# The Economic and Environmental Impact of Nematode Research and Extension Program on the Idaho Agricultural Industry

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## Historical perspective

In Idaho, the first species of nematode was discovered in 1943. Idaho plant pathologist Earl Blodgett reported the discovery of the potato rot nematode in a potato field a few miles southwest of the Aberdeen Experiment Station. As awareness of this pest's presence spread, apprehension over interstate shipments of potatoes from Idaho increased. In 1948, quarantine against Idaho potatoes was being considered by several importing states (1,2). A marketing crisis was facing the Idaho potato industry. In 1948, Idaho had 150,000 acres of potatoes with significant annual revenue. Such quarantine would have severely impacted the state economy and the potential growth of the Idaho potato industry. The Idaho Crop Pest Control and Research Commission, composed of the Governor, the Idaho Commissioner of Agriculture, and the Director of the Idaho Agricultural Experiment Station initiated steps to deal with this threat to the rapidly growing potato industry.

In 1948 a new plant pathologist, C. Eugene Dallimore, was hired to coordinate a research program to determine the extent of the potato rot nematode infestation and to provide appropriate solutions. By 1955, Dallimore had determined that the potato rot nematode was present in only a few eastern Idaho farms. It was also determined that with moderate management, this nematode posed little threat of spread to other Idaho potato fields, or to potato production in states importing Idaho potatoes. This information, plus the discovery of the potato rot nematode in Wisconsin, ended the threat of quarantine against the Idaho potato industry (1).

One potato rot control recommendation resulting from Dallimore's research program was a method of soil fumigation during plowing that proved to be easy, practical, and effective. In addition, wheat was promoted as a logical effective rotation crop to diminish nematodes in potato production. During the decade of the 1970's, it became apparent that "crop rotation with wheat" was losing its effectiveness in suppressing root-knot nematodes on potatoes. It was learned that the loss of rotation effectiveness was due to the emergence of an unknown strain of root knot nematode, which was capable of using wheat as a favorable host plant. Growers who planted wheat to suppress the potato-infesting nematode found that infestations of potatoes became more severe (2).

In 1976, another phytopathologist, Arthur Finley, was assigned to investigate the breakdown of the nematode rotation program. Though not a nematologist, Finley collected soil samples and, with the aid of Washington State University and United States Department of Agriculture nematologists, was able to show a widespread distribution of both the previously known and the new species of root knot nematode in irrigated cropland across Idaho. It was discovered that the older species, *Meloidogyne hapla* (the northern root-knot nematode) could increase on alfalfa but was suppressed by a rotation into wheat. The new strain, *M. chitwoodi*, had the opposite reaction to these hosts. Though morphologically similar, *M. chitwoodi* could be distinguished from *M. hapla* and was called the Columbia root knot nematode because of its distribution in the Columbia River Basin (2, 3, 5). From a practical point of view, it became imperative to identify and distinguish between these two nematode parasites in order to conduct a program of fumigation and crop rotation to effectively control these potato pests.

In 1981, Finley retired leaving a recommendation that a bonafide nematologist be hired to conduct an effective research program for root-knot nematode control. This recommendation was not heeded. Instead, R. Robert Romanko, hitherto a potato and hops researcher at Parma was assigned the responsibility for the root-knot nematode programs made vacant by the retirement of Finley and the transfer of Dallimore. Neither Romanko nor any of his predecessors were qualified nematologists. Because the success of a nematode control program on potatoes hinged on an absolute capability for rapid and accurate diagnoses of nematode species prevalent in individual fields, it became necessary to create and fill a position for which no appropriated funds were available.

Romanko earmarked Potato Commission funds in his program to provide soft monies for a nematologist. Other support funds were obtained by soliciting project support from other College of Agriculture scientists, whose responsibilities included crops with important nematode problems. Sugarbeet specialist John Gallian agreed to share funding for sugarbeet nematode research. These, together with anticipated grants, would provide the salary portion of the funds required. Additional funds were projected to come from fees generated by a proposed nematode diagnostic laboratory, where nematode infested soil and plant samples would be analyzed and the type and extent of nematode infestation determined. Recommendations to control nematodes would be made on the basis of critical or threshold levels of economically important nematodes present (4).

In January 1981, Saad L. Hafez arrived at the Parma Research and Extension Center to provide the needed nematological expertise for Idaho. The development of the diagnostic laboratory was immediate and positive. By the end of 1982, Hafez became the project leader and director of the new nematode diagnostic laboratory.

Prior to the inception of the diagnostic laboratory, samples, representing suspected crop nematode problems, were sent to facilities in other western states where specialists capable of identifying plant parasitic nematodes could process them. Information was often slow in being returned and, at times, subject to handling delays. Although figures are not available, it is believed that only a small portion of needed analyses were actually performed by the out-of-state nematology labs.

**Table 1:** Record of new nematodes identified by the Idaho nematode research and extension program.

**Idaho**

*Heterodera avenae*
*Pratylenchus hexincisus*
*Xiphinema rivesi*
*Trophurus minnesotiensis*
*Heterodera trifoli*
*Geocenamus tenuidens*
*Trophonema avenarium*
*Paratrichodorus porosus*

**United States**

*Ditylenchus exilis*

**Colorado**

*Tylenchorhynchus capitatus*

**Alaska**

*Tylenchorhynchus dubius*
*Trichodorus californicus*
*Tylenchus elegans*
*Ditylenchus exilis*
*Tylenchus exilis*
*Pratylenchus penetrans*
*Helicotylenchus anhelicus*
*Paratylenchus projectus*
*Aphelenchus avenae*

## Nematode species

Since the establishment of the nematode diagnostic laboratory in 1982, the nematode research and extension program directed by Hafez reported a total of 53 species of plant parasitic nematodes in this region. Forty-seven species, including two previously unrecorded, were reported in this region for the first time (Figures 1, 2, and 3). The nematode program also identified eight new nematode records for Idaho, one new nematode record for the United States, one new nematode record for Colorado, and nine new nematode records for Alaska (Table 1). Of the 53 nematode species reported in the region five cause significant productivity loss in the major crops in Idaho. These species are: (1) root knot nematodes (*Meloidogyne spp.*); (2) sugarbeet cyst nematode (*Heterodera Schachtii*); (3) lesion nematode (*Pratylenchus spp.*); (4) stubby root nematode (*Trichodorus spp.*); and (5) Stem nematode (*Ditylenchus spp*).

These nematodes are serious problems in potatoes, sugarbeets, alfalfa, apples, and cherries. Recently it was discovered that nematodes are becoming an increasing problem in irrigated wheat and barley fields in Bingham, Bonneville, Freemont, Jefferson, Madison, and Teton counties. In general, nematodes cause significant loss in both quantity and quality of agricultural products and require high cost-toxic fumigants to control. The Nematode Research and Extension Program, established in Idaho in 1982, developed a diagnostic-managed control method to efficiently control nematode damage. The following section discusses the damage caused by these nematodes and the impact of the managed-control method on nematode control in sugarbeet, potato, and alfalfa.

