This is to certify that the

thesis entitled

INFLUENCE OF ROTATION CROPS AND MANAGEMENT SYSTEMS ON *Pratylenchus penetrans* ASSOCIATED WITH *Solanum tuberosum* PRODUCTION

~~presented by~~

H. C. Olsen

has been accepted towards fulfillment
of the requirements for

Master of Science degree in Entomology

George W. Bird

Major professor
George W. Bird

Date May 18, 1984

# INFLUENCE OF ROTATION CROPS AND MANAGEMENT SYSTEMS ON *Pratylenchus penetrans* ASSOCIATED WITH *Solanum tuberosum* PRODUCTION

by

H. C. Olsen

**A THESIS**

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

**MASTER OF SCIENCE**

Department of Entomology

1984

## ABSTRACT

Influence of Rotation Crops and Management Systems on

Pratylenchus penetrans associated with Solanum tuberosum Production

by

H. C. Olsen

The response of Solanum tuberosum cv Superior to nitrogen and nematicide inputs in corn or alfalfa crop rotation systems was monitored to define the relations of the system inputs. A series of experiments examining P. penetrans population growth with various forage crops was conducted to identify rotation crops which could be used in Michigan to reduce P. penetrans inoculum levels. The objective of these studies was to develop information concerning a crop rotation and management strategy to reduce the impact of P. penetrans and to maximize tuber yields.

Aldicarb reduced P. penetrans population densities and increased marketable or oversized tuber production in both corn and alfalfa rotation systems. The soil fumigant 1,3-D+MIC reduced nematode population densities and increased oversized tuber production in the corn rotation, but had little effect in the alfalfa rotation. When the nematicides were combined, there was an additive marketable tuber yield response. Nitrogen input effects were most apparent in the corn rotation where nitrogen fertilizer increased petiole nitrate

levels, reduced undersized tuber production, and increased yields in the presence of nematicides.

Non-pruned forage grains and the use of shoot growth residues as a mulch resulted in reduced *P. penetrans* population densities when compared to pruning and removing residues. Both forage grains and alfalfa variety screening trials exhibited varietal differences in host suitability to *P. penetrans*. Reduced host suitability of alfalfa varieties was associated with Phytophthora root rot resistance.

## ACKNOWLEDGMENTS

Proverbs 15:22 states, "without counsel purposes are disappointed: but in the multitude of counsellers they are established." I would like to take this opportunity to thank God and a few of the many people who have helped me become who I am and what I will accomplish.

My heartfelt gratitude goes to those who have made significant contributions to my education and development as a scientist. In this regard, I wish to thank Dr. M. B. Tesar, Dr. George Ayers and Dr. G. W. Bird for the challenge and training I received from them.

I would also like to extend my appreciation for the exceptional men who served on my guidance committee: Drs. Jim Bath, Dick Chase, Ed Grafius and Maury Vitosh. Each provided unique contributions to my research and education.

My enthusiastic thanks goes to those of the Nematology program who contributed to the fun and profit of my graduate program. Thanks to Lindy Rose for her readiness to help and her warm friendship. Thanks to Ed Caswell for his friendship and humor. Thanks to Adi Wang for his friendship and attention to detail. Thanks to John Davenport for the many enjoyable hours that we spent together, for the standard of excellence he encouraged, for his friendship and for all the Skoal I borrowed.

I suppose the highest level of gratitude should go to my family. I can not give too much appreciation to my parents who expended so much of their time and energy in raising me and my siblings. Special thanks goes to Mary, my wife, for her support and her commitment to the quality of our family.

## TABLE OF CONTENTS


| | Page |
|---|---|
| List of Tables | v |
| I. Introduction . . . . . . . . . . . . . . . . . . . . . . . | 1 |
| II. Literature Review . . . . . . . . . . . . . . . . . . . . | 3 |
| A. Systematics . . . . . . . . . . . . . . . . . . . . . . | 3 |
| B. Ecology . . . . . . . . . . . . . . . . . . . . . . . . | 3 |
| 1. Survival . . . . . . . . . . . . . . . . . . . . . . | 3 |
| 2. Movement . . . . . . . . . . . . . . . . . . . . . . | 5 |
| 3. Orientation . . . . . . . . . . . . . . . . . . . . | 6 |
| 4. Penetration . . . . . . . . . . . . . . . . . . . . | 7 |
| 5. Pathogenicity . . . . . . . . . . . . . . . . . . . | 7 |
| 6. Plant Nutrition . . . . . . . . . . . . . . . . . . | 9 |
| 7. Rotation Crops . . . . . . . . . . . . . . . . . . . | 12 |
| III. Materials and Methods . . . . . . . . . . . . . . . . . . | 16 |
| A. Potato Production System Management . . . . . . . . . | 16 |
| B. Rotation Crops for Inhibition of P. penetrans . . . . . . | 19 |
| 1. Forage Grain Rotation Crops . . . . . . . . . . . . | 19 |
| 2. Forage Legume Rotation Crops . . . . . . . . . . . . | 21 |

TABLE OF CONTENTS (continued)


| | Page |
|---|---|
| IV. Results | 23 |
| A. Potato Production System Management | 23 |
| 1. Crop Yield and Quality | 23 |
| 2. Nematode Population Management | 26 |
| 3. Soil-Borne Fungi | 28 |
| 4. Nutrient Composition | 28 |
| B. Rotation Crops for Inhibition of *P. penetrans* | 34 |
| 1. Forage Grain Rotation Crops | 34 |
| 2. Forage Legume Rotation Crops | 46 |
| V. Discussion | 47 |
| VI. Bibliography | 54 |

LIST OF TABLES

| | | Page |
|---|---|---|
| 1. | Influence of selected management inputs on tuber yield and specific gravity of Superior following alfalfa. . . . . . . . . . . | 24 |
| 2. | Influence of selected management inputs on tuber yield and specific gravity of Superior following corn. . . . . . . . . . . | 25 |
| 3. | Influence of selected management inputs on population density of P. penetrans on Superior following alfalfa. . . . . . | 27 |
| 4. | Influence of selected management inputs on population density of P. penetrans on Superior following corn. . . . . . . | 29 |
| 5. | Percent of Superior potatoes infected with Verticillium following alfalfa in a crop rotation. . . . . . . . . . . . . . . | 30 |
| 6. | Percent of Superior potatoes infected with Rhizoctonia following alfalfa in a crop rotation. . . . . . . . . . . . . . . | 31 |
| 7. | Percent of Superior potato plants infected with Verticillium following corn in a crop rotation. . . . . . . . . . . . . . . . | 32 |
| 8. | Percent of Superior potato plants infected with Rhizoctonia following corn in a crop rotation. . . . . . . . . . . . . . . . | 33 |
| 9. | Effect of nitrogen rate and nematicides on nutrient composition of potato petioles from Superior, Russet Burbank and Denali potatoes grown in an alfalfa rotation. . . . . . . . . . | 35 |
| 10. | Influence of nitrogen and nematicides on nutrient composition of potato petioles of Superior, Russet Burbank and Denali varieties grown in a corn rotation. . . . . . . . . . . . | 36 |
| 11. | The effect of forage grain varieties and management on the population growth of P. penetrans. . . . . . . . . . . . . . | 37 |
| 12. | The effect of forage grain varieties and management systems on the population density of P. penetrans. . . . . . . . | 39 |
| 13. | The effect of forage grain varieties and management sytems on the population density of P. penetrans. . . . . . . . . . . | 40 |

Page

14. Influence of forage grain varieties and management practices on the population dynamics of P. penetrans. . . . . . . 41

15. Influence of selected management practices on the population dynamics of P. penetrans associated with sorghum-sudangrass hybrid. . . . . . . . . . . . . . . . . . . . . . . 42

16. Influence of selected management practices on the population density of P. penetrans associated with a sorghum-sudangrass hybrid. . . . . . . . . . . . . . . . . . . . . . . 43

17. The influence of P. penetrans on selected alfalfa varieties. . . . . 44

18. The influence of P. penetrans on the growth of selected forage legume varieties. . . . . . . . . . . . . . . . . . . . 45

# I. INTRODUCTION

The root-lesion nematode (Pratylenchus penetrans) is a common pathogen of Solanum tuberosum in Michigan. The pathogenicity and population dynamics of this nematode are influenced by many management factors including variety selection, rotation crops, pesticides, and soil-borne diseases. Verticillium wilt can be an important limiting factor in tuber yields when P. penetrans is endemic (Martin et al. 1981).

Bernard (1973) found that cv Superior was the most susceptible to P. penetrans of five varieties tested. Russet Burbank was the most tolerant, but also the best host as evaluated by population growth of P. penetrans. The potato cultivar Superior is responsive to nematicides when there is P. penetrans population pressure. Superior is a short-season potato; therefore, it must exploit the soil environment quickly to obtain the necessary nutrients and moisture to develop marketable tubers.

Michigan potato production systems frequently include rotation crops, such as forage grains or legumes. The management of interim forage crops in a rotation sequence can affect potato production management. Maintenance of a rotation crop that is a poor host for P. penetrans can affect its economic and agronomic suitability, as well as its potential for nematode control. MacDonald and Mai (1963) reported that some poor hosts of P. penetrans became suitable hosts when the shoot system was pruned. Many forage crops, however, must be mowed periodically throughout the growing season for economic returns. Most growers use the forage for feed, although some potato growers leave the shoot system growth for organic matter accumulation. Another condition of interest is that many of the sorghum-sudangrass hybrids should be allowed to reach 46 cm in height before grazing is allowed. This is necessary because of high concentrations of a glucoside (dhurrin) in the smaller plants. Dhurrin breakdown releases a poison known as prussic acid or hydrocyanic acid (HCN). Because of these potential conditions, there is a need to evaluate shoot system management on the population growth of P. penetrans on these poor hosts.

Genetic research related to alfalfa varieties has resulted in improved yield potential and disease resistance in a significant number of varieties. Resistance to soil-borne diseases is of major concern. Varieties have usually been improved by the addition of resistant genes or selection under high pest pressure. The effect of this change in the plant was of interest in relation to effects on host suitability for P. penetrans.

The overall goal of this research was to investigate the possibility of using rotation crops to manage P. penetrans population densities in a potato production system. Two objectives necessary in accomplishing this goal are:

1) To investigate the impact of potential rotation crops and their management on P. penetrans population density;
2) To quantify the influence of chosen rotation crops and pest management strategies on the nutrition, yield, and quality of potatoes.

# II. LITERATURE REVIEW

The literature review is divided into two parts:; the systematics of P. penetrans, and the ecology of Pratylenchus spp. in relation to an agricultural ecosystem.

## A. SYSTEMATICS

Root-lesion nematodes were first reported in 1865 by Bastain, as Tylenchus obtusus. DeMan described a root-lesion nematode in 1880 as Tylenchus pratensis. In 1917, Cobb described T. penetrans which is the first report of Pratylenchus penetrans on potato. T. penetrans and T. pratensis were synonymized by Goodey (1932) and Steiner (1927). In 1936, Filipjev synonomized T. penetrans with Pratylenchus pratensis. In 1952, Chitwood and Otiefa classified the species name as P. penetrans. The correct citation for this nematode is Pratylenchus penetrans (Cobb, 1917), Filipjev and Shuurmans-Stekhoven 1941 (Elliott, 1980; and Noling, 1981).

## B. ECOLOGY

The ecology of Pratylenchus spp. in an agricultural ecosystem is approached by examining edaphic survival, edaphic movement, orientation, penetration, pathogenicity, nutrition, and crop rotations.

