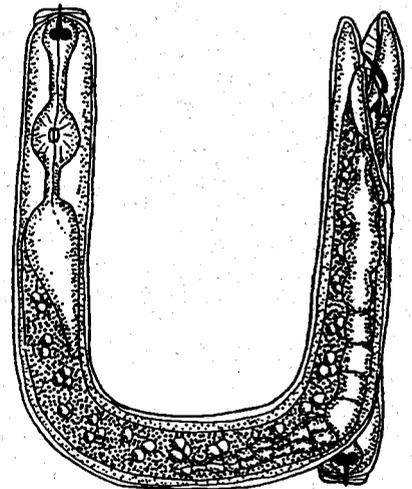
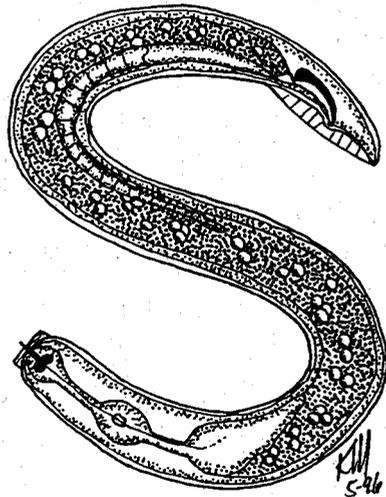
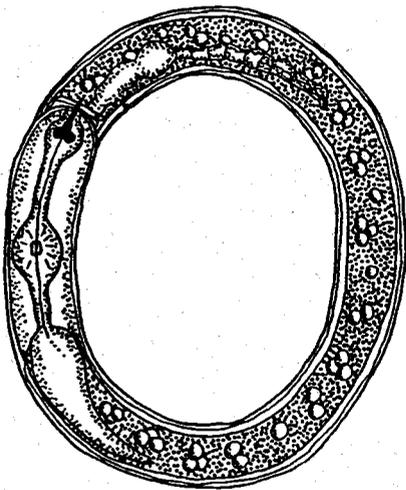


Evaluation of Popcorn Cultivars as Resistant Rotation Crops to Columbia Root-knot Nematode - A Systems Approach

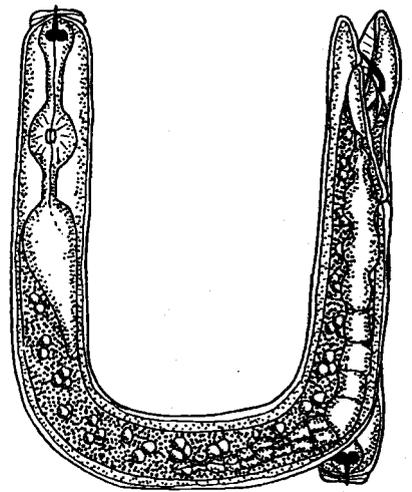
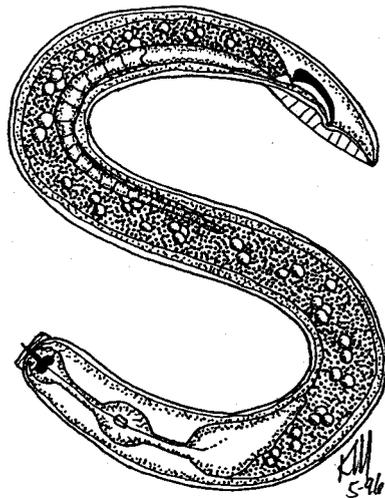
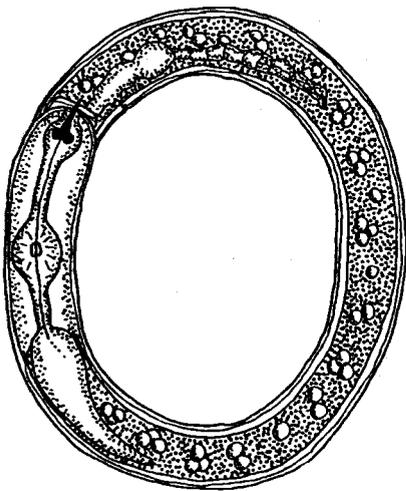
by Derek Cardwell



August 1996

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Columbia Root-knot Nematode - A Systems Approach

by

Derek Cardwell

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Abstract

This study examined the management situation for the Columbia root-knot nematode (*Meloidogyne chitwoodi*) in potato, using an approach with systems thinking and interactive meetings. The focus of current research for control of this nematode was evaluated. Control practices include crop rotation, and this study also evaluated popcorn cultivars for their potential as resistant rotation crops.

Popcorn cultivars were grown in *M. chitwoodi* race 1 infested soil at the Hermiston Agricultural Research and Extension Center (HAREC), Hermiston, OR. Soil samples were taken soon after planting (initial) and before harvest (final), and the number of *M. chitwoodi* juveniles / 250 g dry soil was calculated for each sample. A reproduction index was calculated for the nematode reproduction on each cultivar: $R \text{ value} = \text{initial} / \text{final}$ population. Cultivars were categorized as good, poor- and non-hosts depending on their R values. Popcorn cultivars were also tested for their host status in the greenhouse. Plants were inoculated with approximately 5000 *M. chitwoodi* eggs (initial), and after 55 days, eggs were extracted from the roots (final).

In the field and greenhouse tests, field corn (FC) cv Pioneer 3578 was tested as a good host check. Among cultivars tested in both the field and greenhouse, the seven with the lowest R values as % of FC 3578 were: WOC 9508 (4%), W206 (16%), WOX 9512 (23%), Robust 33-77 (30%), Robust 20-70 (38%), and WOC 9504 (42%). Cultivars more susceptible than field corn were (R values as % of FC 3578 - mean of field, greenhouse tests): W 104 (119%) and

Robust 90477 (102%). Popcorn cultivars WOC 9531, WOC 9556, WOX 9528, and WOX 9511 were more resistant than field corn but still need to be also tested in the field. Cultivars with R values < 1.0 in field tests can be functional in decreasing or stabilizing nematode populations, thus increasing the effectiveness of pre-potato nematicides or winter cover crops.

This nematode pest situation was analyzed with use of diagrams showing interacting components of the system. This system includes people, nematodes, and potatoes. Issues and questions emerged as the situation was viewed in a systems manner. Some of these issues and questions were the foci of a Farmer-Scientist Focus Session conducted on June 28th, 1995 in Hermiston, OR. Participants included growers, researchers, and extension educators. The meeting was interactive and facilitated the expression of ideas, perspectives, and concerns of the crop rotation possibilities for controlling *M. chitwoodi*. The opportunities and challenges using non-host crops in potato rotations were discussed.

Growers expressed desire for more agronomic information about currently available poor- and non-host cultivars. They did not emphasize a need for a more diverse selection of resistant cultivars. From the grower's perspective, the main opportunity of resistant crop rotation is the integration of suppressive winter cover crops. The main challenge is the small market size for most non-host crops. Additional interactive meetings are needed to stimulate the creation of new ideas and to refine the vision and direction of research in a cooperative manner.

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"And whatever you do, whether in word or deed, do all in the name of the Lord Jesus, giving thanks to God the Father through Him." Colossians 3:17

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Evaluation of Popcorn Cultivars as Resistant Rotation Crops to Columbia Root-knot Nematode - A Systems Approach

1.0 A Systems Approach

1.1 Fundamental Improvement vs. the "quick fix"

When researchers and farmers assume they understand the answer to a problem, they may be failing to consider the system as a whole, having many interacting parts. These components may have differing effects on how the problem is perceived, and how research is applied. Researchers may look to the "quick fix", which disappoints because the solution is without significant consideration of a wide variety of alternatives and consequences (William, 1994). When regulations force people into compliance, they become dependent on regulators, who revise and invent more regulations (William, 1994). This cycle can be modified towards fundamental improvement by the consideration of both long and short-term consequences of a solution (Senge, 1990). The consideration of these consequences involves extra time or resources, yet is the common pathway for breaking the regulatory cycle and witnessing fundamental improvement (Senge, 1990). This improvement requires consensus decisions amidst the common interests of all the participants of a situation (Senge, 1990).

1.2 The System Components

My research focused on the control of the Columbia root-knot nematode using resistant crops in rotation with potato. Popcorn

varieties were tested for resistance and found as good, poor-, or non-hosts for *Meloidogyne chitwoodi*. Host status information is available for many different crops and cultivars, allowing farmers to select rotation crops for decreasing *M. chitwoodi* soil densities (Ingham 1990, 1994). Host status information on popcorn is of main interest to potato growers when viewed as an opportunity for the whole management program, and not only for the popcorn crop. The management situation for *M. chitwoodi* can be viewed as a system with interacting components, including: the nematode pest, an agroecosystem, and people and organizations. The nematode pest is *Meloidogyne chitwoodi*; the agroecosystem is a 2-4 year rotation with potato cv Russet Burbank; and the people and organizations include scientists (research), extension educators, potato growers, potato processors, and officials in federal and state agencies (FDA). I started to explore the common interests of these people groups and the sociological, economical, and political factors which affect the system.

Questions which arose:

- i. - What are the factors affecting a farmers' decisions to modify their crop rotation for control of *M. chitwoodi*?
- ii. - What can I learn about these factors by viewing the growers' pest situation as a system of interacting biological, economic, and sociological factors?
- iii. - What meeting format would help scientists and growers learn collectively about making long-lasting improvements to the pest system?

1.3 Communication and Perspectives

In any meeting, communication is a key factor when many types of participants are in discussion. One factor affecting the communication between potato growers and researchers is the diversity of perspectives between them. When scientists state, "control of *M. chitwoodi*", does their definition of "control" correspond to one from a grower's perspective? More importantly, do researchers perceive the pest problem the same as the growers? The growers might think of "control" as the absence of anxiety concerning the need for extra nematicide applications. The scientist may think that "control" is the reduction of *M. chitwoodi* to below 1 juvenile / 250 g dry soil (Ingham, personal communication). These two perspectives are similar but not the synonymous, and each might affect management decisions differently.

Perspectives can include biases which affect the focus of research. Efforts should be made to remove biases, and to strive towards research adaptable to a variety of perspectives. The following questions were aimed for discovering characteristics of the situation:

- i. - What do the farmers perceive as the pest problem/solution?
- ii. - What do the researchers perceive as the pest problem/solution?
- iii. - How do those perspectives affect the perception of the problem? Does there appear to be more than one problem?
- iv. - Is the problem biological, sociological, or economical; or

a combination?

