiphos.

Presently there is no registered control for nematodes in established highbush blueberries. Economic loss from nematodes is estimated to range between 15 and 50 per cent in some fields (Daryl Van Cleave, personal communication). One study indicates that 90 per cent of the blueberry fields in the Willamette Valley harbor plant parasitic nematodes (6). Earlier studies indicate that fenamiphos (Nemacur) is effective in controlling some of the nematodes that inhabit blueberry fields (35). The purpose of this study was to determine efficacy of fenamiphos for controlling Pratylenchus and Trichodorus in blueberry plantings, and establish application rates and times that would not exceed safe levels of residue in the fruit. This information is essential to obtain state and federal registration of fenamiphos for blueberries.

## MATERIALS AND METHODS

### Efficacy Trial

Experimental plots (site 5) for efficacy trials were established according to the known number of Pratylenchus on individual blueberry plants. Fifty plants were sampled initially, and three each were assigned to one of four blocks listed below based on Pratylenchus densities.

Block One	>2500/qt. soil
Block Two	750-1500/qt. soil
Block Three	475-749/qt. soil

#### Block Four      <475/qt. soil

One of three treatments was randomly assigned to each plant within a block: the X rate of 6 lbs ai/A, the 2X rate of 12 lbs. ai/A, and an untreated check. A backpack sprayer was used to deliver fenamiphos to each labelled plot which consisted of a 45 inch square area centered around the blueberry plant. Nematode populations were sampled pretreatment on April 10, 1986, and post treatment on October 21, 1986. Fenamiphos was applied April 25, 1986, and followed by heavy rainfall.

Yield data were not obtained due to the longevity of the growth response. Increased growth and production in response to nematicide treatment would not be fully evident until the 1987 harvest because blueberry fruit is borne on one-year-old wood, by which time many other factors could affect the results. Raski reported that significant yield increases in grapes were found the second and third years after treatment (41). Crop tolerance was evaluated by visual observation as compared to check plots.

Post treatment population densities from all plants were transformed to percent of pretreatment densities to aid in statistical analysis. ANOVA was performed using percent data, and standard error of the treatment was used as a means separation test.

#### Residue Trials

Experimental plots were established at two Oregon (sites one and two) and one Washington site (site four). Plots containing

three blueberry plants each were arranged in a completely randomized block design with 3 replications. Two rates of fenamiphos were applied with a CO2 backpack sprayer. Check plots remained untreated. Harvest dates ranged from 94 to 112 days after treatment. Approximately one quart of randomly picked berries was harvested from each blueberry plot. Labelled quart bags were kept cool until hand delivered to the laboratory, usually within six hours, where they were frozen. The berries were analyzed at the Oregon State University Residue Analysis Laboratory using the method of Thornton (49).

## RESULTS AND DISCUSSION

### Efficacy Trial

The results of fenamiphos trial on the cultivated blueberry are summarized in Tables 6 and 7. At 12 lbs. ai/A the average post treatment densities of Pratylenchus was 1% of the pretreatment populations, while the 6 lbs. ai/A were 11% of the pretreatment populations. Part of this reduction in population was due to the natural population decline. The check plot densities averaged 20% of the pretreatment populations. Furthermore, the population densities of the 6 lbs. and 12 lbs. ai/A treatments were 45%<sup>^</sup> and 95% less, respectively, than those from the check plot. Although there is no significant difference between these two rates and the control, trends indicate that the 12 lbs. ai/A rate reduced population densities to a greater extent than the control, while the 6



Table 6. Effects of 1986 fenamiphos application on Pratylenchus densities (numbers/qt. soil) in a blueberry field.

Rate	April Pretreatment	October Post treatment	Percent of Initial Population	Block
Control	5419	326	6%	>2500 <u>Prat</u> / qt. soil
6 lbs. ai/A	5313	108	2%	
12 lbs. ai/A	2550	108	4%	
Control	1063	315	30%	750-1500 <u>Prat</u> /qt.soil
6 lbs. ai/A	797	101	13%	
12 lbs. ai/A	1381	0	0%	
Control	478	210	44%	475-750 <u>Prat</u> / qt. soil
6 lbs. ai/A	584	53	9%	
12 lbs. ai/A	531	0	0%	
Control	425	0	0%	<425 <u>Prat</u> / qt. soil
6 lbs. ai/A	266	54	20%	
12 lbs. ai/A	425	0	0%	

Table 7. Mean of post treatment Pratylenchus densities expressed as a percent of pretreatment densities.