1. Survival.--Dunn (1972) studied overwintering survival of P. penetrans at Ithaca, New York. He reported a 60% overwintering mortality rate at a 0-15 cm soil depth, and a 14% mortality rate in the 15 to 30 cm zone. The pre-winter population density in the 0-15 cm zone, however, was more than four times larger than the deeper zone. Dunn reported that eggs survive in root tissue. Dickerson et al. (1964) reported that there was much higher mortality among immature stages than among adults, thus biasing the spring populations toward

4th-stage juveniles and adults. Kable & Mai (1968b) reported that overwintering survival of P. penetrans at depths greater than 30 cm is less in clay soil than in sandy soil. Survival was greater in roots than in soil.

Soil texture and compaction can have a significant impact on overwintering survival and movement of P. penetrans to the roots of a host plant. Survival of P. penetrans was poor between 12 and 30°C in saturated soil, but improved as soil moisture potential (SMP) increased up to the permanent wilting point (Kable and Mai 1968a). Townshend and Webber (1971) reported that P. penetrans movement in soil was greatest when 8 to 12% of the pore space was occupied by air. High bulk density and high silt or clay contents reduced movement. They also found that survival increased with increasing soil moisture potential. Kable and Mai (1968a) proposed several possible reasons for better survival in dry than in wet soil:

(1) Nematodes move more freely in moist than in dry soil, and therefore expend their energy reserves more quickly in moist soil;

(2) In moist soil, nematodes must maintain an osmotic balance that requires energy;

(3) Toxin production by anaerobic bacteria can cause nematode mortality in saturated soil;

(4) Nematodes share their environment with microbial organisms pathogenic to them. Under dry conditions, movement and growth of these organisms may be restricted and have less influence on nematodes;

(5) Oxygen supply may be limiting in saturated soil.

Kable and Mai (1968a) reported that the widespread occurrence of high population densities of Pratylenchus spp. in sandy soils can be explained in terms of the interaction of soil moisture with soil type. In sandy soils, there is a sudden increase in the percent of air-filled pore space at a relatively low SMP, and a corresponding increase in nematode survival. In heavy soils, air-filled pore space increases at a steady rate with increasing SMP, as does nematode survival. Although at high SMP survival in heavy soils is greater than in sandy soils, the amount of time the soil environment is favorable for survival and population growth is generally much greater in sandy soils. Another factor is that at low SMP the $CO_2/O_2$ ratio is favorable for survival and population growth to a more shallow soil depth in heavy soils than in sandy soils. Survival decreased with increasing temperature between 0 and 37°C. Nematodes survived less than 15 days at -15 and 37°C. The relationship is probably due to more rapid energy reserve depletion with increasing metabolic rate and to increasing activity of soil micro-organisms acting as pathogens, toxin producers, or oxygen consumers (Kable and Mai, 1968a). In addition, Kable and Mai (1968a) reported that the rate of population increase of *P. penetrans* was greatest at moderate SMP. Soil type had an impact on population growth such that the higher silt and clay content of a soil the greater is the SMP necessary for satisfactory growth. Patterson and Bergeson (1967) reported that the reproduction rate of *P. penetrans* was higher at 30°C than 22.5 or 15°C, but that optimum temperature for population growth can vary with host plant. Dickerson *et al*. (1964) found that the rate of population increase of *P. penetrans* was influenced by the host and agronomic practices. They found the greatest population increases at 16°C in potatoes and 24°C in corn and that corn allowed higher population buildup than potatoes.

2. *Movement*.--A suitable feeding site must be located for *P. penetrans* to survive and reproduce. The ability of the nematode to move through the soil and infect a root can be measured by population growth or by observations of

nematode movement and root penetration. Factors that affect nematode movement to and penetration of the host plant include soil type, bulk density, SMP, and soil temperature. Soils with high bulk density or high clay or silt content reduce the movement and root penetration of P. penetrans as compared to non-compacted sandy soils (Townshend and Webber, 1971). Root penetration by P. penetrans is greatest at moderate SMP (Kable and Mai, 1968a). Townshend (1972) reported that corn root penetration increased in the spring as the soil temperature rose above $6^{\circ}$ C and as SMP increased above zero. The optimal temperature for penetration was affected by soil type but ranged from 20 to $30^{\circ}$C. The adults were more adapted to the cooler temperatures. Townshend (1978) found that females penetrated alfalfa roots at temperatures from 5 to $30^{\circ}$C, with maximum penetration between 10 and $30^{\circ}$C. Males and third stage juveniles penetrated roots only between 10 and $30^{\circ}$C, with maximum penetration at $20^{\circ}$C.

3. Orientation.--P. penetrans apparently uses gradients produced by plant roots to locate a suitable host. Lavallee and Rohde (1962) investigated the attractiveness of a root in agar and in sand. They reported that there was a gradient established by the root more quickly in the agar than the sand. P. penetrans was not attracted to roots when further than 12.5 mm away, and they concluded that a diffusible substance was the attractive factor. Klinger (1972) reported a positive orientation to a temperature gradient when the ambient temperature was below preferred temperature conditions. There was also a migration toward higher concentrations of $CO_2$ (Edmunds and Mai, 1966). These orientation mechanisms are not additive when combined, but $CO_2$ gradient was the dominant mechanism at higher soil temperatures (Klinger, 1972).

4. Penetration.--The preferred region for root penetration is reported as the dense root-hair zone (Townshend, 1978) or the region 3-10 mm behind the root tip (Freckman and Chapman, 1972). Root penetration, however, occurs all along the root system as well (Freckman and Chapman, 1972; Townshend, 1978). Olthof (1982) reported that penetration of one-day-old root tissue was about twice that of 10 or 20-day-old roots.

5. Pathogenicity.--P. penetrans causes a reduction of plant vigor and yield loss in many crops (Pitcher et al., 1960; Shafiee and Jenkins, 1963; Willis, 1976; Dickerson et al. 1964; Oostenbrink, 1958). Olthof and Potter (1973) investigated the pathogenicity of P. penetrans on six vegetable crops. They found that marketable yields were inversely correlated with pre-plant nematode population densities. They reported 17% and 25% marketable yield loss of potatoes grown with initial population densities of 6,000 and 18,000 P. penetrans per 1,000 grams of soil, respectively.

After location and penetration of a root, P. penetrans feeds and reproduces as a migratory endoparasite in the cortex. Townshend (1978) reported that a clear water-soaked area appeared on the surface of the root within hours as the nematode penetrated the epidermis. A yellow-colored lesion, elliptical and ca. 1.0 mm long developed as the nematode fed in the cortex. P. penetrans migrates primarily intracellularly within the root cortex. Nuclei of cells disrupted by nematodes disintegrate and those surrounding the nematode undergo hypertrophy (Oyekan et al., 1972). Damage from the physical activity of the nematode seemed to be more important than chemical or enzymatic reaction induced by the nematode in pea roots (Oyekan et al., 1972). The extent of root necrosis depends on the presence of specific chemical constituents of the plant, which, when acted on by the nematode's enzymes, give rise to products that are toxic to invaded and adjacent host cells, phenolic compounds being among them (Pitcher et al., 1960). The track left by one nematode is often followed by others. Necrotic areas tend to cause migration of juveniles and males while gravid females remain and lay eggs (Pitcher et al., 1960).

P. penetrans enters and feeds in roots, rhizomes and tubers of Solanum tuberosum. Dickerson et al. (1964) found that root lesion formation was evident after five days at 16°C, and the lesions were more extensive under warmer conditions. Some of the affected cells were void of contents. In others, the cytoplasm was granular and brown, nuclei were reduced and granular, and cell walls were brown. Rhizomes were not attacked as severely as roots, and the lesions were relatively shallow, not extending more than 5 or 6 cells into the cortex. When tubers were infected, small shallow lesions appeared, and no reproduction was observed. Bird (1977) suggests that during the growing season there is a migration pattern of P. penetrans from roots to soil and back to root tissue. This mobility possibly explains why P. penetrans might exploit an apparently temporary food source such as tubers. There are differences in susceptibility to P. penetrans infection among cultivars (Bernard and Laughlin, 1976; Vitosh et al., 1980).

A P. penetrans and Verticillium spp. interaction has been reported as being the cause of "early dying" of potatoes. The role of the nematode in this fungus-nematode complex appears to be limited to providing favorable infection courts for the fungus (Conroy et al., 1972). Morsink and Rich (1968) reported a significant interaction of P. penetrans and Verticillium on the dry weights of tubers and top growth of cv Katahdin. Alone, the nematode reduced root weights, and the fungus reduced top growth and increased wilt ratings. Burpee and Bloom (1978) reported that there was only an earlier expression of severe wilt symptoms in Katahdin when both the nematode and fungus were present. A major factor influencing these results may have been the size of container the plants were grown in. Morsink and Rich (1968) used much smaller pots than Burpee and Bloom (1978).

Martin et al. (1981) were able to determine the influence of the nematode-fungi relationship in Superior using a microplot technique. Levels of P. penetrans or Verticillium spp. did not cause tuber yield loss alone, but caused a 70% yield reduction in sandy loam soil when combined. There is much work to be done in this area to understand the influence of cultivars, weather, soil type, and root growth restrictions on this disease relationship.

6. Plant Nutrition.--Around the turn of the century, plant parasitic nematodes were found to have a profound effect on the nutritional status of their host plant (Hunter, 1958). More recently, there have been investigations involving the role of plant nutrition on nematode growth and development (Bird, 1960; Ismail and Saxena, 1977). Studies have also been conducted on the role of host nutrition on nematode community structure (Kirkpatrick et al., 1964a), and nematode reproductive rates (Oteifa and Diab, 1961), as well as nematode influence on host nutrition (Hunter, 1958; Jenkins and Malek, 1966; Oteifa and Elgind, 1962; Van Gundy and Martin, 1961). An excellent review was published by Kirkpatrick et al. (1964b).

Plant parasitic nematodes exhibit varying degrees of specificity for root regions and tissues for penetration and feeding. The type of injury inflicted on the host plant can be classified according to feeding habits. The categories include epidermal, root meristem, vascular system, and cortical feeders. P. penetrans penetrates the epidermal tissue and cortical parenchyma, but is excluded from the vascular system by the endodermis (Oyekan et al., 1975;

Pitcher et al., 1960; Shafiee and Jenkins, 1963). They can induce toxic reactions on endodermal cells when feeding adjacent to them and probing with the stylet (Oyekan et al., 1975; Pitcher et al., 1960). Cortical parenchyma cells are destroyed when Pratylenchus spp. feeds resulting in the loss of root differential permeability. This reduces nutrient transport (Pinochet and Cook, 1976).

Root growth is retarded when extensive cortical feeding occurs in the transition zone between root elongation and maturation and in the recently mature region. High populations of plant parasitic nematodes feeding in the young mature cortex can alter the water balance and reduce element concentrations to deficiency levels, especially when an element is of marginal availability (Kirkpatrick et al., 1964b).

Plant nutrient uptake and feeding habits of P. penetrans have an important relationship. P. penetrans favors the root apex for penetration, but migrates throughout the root system. The role of different root regions in nutrient absorption needs more study. Ammonium ion, phosphorus (P), and potassium (K) uptake has been reported as occurring throughout the root system. These nutrients move symplastically through the cortex and the endodermis to the xylem. Calcium (Ca) has an apoplastic pathway and is blocked by the casparian band of the endodermis. The uptake of Calcium, therefore, is restricted to the unsuberized apical portions of roots (Russell, 1977), which is a penetration zone for P. penetrans. High nematode population densities could have a significant effect on cortical symplastic movement. Destruction of apical cells may restrict the permeability of these cells to nutrient containing solute. Kimpinski (1979) reported that the amount of water moving through the stems of potato plants infected with P. penetrans in the greenhouse was less than that in non-infected plants. The reduction in nutrient and water absorption and transport is probably related to cell destruction and the reduction in soil mass available to the plant due to retarded root growth.