### Sugarbeets

Sugarbeet cyst nematode (SBCN), *Heterodera schachtii*, is the most destructive plant parasitic nematode species. The species attacks sugarbeets and causes yield losses of up to 60 percent in the endemic regions. In Idaho and eastern Oregon more than 50 percent of the sugarbeet acreage is infested with sugarbeet cyst nematodes at a level where treatment is essential to obtain an economically feasible yield. The most common control practice is the use of fumigant nematicides. The fumigants are expensive and cost between $200 and $260 per acre. The results of this research indicate that incorporation of nematode-resistant crops such as oil radish or white mustard in sugarbeet rotation is the most economically viable method for the management of sugarbeet cyst nematodes. Cultivars of oil radish and white mustard stimulate egg hatch while preventing completion of life cycles. They provide an effective method of controlling nematode populations without peril to the environment.

Oil radish and white mustard are referred to as trap crops in this study. A series of experiments were conducted to study the potential efficacy of trap crops on the population of *Heterodera schachtii*, (SBCN) and sugarbeet yield potential. Results showed that sugarbeet yields in plots previously planted with oil radish or white mustard was significantly higher as compared to fallow treatment. Compared to planting sugarbeets after fallow, study results also demonstrate that establishing oil radish or white mustard in late summer, then chopping and plowing under the radish and mustard in the fall prior to planting sugarbeets in the following spring, will significantly increase sugarbeet yields and reduce nematode populations. The results show that using white mustard (Metex) as green manure prior to sugarbeets will increase yield by 21.5 percent compared to fallow and reduce nematode population by 84 percent compared to 41 percent for fallow. Using oil radish (Adagio) as green manure prior to sugarbeets will increase yield by 24.7 percent compared to fallow and reduce nematode population by 92 percent compared to 41 percent for fallow (Table 2).

**Table 2:** Effects of using white mustard and oil radish as green manure in late summer on sugarbeet yield and nematode population.

| Treatment | Yield (ton/acre) | Percent increase in yield | Percent reduction in nematode population[a)] |
|---|---|---|---|
| Fallow | 25.1 | - | 41 |
| White mustard (Metex) | 30.5 | 21.5 | 84 |
| Oil radish (Adagio) | 31.3 | 24.7 | 92 |

a) Reduction in population from previous season.

The effect of fall planting of oil radish and white mustard on sugarbeets yield and nematode population was analyzed in two field experiments. Four varieties of oil radish cultivars were planted and plowed under prior to sugarbeets. These varieties are: Adagio, Pigletta, Ultimo, and Remonta. Results show that the Adagio variety reduced nematode populations by 92 percent and increased yield by 8.8 to 9.3 tons per acre. This is 42 percent higher compared to planting sugarbeets after fallow. Currently, Adagio is the most effective green manure crop for reducing nematode populations while increasing sugarbeet yields. (Table 3).

**Table 3:** Effects of fall planting of oil radish and white mustard cultivars on nematode population and sugarbeet yield.

| | Experiment I | | | Experiment II | | |
|---|---|---|---|---|---|---|
| Treatment | Percent reduction in nematode population[a)] | Yield per acre | Increase in yield per acre | Percent reduction in nematode population | Yield per acre | Increase in yield per acre |
| A. Oil radish | | | | | | |
| Adagio | 92 | 31.4 | 9.3 | 92 | 37.2 | 8.8 |
| Ultimo | 89 | 28.2 | 6.1 | 89 | 33.4 | 5.0 |
| Remonta | 88 | 27.6 | 5.5 | 88 | 29.7 | 1.3 |
| Pigletta | 87 | 28.6 | 6.5 | 87 | 29.7 | 1.3 |
| B. White mustard | | | | | | |
| Metex | 84 | 29.1 | 7.0 | 84 | 30.0 | 1.6 |
| Mexi | 84 | 28.1 | 6.0 | 84 | 36.8 | 8.4 |
| Martigena | 62 | 25.9 | 3.8 | 62 | 28.4 | 0 |
| C. Fallow | 41 | 22.1 | — | 41 | 28.4 | — |

a)Reduction in population from previous growing season.

Three varieties of white mustard were used as green manure followed by sugarbeets. The results showed that the Maxi Variety increased yield by 6 tons per acre in one experiment and by 8.4 tons in the second experiment. However, for both late summer and fall planting, the oil radish variety Adagio seems to have the greatest impact on nematode population and sugarbeet yield (Table 3).

Fall planting of oil radish or mustard cultivars previous to sugarbeet planting reduced the cyst nematode population from 62 percent to 92 percent, depending on the cultivar planted.

However, cultivars of oil radish have more inherent ability to reduce cyst nematode populations (87-92 percent) compared to white mustard (62-84 percent). This is primarily due to the inhibition of the nematode development in the root of the oil radish cultivars. The percent reduction in nematode population density was highest in Adagio planted plots followed by other radish cultivars. Sugarbeet yield was significantly higher in plots previously planted with all cultivars than in fallow plots. The effect of organic manure on reducing nematode population and on improving soil water holding capacity and nutrition content of the soils has contributed to reduced damage to sugarbeet root systems while improving the yield.

Impact of different planting dates of oil radish and white mustard on nematode populations and yield was evaluated. Two planting dates (early, August 9 and late, August 25) were established to determine how late these crops could be planted in southwestern Idaho and still be effective in controlling the sugarbeet cyst nematode. Early planting of oil radish or white mustard is more effective in reducing the nematode populations and increasing sugarbeet yield compared to late planting. Results of these experiments revealed that cultivars of oil radish and white mustard are potential agents, which can be incorporated into the sugarbeet cropping system to control sugarbeet cyst nematode population for sustainable sugarbeet yield without the need for expensive chemical fumigants.

## Potatoes

Nematodes most associated with potato production in Idaho are root knot nematodes (*Meloidogyne spp*), root lesion nematodes (*Pratylenchus spp*), stubby root nematodes (*Trichodorus*), and potato rot nematode (*Ditylenchus destructor*). The root knot and root lesion nematodes are relatively widespread problems in Idaho potato fields. However, stubby root and potato rot nematodes are less ubiquitous. They can be managed with chemical nematicides at a cost of $200 - $260 per acre. A bio-control method that is environmentally friendly and significantly less expensive to control nematodes on potatoes is being developed and tested by the Idaho Nematode Diagnostic Laboratory. The method consists of using green manure crops and other soil amendments to manage potato nematodes. Research is being conducted under greenhouse, microplot, and field conditions to analyze nematode response to the application of green manure and the impact of green manure on yield and quality of potatoes.