These types of questions should be answered before research is started. Researchers can be sheltered from realizing complex grower's needs because of diverse perspectives and non-interactive communication. Even if information transfer from extension educators is effective, if incorrect assumptions are made, researchers may not perceive the complexity of a grower's situation. This is the reason why growers should be involved with research and extension in the initial identification of research topics and issues (William, 1991). The previous questions were explored after research goals were developed; as crop rotation research for control of *M. chitwoodi* started in the early 1980's. Nevertheless, researchers must still evaluate their research. We may be attempting to fit reality to our research tools, rather than developing new methodology to fit growers' needs (Bawden and Macadam, 1988).

1.4 Interactive vs. Conventional Learning Styles

The common method for communication of researched results is the expert model (Senge, 1990). This model describes communication when the scientist (expert) teaches the growers the "correct" management strategy for their situation. In relation to *M. chitwoodi*, nematicides have the potential to provide adequate control, although, there is mild concern that certain fumigant nematicides may be suspended by the EPA. The expert model could communicate that a new management emphasis on crop rotation is a

necessary "change", because of possible chemical suspensions. This communication is unidirectional and only permits the transfer of information. Interactive approaches give learning opportunities. These allow people to discover how existing rotations can be managed to lessen reliability on chemicals, even if suspensions do not occur.

2.0 Using Farmer-Scientist Focus Sessions (FSFS)

2.1 Purpose and Benefits

Interactive communication between farmers and scientists can be accomplished via farmer-scientist-focus-sessions (FSFS) (Lev et al., 1993). FSFS are intended to engage participants in the creation of new ideas. New ideas aid in identifying research needs and solving practical agricultural problems. In these meetings, participants exchange information and ideas.

Collaborative learning (everyone is a learner) and problem solving occur. These sessions are facilitated, and focus on definite topics and issues. FSFS also help to allow diverse thought and perspective to be considered when participants work toward a common consensus. Whipple (1987) outlined four key components in this learning process:

- i. - all participants are active learners
- ii. - the hierarchy between student and teacher is eliminated
- iii. - a sense of community is established
- iv. - knowledge is created, not transferred

2.2 FSFS Components

2.2.1 The Facilitator

The facilitator leads the meeting and controls its flow and direction (Schmuck and Runkel, 1985). Their primary goal is to create an atmosphere for learning (Imel, 1991), and their reaction to discussion should appear neutral. They should exhort all individuals to participate. The facilitator has many roles (Family Community Leadership, 1983):

- i. - keeps the meeting focused on the topic
- ii. - clarifies and accepts communication, i.e. stimulates elaboration of incomplete ideas - "Could you develop that idea more?"
- iii. - accepts feelings from individuals as valid
- iv. - states a problem in a constructive way
- v. - does not allow dominating behaviors to rule

2.2.2 The Recorder

The recorder is responsible for recording ideas and issues spoken by participants. Information often is recorded on paper on easels in full view of the audience. This helps the audience to see their input contribution to the big picture (Doyle and Straus, 1976; Weisbord, 1992). There are often different learning styles in an audience, and the recorder can alter the visual form of the information to aid in the learning process (Kolb, 1984; Wonder and Donovan, 1984; Buzan, 1991). Some people think linearly, i.e. (in a list):

I. *Meloidogyne chitwoodi*

A. Biology

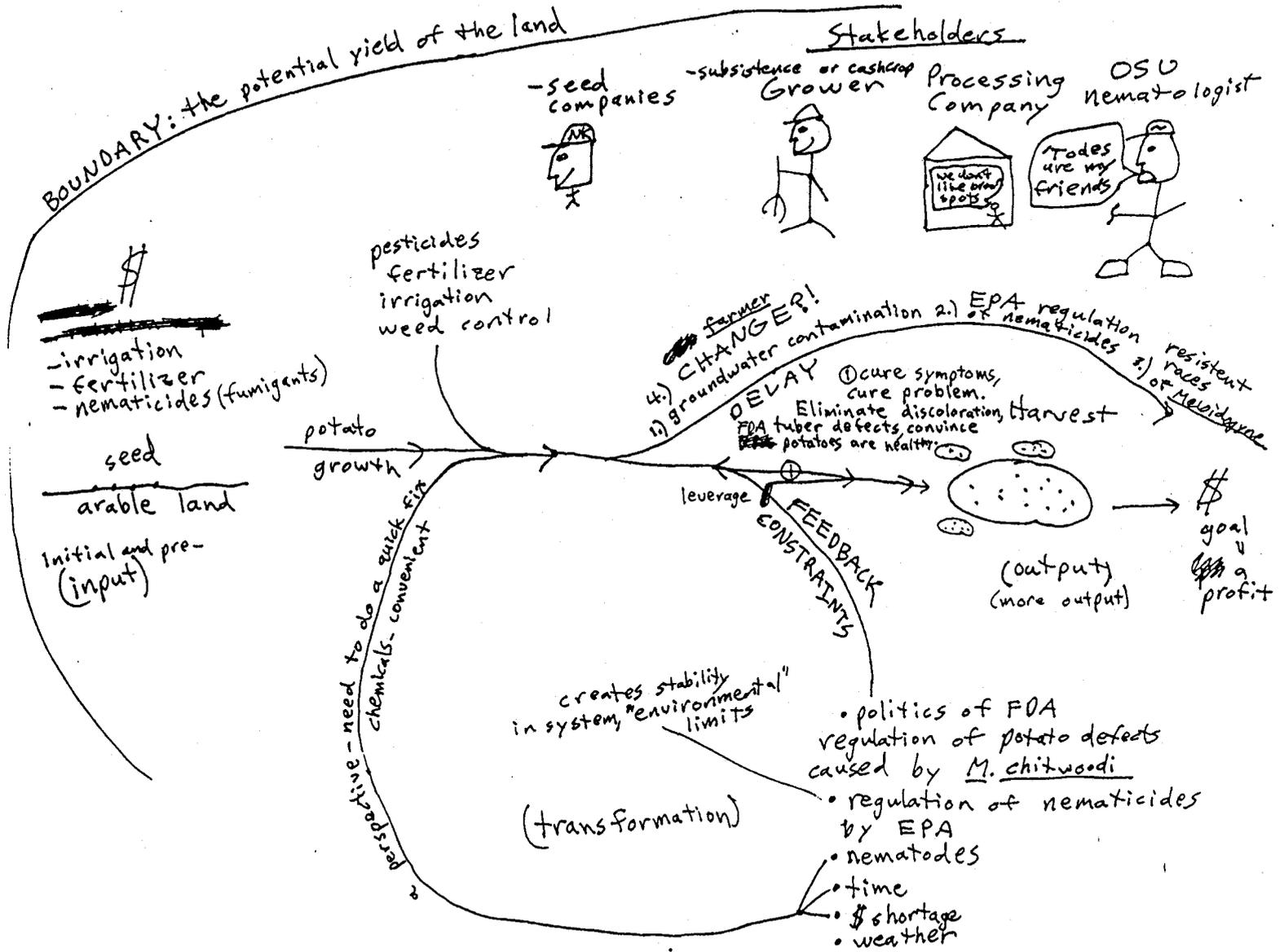
1. life cycle
2. behavior
3. morphology

Others think relationally (Fig. 1). Others also think in a systems manner (Fig. 2).

Systems thinking relies upon the relationship between components (i.e. nematode pest, people, potato market) for understanding how system inputs are transformed into outputs (Kauffman, 1980). By analyzing a system in this manner, relationships of working parts, and areas of change can be visualized (Checkland and Scholes, 1990). Mind maps provide a picture of a system by illustrating relationships and themes. Hoff (1992) recommends their use for remembering oral presentations. The primary benefits of such practices are to help people who think visually and relationally, and to contribute relational thought for linear thinkers.

Figure 2. Systems diagram made before the FSFS in Hermiston, OR.

9



3.1 The Pest Problem

3.1.1 Literature Review

Root-knot nematodes (*Meloidogyne* spp.) cause the most widespread economic damage of all plant-parasitic nematodes. They are named "root-knot" because of a physiological response they induce in the roots of susceptible plants. This response leads to formation of galls, which is a symptom of an increase in number and size of the root cortical cells, and of the enlargement of female nematodes inside the root (Agrios 1988). Root-knot nematodes also damage plants by hindering root growth or causing excessive root production. These symptoms hinder the plant's absorption of water and nutrients, thereby causing aerial stunting and chlorosis in the plant.

In 1980, (Golden et al.) described the Columbia root-knot nematode (*Meloidogyne chitwoodi*) as a parasite of potato (*Solanum tuberosum* L.). This nematode also was described initially as a parasite of wheat, corn, barley, oats, and tomato (Santo et al., 1980, Santo and O'Bannon, 1981). Later, a second race of *M. chitwoodi* was discovered that reproduced on both alfalfa and potato (Santo and Pinkerton, 1985). Mojtahedi et al. (1988) developed a differential host test for discrimination between race 1 and 2 (alfalfa race), and *M. hapla* Chitwood (Northern root-knot nematode). The test revealed that *M. chitwoodi* race 1 reproduced on carrot cv Red Cored Chantenay and not on alfalfa cv Thor, and vice versa for race 2; and *M. hapla* reproduced on pepper, while *M. chitwoodi* did not.

Historically, the Columbia root-knot nematode has been of primary economic concern to potato growers in the Pacific Northwest. Eggs in the soil hatch to release second stage juveniles (J2), the only infective stage (Agrios, 1988). The J2 enter the root adjacent to the tip by penetration, or through existing wounds. The J2 then migrate to phloem elements (Finley, 1981), become sedentary, and feed on cells around their head. All plant-parasitic nematodes are equipped with stylets which they insert into cells for extracting cell contents. *Meloidogyne* spp. secrete enzymes into cells, stimulating the plant to produce enlarged feeding cells (giant cells) which accumulate nutrients (Agrios, 1988; Rowe, 1993; U of Cal, 1986). Giant cells have an accumulation of nutrients, have liquified contents, are large and multinucleated, and give the nematode proper food for its development (Agrios, 1988; Finley, 1981; Rowe, 1993; U of Cal, 1986). J2 molt three times to reach the adult stage. The female adult is pear-shaped and produces eggs with or without fertilization by a male (males are rare). The female lays about 300 eggs in a sticky, gelatinous matrix inside or outside a root. Egg production is most abundant at 15-25 C. Egg hatching is affected primarily by temperature, moisture, and the presence of a host plant. The optimal temperature for egg hatching of *M. chitwoodi* is 25 C (Inserra, 1983).