P. penetrans influences the growth and nutrition of the host plant. Willis (1976) reported that parasitized plants were less efficient in responding to added K fertilizer. Root and shoot growth were suppressed by P. penetrans. Heald and Jenkins (1964) found the effect of P. penetrans on nutrient concentrations varied among woody ornamentals. Generally, P. penetrans increased the concentration of K and Ca in the shoot system, although exceptions existed. Shafiee and Jenkins (1963) reported that infection of pepper (Capsicum frutescens) with P. penetrans increased K concentrations in shoots, as compared to non-infected plants. They hypothesized that the growth rate of the pepper plants were reduced as a result of: (1) direct effect of the parasite on the host through release of toxic metabolic products or production of enzymes which can act on some components of the root, releasing phytotoxic by-products; and (2) toxic effects exerted by an imbalance in essential elements. Reports on nematode-host nutrition relations differ widely. The differences may be due to varying soil types, fertility practices, environmental conditions, host, and nematodes in plant-disease relationships. In summary, nematodes alter plant mechanisms of absorption, translocation and accumulation of various constituents (Heald and Jenkins, 1964).

Host plant nutrition is known to influence the development and reproduction of P. penetrans. Dolliver (1961) found that treatments which inhibited root and plant growth suppressed reproduction of P. penetrans. Unfertilized cotton plants restricted the reproductive rate of Pratylenchus spp. as compared to fertilized plants (Oteifa and Diab, 1961). They further reported that increasing K fertilizer increased the plant tolerance and the reproductive rate of the nematodes. Kirkpatrick et al. (1964a), however, found that P. penetrans population levels on cherry were highest on K-deficient trees and lowest on trees well fertilized with K or P and K. Willis (1976) found that K nutrition did not affect the host-parasite relations between alfalfa or red clover and P. penetrans.

There is no uniform response between host nutrition and Pratylenchus spp. development and reproduction. The observed changes in population levels may be related to changes in plant metabolites that are subject to change by variations in plant nutrition and growth. These metabolic responses may change with host plant species.

7. Rotation Crops.--Crop rotation is an important component in the design of many agricultural production systems. Cropping patterns should be structured so that short-term gains do not result in long-term net losses. Resources that enhance sustained-yield agroecosystems should not be sacrificed for short-term profit. Although clean fallowing has often proven to be effective in reducing soil nematode populations, leaving land fallow allows for increased soil erosion and a loss of soil structure. Highly resistant crops seem to serve equally well as clean fallowing in reducing nematode populations. The use of such crops is preferable (Norton, 1978).

Crop resistance, nematicides, crop rotation, and production management practices can minimize the effects of P. penetrans. Crop rotation is one agronomic practice that can contribute significantly to an overall management strategy of nematode damage. Crop rotation, chemical controls and host resistance are not mutually exclusive and can be complementary. Integration of control measures can increase management efficiency and reliability, as well as possibly retarding nematode resistance and reducing pesticide needs. Objectives of crop rotations to control parasitic nematodes when used alone or with resistant varieties include: (1) reduction of population densities so that they will be below the economic threshold for the following crop; and (2) preserving competitive, antagonistic, and predaceous organisms to buffer from the pathogenic organism's population build-up (Nusbaum and Ferris, 1973). If the crop rotation strategy is used in conjunction with nematicides, the objectives could be an increase in efficiency and reliability of control, and a reduced rate of resistance build-up.

Certain characteristics of nematodes impinge on the feasibility of crop rotation as a pest management strategy. Nematodes with narrow host ranges are more prone to control by rotation practices than those with wide host ranges. Nematodes that utilize long-term survival mechanisms can survive in soils over several seasons without a host and therefore are not amenable to control by rotation practices (Evans and Perry, 1976). Most soils harbor a mixture of nematode species and no single cropping system suppresses all plant parasitic nematodes. For a given location, however, there may be a single nematode species of primary concern and amenable to control by rotation. P. penetrans has a wide host range, but no long-term survival mechanism. A non-host crop, therefore, may prove valuable for management of this nematode with crop rotations.

Plant parasitic nematodes are obligatory parasites; therefore, food quality and supply determine population structure, density, and distribution. The ability of a rotation crop to meet the nematode management objectives can be measured by nematode reproductive rate and equilibrium density. The reporductive rate slows as the population density increases, and an equilibirium density is reached at which the population density is maintained (Nusbaum and Ferris, 1973). The relationship of the reproductive rate and equilibrium density to the temporal establishment of the host plant determines the final population density. Except where the reproductive rate can be significantly reduced, the equilibirum density is the parameter of greatest value in defining a crop's suitability as a pest management tool.

The effectiveness of a cropping system to reduce nematode damage can be influenced by many parameters. The cropping sequence and management practice can have a significant impact on nematode populations. P. penetrans population densities in potatoes increased after fallowing 19 weeks, but only to about 25% of the densities of those grown after a rye crop of 19 weeks (Fawole and Mai, 1975). Olthof (1971) reported similar results from a tobacco-rye rotation study. When fallowing from August through December, P. penetrans population densities stayed constant, but population densities in fallowed soil prior to tobacco were 6-8 times lower than that following a rye cover crop. Mishra and Prasad (1978) reported that fallowing without weeds resulted in a six-fold reduction in nematode population densities when compared to fallow with weeds. Furthermore, in wheat and potato crops, there was a two-fold reduction in nematode populations in plots without weeds in comparison to plots with weeds. Their findings confirm that weed management practices can have an important impact in a nematode management program. Soybeans and corn receiving nitrogen from the activity of a legume supported lower numbers of root-lesion nematodes than when inorganic nitrogen was used. This was not, however, apparent in cotton (Collins and Rodriguez-Kabana, 1971), where it was also reported that higher numbers of nematodes developed in soils deficient in phosphorus.

Another component of agronomic significance that can influence the effectiveness of a poor host is maintenance of the shoot system. MacDonald and Mai

(1963) reported that many poor hosts of P. penetrans were rendered suitable hosts after pruning the top growth. One poor host, that was not altered by pruning was African marigold (Tagetes erecta L.). They reported that sudangrass (Sorghum vulgare var. sudanense (Piper) Hitchc.) was a poor host but they did not submit it to pruning. MacDonald (1966) reported that the host quality of Piper sudangrass was not altered by pruning but a good host, Vicia villosa Roth (hairy vetch), became a better host after pruning.

It is of interest to note that Marks and Townshend (1973) reported that sudangrass was a good host for P. penetrans. They proposed that the race of P. penetrans may have been different than that used by other workers, or possibly a different variety of sudangrass was used. Varietal differences in host quality within a species that is considered a poor host have been reported (Olthof, 1971).

Mechanisms involved in host resistance are not clear. Most of the work has been done comparing the chemical composition of poor hosts to good hosts. MacDonald (1966) found that a poor host, S. vulgare ('Piper'), had lower nitrogen and much higher total phenol content than a good host, hairy vetch (V. villosa). Pruning of the plants altered the nitrogen and phenol content of the roots. The smallest nematode population densities in both crops were present in the roots with the highest total and alcohol-soluble nitrogen and total phenols. This condition was associated with non-pruned shoot systems. Liv-Mei and Rohde (1969) reported a repellent effect of necrotic tissues on P. penetrans. This was apparently due to methanol and oxidized phenol accumulation.

# III. MATERIALS AND METHODS

The materials and methods section is divided into two parts. The first describes a potato production system management experiment conducted at the Montcalm Potato Research Farm. The second describes a series of greenhouse and field experiments related to the suitability of rotation crops for management of P. penetrans.

## A. POTATO PRODUCTION SYSTEM MANAGEMENT

This study was initiated to examine intensive production system management practices on soilborne disease relationships and the yield of potatoes. The objectives were to examine joint influence of nitrogen and nematicides under two crop rotation strategies on the yield and quality of potatoes, cv Superior. Emphasis was placed on P. penetrans, Verticillium, Rhizoctonia, and tuber yields in relation to the selected production practices.

Two field experiments were conducted in 1981 on a McBride sandy loam soil at the Montcalm Research Farm in west-central Michigan. One experiment followed alfalfa grown in 1980, and the second followed corn production. In both tests, cv Superior potatoes were grown at two nitrogen levels (84 and 252 kg/ha) and four pesticide treatments (non-treated control, 1,3-dichloropropene plus methylisothiocynate (1,3-D+MIC), aldicarb, and aldicarb plus 1,3-D+MIC). Two additional cvs, Russet Burbank and Denali received 252 kg N/ha and aldicarb plus 1,3-D+MIC. The experiments were established using a randomized complete block design with five replications of each treatment. The Russet Burbank and Denali cultivars were inadvertantly killed prior to maturity and affected data are not reported.

In the spring of 1980, one range (15.2 m X 182.9 m) of corn and one range of alfalfa at the MSU Montcalm Potato Research Farm were planted adjacent to each other. The alfalfa was cut periodically and the top growth left for soil organic matter accumulation. The corn was harvested for grain and the stalks were left in the field. Both ranges were plowed about 15 cm deep the last week of April, 1981. The plots that required fumigation received 93.5 l/ha of 1,3-D+MIC injected on a broadcast basis at a depth of 20 cm on April 28 ($DD_{10}$=80)[1]. All other plots received the same tillage, but no fumigant was added. Aldicarb applications and planting were completed for both ranges on May 14 ($DD_{10}$=131). The aldicarb was applied in a band beside the seed furrow at a rate of 3.4 kg/ha active ingredient. Each plot consisted of four rows 15.24 m long having a 0.86 m row width. Seed spacing of Superior (whole seed) was 20 cm, and 30 cm for Russet Burbank and Denali. All plots received 84 kg nitrogen (N in the form of urea), 168 kg $P_2O_5$ and 168 kg $K_2O$ per ha. The fertilizer was banded 5 cm to the side and below the seed pieces. One hundred and sixty-eight kg N per ha was sidedressed at hilling in the high N plots. The non-treated controls received no edaphic pesticides.

Insecticide sprays were used as needed throughout the season to minimize the impact of foliar-feeding insects. Irrigation water was applied with a solid set sprinkler system according to need, monitored by tensiometers. Fungicides were applied as a preventative program. Tuber yields and size distribution were determined by harvesting the two center rows, grading and weighing them in the field. Samples were taken for specific gravity and storage evaluation. The corn

[1] Accumulated degree days from planting with a base of 10°C.

rotation range was harvested August 25 ($DD_{10}$=1463) and the alfalfa range on August 26 ($DD_{10}$=1476).

Soil samples were taken for nematode analysis at $DD_{10}$=641 and 1063 (June 30 and July 27) in the center-side of the outside rows from six plants. Each outside row was sectioned into equal thirds and a plant was randomly chosen within each section. Soil and root populations of nematodes were then determined using the centrifugation-floatation technique (Jenkins, 1964) and shaker technique (Bird, 1971), respectively. Estimates of soil and root population densities were based on 100 $cm^3$ of soil and 1.0 gm of root tissue.

Rhizoctonia spp. and Verticillium spp. were monitored every two weeks during the growing season: June 15 and 30, July 14 and 27, ($DD_{10}$= 476, 641, 899, and 1063, respectively). For sampling purposes, each of the two outside rows of each four-row plot were sectioned into three equal lengths and then a stem was randomly chosen from 3 of the 6 sections for fungal analysis. Plant samples were stored at 4°C for less than 3 days until plating out. Stems were rinsed, surface sterilized with 10% chlorine solution for 20 seconds and a 3 mm cross section was cut at the original soil surface level. The section was quartered and placed in a petri plate with water agar. The petri plates were stored in the dark at room temperature for three weeks before microscopic examination for the presence of fungi.

Soil samples for nutrient analysis were pooled within each range for general baseline information. Plant nutrient concentrations were analyzed by collecting recently mature petioles from each treatment. About fifty petioles were pooled from the center rows of each plot on June 30 ($DD_{10}$= 641). Petioles were analyzed for nutrient concentration by an analytical laboratory.