Rate	Mean Percent of Initial Population	Standard Error
Control	20%	6.697
6 lbs. ai/A	11%	
12 lbs. ai/A	1%	

lbs. ai/A rate was not different from the control. Similarly, the 6 lbs. ai/A rate was not different from the 12 lbs. ai/A rate.

Application of fenamiphos at the rate of 12 lbs. ai/A reduced the population of Pratylenchus by 95 %. Based on this information, the 12 lbs. ai/A rate would be the most effective recommended rate for blueberry fields which are infested with Pratylenchus. However, natural population decline in the fall resulted in an 80% reduction in Pratylenchus densities by October. Therefore, to realize the true effect that fenamiphos has on Pratylenchus populations, a slightly earlier application (to allow about 5 months for mortality) followed by samples in the summer months when natural populations are highest would be informative. However, the results of this trial are consistent with effective rates for other crops. The rates determined for annual crops tend to be lower than those for perennial crops. The recommended rate for peanuts is 3-5 lbs. ai/A, and 4-6 lbs ai/A for soybeans and tobacco. In contrast, perennial plants with deeper root systems require greater rates. Recommended rates for apple, cherry, and peach trees are 10-20 lbs. ai/A (35).

Fenamiphos is registered on two other small fruit crops. The recommended rate for grapes, which have an extremely deep root system, is 18 lbs. ai/A, and the rate suggested for red raspberry is 6-12 lbs. ai/A (35). These rates are consistent with the results from this study on blueberries.

Although this trial was designed to determine the levels of Pratylenchus after fenamiphos treatment, Trichodorus densities

were also monitored (data not shown). Trichodorus increased in all plots between pre- and post treatment sampling, but increased to a greater extent in plots that had been treated with either rate. Results from the population dynamics study indicate that Trichodorus populations increase between April and October. Why this nematode increased more in the nematicide-treated plots is difficult to explain. First, it suggests that fenamiphos may be ineffective against Trichodorus, and secondly, it supports earlier evidence (see page 47) that Pratylenchus and Trichodorus may compete. But due to the small number of samples having Trichodorus populations in this study, the low densities found, and inappropriate experimental design for Trichodorus evaluation, it is not possible to make a definitive comparison.

Results of efficacy trials are often difficult to interpret. Chemical agents such as fenamiphos have been shown to stimulate egg hatch which may result in a higher nematode population in treated plots than in untreated plots. In addition, fenamiphos may not initially kill nematodes present, making population data difficult to interpret. Studies have shown that nematodes may be disoriented and their feeding disrupted, causing no damage to plant roots, but still present in Baermann funnel extractions. Eventually most of these will die and if a follow up program is ensued, populations will decrease (35).

One study indicates that fenamiphos interferes with motor activity in nematodes by blocking neuroenzymes (35). Initially this interference is reversible, but continued exposure results in

immobilization and eventually death. There is a very long inactive stage before death, and nematodes exposed to very low concentrations (.1 ppm), although remaining alive for a very long time, eventually will die. During this inactive stage, nematodes are unable to penetrate plant roots (35). Thus, nematodes found in post treatment samples may not be damaging the plant. Furthermore, results indicate that fenamiphos is active for up to three months and may move 25-30 cm. down in the soil.

#### Residue Analysis

Analysis of fruit from fenamiphos treated plants in two Oregon and one Washington blueberry fields resulted in no detectable chemical residues for either of the two rates applied. This is consistent with data available on other crops which indicate that residues greater than 1 ppm are not frequently found on plants treated with effective rates of fenamiphos. The pre-harvest interval (PHI) for both pineapple and grapefruit is 30 days and that for grapes is only two days of harvest (35). Fenamiphos undergoes relatively fast and complete degradation in plant tissues so that residue levels for most crops are less than .1 ppm. (35).

Residue analysis from the current study supports a safe PHI of no less than 94 days. Therefore, treatment of early varieties such as Earlyblue, Bluetta and Spartan, must occur before March 15. Based on data from other crops, it is likely that future trials on blueberries will result in a shorter PHI. Application

of fenamiphos closer to harvest may be desirable to decrease stress to the blueberry plant during berry production and maturation.