Temperature affects the rate of development of *M. chitwoodi* throughout its life cycle. The J2 population in soil declines during winter although some nematodes migrate downward to warmer

temperatures, and some endure subfreezing conditions (Mojtahedi et al., 1991; Pinkerton et al., 1991). In the egg stage, most *M. chitwoodi* enter a quiescent (dormant) state prior to winter temperatures, and are ready to emerge as J2 the following spring and search for susceptible plant roots. When potatoes are planted, overwintering *M. chitwoodi* produce egg masses on roots by 600-800 degree-days base 5 C (DD₅) (Pinkerton et al., 1991). Second-generation and third-generation eggs hatch by 950-1,100 DD₅ and 1,500-1,600 DD₅, respectively. Pinkerton et al. (1991) also observed a fourth generation emerge at 2,150 DD₅. *M. chitwoodi*, unlike *M. hapla*, can infect roots and tubers at temperatures as low as 7-10 C (Finley, 1981; Inserra et al., 1983). Consequently, *M. chitwoodi* can infect roots early in the spring and invade tubers earlier than *M. hapla*. *M. chitwoodi* has a higher reproduction rate at cooler temperatures (Santo and O'Bannon, 1981) and produces 4-5 generations, while *M. hapla* produces only 2-3 generations per season (Pinkerton et al., 1991). Thus, *M. chitwoodi* can infect more tubers over a longer duration than *M. hapla*, and is considered the greater threat to potato tuber quality (Griffin, 1985; Inserra et al., 1983; O'Bannon et al., 1984; Pinkerton et al., 1986; Santo and O'Bannon, 1981). Potatoes in storage also are susceptible to the continued development of *M. chitwoodi*. Potatoes that appear lacking infection initially, may reveal symptoms after storage.

The Columbia root-knot nematode causes symptoms on potato tubers that decrease their quality. Females that have developed

in Russet Burbank tubers cause brown spots in the cortex (Golden et al., 1980; Finley, 1981), which can be seen by peeling off the skin. These spots are the result of oxidation of phenolic compounds (Finley, 1981). When infected tubers are cooked, the spots enlarge and darken in color, causing processed products like french fries to be unacceptable. Bumps are also commonly observed on the surface of tubers, giving them a wart-like appearance and making them unacceptable for fresh market sale (Golden et al., 1980; Finley, 1981). Cultivars other than Russet Burbank differ in the severity of these symptoms.

The Food and Drug Administration (FDA) has zero tolerance for animal matter in processed foods. Thus, potato processors may reject tubers (culls) having just a few nematodes in them. A potato crop with 5-15% culls from nematode infection may be downgraded or entirely rejected. It has been reported that the threshold density of *M. chitwoodi* that avoids this level of culled tubers is <1 J2/250 g dry soil (Ingham, 1990; Santo et al., 1981). Potato growers allowing densities above this economic threshold will be at higher economic risk for tuber rejection.

There are several management strategies for controlling this nematode in potato: prevention of soil infestation, early harvest of potatoes, nematicides, non-host crop rotation, and green manure cover crops. These can be used in combination. However, chemical nematicides (fumigants and non-fumigants) have been the primary control method for root-knot problems. *M. hapla* is easier to control than *M. chitwoodi*, thus the latter species has been

the primary focus of research. Fumigant nematicides (1,3-dichloropropene - Telone products; metham sodium products) are reported as the most effective against *M. chitwoodi* (e.g. Griffin, 1989; Santo et al., 1992; Williams, 1993), and non-fumigants (aldicarb - Temik; ethoprop - Mocap; oxamyl - Vydate) as effective compliments for reducing densities below the economic threshold (e.g. Pinkerton et al., 1986; Santo et al., 1989). Non-fumigants applied alone have not reduced infected tubers to acceptable levels (e.g. Nyczepir et al., 1982; Pinkerton et al., 1986; Santo et al., 1988). Telone products alone provide more consistent control than metham sodium products (e.g. Santo et al., 1988; Williams, 1993).

There are difficulties with these chemical methods. *M. chitwoodi* J2 are reported to migrate downward to depths of 1.5 m in the soil (Santo et al., 1987). This migratory behavior sometimes occurs because of unfavorable conditions in the top 30 cm of soil (Mojtahedi et al., 1991). Mojtahedi et al. (1991) also observed that juveniles as deep as 120+ cm below the surface could migrate upward to infect potato tubers. This migratory behavior becomes a factor in control when chemical nematicides do not penetrate deep enough into the soil profile.

The timing of chemical application is important. In root-knot species, nematicides only kill life stages in direct contact to the toxicant: eggs and J2. It is recommended that fumigants be applied in the fall when soil conditions are more favorable (not cold and wet) to provide uniform control to depth greater than 60

cm. The application of non-fumigants in close proximity to planting time, aids in controlling J2 migrating upward into the root zone.

In fields previously monocultured to potato for five years, Santo et al. (1984) observed that fumigation did not give adequate control in most cases. However, in a field without a history of potato, fumigation provided adequate control. The continuous cropping of susceptible (good host) crops stimulate populations to levels, at which nematicides cannot prevent infection in subsequent potato crops. Wheat, field corn, and alfalfa are commonly rotated with potato in the Pacific Northwest. *M. chitwoodi* reproduces well on these crops (alfalfa - race 2 only). Ingham (1990) tested many different crop cultivars for susceptibility to *M. chitwoodi*. Much variation in susceptibility was found between different cultivars of the same crop. The tested cultivars were not bred for nematode resistance. Ingham (1994) tested different cropping sequences for their control effectiveness by combining resistant and susceptible cultivars with non-fumigant nematicides. He discovered that a wheat-wheat(winter sudangrass)-potato(pre-plant Mocap) rotation resulted in 47% tuber culls; an unacceptable infection level for processors. However, a popcorn-lima bean-potato rotation with no nematicides resulted in only 2% culled tubers. Crop rotation using resistant cultivars can be used to prevent multiplication of *M. chitwoodi* populations, and to significantly decrease existing populations. The lowest risk management approach is to

use cultural practices in ways that enhance the effectiveness of the nematicides.

There are considerations to make when developing a crop rotation scheme for the control of a nematode pest. For some crops, many resistant varieties are continually being identified. The usefulness of these varieties is important in determining whether growers will use them for nematode control (Raymundo, 1985). Many crops and varieties that are resistant to *M. chitwoodi* are not in high demand for production and have a limited market. Also, crop types not commonly grown in a particular area will sometimes require farmers to adapt their management strategies and even learn to grow a new crop.

Field, flour, sweet, and cereal corn generally are good hosts (Ingham, 1990). Supersweet corn and popcorn cultivars generally are poor- or non-hosts. Field corn is the most commonly grown corn in the Columbia Basin. Previous research has demonstrated that certain cultivars of popcorn are less suitable hosts for Columbia root-knot nematode than field corn. Use of poor-host cultivars of popcorn in a potato rotation can reduce nematode population densities and the risk of nematode infection in the next potato crop. However, availability and suitability of popcorn cultivars can change rapidly, therefore known poor-host cultivars may not always be available. New varieties are continually being introduced, and information on their host status for *M. chitwoodi* is needed. Also, seed for many varieties tested in the past is no longer available. The following section

(4.0) describes the tests on popcorn varieties to evaluate their host status to *M. chitwoodi*.

4.0 The Experiment

This experiment is based upon the pest situation identified and defined by past nematologists. It was started before the pest system was critically analyzed using systems techniques and interactive meetings. The systems approach to this situation may affect the future methodology behind experiments of this research topic.

4.1 Materials and Methods

Field Trials (field trial 1 (FT1) and field trial 2 (FT2))

In this study, several cultivars of popcorn (Table 1) were grown on soil infested with *M. chitwoodi* race 1 (WAMC1) at the Hermiston Agricultural Research and Extension Center (HAREC), Hermiston, OR. *M. chitwoodi* populations had previously been increased via a good host wheat (*Triticum aestivum* L. em Thell. cv Stephens) monoculture. Based on recommendations of popcorn seed companies, popcorn cultivars were evaluated for their susceptibility to *M. chitwoodi* reproduction. Their recommendations were based on the evaluation of different breeding lines that were tested in the past, and new lines being prepared for commercial release.

Popcorn was planted on May 13, 1994 (June 3, 1995) {trial 1 and (trial 2)}, with a John Deere 71 Flex Planter in single row

plots, 20 ft long. Each cultivar had six replications in a randomized block design. Seed spacing was six inches and row spacing was 34 inches. A commonly grown cultivar of field corn was planted as a known good host for comparison. Nematode populations were determined from each plot on May 25, 1994 (June 9, 1995) (initial) and November 3, 1994 (October 5, 1995) (final) by taking soil cores 1-inch in diameter to a depth of one foot, next to 10 plants per plot. The 10 soil cores were combined into a single sample per plot. Each soil sample was sieved, mixed and a 250 g sample extracted by a wet sieving-sucrose centrifugation procedure (Jenkins 1964) (see Appendix A for procedure).

Extracted nematodes were stored in a refrigerator (4 C) in bottles with tap water. Each sample was poured onto a counting dish and the number of *M. chitwoodi* J2's per 250 g wet soil were counted. Soil moisture was determined for each sample and the nematode populations per 250 g dry soil was calculated.

Greenhouse Trials (greenhouse test-1,2,3,4 (GH1, GH2 GH3, GH4))

The initial objective of testing cultivars in the greenhouse was to define possible poor- and non-hosts, and to test only those in the field. The same popcorn cultivars were tested during two trials in the greenhouse during the winters of 1995 and 1996. GH1 and GH2 included the same cultivars as tested in FT1, plus Robust 85-210. GH3 and GH 4 included the same cultivars as in FT2, except Robust 90135 was excluded, and WOX 9511, 9528, 9531, and WOC 9556 were added.