## B. ROTATION CROPS FOR INHIBITION OF P. penetrans

Three experiments were conducted to study the impact of forage grain cultivars and management on P. penetrans population density. The three strategies investigated were: no cutting, cutting at various plant heights, and mulching with top growth or removal of top growth. Two experiments were conducted to determine the effects of chosen forage legume cultivars on P. penetrans population growth.

1. Forage Grain Rotation Crops.--Six forage-grain varieties were evaluated in a greenhouse trial for their potential as poor-host crops for use in crop rotations to reduce P. penetrans population densities. The varieties: Sorghum bicolor L. 'Bird-A-Boo' (a high tannin sorghum), two sorghum-sudangrasses ('Hay-R-Grazer' and an unknown cultivar), two forage sorghums ('Milkmaker' and 'Yieldmaker' (Sorghum bicolor)) and a sudangrass (Sorghum vulgare var. sudanese Hitchc. 'Trudan 8') were subjected to three top growth management strategies: no cutting, cut and remove top growth and cut and mulch in a 6 x 3 (completely randomized) factorial design with 6 replications. Four seeds were planted in each of the 108 8-inch diameter field tiles (10,000 $cm^3$ of sandy loam soil) on March 20, 1981. Ten days later, they were thinned to one plant per pot and inoculated with 125 P. penetrans in the root zone of the remaining plant. The nematodes were obtained from a greenhouse culture. All the cut-treatments were cut to 5 cm when the tallest plants reached 61 cm in height, which resulted in two cuttings. The top growth of the mulch-treatment was cut into 5 cm sections and returned to the soil surface as a mulch. Roots (2.0 grams) and soil (100 $cm^3$) were evaluated 125 days from planting for P. penetrans population densities.

Two field experiments were conducted in 1981 on a McBride sandy loam soil to determine the impact of forage grain varieties and management of the top growth on the population dynamics of P. penetrans. Both experiments were established using a randomized complete block design. They were planted on June 4 ($DD_{10}$ = 312). Fertilizer (12-12-12 at 364 kg/ha) and seed (30 kg/ha) were broadcast and incorporated by disking. Superior potatoes were planted as a control plot since much is known about the population dynamics of P. penetrans on this variety. Potatoes were planted in 2 rows per plot. Each plot was 1.83 X 3.66 m. Samples for nematode analysis were taken from the center meter of each plot from three randomly chosen plants. Estimates of soil and root densities were based on 100 $cm^3$ soil and 1.0 gram of root tissue, extracted by centrifugation-flotation and shaker technique, respectively.

In one experiment, three varieties of forage grains were evaluated using two top growth management strategies to determine their suitability for a non-host rotation crop. The varieties were Sorghum bicolor 'Bird-A-Boo,' Sorghum-Sudangrass hyb. 'Hay-R-Graze,' and Sorghum bicolor 'Yield Maker' (a forage sorghum). All forage grain plots were cut when Hay-R-Graze was one meter tall, and top growth was removed or not removed for each variety. On all plots where top growth was to remain as organic matter, the stalks were raked to cover only the center meter of each plot. Plants were cut with a sickle-bar type mower about 5 cm above the ground surface. The logic behind top growth management is that: (1) the organic matter will help retain soil moisture and provide organic matter for the following crop; and (2) the top growth of some varieties contain tannins, phenolic acids, and a glucoside which may leach into the soil and inhibit population growth of plant parasitic nematodes.

The objective of the second experiment was to determine the effects of top growth management on a poor-host rotation crop, sorghum-sudangrass hyb. 'Hay-R-Graze.' The top growth management strategy consisted of leaving the top growth for organic matter after cutting, or removing top growth from the plot. When top growth was left, it was raked into the center meter of the plot. There were two cutting schedules that had both top growth treatments applied: (1) cut when the average height of the top growth was 36 cm, and (2) cut when the average height of the top growth was 69 cm. The remaining treatments were: cut when 127 cm high and leave top growth, no cutting, and Superior potatoes as a control.

2. Forage Legume Rotation Crops.--Eight varieties of alfalfa were screened for their host crop potential by monitoring the population growth of *P. penetrans*. A completely randomized design was used in a greenhouse study with six replications. One seed of each of eight cultivars (Saranac, Syn XX, Vernal, Agate, Pioneer 531, Pioneer 545, Iroquois, and Oneida) was planted into non-sterilized sandy loam soil with 52 *P. penetrans* per 100 $cm^3$ in 15.2 cm pots (1500 $cm^3$ soil) on June 8, 1981. Varieties that have been improved by addition of resistance in this test are Vernal and Iroquois. Resistance to Phytopthora root rot caused by *Phytopthora megaposoran* was added to Vernal and named Agate. Resistance to Phytophthora root rot was added to Iroquois and became Oneida. Resistance to spotted alfalfa aphid and Anthracnose was emphasized in developing 531 (Pioneer). Resistance to spotted alfalfa aphid and Phytopthora root rot was emphasized in selecting 545. The soil was mixed in a cement mixer to improve the uniformity of nematode density distribution. Syn XX is a *Meloidogyne hapla*-resistant variety reported by Hartman *et al*., 1978.

After 112 days the plants were setting seed; root and shoot fresh and dry weights were recorded and root and soil samples were taken. _P. penetrans_ densities were determined from 2.0 grams of root tissue and a 100 $cm^3$ soil sample, using the gyratory shaker and centrifugation-flotation techniques.

Four varieties of alfalfa (_Medicago sativa_) and one variety of birdsfoot trefoil (_Lotus corniculatus_) were evaluated for their potential as a poor-host crop for _P. penetrans_ in a completely randomized design with eight replications in a greenhouse. One plant per 20.3 cm clay pot (3500 $cm^3$ soil) of each of four alfalfa varieties (Saranac, Vernal, Iroquois, Oneida) and birdsfoot trefoil (Viking) were grown for 144 days, planted October 14, 1982. The sandy loam soil was steamed to kill any resident nematodes. Nitrogen-fixing inoculant was applied to the birdsfoot trefoil (BFT) pots, but the alfalfa utilized residual bacteria; all plants were well nodulated at harvest. All plants were inoculated with 300 _P. penetrans_ in their root zones at day 15 (alfalfa varieties had two trifoliate leaves). _P. penetrans_ was obtained from a greenhouse culture maintained on dry beans. Top growth was harvested when alfalfa plants were in full bloom, on day 98; fresh weight and dry weights were recorded. On day 144, the experiment was terminated, as alfalfa plants were beginning to flower. Top growth fresh and dry weights were recorded. Nematode population densities were evaluated from 100 $cm^3$ soil and 2.0 grams root tissue, using the centrifugation-flotation and gyratory shaker techniques, respectively.

# IV. RESULTS

## A. POTATO PRODUCTION SYSTEM MANAGEMENT

1. Crop Yield and Quality.--At the low level of nitrogen (84 kg/ha) following alfalfa, aldicarb and aldicarb plus 1,3-D+MIC significantly increased marketable tuber yields (tubers larger than 5 cm in diameter and free of visible rot) above the check by 16 and 17%, respectively (Table 1). 1,3-D+MIC did not significantly increase yields above the check at either nitrogen level. At both levels of nitrogen, aldicarb and aldicarb plus 1,3-D+MIC resulted in higher marketable yields than their respective checks.

With high N, after alfalfa, aldicarb plus 1,3-D+MIC resulted in a significantly higher marketable tuber yield than all treatments except the high N with aldicarb (Table 1). Aldicarb and aldicarb plus 1,3-D+MIC resulted in 16 and 24% yield increases over the high N check, respectively. Aldicarb with high N increased oversize tuber yields (tubers larger than 8.2 cm in diameter) over all the low N treatments and the high N check and 1,3-D+MIC, indicating a response to added N in the presence of a nematicide. Aldicarb plus 1,3-D+MIC with high N resulted in significantly higher oversized tuber yield than the low N check. In relation to undersize tubers (less than 5 cm in diameter), the only treatments with significantly different tuber yields were low N aldicarb plus 1, 3-D+MIC over high N check, but the total yield of the former treatment was greater also. Tuber specific gravity was not significantly affected by the pesticide and fertilizer treatments.

Following corn, nematicides did not affect marketable tuber yields at the low N level (Table 2). Increasing the N level in the absence of nematicides did not significantly increase yields. At the high N level, 1,3-D+MIC and aldicarb

Table 1. Influence of selected management inputs on tuber yield and specific gravity of Superior following alfalfa.

| Treatment | | Tuber yield (t/ha) | | | Specific |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | <5 cm | ≥5 cm | >8 cm | gravity |
| 84 | Check | 1.28ab[1] | 35.78a | 2.80a | 1.071a |
| 84 | 1,3-D+MIC[2] | 1.31ab | 39.71abc | 4.97ab | 1.070a |
| 84 | Aldicarb[3] | 1.38ab | 42.44bc | 4.55ab | 1.069a |
| 84 | Aldicarb & 1,3-D+MIC | 1.57b | 43.47bc | 5.50ab | 1.069a |
| 252 | Check | 1.12a | 37.97ab | 4.76ab | 1.071a |
| 252 | 1,3-D+MIC | 1.22ab | 39.95abc | 4.88ab | 1.072a |
| 252 | Aldicarb | 1.43ab | 45.43cd | 8.07c | 1.069a |
| 252 | Aldicarb & 1,3-D+MIC | 1.45ab | 49.77c | 6.87bc | 1.072a |

[1] Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

[2] Injected on a broadcast basis at the rate of 93.5 l/ha on $DD_{10}$ = 78.

[3] Applied at planting in a band beside the seed furrow at a rate of 3.4 kg ai/ha.

Table 2. Influence of selected management inputs on tuber yield and specific gravity of Superior following corn.

| Treatment | | Tuber yield (t/ha) | | | Specific gravity |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | <5 cm | >5 cm | >8 cm | |
| 84 | Check | 2.50b[1] | 30.83a | .93a | 1.072b |
| 84 | 1,3-D+MIC | 2.43b | 34.14ab | 1.12a | 1.072b |
| 84 | Aldicarb[3] | 2.56b | 34.29ab | .83a | 1.072b |
| 84 | Aldicarb & 1,3-D+MIC | 2.62b | 34.75ab | .98a | 1.070b |
| 252 | Check | 1.61a | 34.19ab | 1.93a | 1.067a |
| 252 | 1,3-D+MIC | 1.61a | 39.38bc | 3.93b | 1.069ab |
| 252 | Aldicarb | 1.83a | 40.32bc | 4.72b | 1.067a |
| 252 | Aldicarb & 1,3-D+MIC | 1.74a | 44.16c | 6.32c | 1.068a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

[2]Injected on a broadcast basis at the rate of 93.5 l/ha on $DD_{10}$ = 78.

[3]Applied at planting in a band beside the seed furrow at a rate of 3.4 kg ai/ha.

increased marketable tuber yields above the low N check. Aldicarb plus 1,3-D+MIC increased yields above all the low N treatments and the high N check.

Nematicides had no effect on yields of oversized tubers at the low N level (Table 2). At the high N level both 1,3-D+MIC and aldicarb increased oversized tuber yields above all the low N treatments and the high N check. With high N oversized tuber yields of aldicarb plus 1, 3-D+MIC were greater than all other treatments. In general, oversized tuber production was significantly increased by the high rates of nitrogen in the presence of aldicarb. The yields of undersized tubers were reduced in all treatments by increasing the N level. Increasing the N level reduced the specific gravities in all but the 1, 3-D+MIC treatment.