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## APPENDICES

Figure 15. 1985-86 mean soil moisture for a Salem, Oregon  
blueberry field (site one).

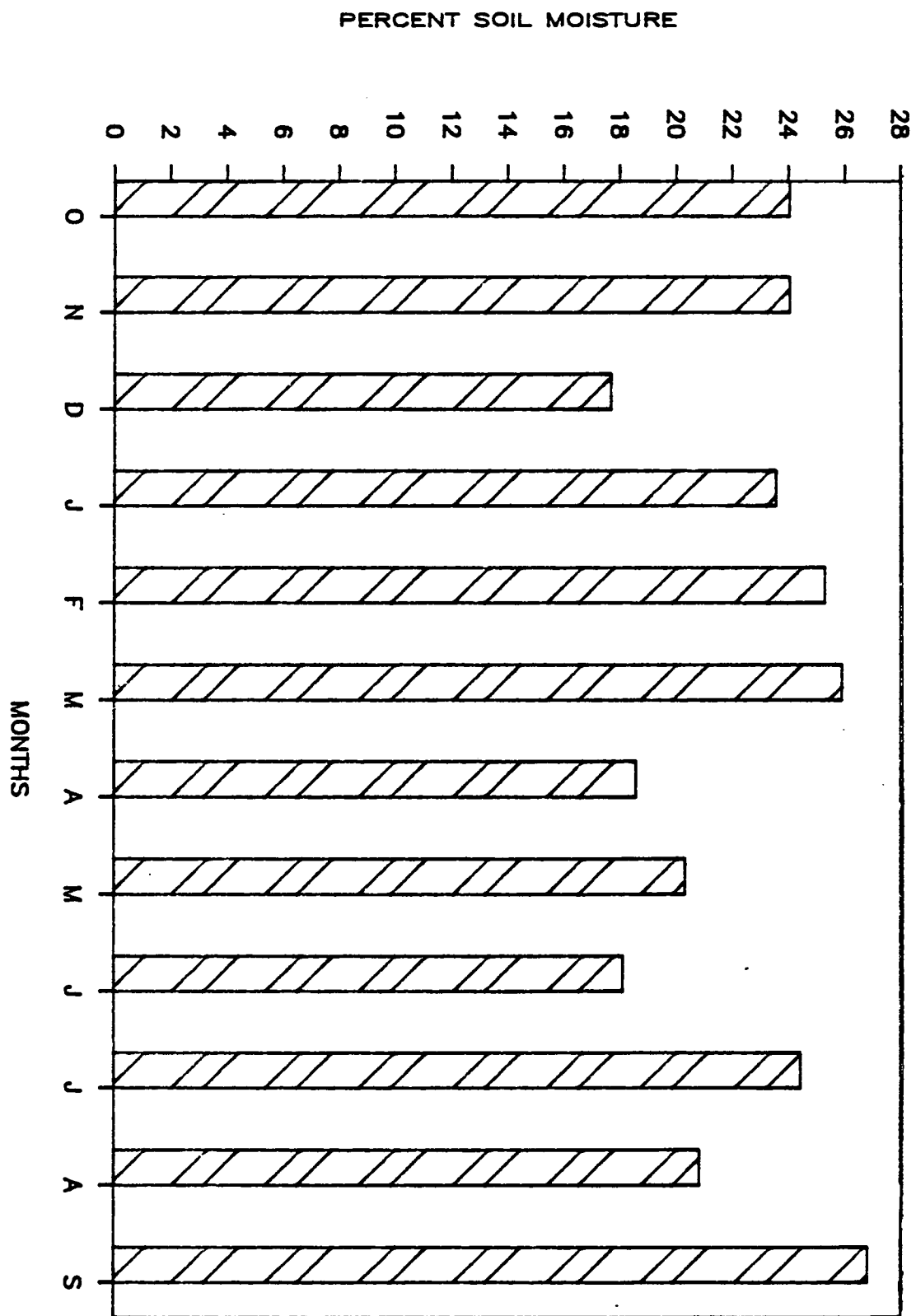


Figure 15.

Figure 16. 1985-86 mean soil moisture for a Albany, Oregon  
blueberry field (site two).