Two types of trap crops are being used: oil radish and rapeseed. The effect of oil radish and rapeseed as green manure on Columbia root-knot nematode populations and potato yields was analyzed in the laboratory and under field conditions in two experiments conducted in 1996-97. Oil radish and rapeseed were planted in mid-August 1996, following a wheat harvest, and incorporated in the soil in October 1996. Potatoes were planted following incorporation in April 1997 and harvested in September 1997. Nematode populations for each type of green manure were determined before green manure was sowed into the soil, and after incorporation of green manure in the soil. Nematode populations were also calculated before potato planting, after potato planting, and at potato harvest.

The results are shown in table 4. Columbia root-knot populations for soils planted in oil radish in August were 213 per 500-cc soil, for soils planted in rapeseed were 253 per 500-cc soil, and for fallow were 293 per 500-cc soil. In October and after incorporation of the green manure, the nematode populations were 98 per 500-cc soil for the oil radish plot, 61 per 500-cc soil for the rapeseed plot, and 106 per 500-cc soil for the fallow plot. At the time of potato planting in April, nematode populations were 18 per 500-cc soil for the oil radish plot, 60 per 500-cc soil for the rapeseed plot, and 82 per 500-cc soil for the fallow plot.

Compared to August 96, the nematode population in April 97 declined by 91.55 percent for the oil radish plot.

Potato plots treated with oil radish as a green manure had the highest yield of 392 cwt per acre compared to 337 cwt for the fallow treatment. This is 55 cwt or 16 percent higher yield. This plot also had the lowest Columbia root-knot nematode infection rate of 26 percent. Potato plots treated with rapeseed as a green manure had a yield of 381 cwt per acre and tuber infection of 45 percent. Potato plots with fallow treatment had 337 cwt per acre and 62 percent tuber infection. Research experiments to control nematodes on potatoes with green manure in the rotation system will continue until an effective method is developed.

## Alfalfa

The alfalfa stem nematode *Ditylenchus dipsaci*, the root knot nematode, *Meloidogyne spp.*, and the root lesion nematode, *Pratylenchus spp.* are the most common nematodes found in alfalfa fields. These nematodes affect alfalfa by damaging the stem and the root systems. This results in reduced growth, abnormal development of foliar and floral parts, excessive wilting in hot dry weather, and nutrient deficiencies. Consequently yield and quality of hay or seed production are reduced. These nematodes also play a role in disease complexes of alfalfa such as fusarium and bacterial wilts.

Chemical options for nematode control are limited to preplant fumigation. Other chemicals are not presently registered for nematode control in alfalfa. Preplant fumigation of alfalfa fields is expensive and rarely used. Crop rotation to non-host crops can reduce populations of stem and root knot nematodes. Rotation is generally not effective with root lesion nematodes because of their wide host range. Planting nematode-free seed, using good sanitation practices, and cutting stem nematode infested fields when the soil surface is dry can significantly reduce stem nematode populations.

Development and use of nematode resistant alfalfa cultivars are the most effective and economically viable method for management and control of nematodes in alfalfa.

**Table 4.** The effects of oil radish, rapeseed, and fallow green manure treatments on the population of Columbia root-knot nematodes,potato yield, and tuber infection.

| | Columbia root-knot population (Ct per 500-cc soil) | | | | | |
|---|---|---|---|---|---|---|
| Treatment | August 96 | October 96 | April 97 | Sept. 99 | Yield (Cwt/acre) | Tuber infection (percent) |
| Oil radish | 213 | 98 | 18 | 306 | 392 | 26 |
| Rapeseed | 253 | 61 | 60 | 197 | 381 | 45 |
| Fallow | 293 | 106 | 82 | 610 | 337 | 62 |

**Table 5.** Seasonal average yield reductions caused by stem nematodes and northern root-knot nematodes for six common alfalfa varieties planted in Idaho.

| | Seasonal average yield reduction (%) | |
|---|---|---|
| Variety | Stem nematode | Northern root-knot nematode |
| Ranger | 12.8 | 2.2 |
| EXP 49 | 7.3 | -2.6 |
| EXP 107 | 7.0 | 0.6 |
| Lahontan | 7.7 | 5.5 |
| Apollo II | 7.1 | 0.3 |
| Washoe | 5.5 | 4.2 |

**Table 6:** Nematode resistant alfalfa varieties developed by the Idaho nematode research and extension program in cooperation with the private alfalfa seed industry.

| Variety | Average annual yield (t/acre) |
|---|---|
| Archer[1] | 11.69 |
| Vernema[2] | 10.31 |
| ABI 700[1] | 11.85 |
| Zahgntan | 9.00 |
| Zolio[3] | 11.26 |
| Nemagone | 12.68 |

[1]Proprietary variety of Agri-Bio Tech, Inc.
[2]Public variety
[3]Proprietary of Eureka Seeds, Inc.

Experiments were conducted under greenhouse conditions to evaluate dry matter production of alfalfa varieties planted in nematode-free and nematode-infested soils. Six alfalfa varieties were compared for their response to alfalfa stem nematodes (*Ditylenchus dispaci*) and northern root-knot nematodes (*Meloidogyne hapla*). All present alfalfa varieties are susceptible to stem nematodes. Yield reduction in all present alfalfa varieties by the stem nematode is shown in table 5. Ranger is considered to be susceptible to stem nematodes, and exhibited the highest reduction of yield. Other varieties in the stem nematode study had significantly less yield reduction. Washoe exhibited the least yield reduction, 5.5 percent, in soils infested with stem nematodes.

Significant differences among varieties in the root-knot nematode study were also observed. The yields of the two experimental lines, EXP 49 and EXP 107, and Apollo II were least affected by the presence of root-knot nematodes. Lahontan's was significantly reduced by root knot nematodes compared to the other varieties with the exception of Washoe. A similar study involving root lesion nematode (*Pratylenchus penetrans*) and five alfalfa varieties was conducted under greenhouse conditions. All had yield reduction at different levels. In general, all available alfalfa varieties are susceptible to one species of nematode or another. (Table 5) New varieties need to be developed.

The University of Idaho Nematology program has cooperated for several years with private alfalfa seed companies in developing and evaluating alfalfa germplasm for resistance to nematodes. Several lines were tested and seven new varieties that are resistant to nematodes were developed. Table 6 shows the average yield per acre. Average alfalfa yield per acre of these nematode resistant varieties, planted in several different locations in Idaho and eastern Oregon, ranged from a high 12.68 tons per acre for the Nemagone variety to a low of 9 tons per acre for the Zolis variety. Yields per acre for all the nematode resistant varieties are significantly higher than the yields of present varieties that are susceptible to nematodes.