2. Nematode Population Management.--Following alfalfa, there were no significant (P=0.05) differences among treatments in at-plant soil population densities of *P. penetrans* (Table 3). At all the remaining sampling dates, treatments with aldicarb reduced the combined root and soil density of *P. penetrans*. 1,3-D+MIC did not reduce the *P. penetrans* population density as compared to the check. Root populations at the initial sampling date, June 30 ($DD_{10}$=641) were significantly reduced by aldicarb plus 1,3-D+MIC at both levels of N. At this early sampling date, high N-aldicarb resulted in a significant reduction of *P. penetrans* root population as compared to both checks and both 1,3-D+MIC treatments, but the low N aldicarb was only significantly different from the high N check. All treatments with aldicarb significantly reduced root populations on the second sampling date, July 27 ($DD_{10}$=1063) as compared to non-aldicarb treatments. Treatment effects on population density were most prominent on $DD_{10}$=1063 in both root and combined root plus soil estimates. Nitrogen levels had no significant impact on the population density of *P. penetrans*.

Table 3. Influence of selected management inputs on population density of *P. penetrans* on Superior following alfalfa.

| Treatment | | *P. penetrans* ($DD_{10}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Per 1 gram root + 100 $cm^3$ soil | | | | Per 1 gram root | |
| Nitrogen kg/ha | Nematicide | 131 | 635 | 1063 | 1476 | 625 | 1063 |
| 84 | Check | 3.6a[1] | 18.4b | 91.2b | 18.8b | 14.8cd | 84.8b |
| 84 | 1,3-D+MIC[2] | 2.8a | 15.2b | 108.4b | 10.0ab | 14.4bcd | 103.2b |
| 84 | Aldicarb[3] | 3.6a | 3.2a | 3.6a | 1.2a | 3.2abc | 2.8a |
| 84 | Aldicarb & 1,3-D+MIC | 3.6a | 1.2a | 3.2a | 2.0a | 0.8a | 2.0a |
| 252 | Check | 3.6a | 18.4a | 79.2b | 20.0b | 17.2d | 72.8b |
| 252 | 1,3-D+MIC | 2.0a | 11.6a | 100.0b | 13.6b | 9.2bcd | 95.6b |
| 252 | Aldicarb | 2.0a | 1.2a | 0.4a | 1.2a | 0.4a | 0.4a |
| 252 | Aldicarb & 1,3-D+MIC | 0.8a | 1.2a | 2.4a | 2.4a | 4.0ab | 1.2a |

[1] Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

[2] Injected on a broadcast basis at the rate of 93.5 l/ha on $DD_{10}$ = 78.

[3] Applied at planting in a band beside the seed furrow at a rate of 3.4 kg ai/ha.

Following corn there were no significant (P=0.05) differences between treatments in at-plant soil population levels (Table 4). On $DD_{10}$=1063, 1,3-D+MIC resulted in a significant reduction of P. penetrans in combined root and soil or root population densities as compared to checks. Aldicarb resulted in a significant reduction as compared to 1, 3-D+MIC at harvest ($DD_{10}$=1476). There were no significant differences between nematicide treated plots. They contained lower population levels than the low nitrogen check, but not the high nitrogen check. Nitrogen levels had no significant effect on the population density of P. penetrans in the absence of nematicides.

3. Soil-borne Fungi.--Following alfalfa there were no significant differences (P=0.05) in percent of plants infected with Verticillium between treatments at any sampling date (Table 5). Percent of plants infected over the sampling period increased from less than 10% to over 60%. After this crop, there was a greater amount of Rhizoctonia infection in the low N aldicarb plus 1, 3-D+MIC than in either check on June 30 ($DD_{10}$=641, Table 6). There were no significant differences between treatments on any other sampling date. The percent of plants infected was generally highest on the first sampling date ($DD_{10}$=476), around 60%.

Following corn, there were no significant differences in percent-infection by Verticillium between treatments at any sampling date (Table 7). The percent of plants infected over the sampling period generally increased from less than 10% to over 60%. After this crop there were no significant differences in percent Rhizoctonia infection between treatments at any sampling date (Table 8). The percent of plants infected was never above 30% at any sampling date.

4. Nutrient Composition.--Following alfalfa, nitrate-nitrogen in petioles was significantly increased (P=0.05, LSD test) by increasing N when high N

Table 4. Influence of selected management inputs on population density of *P. penetrans* on Superior following corn.

| Treatment | | *P. penetrans* ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| | | Per 1 gram root + 100 $cm^3$ soil | | Per 1 gram root | |
| Nitrogen kg/ha | Nematicide | 131[1] | 1063 | 1476 | 1063 |
| 84 | Check | 2.0a | 86.4c | 30.0b | 80.0c |
| 84 | 1,3-D+MIC[2] | 1.6a | 19.6b | 8.4a | 18.8b |
| 84 | Aldicarb[3] | 5.6 | 0.4a | 0.0a | 0.4a |
| 84 | Aldicarb & 1,3-D+MIC | 2.8a | 0.4a | 0.0a | 0.4a |
| 252 | Check | 5.2a | 62.4c | 17.7ab | 55.6c |
| 252 | 1,3-D+MIC | 2.0a | 24.8b | 10.0a | 24.0b |
| 252 | Aldicarb | 3.2a | 0.4a | 1.6a | 0.0a |
| 252 | Aldicarb & 1,3-D+MIC | 2.4a | 2.4a | 1.2a | 2.0a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

[2]Injected on a broadcast basis at the rate of 93.5 l/ha on $DD_{10}$ = 78.

[3]Applied at planting in a band beside the seed furrow at a rate of 3.4 kg ai/ha.

Table 5. Percent of Superior potatoes infected with _Verticillium_ following alfalfa in a crop rotation.

| Treatment | | Percent _Verticillium_ infection ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | 476 | 641 | 899 | 1063 |
| 75 | Check | 0a[1] | 20a | 20a | 67a |
| | Vorlex | 0a | 47a | 20a | 67a |
| | Temik | 7a | 27a | 27a | 60a |
| | Temik & Vorlex | 7a | 0a | 47a | 60a |
| 225 | Check | 0a | 27a | 33a | 73a |
| | Vorlex | 7a | 53a | 20a | 60a |
| | Temik | 0a | 53a | 47a | 60a |
| | Temik & Vorlex | 13a | 13a | 20a | 60a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 6. Percent of Superior potatoes infected with Rhizoctonia following alfalfa in a crop rotation.

| Treatment | | Percent Rhizoctonia infection ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | 476 | 641 | 899 | 1063 |
| 75 | Check | 13a[1] | 0a | 13a | 40a |
| | Vorlex | 60a | 27ab | 33a | 33a |
| | Temik | 60a | 40ab | 40a | 20a |
| | Temik & Vorlex | 73a | 53b | 13a | 40a |
| 225 | Check | 73a | 0a | 0a | 20a |
| | Vorlex | 53a | 7ab | 33a | 33a |
| | Temik | 73a | 20ab | 47a | 40a |
| | Temik & Vorlex | 67a | 40ab | 40a | 27a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 7. Percent of Superior potato plants infected with *Verticillium* following corn in a crop rotation.

| Treatment | | Percent *Verticillium* infection ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | 476 | 641 | 899 | 1063 |
| 75 | Check | 7[1] | 40 | 60 | 87 |
| | Vorlex | 0 | 20 | 73 | 47 |
| | Temik | 7 | 27 | 73 | 73 |
| | Temik & Vorlex | 0 | 20 | 67 | 73 |
| 225 | Check | 0 | 47 | 47 | 60 |
| | Vorlex | 0 | 13 | 53 | 80 |
| | Temik | 7 | 33 | 60 | 60 |
| | Temik & Vorlex | 13 | 47 | 47 | 47 |

[1]Column means are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 8. Percent of Superior potato plants infected with *Rhizoctonia* following corn in a crop rotation.

| Treatment | | Percent *Rhizoctonia* infection ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| Nitrogen kg/ha | Nematicide | 476 | 641 | 899 | 1063 |
| 75 | Check | 0[1] | 7 | 7 | 0 |
| | Vorlex | 7 | 27 | 20 | 7 |
| | Temik | 13 | 27 | 13 | 13 |
| | Temik & Vorlex | 20 | 20 | 7 | 27 |
| 225 | Check | 0 | 0 | 0 | 7 |
| | Vorlex | 7 | 7 | 0 | 0 |
| | Temik | 20 | 13 | 27 | 7 |
| | Temik & Vorlex | 0 | 13 | 27 | 13 |

[1]Column means are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

treatments are compared to the low N check or aldicarb plus 1, 3-D+MIC (Table 9). Calcium concentrations were increased in the high N aldicarb and aldicarb plus 1, 3-D+MIC as compared to low N aldicarb. Both calcium and magnesium concentrations were increased in the high N aldicarb and aldicarb plus 1, 3-D+MIC as compared to the low N check and aldicarb plus 1,3-D+MIC. Zinc concentrations were increased in the high N aldicarb and aldicarb plus 1,3-D+MIC as compared to low N and 1,3-D+MIC treatment. P, K, Fe and Mn were not influenced by any treatment.

Following corn, nitrate concentrations were directly related to the addition of nitrogen fertilizer (Table 10). At the high level of N the nitrate concentration was lower in the 1, 3-D+MIC treatment than the aldicarb treatment. P, K, Ca, Mg, Zn, Fe and Mn were not significantly influenced by any treatments.

## B. ROTATION CROPS FOR INHIBITION OF P. PENETRANS.

1. Forage Grain Rotation Crops.--Analysis of root population densities indicated that host quality was influenced by pruning (Table 11). Trudan 8, Yieldmaker, and sorghum-sudangrass hybrids (SSH) maintained *P. penetrans* population densities at significantly lower levels than Bird-A-Boo. Pruning and removal of top growth of all varieties except Bird-A-Boo resulted in higher population densities than no pruning. There were no significant differences between varieties in the prune and remove level. All but Hay-R-Grazer were significantly better hosts after pruning and mulching. In the prune and mulch level, Hay-R-Grazer resulted in a significantly lower population density than Bird-A-Boo or Milkmaker.

Root plus soil population densities followed a similar pattern as root tissue densities (Table 12). With no pruning, Bird-A-Boo supported the highest population density, though significantly higher than Haygrazer only. Pruning and

Table 9. Effect of nitrogen rate and nematicides on nutrient composition of potato petioles from Superior, Russet Burbank and Denali potatoes grown in an alfalfa rotation.

| | | | | Nutrients[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nematicide | | | Parts per million | | | | Per cent | | | |
| Nitrogen[2] | Aldicarb | 1,3-D+MIC | Variety | $NO_3$ | Zn | Fe | Mn | P | K | Ca | Mg |
| 84 | -[3] | - | Superior | 28,985a[4] | 38abc | 99a | 127a | 0.38a | 9.2a | 0.89a | 0.44a |
| 84 | - | + | Superior | 29,731ab | 31a | 94a | 98a | 0.36a | 9.3a | 0.89a | 0.47ab |
| 84 | + | - | Superior | 31,447abc | 35ab | 80a | 106a | 0.37a | 8.8a | 0.90ab | 0.47ab |
| 84 | + | + | Superior | 28,999a | 42abc | 88a | 136a | 139.0a | 9.0a | 0.89a | 0.48a |
| 252 | - | - | Superior | 34,314cde | 37ab | 93a | 129a | 0.35a | 9.4a | 0.91ab | 0.48a |
| 252 | - | + | Superior | 32,165bcd | 37ab | 89a | 109a | 0.32a | 9.0a | 0.90ab | 0.50ab |
| 252 | + | - | Superior | 34,899cde | 47bcd | 90a | 134a | 0.40a | 9.7a | 1.05b | 0.61b |
| 252 | + | + | Superior | 35,501e | 56d | 102a | 132a | 0.36a | 9.7a | 1.01b | 0.6ab |
| 252 | + | + | Russet | 31,008ab | 51cd | 90a | 172a | 0.40a | 9.3a | 1.03b | 0.61b |
| 252 | + | + | Denali | 29,124a | 41abc | 94a | 135a | 0.29a | 9.0a | 0.79a | 138a |
| Sufficiency Levels | | | | 16,000 | 30 | 30+ | 30 | 0.18 | 6.0 | 0.36 | 0.17 |
| | | | | 20,000 | 100 | | 200 | 0.22 | 9.0 | 0.50 | 0.22 |

[1]Sampled June 30, 1981 ($DD_{10}$ = 641). [2]Kg/hectare. [3](+) = Yes; (-) = No.