Field corn Pioneer 3732 was included in GH1 and GH2 for comparison with Pioneer 3578, since 3732 was previously studied. Egg inoculum was extracted using 10% bleach (Hussey and Barker, 1973) from the roots of tomato (*Lycopersicon esculentum* Mill. cv Columbian) and wheat cv Stephens previously inoculated with *M. chitwoodi* race 1 (WAMC1). Popcorn seedlings were 15 days old when they were transferred to 6 in. pots, and inoculated with *M. chitwoodi* by pippeting eggs onto root systems before transplanting. Eggs were inoculated on February 3, 1995 (February 17, 1995) in GH1 (GH2), and on January 24, 1996 (February 7, 1996) in GH3 (GH4). Each of the five replicates of the cultivars were inoculated with 8062 (4972) eggs (initial populations) in GH1 (GH2) and with 6142 (3071) eggs in GH3 (GH4). Pots in each test were placed in a randomized block design on the greenhouse bench, and given supplemental lighting to provide 12 hours day : 12 hours night. A fertilizer solution of CaNO₃, CaHPO₄, and Potash (0-0-60) in ratios of 9.8-9.5-9.5, was applied every 10 days. After 55 days in the greenhouse, plants were removed from pots, roots were cut into 2-4 cm pieces, shaken in a 10% bleach, and the extracted eggs (final populations) were collected on a 500-mesh sieve.

Data analysis

Initial and final populations were analyzed using the reproductive index (**R value** = final population / initial population). The host status of cultivars to *M. chitwoodi* was

categorized as follows: $R > 10.0$ (excellent host) $R > 1.0$ (good host); $1.0 > R > 0.1$ (poor-host); $R < 0.1$ (non-host). R values were transformed by calculating the R value as a % of the R value of FC 3578 in the same test. This modification standardized the values obtained from different tests, permitting comparisons of the host status among different GH and FT's and between GH and FT's.

Statistical Analysis

The nematode reproductive index was calculated for each replicate in the field and greenhouse to determine the average host suitability for each cultivar. Nematode populations were transformed to $\log(x+1)$ and population and R value data were analyzed using ANOVA. Differences between means were determined with an LSD procedure only when the probability of the F statistic from the ANOVA was less than 0.05.

4.2 Results and Discussion

Wheat cv Stephens was included in greenhouse tests 3 and 4 as an inoculum check. In GH3, previously tested cultivars (FC 3578 and W206) had relatively low R values (Table 1) (see Appendix B for discussion on the low R values of GH3). Wheat also had a low R value in GH3 with respect to a normal value of 10.0 or higher (Santo and O'Bannon, 1981). This confirmed that the cause for the low nematode reproduction could not be solely attributed to cultivar resistance. It is probable however, that the inoculum in GH3 was imperfect. As a result, R value analyses on GH3 cultivars

is based only on field trial performance. In GH4, R values of FC 3578 and W206 were relatively normal, and again the R value of wheat demonstrated the viability of the inoculum (Table 1).

Field corn (FC) was the standard of comparison for popcorn cultivars because it would be replaced by popcorn in rotation. FC 3732 was used for previous tests, but FC 3578 is grown currently. In GH1 and GH2, FC 3732 had R values significantly lower ($P < 0.05$) than FC 3578 (Table 1). The mean value for FC 3578 was 3.1, compared to 1.1 for FC 3732. This ratio can be used for comparison of the results between previous studies and current ones. Field corn 3732 was found as a significantly poorer ($P < 0.05$) host than FC 3578, it is suggested that some variability in host status may occur among field corn.

FC 3578 is commonly grown in the Columbia Basin and can support at three-fold increases in Columbia root-knot nematode populations. In FT1 and FT2, FC 3578 had R values of 5.5 and 1.0, respectively (Table 2). The unusually low field corn and popcorn R values in FT2 can be explained by a severe hail storm on July 8, 1995. In FT2, the cultivars tested expressed lower R values than respective greenhouse tests, even though *M. chitwoodi* produces three or more generations during field tests (depending on length of season (degree-days (DD#)), but only two generations during greenhouse tests. During the storm, all foliage was severely damaged, but the plants re-grew shoots and leaves, developing normally until the final soil sample. However, because nutrients were utilized for shoot and foliage regrowth, root

systems likely were less developed and supported fewer root-knot nematodes.

The climate is a significant factor in nematode reproduction, and it is common to observe variability in R values between tests at different seasons and years (Ingham 1990). Therefore, comparisons of R values between tests are most consistent when based on the % of the R value of the good host standard (FC 3578). In this study, weather directly affected plant/root health (in both the field and greenhouse), and comparative analyses of R values between tests were emphasized with respect to field corn R values. This permitted generalizations in defining the host status of cultivars.

Most popcorn cultivars tested in the greenhouse also were in field trials. Of these cultivars, the seven with the lowest R values as % of FC 3578 were (mean of field and greenhouse tests; mean of greenhouse tests-Table 1; mean of field tests-Table 2): WOC 9508 (4%, FT2 data only), WOC 9554 (13%, 8%, 17%), W206 (16%, 9%(mean), 23%(mean)), WOX 9512 (23%, 15%, 30%), Robust 33-77 (30%, 16%, 38%(mean)), Robust 20-70 (38%, 21%, 54%), and WOC 9504 (42%, 21%, 63%). These cultivars in rotation would prevent increases in *M. chitwoodi* as compared with field corn. W206 has been tested three times in the greenhouse and twice in the field, and it represents the most reliable resistance in popcorn. If W206 is planted in rotation before potato, a pre-potato sample should result in at least 77% fewer *M. chitwoodi*. In this example, if the initial *M. chitwoodi* population was 100 J2 / 250

g dry soil, then the popcorn cv W206 would suppress the nematode to around 23 J2 / 250 g dry soil. If prior to potato, this J2 level of J2 in the soil could be reduced to an acceptable level with a pre-plant application of a non-fumigant nematicide. Santo et al. (1988) reported that spring populations below 30 J2 / 250 g dry soil resulted in < 5% tuber culls with a pre-plant Mocap application of 12 lb ai/acre (6EC, 10G or 20G). Higher populations required complimentary applications of fumigants (Telone products) to avoid unacceptable culls (Santo et al., 1989).

Cultivars only yet tested in the greenhouse, but that have more resistance than FC 3578 are (R value as % of FC 3578) (Table 1): WOC 9531 (7%), WOC 9556 (8%), WOX 9528 (19%), and WOX 9511 (46%). These cultivars appear to be more resistant than FC 3578, but field testing is required before they can be recommended as resistant alternatives to FC 3578.

Popcorn cultivars more susceptible than FC 3578 were (R value as % of FC 3578 - mean of field and greenhouse tests): W104 (119%) and Robust 90477 (102%). In the field alone, WOC 9503 (124%), WOC 9506 (123%), and WOC 9507 (107%) also were more susceptible than FC 3578 (Table 2). Other cultivars had similar R values, but did not significantly differ ($P < 0.05$) from FC 3578 in field tests in their final populations.

The marketable value of good host popcorn cultivars is not primarily based on their susceptibility. Cultivars may be good hosts yet have in-bred characteristics which increase their

marketable value. Robust 90135 is not notable for *M. chitwoodi* resistance, yet it was previously a favorite among growers because of its quality and yield characteristics.

Root-knot nematode control is only one aspect of farm management, and popcorn may rarely be grown solely for *M. chitwoodi* control. Overall, a rotation including fumigant and non-fumigant nematicides will likely have adequate control if *M. chitwoodi* densities are low. Therefore, the substitution of any popcorn variety in place of an excellent host (high R value, i.e. cereal corn, R value=58.53; Ingham, 1990) would be of benefit to the overall plan.

There were no significant differences ($P < 0.05$) in initial populations among cultivars in each field trial (Table 2). In both field trials, there were no significant differences ($P < 0.05$) among R values of cultivars (Table 2). The high degree of variation in populations among replicate plots prevented any significant differences from being observed. Variance also affected the statistics among R values in the greenhouse tests. Therefore, significance among final populations can aid in interpreting cultivar differences. In FT1, W206 and Robust 33-77 had significantly lower ($P < 0.05$) final populations than all other popcorn cultivars except W204. In FT2, WOC 9508 supported final populations significantly lower ($P < 0.05$) than seven other popcorn cultivars, and WOC 9506 supported populations significantly higher ($P < 0.05$) than six other cultivars (Table 2).

In the greenhouse, statistical differences in R values help confirm the differences in resistance found in the field. In addition, greenhouse studies can provide statistical information helpful in choosing cultivars for field testing. In the greenhouse, Robust 33-77 (GH1) and W206 (GH2) had the lowest R values (Table 1). In GH3, no significant differences ($P < 0.05$) were found among R values of different popcorn cultivars, nor between the R values of FC 3578 and popcorn cultivars (Table 1). In GH4, no significant differences ($P < 0.05$) were found among popcorn cultivars, but WOC 9554, WOC 9556, W206, and WOX 9531 had R values significantly lower ($P < 0.05$) than FC 3578 (Table 1).

Any cultivar with an R value > 1.0 is not solely capable of decreasing nematode populations. In potato systems where the primary objective of rotation is *M. chitwoodi* suppression, many crops other than popcorn are preferred as resistant (non-host) options for rotation. Ingham (1994, 1995) found many non-hosts crops: lima bean, pepper, watermelon, cowpea, and supersweet corn (certain cultivars). Oregon and Washington State University researchers found summer and winter cover crops that suppressed *M. chitwoodi*: sudangrass (Ingham, 1995; Mojtahedi, 1993a), rapeseed (Ingham, 1994; Mojtahedi, 1993b), and mustard (Ingham, 1994). Depending on the severity of soil infestation, rotation crop selection is often given to desirable characteristics other than nematode resistance. Potato growers must manage many pests, and crops that suppress multiple pests, and are easily integrated into existing management systems, are more economically

appealing. For instance, a management plan in a field corn-potato rotation, may rely on the herbicide Atrazine for weed control. Atrazine has specificity for corn and the substitution of a poor-host popcorn for field corn would not require new weed control strategies. Additionally, few modifications would be needed in the areas of planting, irrigation, and harvest procedures. Conversely, a substitution to pepper could require a new management strategy, including new farming equipment.