## The benefits of public investment in Idaho's nematode research and extension program

This study, using an ex-ante approach, will analyze the economic impacts in Idaho of investment in the Nematode Research and Extension Program on potatoes, sugarbeets, and alfalfa. In addition to the cost of research, implementation, maintenance, and technology, transfer costs are analyzed and incorporated in the model to assess the net benefit of the Idaho nematode program on the state agricultural industry.

### The model

The flow of benefits from the development and adoption of the results of the nematodes research and extension program are estimated by the following equation:

$$\beta_{jt} = A_{jt}\left\{\left(\Delta P_{jt} V_t - V_o\right) - C_{jt}\right\} \qquad (1)$$

Where:

$\beta_{jt}$ = the benefits accruing to the j^th^ product in year t

$A_{jt}$ = the expected total production or acreage of the $j^{th}$ product affected by the adoption of the results of the nematode program in year t

$\Delta P_{jt}$ = the expected change in net productivity and or quality of the $j^{th}$ product due to the adoption of the results of the nematode program in year t

$V_t$ = the expected price received per unit of the $j^{th}$ product affected by the adoption of the results of the nematode program in year t

$V_t = \left\{V_o + V_o\left(f\Delta P_t\right)\right\}$

where f is the flexibility ratio and $V_o$ is the price per unit in the base year.

$C_{jt}$ = is the costs associated with the development, technology transfer, implementation, and maintenance of the nematodes managed-control program for the j^th^ product in year t.

Bjt is the benefit that accrues to producers and processors as a result of adopting and implementing the nematode managed-control method. The outcome $B_{jt}$ is probabilistic because it depends on the probability of successful development of the nematodes managed - control method, (P(S)), and the probability of adopting the nematode managed-control method by the j^th^ product (P(A)). The expected value of is defined as:

$$E\left(\beta_j\right) = \sum_{t=1}^{N} \beta_{jt}\left\{P(A) \cap P(S)\right\} \qquad (2)$$

The present value of the expected flow of benefits from adopting the nematodes managed-control method by the product is calculated by "discounting" the right-hand side of equation (2) as shown in equation (3) below.

$$E\left(\beta_j\right) = \frac{\sum_{t=1}^{N} \beta_{jt}\left\{P(A) \cap P(S)\right\}}{(1+r)^t} \qquad (3)$$

Where:

r = the social discount rate.

N = number of years for which the nematodes managed-control method affects productivity, quality, and/or cost of the product

A six percent social discount rate was used to discount the flow of future return. The flow of benefits was calculated over 20 years from the first year of adoption.

The present value of the flow of costs is expressed as:

$$C_{jt} = \sum_{t=1}^{N} \left\{\left(R_{jt} + T_{jt} + I_{jt} + M_{jt}\right)\right\} \Big/ \left\{(1+r)^t\right\} \qquad (4)$$

Where:

Cjt = the present value of total costs associated with the development of the nematodes managed-control method.

Rjt = direct research investment in the development of the nematodes managed-control method.

Tjt = technology transfer cost to help the industry adopt the nematodes managed-control method.

Ijt = implementation cost by the industry to adopt the nematodes managed-control method.

Mjt = the cost of maintenance research required to sustain the effectiveness of the nematodes managed-control method.

Expenditure in the development, transfer, implementation, and maintenance of the nematodes managed control-method for the jth product from 1982-1998 were compounded at 6 percent to bring it to the 1998 level. The flow of expenditure after 1998 was discounted by 6 percent to bring it to the 1998 level.

# Results

The 1995-1997 average acreage, production, and prices shown in Table 7 were used to calculate the expected benefit to the Idaho agricultural industry. The results developed by the Idaho nematode program have direct application to sugarbeets, alfalfa, and potatoes in eastern Oregon, several counties in Washington, and other western states. However, the impact of the Idaho nematode program was not considered in these states and the flow of benefit may have been underestimated.

The gross annual benefit, net annual benefit, the present value of flow of benefits, cost, and the benefit-cost ratio associated with the development, transfer, and implementation of the control methods are analyzed in this section.

## Gross annual benefit

Several areas of expected benefits attributed to the development and adoption of the nematode-managed control method are analyzed. These areas are classified by the major crops directly affected by the nematode managed-control program. These crops are sugarbeets, potatoes, and alfalfa. The direct benefit of the program for each crop is analyzed in the following sections.

### 1. Sugarbeets

The diagnostic managed control method with the Adagio radish variety as a green manure will benefit the Idaho sugarbeet industry in two direct ways. First, the use of Adagio as a green manure in the rotation system of sugarbeets will reduce the nematode population by 92 percent and, thus, the need for expensive fumigants. Second, the results of the two experiments show that the use of this variety of oil radish as a green manure in the rotation system of sugarbeets increased yield between 8.8 tons to 9.3 tons per acre compared to the fallow treatment. This was 42 percent increase in yield for the first experiment and 30.98 percent for the second experiment. The increase in yield is due to reduced damage to the plant root system, increased water holding capacity of the soil due to increased soil organic matter, and increase in soil nutrients due to the green manure.

Idaho had a 1995-97 average of 192,667 acres planted in sugarbeets. The 1995-1997 average annual production was 4,833,667 tons at an average yield of 25.06 tons per acre. The 1995-1997 average price received by farmers for sugarbeets was $44.23 per ton. An estimated 50 percent of the sugarbeet acreage in Idaho is infested with nematodes. More than 50 percent of these infested acreage require fumigant to control nematodes at $200-$260 per acre cost.

The gross annual benefit to the Idaho sugarbeet industry from the development and adoption of the diagnostic managed control method is analyzed below.

a. Reduced fumigants cost, using a low fumigant cost of $200 per acre.

   [(192,667)(0.50)(0.50)($200)] = $9,633,350

b. Improved yield, using a low estimate of a 2-ton increase in yield per acre.

   [(192,667)(0.50)(0.50)(2)($44.32)] = $4,269,500.72

**Table 7:** Acres harvested, yield production, and price for potatoes, sugarbeets, and alfalfa. Idaho 1995-1997 average.

| Commodity | Acre harvested | Yield | Total production | Price ($) |
|---|---|---|---|---|
| Potatoes | 393,000 | 340.70 cwt/acre | 136,962,333 cwt | 5.03/cwt |
| Sugarbeets | 192,667 | 25.06 ton/acre | 4,833,667 cwt | 44.23/ton |
| Alfalfa | 1,040,000 | 4.23 ton/acre | 4,399,333 ton | 98.00/ton |

Source: Idaho Agricultural Statistics Service, 1998 Idaho Agricultural Statistics, and Boise Idaho.