[4]Column means followed by the same letter are not significantly different (P=0.05) according to the Least Significant Difference Test.

Table 10. Influence of nitrogen and nematicides on nutrient composition of potato petioles of Superior, Russet Burbank and Denali varieties grown in a corn rotation.

| | Nematicide | | | Nutrients[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Parts per million | | | | Per cent | | | |
| Nitrogen[2] | Aldicarb | 1,3-D+MIC | Variety | $NO_3$ | Zn | Fe | Mn | P | K | Ca | Mg |
| 84 | -[3] | - | Superior | 16,687a[4] | 55a | 138a | 242a | 0.51a | 10.5a | 0.76a | 0.33a |
| 84 | - | + | Superior | 14,906a | 50a | 135a | 221a | 0.48a | 10.1a | 0.71a | 0.33a |
| 84 | + | - | Superior | 16,392a | 66a | 129a | 274a | 0.43a | 10.8a | 0.76a | 0.31a |
| 84 | + | + | Superior | 14,515a | 68a | 130a | 224a | 0.41a | 9.4a | 0.66a | 0.32a |
| 252 | - | - | Superior | 27,230bc | 73a | 141a | 244a | 0.44a | 9.5a | 0.68a | 0.34a |
| 252 | - | + | Superior | 24,882b | 70a | 119a | 181a | 0.42a | 10.4a | 0.74a | 0.39a |
| 252 | + | - | Superior | 29,140c | 68a | 140a | 217a | 0.47a | 9.7a | 0.79a | 0.38a |
| 252 | + | + | Superior | 27,212bc | 72a | 128a | 193a | 0.42a | 9.8a | 0.76a | 0.42a |
| 252 | + | + | Russet | 23,980b | 82a | 113a | 231a | 0.40a | 9.1a | 0.67a | 0.36a |
| 252 | + | + | Denali | 24,766b | 80a | 145a | 237a | 0.44a | 9.5a | 0.64 | 0.32a |
| Sufficiency Levels | | | | 16,000 | 30 | 30+ | 30 | 0.18 | 6.0 | 0.36 | 0.17 |
| | | | | 20,000 | 100 | | 200 | 0.22 | 9.0 | 0.50 | 0.22 |

[1]Sampled June 30, 1981 ($DD_{10}$ = 641). [2]Kg/ha. [3](+) = Yes; (-) = No.

[4]Column means followed by the same letter are not significantly different (P=0.05) according to the Least Significant Difference Test.

Table 11. The effect of forage grain varieties and management on the population growth of *P. penetrans*.

| Variety | *P. penetrans*/100 $cm^3$ soil + 1.0 gram root | | |
|---|---|---|---|
| | No pruning | Prune and remove | Prune and mulch |
| Bird-A-Boo | 14.8cdef[2] | 30.3efg | 37.2g |
| Haygrazer | 6.3abc | 22.0defg | 13.5bcd |
| Sorghum-sudangrass[1] | 4.2ab | 23.2defg | 13.3cdef |
| Milkmaker | 6.2abc | 33.5fg | 27.5efg |
| Yieldmaker | 3.2a | 33.3defg | 24.defg |
| Trudan 8 | 4.0a | 17.8defg | 12.3cde |

[1]Varietal name unknown.

[2]Means followed by the same letter are not significantly different (P=0.05) according to Tukey's Multiple Range Test.

removing the top growth significantly increased the population density in all varieties except in Bird-A-Boo. Pruning and mulching with the top growth significantly increased population densities over no pruning of Milkmaker, but did not increase densities in Bird-A-Boo, Hay-R-Grazer, Trudan 8, and the SSH.

Soil population density was not significantly different between treatments except for the lowest, Haygrazer cut and mulch, and the highest, Trudan 8 cut and remove (Table 13).

In the forage grain variety field study, the initial population density of P. penetrans was not significantly different (P=0.05) between treatments (Table 14). On both subsequent sampling dates, August 17 and October 18 ($DD_{10}$ = 1355 and 1812), based on root or root plus soil populations, a significantly higher population density occurred in Superior potatoes than in the forage grain varieties. There were no significant differences between forage grain varieties or between top growth management levels. When the grand mean of the initial sampling (3.3) is compared to the mid-season population density, there is at most a three-fold population increase in the forage grains but an eight-fold increase in the potato.

In the forage grain management field study, the initial population densities of P. penetrans associated with the treatments were not significantly different (Table 15). After 1246 degree days (Base 10°C), the root plus soil population densities of P. penetrans associated with Superior potatoes were significantly greater than those associated with the SSH treatments. After 1593 degree days, the root plus soil population density of P. penetrans on Superior was significantly greater than any SSH treatment. There was a significant interaction between the most intensive cutting schedule (36 cm) and removal of top growth. Root plus soil population density of 36 cm-remove was significantly greater than all

Table 12. Effect of forage grain varieties and management systems on the population density of *P. penetrans*.

| | *P. penetrans*/100 $cm^3$ soil + 1.0 gram root | | |
|---|---|---|---|
| Variety | No cutting | Cut and removed | Cut and mulched |
| Bird-A-Boo | 26.2bcdef[2] | 41.3ef | 49.8f |
| Haygrazer | 11.0a | 32.4cdef | 16.9abc |
| Sorghum-sudangrass[1] | 12.8ab | 36.5cdef | 19.0cde |
| Milkmaker | 11.5ab | 43.5ef | 41.1f |
| Yieldmaker | 15.2ab | 42.7def | 37.6def |
| Trudan 8 | 15.6ab | 39.5cdef | 17.0abcd |

[1]Varietal name unknown.

[2]Means followed by the same letter are not significantly different (P=0.05) according to Tukey's Multiple Range Test.

Table 13. The effect of forage grain varieties and management systems on the population density of *P. penetrans*.

| | *P. penetrans*/100 $cm^3$ soil | | |
|---|---|---|---|
| Variety | No cutting | Cut and removed | Cut and mulched |
| Bird-A-Boo | 11.4ab[2] | 11.0ab | 12.6ab |
| Haygrazer | 4.6ab | 10.4ab | 2.4a |
| Sorghum-sudangrass[1] | 8.6ab | 13.4ab | 5.6ab |
| Milkmaker | 5.4ab | 10.0ab | 13.6ab |
| Yieldmaker | 12.0ab | 9.4ab | 11.6ab |
| Trudan 8 | 11.6ab | 21.6b | 4.6ab |

[1]Varietal name unknown.

[2]Means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 14. Influence of forage grain varieties and management practices on the population dynamics of *P. penetrans*.

| Treatment | | *P. penetrans* ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| | | Per 100 $cm^3$ soil + 1 gram root | | | Per 1 gram root |
| Variety | Shoot growth management | 312 | 1355 | 1812 | 1355 |
| Bird-A-Boo | Mulch | 4.0a[1] | 6.8a | 6.0a | 5.6a |
| Bird-A-Boo | Remove | 3.2a | 9.6a | 4.8a | 8.0a |
| Hay-R-Graze | Mulch | 3.6a | 5.6a | 6.8a | 4.4a |
| Hay-R-Graze | Remove | 3.6a | 8.8a | 3.6a | 6.4a |
| Yieldmaker | Mulch | 3.6a | 6.8a | 4.8a | 5.6a |
| Yieldmaker | Remove | 2.8a | 0.9a | 2.4a | 0.4a |
| Superior potatoes | | 2.0a | 24.4b | 20.8b | 20.8b |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 15. Influence of selected management practices on the population dynamics of *P. penetrans* associated with Sorghum-sudangrass hybrid.

| Treatment | | *P. penetrans*/100 $cm^3$ soil + 1 gram root ($DD_{10}$) | | | |
|---|---|---|---|---|---|
| Plant height after cutting (cm) | Shoot growth management | 312 | 1246 | 1593 | 1812 |
| 36 | Mulch | 5.6a[1] | 12.0a | 9.2bc | 7.6a |
| 36 | Remove | 4.0a | 15.2a | 19.2c | 6.4a |
| 69 | Mulch | 8.0a | 13.6a | 6.4ab | 4.8a |
| 69 | Remove | 4.4a | 10.4a | 4.4a | 5.6a |
| 127 | Mulch | 4.4a | 4.8a | 4.8ab | 4.0a |
| Uncut | None | 3.6a | 8.4a | 2.4a | 2.0a |
| Superior Potatoes | | 2.8a | 56.4b | 71.2d | 18.0a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

Table 16. Influence of selected management practices on the population density of _P. penetrans_ associated with a Sorghum-sudangrass hybrid.

| Treatment | | _P. penetrans_ ($DD_{10}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Per 100 $cm^3$ soil | | | | Per 1 gram root | |
| Plant height after cutting (cm) | Shoot growth management | 312 | 1246 | 1593 | 1812 | 1246 | 1593 |
| 36 | Mulch | 5.6a[1] | 0.8a | 5.2a | 7.6a | 11.2a | 4.0ab |
| 36 | Remove | 4.0a | 3.6ab | 6.8a | 6.4a | 11.6a | 12.4b |
| 69 | Mulch | 8.0a | 4.8ab | 4.4a | 4.8a | 8.8a | 2.0ab |
| 69 | Remove | 4.4a | 1.2a | 2.4a | 5.6a | 9.2a | 2.0ab |
| 127 | Mulch | 4.4a | 0.8a | 3.2a | 4.0a | 4.0a | 1.6ab |
| Uncut | None | 3.6a | 1.2a | 1.6a | 2.0a | 7.0a | 0.8a |
| Superior Potatoes | | 2.8a | 9.2b | 18.4b | 18.0a | 57.2b | 52.8c |

[1]Column means followed by the same letter are not significantly different (P=05) according to the Student-Newman-Keuls Multiple Range Test.

Table 17. The influence of P. penetrans on selected alfalfa varieties.

| | *P. penetrans* | | Shoot system weight (g) | |
|---|---|---|---|---|
| Variety | Per 1 gram root | Per 100 $cm^3$ soil + 1 g root | Fresh | Dry |
| Vernal | 109.5b[1] | 112.5b | 6.37ab | 1.82ab |
| Agate | 63.6ab | 66.8ab | 6.14ab | 1.73ab |
| Pioneer 531 | 58.8ab | 62.8ab | 4.52a | 1.26a |
| Pioneer 545 | 30.2ab | 40.2ab | 7.99b | 2.18b |
| Iroquois | 47.2ab | 51.8ab | 7.10b | 2.06b |
| Oneida | 18.8a | 22.0a | 7.32b | 2.13b |
| Sarana | 66.8ab | 71.2ab | 6.23ab | 1.75ab |
| Syn XX | 102.5ab | 106.8ab | 7.39b | 2.11b |

[1]Column means followed by the same letter are not significantly different ($P=0.05$) according to the Duncan Multiple Range Test.