Significant differences between R values of popcorn cultivars only have real-world relevance if they affect the overall management practices for control of the Columbia root-knot nematode. For example, if a management plan for a popcorn-pepper-potato rotation included winter rapeseed after pepper, and a pre-potato non-fumigant, the control efficacy of *M. chitwoodi* would be excellent regardless if the R value of popcorn was 1.84 (McHone 910) or 0.41 (Robust 33-77). Note: these are significantly different values from GH1 - Table 1. In that rotation, the presence of popcorn is fundamental in preventing a large (three-fold or more) increase in *M. chitwoodi* populations, as would have occurred with FC 3578. In a rotation excluding excellent hosts, and including non-hosts and green manures or nematicides, poor-host cultivars can serve in stabilizing nematode populations for a season. This stabilization enhances the effectiveness of the chemical/green manure control. Ingham (1994) tested a popcorn-lima bean-(pre-plant Mocap) potato rotation, and found that the non-fumigant application before

popcorn did not reduce post-potato populations significantly more ($P < 0.05$) than the absence of the non-fumigant. Therefore, even in a rotation without nematicides, the non-host lima bean and poor-host popcorn were sufficient in resisting significant *M. chitwoodi* reproduction.

In management emphasizing chemical use, it is desirable to maintain *M. chitwoodi* populations at levels in which pre-plant applications can further reduce densities to $< 1 \text{ J2} / 250 \text{ g dry soil}$. In fields with very high densities, Santo et al. (1984, 1989) found that only fumigants + non-fumigants consistently reduced culled tuber % to commercially acceptable levels. In consideration that non-fumigants are less expensive than fumigants, it is an incentive to reduce *M. chitwoodi* densities via crop rotation to levels in which only a single non-fumigant application is needed.

In systems without pesticide use, the resistant popcorn varieties may be favored by growers, especially when suppressive green manures are not grown in rotation. In the selection process for popcorn varieties in this system, statistical differences in resistance would play a more relevant role, than in a system primarily using nematicides.

In any acreage grown to Russet Burbank potatoes with *M. chitwoodi* infestation, the ultimate goal is to avoid unacceptable tuber infection. Many crop varieties have been tested and categorized as non-hosts or poor-hosts. There is not one resistant cultivar that is best for *M. chitwoodi* control. Much of

cultivar selection for cropping sequences depends on the existing market and management practices in a region. It also may depend on the availability of registered nematicides. The EPA is in a process of re-registration of pesticides, and if fumigant nematicides as Telone II or metham sodium were suspended, the importance of non-host crop rotation would be clear.

The seed availability and market for popcorn is continually changing, and scientists are in the process of working with breeders to test new varieties. Cultivars WOX 9528, WOX 9512, and WOX 9531 were poor-hosts and received maternal genes from W206, the most consistent poor-host. Information as this assists the scientist in evaluating cultivars related to resistant breeding lines, and assist the breeder in continued definition of the resistance in those lines.

Table 1. Reproduction of *Meloidogyne chitwoodi* on field corn and popcorn cultivars after 55 days in the greenhouse (tests 1,2,3,4 n=5).

Cultivar	Final Population ¹	R Value ²	% R value of Field Corn 3578
GH1 - test 1			
Field corn			
Pioneer 3578	21,033 d ³	2.61 cd	100
Pioneer 3732	7,759 bc	0.96 ab	37
Popcorn			
Robust 90477	27,191 d	3.38 d	130
Robust 90135	21,221 d	2.63 cd	101
McHone 910	14,852 c	1.84 bc	70
Robust 20-70	4,332 ab	0.54 ab	21
Robust 33-77	3,309 a	0.41 a	16
GH2 - test 2			
Pioneer 3578	18,167 de	3.65 d	100
Pioneer 3732	6,519 bc	1.31 abc	36
Popcorn			
W 104	29,701 e	5.98 e	164
W 108	13,233 cd	2.66 cd	73
W 110	9,920 cd	2.00 bc	55
W 204	9,620 bc	1.93 bc	53
Robust 85-210	7,995 bc	1.61 abc	44
Robust 30-77	4,673 b	0.94 ab	26
W 206	1,916 a	0.38 a	10
GH3 - test 3			
Wheat	13,752 e	2.24 b	224
Pioneer 3578	2,455 d	0.40 a	100
Popcorn			
WOC 9506	1,180 cd	0.20 a	49
WOC 9510	846 bcd	0.14 a	35
WOX 9507	746 abcd	0.12 a	30
WOC 9503	614 abcd	0.10 a	25
WOC 9504	526 abc	0.08 a	21
W206	312 a	0.05 a	13
WOC 9508	295 ab	0.05 a	12
GH4 - test 4			
Wheat	76,467 f	24.90 c	634
Pioneer 3578	12,066 e	3.93 b	100
Popcorn			
WOX 9511	5,575 d	1.82 ab	46
WOX 9528	2,242 c	0.73 ab	19
WOX 9512	1,761 bc	0.57 ab	15
WOC 9554	971 ab	0.32 a	8
WOC 9556	937 ab	0.31 a	8
W206	873 a	0.29 a	7
WOX 9531	864 ab	0.28 a	7

¹Eggs extracted from root systems. Initial inoculum was 8062 (test 1), 4972 (test 2), 6142 (test 3), and 3071 (test 4) eggs/plant.

²Reproductive index (R = final egg population/initial eggs inoculated).

³In each separate test, means within the same column that are followed by the same letter are not significantly different, p=0.05.

Table 2. Reproduction of *Meloidogyne chitwoodi* on field corn and popcorn cultivars in the field during summer growing season. Hermiston, OR 1994,1995 (tests 1 and 2).

Cultivar	Initial Population ¹	Final Population ²	R Value ³	% R value of Field Corn 3578
FT1 - test 1				
Field Corn				
Pioneer 3578 Popcorn	1,029	4,344 cd ⁴	5.55	100
W108	1,535	4,097 bcd	4.86	89
W110	1,081	3,279 bcd	4.54	82
Robust 90477	2,522	6,430 d	3.96	73
W104	1,561	4,696 cd	3.95	73
W204	1,273	3,018 ab	3.56	65
McHone 910	2,068	4,225 cd	3.20	58
Robust 90135	2,037	2,643 bc	2.98	54
Robust 20-70	1,278	2,357 bc	2.98	54
Robust 30-77	2,019	2,748 bcd	1.57	29
W206	1,207	1,083 a	1.42	25
Robust 33-77	1,270	1,136 a	1.23	22
	NS		NS	
FT2 - test 2				
Pioneer 3578 Popcorn	1,565	675 e	1.00	100
WOC 9503	1,299	496 de	1.24	124
WOC 9506	550	717 e	1.23	123
WOC 9507	1,010	370 cde	1.07	107
Robust 90135	1,107	347 cde	0.63	63
WOC 9504	1,066	282 bcd	0.63	63
Robust 33-77	309	110 bcd	0.53	53
WOC 9510	425	185 bcde	0.47	47
WOC 9512	665	71 abc	0.30	30
W206	623	32 ab	0.20	20
WOC 9554	469	80 abcd	0.17	17
WOC 9508	414	13 a	0.04	4
	NS		NS	

¹Initial population (J2/250 g dry soil) at planting, May 25, 1994 (trial 1), and June 9, 1995 (trial 2).

²Final population (J2/250 g dry soil) after harvest, November 3, 1994 (trial 1), and October 5, 1995 (trial 2).

³Reproductive index (R=final population/initial population).

⁴In each separate trial, means followed by same letter are not significantly different, p=0.05.

5.0 FSFS in Hermiston, OR

An FSFS was conducted on June 28th, 1995 on the Irrigation and Potato Field Day at the Hermiston Agricultural Research and Extension Center (HAREC). The meeting was held outside because the weather was favorable. Easels were set up facing about 25 chairs. People also stood up behind the chairs.

A goal of this meeting was that research information would be presented in a format favorable to all learning types. This would help everyone to learn of the opportunities and challenges in this research. Related research and FSFS information can be found in Appendix C.

5.1 Perspectives - Effect on Research

The amount of quality discussion that occurred in one meeting was not sufficient for total comprehension of the diversity of perspectives among growers and scientists. Farmers and scientists both perceived that control methods would be in constant need for *M. chitwoodi*, and that these methods needed to be economically attainable. Some farmers perceived this need would continue to be supplied through available nematicides. Others appeared more interested in how poor-, non-hosts could compliment their nematicide use. Based on observation, some farmers grew their rotation crops for the fresh market, but most grew their potatoes for processors and their rotation crops for animal feed and grain. The latter group likely maintained larger individual acreage and more capital. This group's perspective appeared to be

comfortable with current nematicide methods. It appeared most growers based their perspective on economic values.

Many participants commented that there was a need to have information concerning the market of poor-, and non-host cultivars. Most growers were not familiar with growing crops like lima beans or watermelon, because common potato rotations include field corn, wheat, or alfalfa. Nobody expressed concern that too few cultivars had host status information, rather more information was desired about specific cultivars that were popular in the area. My research perspective however, emphasized the need for host status information of more cultivars. If research and extension services together are to improve management options for control, additional information should be gathered for popular cultivars concerning: yield, multiple pest resistance, fresh market quality, weed suppression, and available contractors.

Because the problem has biological, sociological, and economical factors affecting it, the research approach should also be integrated in these areas. In practical terms, this approach should be to organize interactive meetings involving representatives from the farm, the regulatory agencies, the extension services, and the university. Then, research foci could be founded upon common interests and ideas.

5.2 Content of the FSFS - Hermiston, OR (in chronological order)

This is a description of the content of the FSFS, Hermiston,

OR, in chronological order:

- i. - researchers described nematode biology (life cycles and degree-days (DD#'s)) - lecture style
- ii. - researchers described non-host cash crops and cover crops available for rotation with potato - lecture style (Fig. 3)
- iii. - growers listed existing rotations, and their idea of an ideal hypothetical rotation using non-hosts (Fig. 4)
- iv. - three existing and three hypothetical rotations were analyzed for their overall nematode control (the nematologist gave comments on each for audience) (Fig. 5)
- v. - brainstorming and discussion exercises focused on: the opportunities and challenges of integrating poor- or non-hosts into existing rotations. Issues involved:
 - a. - How convenient is the change from good host cultivars to non-host cultivars of the same crop?
 - b. - What farming skills and time management skills must be learned for growing new crops like lima beans or peppers?
 - c. - Are nematicides necessary for control after two years of non-host cover crops?
 - d. - What is the market of poor- and non-host crop cultivars compared to the good host cultivars?
 - e. - What is the best way to manage cover crop growth to utilize the nematode suppressive characteristics?