# PERCENT SOIL MOISTURE

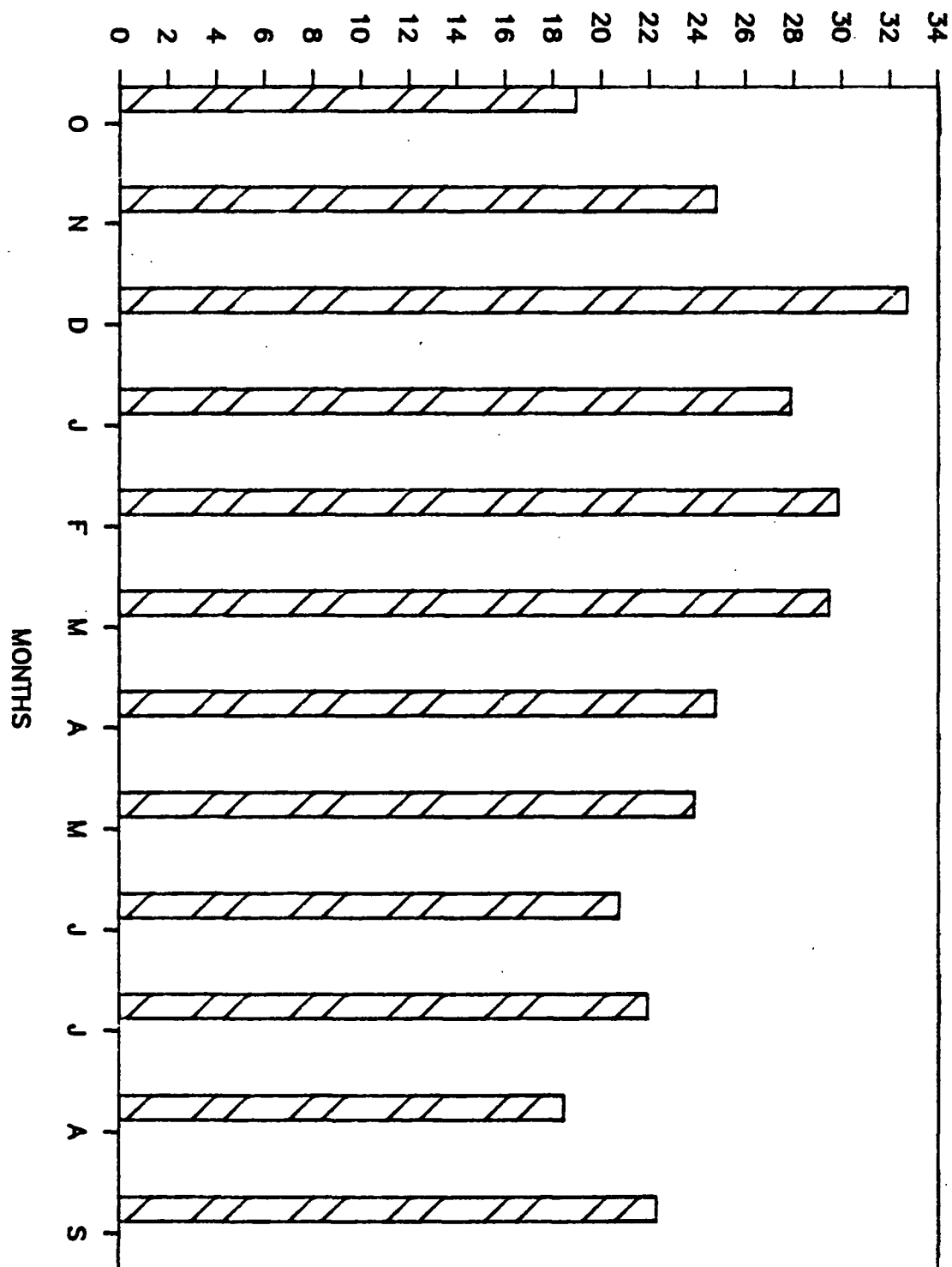


Figure 16.

Figure 17. 1985-86 mean soil moisture for a Peoria, Oregon  
blueberry field (site three).