Table 18. The influence of *P. penetrans* on the growth of selected forage legume varieties.

| | *P. penetrans* | | Shoot system weight (g) | | | |
|---|---|---|---|---|---|---|
| | | | First cutting | | Second cutting | |
| Variety | Per 1 gram root | Per 100 $cm^3$ soil + 1 g root | Fresh | Dry | Fresh | Dry |
| Saranac | 3.2a[1] | 3.3a | 8.63b | 2.23b | 17.07b | 4.48b |
| Vernal | 2.2a | 2.2a | 6.3b | 1.58b | 13.00b | 3.40b |
| Iroquois | 7.0a | 7.3a | 6.77b | 1.68b | 13.66b | 3.48b |
| Oneida | 2.0a | 2.1a | 7.29b | 1.74b | 14.73b | 3.73b |
| Viking | 15.0a | 15.5a | 3.10a | 0.55a | 7.59a | 1.56a |

[1]Column means followed by the same letter are not significantly different (P=0.05) according to the Student-Newman-Keuls Multiple Range Test.

other SSH treatments and the uncut treatment was significantly less than both the 36 cm treatments. After 1246 degree days (Base 10$^{o}$C), the root population densities associated with Superior potatoes were significantly greater than those of the SSH treatments (Table 16). The soil population density of Superior was significantly greater than all treatments except 36 cm-remove and 69 cm-mulch (Table 16). After 1593 degree days, root population density in Superior was significantly greater than all SSH treatments. Within the SSH treatments the only significant differences were between uncut and 36 cm-remove, the latter having the greatest population density. Soil population densities associated with Superior were greater than densities from all SSH treatments. On the last sampling date ($DD_{10}$ = 1812) none of the treatments were actively growing due to frost damage. There were no significant differences in soil population densities between treatments at the P=0.05 level. At the P=0.10 level soil population levels of Superior were significantly higher than both 127 cm-mulch and the uncut SSH treatment.

2. Forage Legume Rotation Crops.--In the first forage legume study the population density of P. penetrans in alfalfa roots or root plus soil was significantly greater in Vernal than Oneida (Table 17). In the presence of this nematode, the fresh and dry weight of the shoot system of Pioneer 545, Iroquois, Oneida, and SynvXX were significantly greater than those of Pioneer 531.

In the second forage legume study there were no significant differences in the final P. penetrans population densities among the six varieties (Table 18). The P. penetrans population failed to increase in 35% of the experimental units causing considerable variability within treatments. There were no significant differences in shoot weight among alfalfa varieties at the first or second cutting; however, they were all significantly greater than that of the birdsfoot trefoil.

## V. DISCUSSION

The 1981 growing season in Montcalm County was favorable for early season potatoes. Soil moisture was adequate in the spring and irrigation water was available in a timely manner throughout the growing season. The soil environment in which these potatoes were grown is excellent for P. penetrans population growth. The sandy loam soil is irrigated to maintain optimum moisture levels for potato growth. This texture allows for good aeration. The practice of hilling provides a non-compacted root zone with good aeration and generally good moisture levels.

Superior potatoes responded well to management inputs following the alfalfa rotation, except where 1, 3-D+MIC was the primary edaphic pest control input. 1, 3-D+MIC did not significantly increase tuber yields over the check at either nitrogen level. The lack of response may be due to the large amount of organic matter and living tissue remaining after the spring plowing of the alfalfa. Organic matter increases adsorption of soil fumigants, and living root tissue provide refuge for organisms such as P. penetrans (Munnecke and VanGundy, 1979). Aldicarb plus 1, 3-D+MIC appeared to contribute to an improved utilization of the added nitrogen. The marketable tuber yield of the checks was not significantly different. Aldicarb plus 1, 3-D+MIC significantly increased yields at the low nitrogen level when compared to the check. The same nematicide treatment at the high nitrogen level resulted in significantly higher yields than the treatment at the low nitrogen level. A similar relationship occurred with aldicarb and oversized tuber yields. These relationships indicate that nitrogen fertilizer was utilized more effectively by the plant when nematicides were applied. There are many factors which may be involved in this phenomena. Aldicarb greatly reduced the possibility of P. penetrans damaging the growth or function of the root system. Aldicarb may have contributed a growth stimulating component also. Soil fumigation can inhibit microbial nitrogen assimilation possibly increasing the amount of nitrogen available to the potatoes (Mengel and Kirkby, 1979).

Pre-plant population densities may have been higher than the data indicate. The alfalfa was plowed about two weeks prior to sampling and there may have been a substantial number of nematodes remaining in the decaying root tissue, which was not sampled. Aldicarb maintained P. penetrans population densities at low levels throughout the entire season. 1, 3-D+MIC had no apparent impact on P. penetrans population density for reasons discussed earlier.

At the low nitrogen level in the corn rotation, oversized (>8 cm diameter) tuber production was low and undersized (<5 cm diam.) was high. The nutrient analysis and symptomology indicated that nitrogen was limiting growth response. The treatments with the high nitrogen fertilizer level showed no symptoms of nitrogen deficiency. However, the addition of nitrogen without nematicides had no significant influence on yield except to reduce undersized tuber production. Nitrogen added to the nematicide treatments raised oversized tuber production by greater than 50% over the high nitrogen check. There was a yield response to 1, 3-D+MIC following corn where no living roots and less organic matter accumulated than in the alfalfa rotation.

Soil fumigation had an impact on tuber production not necessarily related to nematode control. Although fumigation appeared to have no impact on the oversized tuber production, it increased marketable tuber yield. In the alfalfa rotation system, 1,3-D+MIC alone did not influence tuber yields but when combined with aldicarb, the tuber yield was greater than either inputs alone.

Following corn, 1,3-D+MIC did have an impact on nematode control and yield, as did aldicarb. When the two were combined, they had an additive effect on marketable tuber yield. Aldicarb, however, was the primary influence on oversized tuber production.

Nitrate levels in potato petioles tended to increase with aldicarb as compared to 1,3-D+MIC. In the alfalfa rotation, high N with aldicarb had higher nitrate levels than low N with 1,3-D+MIC. High N with 1,3-D+MIC was not, however, significantly different than low N with 1,3-D+MIC. In the corn rotation, high nitrogen with aldicarb had higher nitrate levels than high N with 1,3-D+MIC. At the low nitrogen level there were significant (P=0.05) differences in nitrate levels, but aldicarb tended to be higher than 1,3-D+MIC. In both rotation systems, aldicarb provided better control of P. penetrans than did 1,3-D+MIC alone, but the difference was greatest in the alfalfa rotation. The nitrate level differences were more pronounced in the corn rotation where 1,3-D+MIC had a more complete impact. When all these factors are considered, it appears that the relationship of nitrate levels between aldicarb and 1,3-D+MIC may be primarily due to the fumigants impact on the nitrogen cycle in the soil. However, the impact of a growth regulator effect of aldicarb may be influential in nitrate concentrations.

In the corn rotation system, there was an indication that increasing nitrogen inputs reduced the nematode population growth. On the last sampling date, the nematicide treatments had significantly lower P. penetrans population levels than the low nitrogen check, but not the high nitrogen check.

Early in the growing season Rhizoctonia can result in the formation of cankers on stems especially in cold, wet soils. Later in the season symptoms include rosetting of plant tops and aerial tubers. Black or dark brown sclerotia on the tubers appear at harvest as irregular lumps commonly called black scurf. Early symptoms were never common or severe during this experiment, although a minor amount of black scurf was endemic on tubers at harvest. On one sampling date infection levels appeared to be higher in the aldicarb plus 1, 3-D+MIC treatment than the checks. The water agar-alcohol medium was not ideal for selection for Rhizoctonia, but this phenomena has also occurred in other experiments investigating the effects of fumigation on potatoes (Hawkins and Miller, 1971). The cause of this occurrence is undetermined. Rhizoctonia grows very vigorously and may be the first major pathogen to fill the niche that was emptied by the biocidal action of the fumigant.

There were no differences in infection levels of Verticillium between treatments following corn. Potato plants grown under the low nitrogen treatments senesced earlier than those in the high nitrogen treatments. Although the role of Verticillium could not be quantified, lack of available nitrogen was probably the critical factor. There were no significant differences in Rhizoctonia infection levels.

The host quality of the sorghum-sudangrass hybrid for nematode reproduction was improved by intensive pruning. In the greenhouse experiment, pruning and removing the top growth improved the host quality of apparently poor-host cultivars. When the top growth, however, was returned to the soil surface as a mulch, the P. penetrans population densities of the sudangrass and sorghum-sudangrass hybrids were not significantly increased over the non-pruned level. MacDonald (1966) found that pruning of forage grain decreased plant chemical concentrations associated with host plant defense. The studies conducted for this thesis indicate that plant defense mechanisms against P. penetrans are hindered by pruning. Nematode population density growth associated with poor-hosts, however, was maintained at the expected low levels when the shoot system biomass was returned to the soil surface.

In the field study examining management of forage grains, there was an interaction between the pruning schedule and shoot growth placement. The interaction was apparent where pruning was most intensive and the shoot-growth was removed. Intensive pruning apparently reduces P. penetrans defensive capabilities. Placing the shoot-growth on the soil surface apparently produces a biotic environment unfavorable for P. penetrans. Leachates from this procedure do not cause direct nematode mortality to all species, since free-living nematodes were more abundant in these treatments. Both in the greenhouse and the field experiments, placing foliage on the soil surface provided a more constant soil moisture level than that of unmulched plots. One would expect that this would be optimal for P. penetrans population growth, but it was not. Nevertheless, the intensiveness of the cutting schedule was the primary factor in P. penetrans population growth. Only the two treatments in the forage grain management field study that were allowed to grow the tallest had significantly (P=0.10) lower population levels in the soil than those associated with Superior potatoes. It appears that the host plant's defense mechanisms are more important than the mulch's effect on the biotic environment. Further study in this area should use higher population levels and determine if plant height or plant maturity is more important in a cutting schedule for optimizing defense mechanism levels.

In the field experiments, leaving the top growth on the soil surface as a mulch generally did not affect the population density, indicating that at least during one growing season the leachates and organic matter contributed by the leaves are not of great importance in managing plant parasitic nematode populations. Although in the greenhouse variety management experiment, Bird-A-Boo appeared to be a better host than the other varieties, this relationship did not occur in the field variety management experiment. Three major factors that possibly influenced this relationship were: 1) the change of growing conditions, 2) less intensive cutting in the field, and 3) more precision in the greenhouse experiment. Evaluation of cutting schedules and top growth management indicated that within a given variety alteration of top growth management practices influences host quality. Initial soil population density and final soil density in the field experiments were about the same in the forage grain varieties, while the final density associated with Superior potatoes averaged 8 times greater than the initial density. Superior was used as a control for comparing population growth because much is known about the population dynamics of P. penetrans in this cultivar. A host with a known P. penetrans population response that could be grown in a broadcast manner with similar root distribution to the forage grains would be necessary for more conclusive data. Although comparisons of host quality can be made using Superior, it would be of benefit to be able to accurately compare population changes on a per volume of soil basis.

The results indicate that additional research in the area of alfalfa varieties and P. penetrans population density increase is necessary. The initial screening experiment indicated that some of the high yielding varieties of alfalfa which provide Phytophthora root rot resistance may limit population growth of P. penetrans compared to nematode populations associated with common varieties. Examination of alfalfa varieties uncovered encouraging results. At the conclusion of an initial variety screen, a five-fold greater P. penetrans population developed on Vernal compared to Oneida. Vernal resulted in twice the original inoculum level and Oneida in only one-half the original inoculum level. Related varieties, ie. Vernal-Agate, and Iroquois-Oneida, resulted in about one-half the population levels with the Phytopthora resistant sibling as compared to the non-resistant relative. In general it appeared that the addition or emphasis of Phytophthora sp. resistance was positively associated with a variety's resistance to the population growth of P. penetrans. The Meloidogyne hapla resistant variety, Synthetic XX, allowed P. penetrans to increase rapidly to high population densities. As with any control input, the use of tolerant varieties can result in other problems. The effectiveness of any control measure should be judged by the overall impact on the system, and not just the single factor it is designed to control.