5.3 Opportunities and challenges of poor-, non-host rotation control

5.3.1 Opportunities

In the FSFS, growers thought of opportunities that accompany using crop rotation for control. Growers expressed mild concern that some nematicides could be suspended by the EPA. This however, does not seem to be the main incentive for adopting alternative methods. Nematicides alone do not prevent potato culls when very high *M. chitwoodi* populations are present, and the addition of non-host cover crops can give more consistent control to growers. Currently though, nematicides are perceived by growers as comparatively easier and accompanied by less risk.

Winter cover crops were viewed as a much greater opportunity than summer non-host cash crops. There was participation and testimony of the suppressive effect of cover crops on nematode populations. In addition, winter cover crops can be incorporated before spring and not interfere with the summer crop. Some growers fallow over the winter. Some growers expressed concern that winter cover crops could result in volunteer weed problems.

Growers with a long-term view were more interested in reduced nematicide use than growers with short-term views. In long-term land use, it is an incentive to adapt to a non-host rotation sequence, and thus have assurance of less minimal adjustment if certain nematicides are suspended.

A comment was made asking about new technologies that would stimulate nematode eggs to hatch in unfavorable conditions. This

would prevent *M. chitwoodi* eggs from remaining in a dormant state in the presence of non-hosts. Juveniles that emerge and cannot find hosts will die. Ideas as this are important when meeting participants are investigating inter-disciplinary alternatives.

5.3.2 Challenges

Growers expressed their ideas about the challenges that poor-, non-host crop rotation presents. The main challenge is that most non-host crops have smaller or more specialized markets. Some growers were only familiar with growing wheat, field corn and potatoes. They expressed a concern that small market crops like lima beans would require too much management change. For many non-host crops, new farming equipment might be required for harvest. Even so, growers seemed more uncertain about the stability of the market for specific crops, and not of the management changes in general.

Potato growers that grew field corn for livestock feed faced another challenge. They desired *M. chitwoodi* resistant crops which could be used for feed/hay. Alfalfa is an option as a non-host for *M. chitwoodi* race 1, but it is a good host for race 2.

Another significant challenge is that most growers are continually leasing land to grow potatoes, and only few have leases with a four year cycle. Growers leasing land for only one season for potatoes are not concerned about other crops, except for winter cover crops. Acreage for lease with a history of winter cover crops would be more attractive to potato growers

than acreage with a history of winter wheat (good host). If land has a history of continuous non-hosts, it may be leased at higher prices to potato growers than land with a history of susceptible crops.

6.0 Next Steps

In the future, changes will occur in this pest situation that will affect other components of the system. There still is need to properly identify the situation in context of the whole agroecosystem, which includes other potato pests. This identification must be a consensus decision among those affected by this pest. Interactive meetings like FSFS are avenues for reaching these decisions.

Many people are not accustomed to the style of an FSFS. Growers are normally expecting research and extension workers to transfer information to them. It can be a surprise when they are encouraged to be creative with research and extension participants, in producing new ideas. Only one meeting was scheduled for this research, and in the future, at least two meetings should be held. This will help people to become accustomed to the FSFS style.

In addition, prior to any pioneering research in this pest system, a series of FSFS should be conducted. The main goal should be that research and extension workers could share a vision with all other participants of the situation. This vision will only be clear if all participating groups are strongly

represented in the meetings. This will ensure that the diversity of concerns, interests, and information can be shared before consensus decisions are made. These decisions concerning vision and direction can represent many perspectives if the FSFS are conducted properly.

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8.0 APPENDIX A - Method for Collection, Extraction and Calibration of *Meloidogyne chitwoodi* Eggs for Inoculum

1. *M. chitwoodi* (WAMC1) eggs on previously inoculated wheat and tomato plants were used for inoculum of popcorn. For counting purposes, tomato plants were the preferred inoculum source, offering less root debris.
2. Tomato and wheat plants were pulled from pots, and dirt was thoroughly rinsed off roots.
3. Roots were cut into 2-4 cm pieces and placed in containers.
4. 10% bleach was added and containers were shaken by machine for 3 minutes on high speed.
5. Immediately after shaking, the roots and egg suspension of each sample were poured through a 35-mesh (500 micrometer) or 125-mesh sieve, resting on a 500-mesh (26 micrometer) sieve. Eggs were rinsed from the upper sieve with water and collected on the underlying sieve. Residual bleach was rinsed from eggs on the sieve.
6. A 250 ml beaker was calibrated for 200 ml. Eggs that collected on the 500-mesh sieve were washed carefully into the beaker and brought to a aqueous volume of 200 ml.
Note: It is sometimes necessary to add another dilution step if the egg count is too high in the subsequent aliquot taken for counting.
7. From the 200 ml egg suspension, a 5 ml aliquot was transferred onto a counting dish and evenly distributed. By use of subdivided reference circles on the counting dish and comitant multiplication factors, the egg population of the 5 ml was calculated. Through a second trial, an average was obtained.
8. The #eggs / mL and then the #eggs / single plant was calculated.
9. Three plants were needed for the inoculum. Eggs from each were combined into a single volume, and the inoculum volume was calculated for 5000 eggs / plant.
10. During inoculations, five samples of 5 mL egg suspensions were taken and counted to calculate the actual inoculum per plant.

9.0 APPENDIX B - Variability of R values in Greenhouse and Field Tests

It is noted that there are differences in a cultivar's R value between field and greenhouse tests. For example, wheat, FC 3578, and W206 had R values approximately 9x higher in GH4 than in GH3. This was likely the result of two factors. The viability of inoculum in GH3 may have been imperfect, for reasons unknown. Another probable cause was the higher root biomass (also more secondary root growth) of plants in GH4, observable as a substantial increase in root debris in samples. A possible explanation for this increase was the sunny weather present during most of GH4, as compared to the cloudy conditions during GH3. It is suggested that natural sunlight stimulated better secondary root growth in these plants (personal communication). Root-knot nematodes enter at the tip of growing roots. More secondary root growth would result in more nematode entry sites. This phenomenon appeared to occur also in GH1 (winter) compared with GH2 (spring), and in previous greenhouse tests conducted by Ingham (1990). In conclusion, field trials most closely simulate real field conditions, and thus values from the field should receive more weight in host status determination.

10.0 APPENDIX C - Materials from FSFS, Hermiston, OR.

To: Derek Cardwell
of Botany & Plant Pathology

fax # 503-737-3573

From: JEFF McMORRAN
OSU Extension

fax # ~~737-3573~~ 567-2240

Date: 5/25/95

number of pages (including cover sheet) 2

Comments: Posited stuff added will be in next
NEWS LETTER



Farm-Focus Session on Control of Potato Nematodes
With Rotational Crops
Wednesday, June 28, 2:00 p.m.
Hermiston Ag Research & Extension Center
(In conjunction with Irrigation Field Day & Roguing School)

The use of non-host rotational/cover crops have been proven through OSU research to significantly decrease nematode populations. The crops effectively control nematodes with or without the complimentary use of chemicals.

like popcorn, super sweet corn, lima bean
 Sudan grass, rabe seed, etc

How can you integrate non-host rotation/cover crops into your production system? What are the benefits; the problems? What is the market for non-host crops? Derek Cardwell, Session Coordinator, and OSU Nematologist, Russ Ingham, along with Jeff McMorran and Phil Hamm are organizing an interactive meeting that will address these opportunities and issues.

Ray Williams,

W

IRRIGATION & POTATO FIELD DAY June 28, 1995

TENTATIVE AGENDA OF ACTIVITIES

POTATO ROGUING SCHOOL

9:00-10:00 in conference room, 10:00-11:00 in field)

9:00-9:30 Oscar Guthrod, OSU-Certification Service
Rouging Seed Potatoes: general methodology & concepts.

9:30-10:00 Phil Hamm, OSU-Extension Pathologist
Identification of potato diseases.

10:10-11:00 Field Roguing School (Jeff McMorran, Oscar Guthrod, & Phil Hamm, at site of commercial seedlot trials.

TRADE SHOW AND EQUIPMENT DEMONSTRATIONS

10:00 A.M. - 6:00 P.M.

IRRIGATION TALKS (conference room, see separate agenda)

10:00-12:00 A.M & 1:00-6:00 P.M.

FREE TESTING OF DOMESTIC WELL WATER 1:00-5:00 P.M.

Rich Topielec, OSU-Extension Energy Agent

OPEN FIELD DAY FOR POTATO SEED TRIALS (OSLOP)

1:00-2:30 P.M., Oscar Guthrod, OSU Certification Service

CALIBRATION OF APPLICATORS for ADMIRE INSECTICIDE

1:00 & 3:00 P.M. Gary Reed, Pivot #___

FARMER-SCIENTIST FOCUS SESSION ON

CONTROL OF POTATO NEMATODES WITH ROTATIONAL CROPS

2:30-4:30 P.M. Office Coffee room (down stairs)

Derek Cardwell, Russ Ingham, Ray Williams.

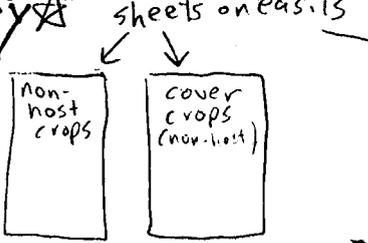
TOURS OF STATION RESEARCH PLOTS & AGRIMET STATION.

Credits for certified crop advisors should be available (no pesticide recertification credits).

Food available from {?Rotary} snack wagon.