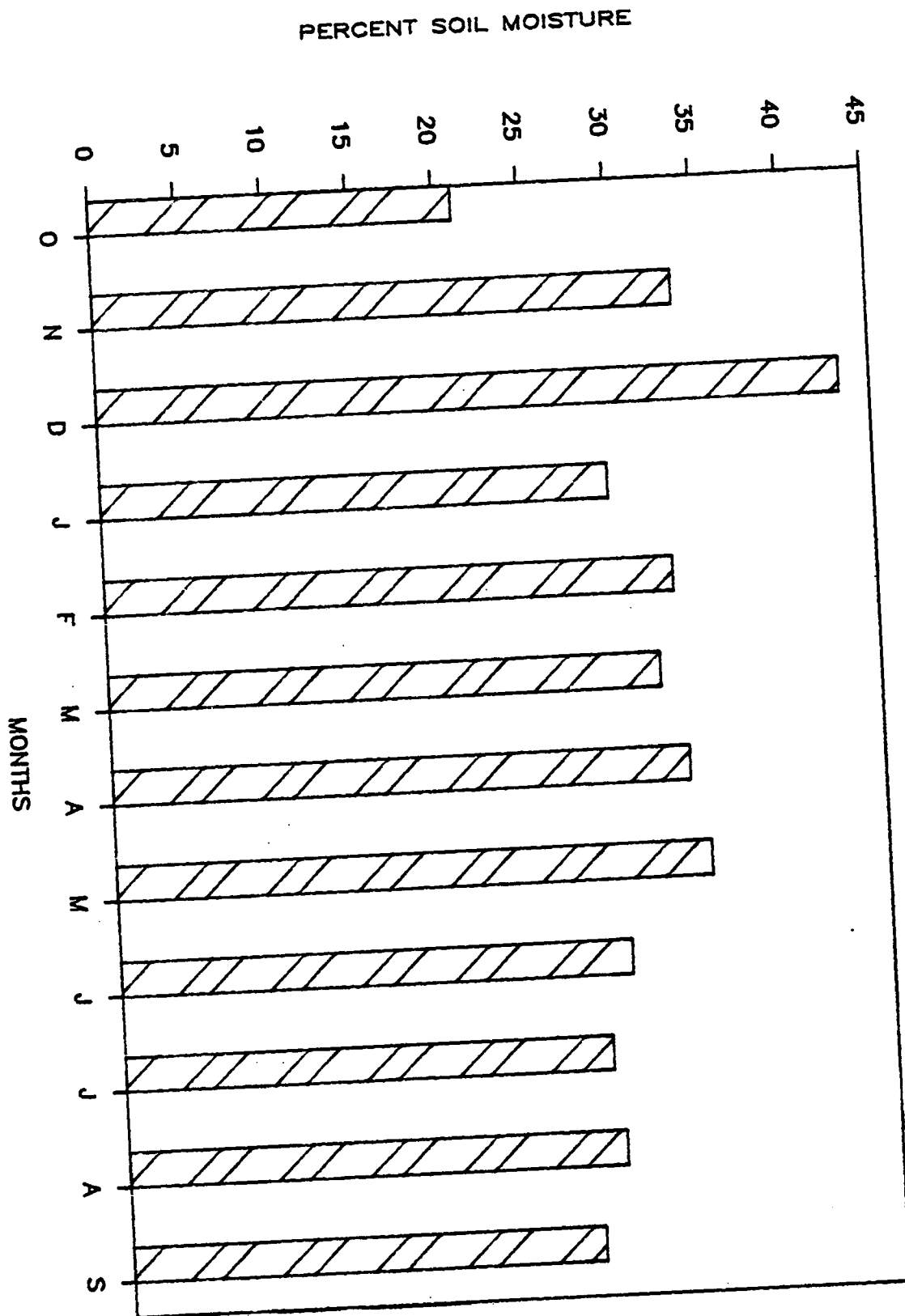


Figure 17.

Table 8. Mean population densities of Pratylenchus/qt. soil at different depths, orientations and distances from a blueberry plant.

	One Foot	Two Feet
Within Row 0-3''	0	10
Within Row 3-9''	407	199
Within Row 9-15''	524	827
Between Rows 0-3''	0	326
Between Rows 3-9''	424	749
Between Rows 9-15''	624	255

Table 9. Mean population densities of Trichodorus/qt. soil at different depths, orientations and distances from a blueberry plant.

	One foot	Two Feet
Within Row 0-3''	9	0
Within Row 3-9''	37	0
Within Row 9-15''	162	0
Between Rows 0-3''	15	29
Between Rows 3-9''	39	10
Between Rows 9-15''	29	0