In summary, potatoes responded better to nitrogen inputs when effective P. penetrans population control was achieved. Forage grain varieties that exhibited defensive qualities against P. penetrans generally maintained the defensive qualities when pruned infrequently and when leaf tissue was returned to the soil surface. The alfalfa varieties that exhibited the poorest host qualities for P. penetrans population growth were those with Phytophthora root rot resistance.

The results of this research program indicate potential for rotational crop variety and management selection which would allow a minimization of P. penetrans damage in a potato production system. More research needs to be conducted in this area to develop information for integration of farm management decisions to reduce P. penetrans disease pressures. Future research should examine effects of varietal selection and top growth management of forage legumes and grains in relation to nematode community structure and potato yield and quality in the rotational regimes.

## VI. BIBLIOGRAPHY


Bernard, E. C. 1974. The pathogenicity and population management of Pratylenchus penetrans on potato. MS Thesis. Michigan State University. 45 pp.

Bernard, E. C. and C. W.Laughlin. 1976. Relative susceptibility of selected cultivars of potato to Pratylenchus penetrans. J. Nematol. 8:239-242.

Bird, A. F.1960. The effect of some single element deficiencies on the growth of Meloidogyne javanica. Nematologica 5:78-85.

Bird, G. W. 1968. Influence of six cover crops on population density of Pratylenchus penetrans. Can. Plant Dis. Surv. 48:113.

Bird, G. W. 1971. Influence of incubation solution on the rate of recovery of Pratylenchus brachyurus from cotton roots. J. Nematol. 3:378-385.

Bird, G. W. 1977. Population dynamics of Pratylenchus penetrans associated with three cultivars of Solanum tuberosum. J. Nematol. 9:265 (abstract).

Burpee, L. L. and J. R. Bloom. 1978. The influence of Pratylenchus penetrans on the incidence and severity of Verticillium wilt of potato. J. Nematol. 10:95-99.

Collins, R. J. and R. Rodriguez-Kabana. 1971. Relationship of fertilizer treatments and crop sequence to populations of lesion nematodes. J. Nematol. 3:306-307.

Conroy, J. J., R. J. Green, Jr., and J. M. Ferris. 1972. Interaction of Verticillium albo-atrum and the root-lesion nematode, Pratylenchus penetrans, in tomato roots at controlled inoculum densities. Phytopathology 62:362-366.

Dickerson, O. J., H. M. Darling and G. D. Griffin. 1964. Pathogenicity and population trends of Pratylenchus penetrans on potato and corn. Phytopathology 54:317-322.

Dolliver, J. S. 1961. Population levels of Pratylenchus penetrans as influenced by treatments affecting dry weight of Wando pea plants. Phytopathology 51:364-367.

Dunn, R. A. 1972. Importance of depth in soil, presence of host roots and role of eggs as compared to vermiform stages in overwintering of Pratylenchus penetrans at Ithaca, New York. J. Nematol. 4:221-222 (abstract).

Edmunds, J. E. and W. F. Mai. 1966. Effect of Fusarium oxysporum and F. oxysporum-infected roots on the behavior of Pratylenchus penetrans. Nematologica 12:89 (abstract).

Elliott, A. P. 1980. Ecology of Pratylenchus penetrans associated with navy bean (P. vulgaris L.). PhD dissertation. Dept. of Entomology, Michigan State University.

Evans, A. A. and R. N. Perry. 1976. "Survival strategies in nematodes", (in) The Organization of Nematodes. Croll, N. A. (Ed.). Academic Press Inc., New York, NY. pp. 383-424.

Fawole, B. and W. F. Mai. 1975. Population dynamics of Pratylenchus penetrans in a potato-rye crop rotation. Proc. Am. Phyto. Soc. 2:97.

Freckman, D. W. and R. A. Chapman. 1972. Infection of red clover seedlings by Heterodera trifolii Goffart and Pratylenchus penetrans (Cobb). J. Nematol. 4:23-28.

Hartman, B. J., B. D. Thyr and O. J. Hunt. 1978. Report of the 26th alfalfa improvement conference, South Dakota.

Hawkins, A. and P. M. Miller. 1971. Row fumigation with Vorlex for control of a meadow nematode (Pratylenchus penetrans) in potatoes. Am. Pot. J. 48:65-68.

Heald, C. M. and W. R. Jenkins. 1964. Aspects of the host-parasite relationship of nematodes associated with woody ornamentals. Phytopathology 54:718-722.

Hunter, A. H. 1958. Nutrient absorption and translocation of phosphorus as influenced by the root knot nematode (Meloidogyne incognita acrita). Soil Science 86:245-250.

Ismail, W. and S. K. Saxena. 1977. Effect of different levels of potassium on the growth of root-knot nematode, Meloidogyne incognita, on tomato. Nematologica 23:263-265.

Jenkins, W. R. 1964. A rapid centrifugal-floatation technique for separating nematodes from the soil. Plant Dis. Reporter 48:692.

Jenkins, W. R. and R. B. Malek. 1966. Influence of nematodes on absorption and accumulation of nutrients in vetch. Soil Science 101:46-49.

Kable, P. F. and W. F. Mai. 1968a. Influence of soil moisture on Pratylenchus penetrans. Nematologica 14:101-122.

Kable, P. F. and W. F. Mai. 1968b. Overwintering of Pratylenchus penetrans in a sandy loam and a clay loam soil at Ithaca, New York. Nematologica 14:150-152.

Kimpinski, J. 1979. Root lesion nematodes in potatoes. Am. Pot. J. 56:79-86.

Kirkpatrick, J. D., W. F. Mai, K. G. Parker, and E. G. Fisher. 1964. Effect of phosphorus and potassium nutrition of sour cherry on the soil population levels of five plant-parasitic nematodes. Phytopathology 54:706-712.

Kirkpatrick, J. D., S. D. VanGundy, and W. F. Mai. 1964. Interrelationships of plant nutrition, growth and parasitic nematodes. Plant Analysis and Fertilizer Problems IV:189-225.

Klinger, J. 1972. The effect of single and combined heat and $CO_2$ stimuli at different ambient temperatures on the behavior of two plant-parasitic nematodes. J. Nematol. 4:95-100.

Lavallee, W. H. and R. A. Rohde. 1962. Attractiveness of plant roots to Pratylenchus penetrans (Cobb). Nematologica 8:252-260.

Liv-Mei Chang and R. A. Rohde. 1969. The repellent effect of necrotic tissues on the nematode Pratylenchus penetrans. Phytopath. 59:398.

MacDonald, D. H. 1966. Some relationships between the chemical composition of plant roots and the population levels of Pratylenchus penetrans. Nematologica 12:95.

MacDonald, D. H. and W. F. Mai. 1963. Suitability of various cover crops as hosts for the lesion nematode, Pratylenchus penetrans. Phytopath. 53:730-731.

Marks, C. F. and J. L. Townshend. 1973. Multiplication of the root lesion nematode Pratylenchus penetrans under orchard crops. Can. J. Plant Sci. 53:187-188.

Martin, M. J., R. M. Reidel, and R. C. Rowe. 1981. A disease interaction with fungi and nematodes. Ohio Report 66:53-54.

Mengel, K. and E. A. Kirkby. 1979. Principles of Plant Nutrition. International Potash Institute, Switzerland. 593 pp.

Mishra, S. D. and Prasad, S. K. 1978. Effect of fallow and crops with or without weeding operations on nematodes. Indian J. Entomology 39:378-379.

Morsink, F. 1963. Penetration of roots of potato seedlings by Pratylenchus penetrans. Phytopathology 53:351 (abstract).

Morsink, F. and A. E. Rich. 1968. Interactions between Verticillium albo-atrum and Pratylenchus penetrans in the Verticillium wilt of potatoes. Phytopathology 58:401 (abstract).

Munnecke, D. E. and S. D. VanGundy. 1979. Movement of fumigants in soil, dosage responses and differential effects. Ann. Rev. Phytopathol. 17:405-429.

Noling, J. W. 1981. The joint role of Pratylenchus penetrans and associated abiotic and biotic stress factors on the ontogeny of Solanum tuberosum. MS Thesis, Dept. of Entomology, Michigan State University.

Norton, D. C. 1978. Ecology of Plant-parasitic Nematodes. John Wiley & Sons, New York, NY. 439 pp.

Nusbaum, C. J. and Ferris, H. 1973. The role of cropping systems in nematode population management. Ann. Rev. Phytopathology 2:423-440.

Olthof, Th. H. A. 1971. Seasonal fluctuations in population densities of Pratylenchus penetrans under a rye-tobacco rotation in Ontario. Nematologica 17:453-459.

Olthof, Th. H. A. 1979. Effects of Pratylenchus penetrans and Meloidogyne hapla on potential crops for the tobacco-growing areas of southwestern Ontario. Can. J. Plant Sci. 59:1117-1121.

Olthof, Th. H. A. 1982. Effect of age of alfalfa root on penetration by Pratylenchus penetrans. J. Nematol. 14:100-105.

Olthof, Th. H. A. and J. W. Potter. 1973. The relationship between population densities of Pratylenchus penetrans and crop losses in summer-maturing vegetables in Ontario. Phytopathology 63:577-582.

Oostenbrink, M. 1958. An inoculation trial with Pratylenchus penetrans in potatoes. Nematologica 3:30-33.

Oteifa, B. A. and K. A. Diab. 1961. Significance of potassium fertilization in nematode infested cotton fields. Plant Dis. Reporter 45:932.

Oteifa, B. A. and D. M. Elgindi. 1962. Influence of parasitic duration of Meloidogyne javanica (Treub) on host nutrient uptake. Nematologica 8:216-220.

Oyekan, P. O., C. D. Blake and J. E. Mitchell. 1972. Histopathology of pea roots axenically infected by Pratylenchus penetrans. J. Nematol. 4:32-35.

Patterson, M. T. and g. B. Bergeson. 1967. Influence of temperature, photoperiod and nutrition on reproduction, male-female-juvenile ratio and root-to-soil migration of Pratylenchus penetrans. Plant Dis. Reporter 51:78-82.

Pinochet, J. B. and J. A. Cook. 1976. Individual and combined effects of Pratylenchus vulnus and Xiphinema index on potassium and zinc levels in Vitis vinifera 'Thompson Seedless'. Am. J. Enol. Vitic. 27:186-189.

Pitcher, R. S., Z. A. Patrick and W. B. Mountain. 1960. Studies on the host-parasite relations of Pratylenchus penetrans (Cobb) to apple seedling. Nematologica 5:309-314.

Russel, A. S. 1977. Plant Root Systems: Their Function and Interaction with the Soil. McGraw-Hill Book Co. (UK) Ltd., London. 289 pp.

Shafiee, M. F. and W. R. Jenkins.1963. Host-parasite relationships of Capsicum frutenscens and Pratylenchus penetrans, Meloidogyne incognita acrita, and M. hapla. Phytopathology 53:325-327.

Townshend, J. L. 1972. Influence of edaphic factors on penetration of corn roots by Pratylenchus penetrans and P. minyus in three Ontario soils. Nematologica 18:201-212.

Townshend, J. L.1978. Infectivity of Pratylenchus penetrans on alfalfa. J. Nematol. 10:318-323.

Townshend, J. L. and L. R. Webber. 1971. Movement of Pratylenchus penetrans and the moisture characteristics of three Ontario soils. Nematologica 17:47-57.

VanGundy, S. D.and J. P. Martin. 1961. Influence of Tylenchulus semipenetrans on the growth and chemical composition of sweet orange seedlings in soils of various exchangeable cation ratios. Phytopathology 51:146-151.

Vitosh, M. L., J. W. Noling, G. W. Bird and R. W. Chase. 1980. The joint action of nitrogen and nematicides on Pratylenchus penetrans and potato yield. Am. Pot. J. 57:101-111.

Willis, C. B.1976. Effects of potassium fertilization and Pratylenchus penetrans on yield and potassium content of red clover and alfalfa. J. Nematol. 8:116-121.