Itinerary of FSFS



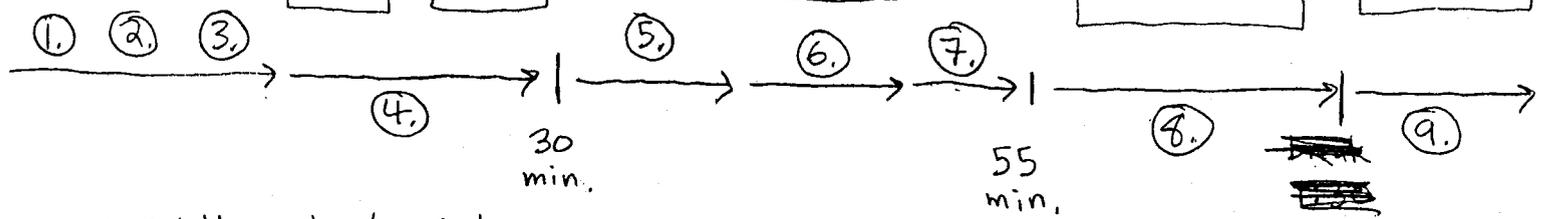
W-W-W-P
W-C-W-P
S-C-C-P

opportunities, challenges
[sequence efficiency]

market

2:30-4:30

mcmorraj@oes.orst.edu



What do the grower need to know to make a non-host rotation work for them?

name/address sheet passed around during intros: for sending out paper w/ THM's

- ① Jeff M./Phil H. introduce Derek C., Ray W. and Russ I. and title of meeting
- ② Derek - brief overview of topic, meeting's agenda
- ③ Russ - presentation of nematodes - biology life cycles degree days
give handouts
- ④ Derek - what non-host (c.c.) crops are available to implement into rotation. How they work to suppress nematode populations.
- ⑤ take 5 min for growers to list their existing 4 yr. rotation (ending w/ potato) plans and also hypothetical ones using non-host crops/c.c. This is done on handout of model non-host rotation.

- ⑥ look at 3 existing rotations taken from grower's listings, and see how nematode pops. are affected after each crop. Russ will facilitate/present here, with discussion
- ⑦ same thing as ⑥, but analyzing hypothetical non-host rotation sequences the farmer's thought of
- ⑧ brainstorm/discussion roles:
Derek - facilitator
Russ/Ray - recorders

- ⑨ market discussion - similar to ⑧

ask growers if the crops increase pops. 1:50

ADOPTION
~~How to achieve goals?~~
How to overcome constraints?

closing

- what is next step - researchers/extension
- go round the room
 - what is your take-home message?
 - ~~How much of what you learned is applicable?~~

We want to keep a perspective on rotations and not on individual crops. Also included here are subtopics of Vert. wilt and weeds (beetroot and ...)

2:00

Can we go longer if necessary, and if people want to stay

Prat. M1 probs w/

Handout ^(A) for FSFS

NON-HOST COVER CROPS - GREEN MANURE

<u>Common name</u>	<u>Cultivar name</u>	<u>R Value</u>	<u>Season Range</u>
Sudangrass	Piper	0.21 ¹	Plant late summer after short season crop (i.e. wheat, sweet corn). Till in after drought or frost stress, or leave standing as cover for soil stabilization.
	Hidden	0.08 ¹	
	Sordun 79	0.02 ¹	
	Trudan 8	0.02 ¹	
Rapeseed	Humus	0.01 ²	Plant late summer after short season crop. Allow to grow through winter and incorporate in mid-March.
	Jupiter	0.00 ²	

POOR/NON-HOST CASH CROPS

Sudangrass	Trudan 8	0.5 - 1.0 ³	Plant late spring, harvest hay when appropriate (2-3 times). Regrowth since last cutting (August) can be a cover crop and then green manure.
Popcorn	All cultivars determined to be poor/non-hosts in previous studies are no longer available. Currently, the best available cultivar is Weaver (W206), which keeps nematode densities nearly the same from planting to harvest.		
Canola and Mustard Rapeseed Mustard	All cultivars tested have been non-hosts with R values < 0.10		Plant: August Harvest: mid June/July
Supersweet- Corn	(710) Crisp and Sweet	0.66 ⁴	April 1 - May 30 to July 10 - Sept 15
	Style sweet	0.43 ⁴	
	Style pac	0.28 ⁴	April 10 - Dec 1 (cover crop) - June 30 (harvest)
	(711) Crisp and Sweet	0.07 ⁴	
Turnip	Forage Star	0.07 ⁴	Plant: April 25 until frost: Sept 15 - Oct. 1
Pepper	Calif. Wonder	0.008 ⁴	

- ¹Sudangrass Field Plots: August 22 - October 30
- ²Rapeseed Field Plots: August 22 - March 3
- ³Sudangrass Field Plots: June 15 - November 22
- ⁴Non-host cash crops Field Plots: May - September

Handout ^(A) (cont.)

POOR/NON-HOST CASH CROPS

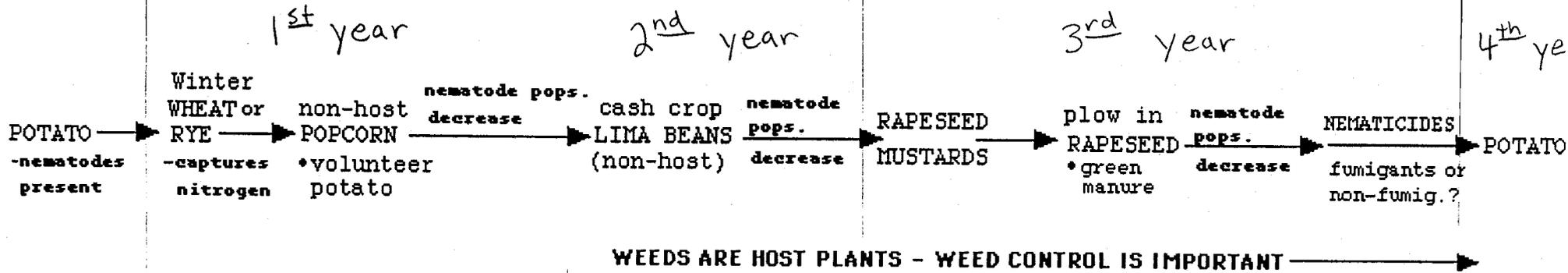
Muskmelon	Tokyo King	0.001 ⁴	April 25 - June 1 to
	Superstar-Hybrid	0.000 ⁴	July 15 - Sept.30
Squash	Butternut	0.001 ⁴	April 25 - June 1 to Aug 15 - Sept.30
Cowpea	California-Blackeye	0.000 ⁴	May 1 to frost (cover, feed crop) * popular food crop in SE U.S.
Lima Bean	Henderson Bush	0.000 ⁴	May 15 - June 20 to Aug.28 - Oct.5

⁴Non-host cash crops Field Plots: May - September

Handout (B) - Growers fill in the blanks.

Existing rotation

Potato



Possible Grower rotation # 1

Potato

2

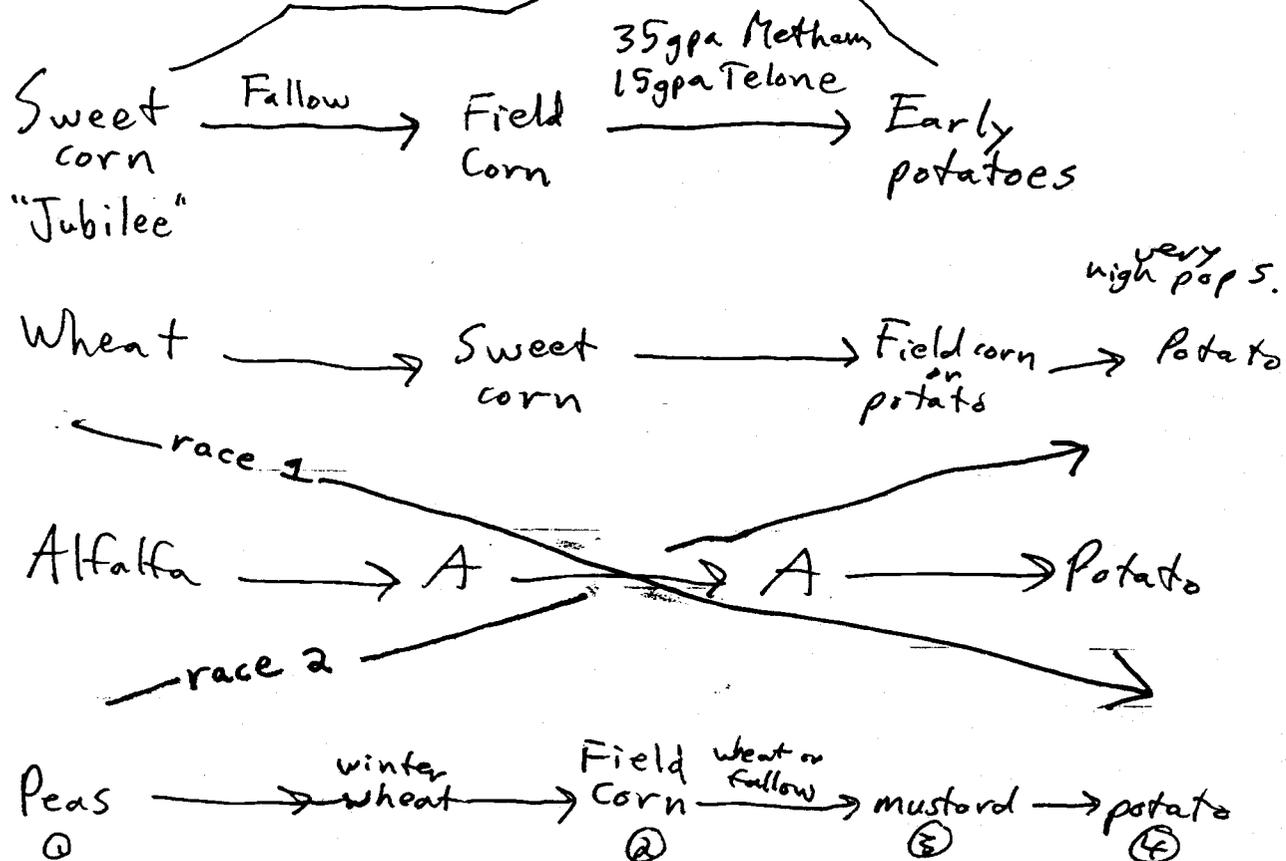
Potato

3

Potato

Results of Handout (B) - some rotations were recorded on easils

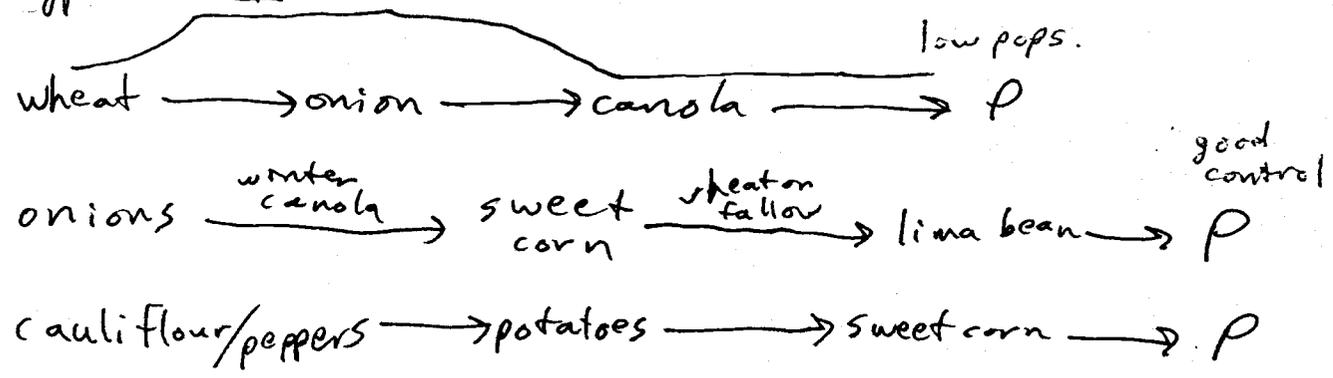
Existing Rotations



very high pop 5.