Total gross annual benefit to the Idaho sugarbeet industry from the development and adoption of the diagnostic managed-control method is estimated at $13,902,850.

### 2. Potatoes

The diagnostic services and the managed control method, with oil radish as the trap crop, will benefit the Idaho potato industry in three direct ways. First, the implementation of the diagnostic and managed-control program reduced the percentage of potato acreage damaged by nematodes that used to be rejected by processors from 4 percent prior to 1996 to 0.1 percent in 1996 and thereafter. Second, an estimated 30 percent of Idaho potato acreage is infested with nematodes. Of this 30 percent, an estimated 50 percent requires annual fumigation to control nematodes at $200-$260 cost per acre. The diagnostic services and the managed control method, using oil radish as the trap crop, is expected to reduce nematode infestations by 92 percent and, thus, the need for expensive fumigation. Third, the use of green manure increased the yield by 55 cwt or 16 percent per acre because of improved soil organic matter and thus soil moisture and soil nutrient content.

Idaho had a 1995-97 average of 402,000 acres planted in potatoes. The 1995-1997 average annual production was 136,962,333 cwt The 1995-1997 average price received by farmers was $5.03 per cwt. The annual gross benefit to the Idaho potato industry from the adoption of the diagnostic services and the managed-control method, using green manure as trap crop, is calculated as follows:

a. Reduced the percentage of rejected potatoes:

   [(129,520,000)(0.30)(0.50)(0.039)($4.83)] = $3,659,652

b. Reduced fumigation cost, using $200 per acre fumigant cost:

   [(393,000)(0.30)(0.50)($200)] = $11,790,000

c. Improved yield, using a low estimate of 8 cwt increase in yield per acre

   [(393,000)(0.30)(0.50)(8 cwt)($4.83)] = $2,277,828

The total annual gross benefits to the Idaho potato industry from the development and adoption of the diagnostic managed-control nematodes on potatoes are estimated at $18,516,657 annually.

### 3. Alfalfa

Idaho had a 1995-97 average of 1,040,000 acres planted in alfalfa annually. The 1995-1997 average yield per acre is 4.9 tons irrigated area and 1.61 tons for rain fed area. The 1995-97 average production was 4,399,333 tons. The 1995-1997 average price received by farmers is $98 per ton. About 50 percent of the acreage is infested with nematodes. The six alfalfa varieties common in Idaho are susceptible to stem nematode and northern root-knot nematodes. The new alfalfa varieties developed and tested by the nematode diagnostic lab in cooperation with the private alfalfa seed industry in Idaho are resistant to these nematodes and significantly higher yielding than present varieties. Experiment and field tests of these varieties show they are more than 20 percent higher yielding than present susceptible varieties under similar conditions.

Annual gross benefit to the Idaho alfalfa industry from the development and adoption of the new alfalfa varieties is estimated below.

a. Improve yield or reduce loss due to nematode resistant varieties by a minimum of 10 percent.

   [4,399,333 t)(0.50)(0.10)($98)] = $21,556,731

It is estimated that only 50 percent of this gross annual benefit may be attributed to the nematode research in the development of the new alfalfa varieties. The other 50 percent are attributed to the breeding program conducted by the private sector. The annual gross contribution of the nematode research is estimated at $10,778,365.

## Implementation costs

The cost per acre to plant, grow, chop, and plow under of green manure is shown in Table 8. Total cost per acre is calculated to be $124.51. This cost includes $90.80 of operating cost, $5.55 of ownership cost, and $28.89 of non-cash cost. The operating cost includes the cost of irrigation, fertilizer, seed, labor, fuel, and machinery. The cash ownership cost includes overhead, property tax on machinery, and property insurance. The non-cash ownership cost is primarily depreciation and interest cost on equipment.

The implementation cost for sugarbeets and potatoes was calculated by applying the cost of green manure per acre to the number of acres that require treatment to control nematodes. Results of soil testing samples for nematodes on sugarbeets over a period of several years show that 50 percent of the sugarbeet acreage in Idaho is infested with nematodes. Of this, 50 percent require treatment to control nematodes. The annual implementation cost of the green manure to Idaho sugarbeet producers, based on the 1995-97 average acreage, is estimated at $5,997,235. In addition to the cost of the green manure, an annual transportation cost for the additional sugarbeet production due to increase in the yield is estimated at $334,349. This cost is based on a 96,333 t increase in production transported an average of six miles at $3 per t for the first three miles and $0.15 per ton mile for each additional mile. The total annual implementation cost to sugarbeet producers is $6,329,584.

The results of soil testing samples for nematodes in potato fields show that 30 percent of the potato fields are infested with nematodes. Of this, 50 percent require treatment to control nematodes. The annual implementation cost to Idaho potato producers, based on the 1995-97 average acreage, is estimated at $7,507,953. There is no implementation cost for alfalfa.

## Flow of benefit

The flow of benefit for each crop was based on a projected adoption profile of the nematode diagnostic managed control method for that crop. For example, in 1997, an

**Table 8:** Costs to plant, grow, chop, and plow green manure.

| Cost item | Quantity/acre | Unit | Cost/Unit ($) | Cost/acre ($) |
|---|---|---|---|---|
| **I. Operating costs** | | | | |
| A. Irrigation: | 7.00 | acres | 0.65 | 4.55 |
| Power | 0.49 | hr | 7.70 | 3.77 |
| Labor | 7.00 | acres | 0.56 | 3.92 |
| Repairs | | | | |
| B. Custom: | | | | |
| Custom fertilize | 1.00 | acre | 5.35 | 5.35 |
| C. Fertilize: | | | | |
| Nitrogen | 50.00 | lb | 0.30 | 15.00 |
| P205 | 50.00 | lb | 0.23 | 11.50 |
| D. Seed | 800 | lb | 1.50 | 12.00 |
| E. Labor | | | | |
| Machine | 1.18 | hrs | 12.85 | 15.16 |
| Non-machine | 0.29 | hrs | 7.85 | 2.28 |
| F. Fuel-diesel | 9.62 | gal | 0.72 | 6.92 |
| G. Lube | 1.04 | | | |
| H. Machinery repair | | | | 5.89 |
| I. Interest at 9.501 | | | | 2.70 |
| **Total operating cost** | | | | 90.08 |
| **II. Cash ownership cost** | | | | |
| A. General overhead | | | | 2.91 |
| B. Property tax (machinery) | | | | 1.94 |
| C. Property insurance | | | | 0.69 |
| **Total ownership costs** | | | | **5.55** |
| **III. Non-cash ownership costs** | | | | |
| A. Depreciation and interest on equipment | | | | 28.89 |
| **Total cost/acre** | | | | 124.51 |

Source: Smathers, Robert "1997 Idaho Crop Costs and Returns Estimates," Department of Agricultural Economics and Rural Sociology, University of Idaho.

**Table 9:** Gross annual benefit, implementation cost, and present value of the flow of benefit associated with the nematodes diagnostic managed-control method.

| Commodity | Gross annual benefit ($) | Implementation cost ($) | Net annual benefits ($) | Net value of net annual benefits (S) | Annual present value (S) |
|---|---|---|---|---|---|
| Potato | 18,516,657 | 7,507,953 | 11,008,704 | 58,714,113 | 2,935,705 |
| Sugarbeets | 13,902,850 | 6,329,584 | 7,573,266 | 39,924,331 | 1,996,216 |
| Alfalfa | 10,778,365 | 0 | 10,778,365 | 63,140,562 | 3,157,028 |
| Total | 43,197,872 | 13,837,537 | 29,360,335 | 161,779,006 | 8,088,949 |

estimated 4 percent of the sugarbeet acreage adopted the managed-control method using green manure in the rotation. However, because of the high cost of fumigants and the recent re-organization of the Idaho Sugarbeet industry, it is projected that the adoption will increase to 8 percent of the acreage in year 2000 and it will reach 70 percent of the acreage in year 2010.

The adoption by the potato industry of the diagnostic managed-control method to reduce the percentage of potato rejection due to nematode damage was complete in 1996. However, the adoption rate of the nematode managed-control method with green manure in the rotation system to reduce fumigation cost and yield loss will not begin until the year 2006. After further research, extensive field-testing, and refinement of the method, it is projected that in year 2006 only 2 percent of potato fields infested with nematodes will adopt green manure in the rotation to reduce fumigation cost and yield loss. The adoption profile will increase at small increments to reach a maximum of 70 percent of the potato fields infested with nematodes by year 2017. In general, the rate of adoption is significantly affected by cost of fumigants, environmental regulations, and an expected ban of presently used fumigants by the Environmental Protection Agency.

In 1997, about 2.8 percent of the nematodes infested alfalfa acreage in Idaho adopted the new nematodes resistant varieties. The expected rapid increase in seed production of the new varieties to satisfy the national and international markets for the new seeds will increase the adoption. It is projected that 70 percent of the infested alfalfa acreage will use the new nematode resistant seed varieties by the year 2010. These projected adoption profiles were used to estimate the flow of benefit over the expected life of the technology.

## Net benefit

Gross annual benefits, implementation costs, net annual benefit and the present value of the flow of net annual benefit are show in Table 9. Net annual benefit is gross annual benefit minus annual implementation cost. Present value is flow of net annual benefit over 20 years discounted by 6 percent social discount rate. Gross annual benefit to the Idaho sugarbeet industry is estimated at $13,902,850, to the potato industry at $18,516,657 and to the alfalfa industry at $10,778,365. Total gross annual benefit to the Idaho agricultural industry from the development and adoption of the nematode managed control method is estimated at $43,197,872.

Net annual benefit to the Idaho potato industry is estimated at $11,008,704, to the sugarbeet industry is estimated at $7,905,000, and to the alfalfa industry is estimated at $10,778,365. Total net annual benefit to the Idaho agricultural industry is estimated at $29,505,188.

## Present value

The present value of the flow of net annual benefits to the Idaho potato industry from the development and adoption of the diagnostic managed-control method is estimated at $58,714,113 over a 20-year period at the 1998 purchasing value of the dollar. The annual present value is $2,935,705 at the 1998 purchasing power of the dollar. The present value of the flow of benefits to the Idaho sugarbeet industry is estimated at $39,924,331 over a 20-year period. The annual present value is $1,996,216 at the 1998 purchasing power of the dollar. The present value of the flow of benefits to the Idaho alfalfa industry is estimated at $63,140,562 over a 20-year period. The annual present value is estimated at $3,157,028 at the 1998 purchasing power of the dollar. The total present value to the Idaho agricultural industry is estimated at $161,779,006 at the 1998 purchasing value of the dollar. The annual present value is $8,088,950 at the 1998 purchasing value of the dollar.

## Research and technology transfer costs

Since its establishment in 1982, the nematode program is coordinated as applied research, extension, and services. The services provided are diagnosis and soil testing. The soil testing is provided to farmers with a minimal fee. Several types of costs are incurred in the development and transfer of the diagnostic managed control of nematodes in Idaho. These costs are: (1) research expenditures in the development of the technology; (2) technology transfer cost to the final users; (3) maintenance cost to maintain the effectiveness of the managed-control method and the productivity of the new alfalfa resistant varieties; (4) diagnosis and soil testing cost; and (5) indirect cost in overhead and administration. The maintenance is part of the research and extension function. The diagnosis and soil testing is part of the service provided by the nematode lab and partially covered by fees paid by farmers. Two types of overhead and administrative costs were calculated from expenditure data compiled by the college of agriculture fiscal office. They are college overhead and administrative cost and department overhead and administrative cost.

Annual direct research and extension expenditures since the inception of the diagnostic managed control method in 1982 to 1998 are compiled by the UI College of Agriculture fiscal office. Expenditures from 1999 until the final development of the managed-control method for potatoes, projected for year 2006, are based on 1998 expenditures. All expenditures prior to 1998 were compounded by a 6 percent social compounding rate to bring them to the 1998 purchasing power of the dollar. College and departmental overhead costs were calculated for the years 1992 through 1997. The average 1992-1997 annual overhead cost for the UI Department of Plant, Soils and Entomological Sciences was calculated at $17,656 per FTE. One FTE in research and extension has been allocated to the diagnostic managed control nematode program in Idaho.

This overhead cost was used for every year since the inception of the nematode program until the completion of ongoing work projected in 2006.

Direct research and extension expenditures from 1982-1998 compounded at a 6 percent social compound rate are $1,655,020. Direct research and extension expenditures projected for the 1999-2000 period are $1,004,768. Total research and extension expenditures in the final development and transfer of the diagnostic managed-control method for sugarbeets, potatoes, and alfalfa are projected at $2,659,787. Departmental and college overhead and administrative costs are projected at $441,406. Total costs from the inception until the completion for the nematodes control program, not including implementation cost, are projected to reach $3,101,193. (Table 10)

**Table 10:** Present value of the flow of benefit, direct research and extension cost, and overhead cost associated with the development and transfer of the nematode diagnostic managed-control method measured at the 1998 purchasing power of the dollar.

| Categories | Benefit or cost ($) |
|---|---|
| Research and extension cost | 2,659,787 |
| Overhead cost | 441,406 |
| Total | 3,101,193 |
| Present value | 161,779,006 |
| Benefit-cost ratio | 52.17 |

## Benefit-cost ratio

The benefit-cost ratio is a unit of measurement that relates the present value of the flow of benefit to the present value of the flow of cost. This unit of measurement is estimated to be 52.17 (Table 10). The benefit-cost ratio indicates that for every $1 of expenditures in the development, transfer, and maintenance of the nematodes program, Idaho agricultural industry will benefit by 52.17. This return to investment excludes the direct environmental benefits associated with the nematodes program.