need nematocide before potato

Hypothetical



low pops.

good control

Control of Columbia Root-knot Nematode in Potato

Derek Cardwell (cardwell@ucs.orst.edu),
Russ Ingham (inghamr@bcc.orst.edu),
Department of Botany and Plant
Pathology;
Ray William (williamr@bcc.orst.edu),
Department of Horticulture, Oregon
State University, Corvallis, OR

The Problem

The Columbia root-knot nematode (*Meloidogyne chitwoodi*) attacks potato and causes injury to tubers in the Columbia Basin of Oregon and Washington. Infected potato tubers become rough and bumpy on the surface. Inside the potato, adult females cause brown spots which discolor during cooking. Growers are using various methods for suppressing this nematode. Common methods include chemical nematicides, cover crops, crop rotation and fallow.

A potato field escapes economic damage if Columbia root-knot nematode levels are at 0 juveniles per 250 g dry soil. The FDA does not allow nematodes in processed potato products. If 5-15% of the tubers in a field are rejected because of infection, the entire field is rejected. This can result in a loss of about \$250,000 for a grower working a 65 ha irrigated circle.

FILL IN THE
BLANK PLEASE.

nematode populations sufficiently. Ed Snyder, a potato grower from Franklin county, WA, is using an alfalfa-wheat-potato (Russet Burbank) rotation. His fields are infested with *M. chitwoodi* race 1. His alfalfa (non-host) is suppressing the nematode populations. Ed also applies Vapam (non-fumigant) or Telone II in the fall before potato. Yet, even with those control measures, his root-knot problems are increasing. He is considering rotating with a non-host white mustard or sudangrass to further suppress the nematode densities.

A further concern is that pesticides have been known to experience sudden suspensions by the EPA (the fumigant Telone was suspended in CA several years ago). Jeff McMoran, OSU potato extension agent in Umatilla county and Russ Ingham, nematologist at Oregon State University, comment, "If we lost fumigants, acreage that could be successfully grown to potatoes would be drastically reduced." If some fumigant products are not available in the future, OSU research has shown that non-fumigants alone will not provide adequate control (Ingham, 1994).

Research at Oregon State and Washington State Universities has documented that crop rotation has decreased *M. chitwoodi* populations in the soil to levels resulting in < 5% potato yield rejection (Ingham, 1994).

harvest. A reproductive index (R value) is calculated that measures the reproductive efficiency of the nematode on each crop cultivar as follows:

R value = (final populations + initial populations). This index is assigned to each cultivar tested, i.e. its host status.

{R > 1.0} = good hosts;
{R < 1.0} = poor-hosts;
{R < 0.1} = non-hosts.

Most crops currently favored for rotation with potato (wheat, field corn, cereal corn, alfalfa) increase Columbia root-knot nematode populations greatly. Alfalfa only increases populations if *M. chitwoodi* race 2 is present. In a study by Ingham (1994) in Hermiston, OR, good host and poor-/non-host crops were grown in rotation with potato. The outcome:

- wheat-wheat-potato rotation resulted in 91% tuber culls
- addition of winter sudangrass and pre-potato Mocap (non-fumigant) treatment allowed 47% culls
- two years of non-hosts + winter rapeseed before potato reduced culls below FDA tolerance (Fig. 1).

The best rotational control before potato for the Columbia root-knot nematode involves planting a summer non-host crop, and a winter cover crop (rapeseed) incorporated as a green manure (Fig. 1). A grower can use any of the following non-hosts (Ingham,

If your potato plots are infested with *M. chitwoodi*, what control methods are you using to avoid root-knot symptoms?

- 1.
- 2.
- 3.

M. chitwoodi can complete many generations during the long, warm growing seasons of the Columbia Basin. As populations increase, damaging levels of nematodes can occur even after chemical applications. Growers are discovering they need great control because of the FDA's regulation. Telone (a fumigant) can provide great control but other chemicals are not suppressing

Rotating crops with potato can be managed so that it's possible to decrease uses of fumigant or non-fumigant nematicides.

Control with Rotation

Several crops have been identified that suppress *M. chitwoodi* in the soil. To select suppressive crops, soil samples are taken before planting and after

1990): supersweet corn (certain cultivars), pepper, lima bean, turnip, cowpea, muskmelon, watermelon, squash, rapeseed, canola, mustard, and sudangrass (Trudan 8, other cv's are poor-hosts). The diversity of these choices is increasing each year as more varieties are being tested. Perhaps growers can turn these crops into viable economic

enterprises or treat them as an alternative to pesticides.

The Role of Cover Crops in Rotations

Sudangrass, rapeseed, and some cultivars of canola and mustard release nematicidal compounds when their plant tissues decompose, providing excellent control (Mojtahedi et al., 1993a, 1993b). To maximize this effect, winter sudangrass should be plowed down after it is stressed (i.e. the 1st frost, stopping irrigation), and winter rapeseed and canola should be incorporated in mid-March.

Cover crop rotations are common in the Columbia Basin for wind erosion control. "Why not take advantage of the situation and grow a non-host cover crop, and reduce the risk of major potato losses the following summer?" This is a question that should be asked by any spudman, especially considering that non-fumigants (\$120-140/acre) could replace fumigants (\$200-250/acre) as the nematicide choice to accompany non-host crops.

Non-host crops can decrease *M. chitwoodi* populations to levels, in which non-fumigants can further suppress them to 0 juveniles / 250g dry soil.

Bruce LePage is a spudman from Franklin county, WA. He has taken advantage of the nematode suppression given by non-host cover crops. He is successfully growing a monoculture of Norkota potato in its 4th year. *M. chitwoodi* densities in his plots initially were at dangerous levels, but have decreased to 0 juveniles / 250g dry soil via a winter rotation of hybrid-sudangrass cv Super-graze 2. In addition, Norkotas are harvested early, preventing late-season damage. Bruce is spending about \$90/acre total for sudangrass management, compared to a higher fumigation cost, which Bruce has occasionally paid to control Verticillium wilt (potato early dying).

The money saved through these types of control measures allows growers to focus their resources on enhancing the fertility of the soil. Cover crops (rapeseed and canola survive frosts) can increase or maintain the soil organic matter when their biomass is plowed under as a green manure. Some winter cover crops are functional for capturing inorganic nitrogen in the soil. Organic matter amendments add carbon and nitrogen to the soil and enhance potato plant health, which is very important for plant tolerance to diseases like Verticillium wilt. Green manures also can aid in the control of early-emerging summer weeds. The control of summer mustards and nightshade can reduce the

alternate hosts of the green peach aphid, and the reservoir of potato leafroll virus. The manures also can serve as a habitat for beneficial insects. Some growers are finding benefit in growing white mustard as a cover crop. Ron Reimann, chairman of the Washington potato commission, has some hot spots of root-knot nematodes in his potato plots, and is thinking of control with a non-host white mustard, which he will also use to control volunteer wheat, which is a good host for *M. chitwoodi*. The elimination of good host weeds or volunteers is important when using a non-host cash crop or cover crop to reduce nematode reproduction.

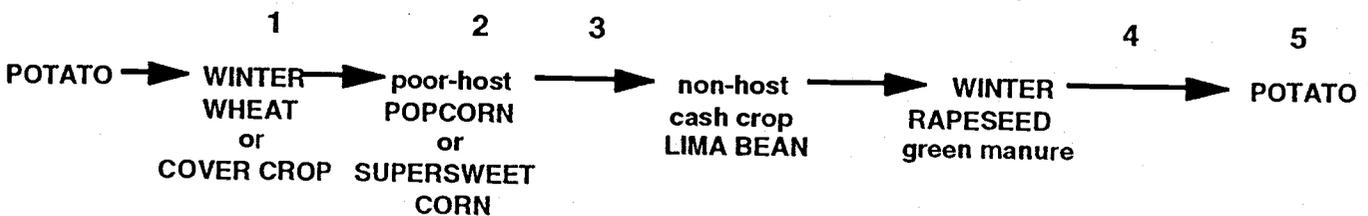
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Mojtahedi, H., G.S. Santo, and R.E. Ingham. 1993a. Suppression of *Meloidogyne chitwoodi* on potato with sudangrass cultivars as green manure. *Journal of Nematology*. 25(2): 303-311.

Mojtahedi, H. G.S. Santo, J.H. Wilson, and A.N. Hang. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. *Plant Disease*. 77:42-46.

Figure 1. Possible 2 year rotation with potato using non-host crops and cover crops.



- 1 - captures nitrogen, prevents nitrate leaching into groundwater; may act as trap crop
- 2 - popcom varieties- Purdue 410, Weaver W206; supersweet com- Crisp and Sweet 710/711, Style pac
- 3 - nematode densities will not change or will decrease
- 4 - best to incorporate mid-March
- nematode numbers can be reduced to: 0-1 juveniles / 250 g dry soil
- 5 - a preplant application of Mocap may not be necessary, but will ensure less than 5% culled tubers
- an additional winter rapeseed after popcorn/supersweet com will provide comparable suppression to Mocap