## Environmental benefit

The development and adoption of the diagnostic managed control method using green manure will eliminate fumigation to control nematodes on potatoes and sugarbeets. Two fumigants are used to control nematodes on potatoes: Telone II and Metam Sodium. Two fumigants are also used to control nematodes on sugarbeets: Telone II and Temick. The amount of active toxic materials that can be eliminated from the environment with adoption of the diagnostic managed-control program is calculated by the following equation.

ATM = {(AC)(In)(Ad)(PT)(GL(TX)}

Where:

ATM = active toxic materials in each fumigant

AC = Average 1995-97 acreage (402,000 for potatoes and 192,667 for sugarbeets)

In = Percentage of acreage infected with nematodes (30 percent for potatoes and 50 percent for sugarbeets)

Ad = Percent of In acreage that will require the diagnostic managed control method to control nematodes (50 percent for potatoes and 50 percent for sugarbeets)

PT = Percent of In acreage using the chemical Telone-II (60 percent in potatoes and 50 percent in sugarbeets)

PMS = Percent of In acreage using the chemical Metame Sodium (40 percent in potatoes)

PTM = Percent of acreage using the chemical Temik (50 percent in sugarbeets)

GLT = Gallons of Telone-II used per acre (20 gallons in potatoes and 20 gallons in sugarbeets)

GLMS = Gallons of Metame Sodium used per acre (50 gallons in potatoes)

Pn = Pounds of Temik used per acre (25 lb in sugarbeets)

TX = Percent of active toxic materials (94 percent for Telone-II, 38 percent for Metame Sodium, and 15 percent for Temik)

Pn/GL = Pounds per gallon (8.3 lb)

### Reduction in active toxic materials

The annual reductions in active toxic materials on potato fields by eliminating the use of two fumigants are:

(1.) Telone-II

Annual reduction in active toxic materials = 5,519,134 lb

(2.) Metam Sodium

Annual reduction in active toxic materials = 1,467,855 lb

The annual reduction in active toxic materials on sugarbeet fields by eliminating the use of Telone-II and Temik are:

(1.) Telone-II

Annual reduction in active toxic materials = 3,881,495 lb

(2.) Temik

Annual reduction in active toxic materials = 93,281 lb

It is estimated that the adoption of the nematodes diagnostic managed-control method will eliminate 13,609,950 lb of active toxic materials from the environment annually.

# SUMMARY

The Idaho nematode diagnostic managed control program went through several historical steps for its final development. The potato rot nematode was the first species of nematode discovered in Idaho in 1943. In 1948, quarantine against Idaho grown potatoes was being considered by several importing states. The Idaho Crop Pest Control and Research Commission initiated steps to deal with this threat to a rapidly growing potato industry. In 1948, a plant pathologist was hired to coordinate a research program to determine the extent of potato rot infestation. In 1955 it was determined that potato rot nematode was present in a few eastern Idaho fields and with modern management it posed little threat of spreading to other Idaho fields. Fumigation and wheat in the rotation system was recommended as an effective control method.

In 1970 it became apparent that "crop rotation with wheat" was losing its effectiveness in suppressing root knot nematodes on potatoes. This was primarily due to the emergence of an unknown strain of root knot nematodes capable of using wheat as a favorable host plant.

In 1976, with extensive soil sampling by a new plant pathologist, a widespread distribution of both previously known and new strains of root-knot nematode in irrigated cropland across Idaho was discovered. The older strain, *Meloidogyne hapla* (the northern root-knot nematode) was found to increase on alfalfa but was suppressed by a rotation into wheat. The new strain, *M. chitwoodi*, had the opposite reaction to these hosts. Though morphologically similar, *M. chitwoodi* could be distinguished from *M. hapla* and was called the Columbia root knot nematode because of its distribution in the Columbia River and its tributary system.

In 1980, a retiring plant pathologist recommended that a professional nematologist be hired to develop an effective research program for the control of root knot nematodes. In 1981, a nematologist was hired and the development of the Idaho Nematode Diagnostic Laboratory began. By the end of 1982, the new nematologist assumed the role of director of the new Idaho Nematode Diagnostic Laboratory. The lab initiated sample testing. In the past that testing was conducted in other states.

Since its establishment in 1982, the nematode research and extension program reported a total of 53 species of plant parasitic nematodes in this region. Forty-seven species, including two undescribed, have been reported in this region for the first time. The nematode program also identified eight new nematode records in Idaho, two new nematode records in other states, and eight new nematode records in Alaska. Of the 53 nematode species reported in the region, five species cause significant loss in productivity of the major crops in Idaho such as sugarbeets, potatoes, alfalfa, apples, etc. These species are: (1) root knot nematodes (*Melzidogyne spp.*); (2) sugarbeet cyst nematodes (*Heterodera Schachtii*); (3) lesion nematodes (*Pratylenchus spp.*); (4) stubby root nematodes (*Trichodorus spp.*); and (5) stem nematodes (*Ditylenchus spp*).

Sugarbeet cyst nematodes are the most destructive plant parasitic nematode species to sugarbeets. They cause yield loss of up to 60 percent in the endemic regions. In Idaho and eastern Oregon more than 50 percent of the sugarbeet acreage is infested with Sugarbeet cyst nematode at a level where treatment is essential to obtain economically feasible yield. The most common control practice is the use of fumigants at a cost ranging between $200-$260 per acre. The results of this research indicate that cultivars of oil radish or white mustard in a sugarbeet rotation system stimulate nematode egg hatch while preventing completion of life cycles. Specifically, the Adagio variety of oil radish is the most effective. It reduces the nematode population by 92 percent. This control method has successfully been adopted by more than 4 percent of the sugarbeet acreage in Idaho and is projected to receive wide adoption.

The predominant nematode species associated with potato production in Idaho are root knot nematodes (*Meloidogyne spp*); root lesion nematodes (*Pratylenchus spp*); stubby root nematodes (*Trichodorus*) and potato rot nematodes (*Ditylenchus destructor*). The root knot and root lesion nematodes are relatively widespread problems in Idaho potato production areas. However, stubby root and potato rot nematodes are less common nematodes. These nematodes are presently being controlled with chemical nematicides at a cost of $200 - $260 per acre. The Idaho Nematode Diagnostic Laboratory is developing a bio-control method that is environmentally friendly and significantly less expensive to control nematodes on potatoes. The effect of oil radish and rapeseed as green manures on Columbia root-knot nematode population and on potato yields was analyzed in the laboratory and under field conditions in two experiments conducted in 1996-97. Preliminary results show that potato plots treated with oil radish as a green manure in the rotation system had the lowest Columbia root-knot nematode population; lowest tuber infection; and significantly higher yield compared to fallow. Research experiments to develop a bio-control method for nematodes on potatoes will continue until an economically effective method is developed.

The alfalfa stem nematode *ditylenchus dipsaci*; the root knot nematodes, *meloidogyne spp.*; and the root lesion nematodes, *Pratylenchus spp.* are the most common nematodes found in alfalfa fields. These nematodes affect alfalfa by damaging the stem and the root systems. This results in reduced growth; abnormal development of foliar and floral parts; excessive wilting in hot dry weather; and nutrient deficiencies. These nematodes also play a role in disease complexes of alfalfa such as Fusarium and bacterial wilts. Pre-plant fumigation of alfalfa fields is expensive and rarely used. Crop rotation has not been very effective in controlling nematodes on alfalfa.

All present alfalfa varieties are susceptible to nematodes. The most effective and economically viable method for management and control of nematodes on alfalfa is the development of nematode resistant alfalfa varieties. The Idaho Nematode Diagnostic Laboratory, in cooperation with

breeders in the alfalfa seed industry; successfully developed and tested several resistant varieties. These varieties are significantly higher yielding and resistant to nematodes compared to present varieties. About 3 percent of alfalfa acreage is planted with seeds from the new varieties. As the seeds become available it is projected that up to 70 percent of alfalfa acreage infested with nematodes will adopt the new seed varieties.

The diagnostic managed-control method with the Adagio oil radish variety as green manure will benefit the Idaho sugarbeet industry in two direct ways. First, the use of Adagio oil radish as green manure in the rotation system of sugarbeets reduces nematode population by 92 percent and thus the need for expensive fumigants. Second, green manure increases organic matter, soil nutrient content, and soil water holding capacity. The gross annual benefit to the Idaho sugarbeet industry is estimated at about $13.90 million.

The diagnostic managed control method, using an oil radish crop, will benefit the Idaho potato industry in three direct ways. First, the implementation of the diagnostic and managed control program has reduced the percentage of potato acreage that used to be rejected by processors due to nematodes damaged from 4 percent prior to 1996 to 0.1 percent in 1996 and thereafter. Second, an estimated 30 percent of Idaho potato acreage is infested with nematodes. Of this 30 percent, an estimated 50 percent requires annual fumigation to control nematodes at $200-$260 cost per acre. The diagnostic managed-control method, using oil radish as a trap crop, is expected to reduce nematode infestation by 92 percent and, thus, the need for expensive fumigation. Third, the use of green manure increased soil organic matter, improved soil water holding capacity, and nutrient content. This has resulted in a 16 percent increase in yields compared to the use of fumigant in controlling nematodes. Total annual gross benefit to the Idaho potato industry is projected to reach about $19 million from the development and adoption of the nematode diagnostic managed control method.

The six alfalfa seed varieties presently planted by Idaho farmers are susceptible to stem nematodes and northern root-knot nematodes. Field tests, in several different locations in Idaho and eastern Oregon, show that the new nematode resistant varieties are higher yielding and produce better quality hay than present varieties. The annual gross benefit to the Idaho alfalfa industry from the adoption of new seed varieties is projected to reach about $11 million.

The cost to sugarbeet and potato farmers to plant, grow, and plow under the green manure is $125 per acre. Total annual implementation cost to sugarbeet producers is about $6 million. The implementation cost to potato producers is more than $7.5 million annually. There is no implementation cost to alfalfa producers for the new seed varieties.

The net annual benefit to sugarbeet producers is $7.9 million, to potato producers is $10.8 million, and alfalfa to producers is $11 million. The total annual net benefit to the Idaho agricultural industry is more than $29.7 million. The projected flow of benefit over 20 years measured at the 1998 purchasing value of the dollar is $59 million to potato producers, $41 million to sugarbeet producers, and $63 million to alfalfa producers. The total projected benefit measured at the 1998 purchasing power of the dollar is more than $163 million.

Direct research and extension expenditures in the development and maintenance of the diagnostic managed control program from its inception in 1982 to projected completion of all its aspects in the year 2006 is estimated to be $2.7 million measured at the 1998 purchasing power of the dollar. Overhead and administrative cost is projected to exceed $441,000. Total projected cost will exceed $3 million. The benefit-cost ratio is about 53. The benefit-cost ratio indicates that for every $1 of investment in this program, Idaho agricultural industry is expected to benefit by an estimated $53.

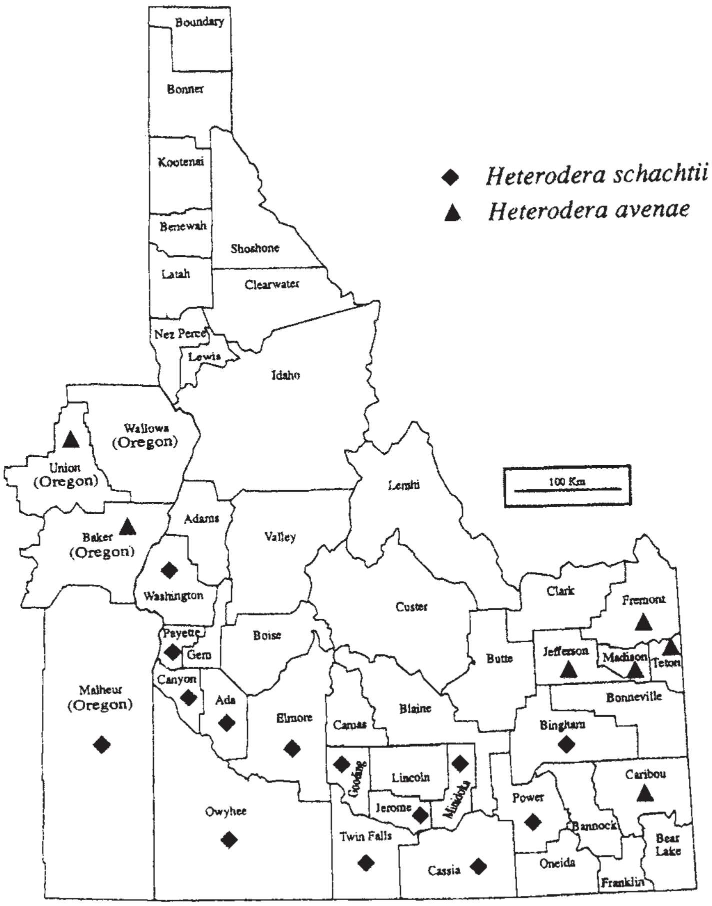


Fig. 1. Distribution map by county of *H. schachtii* and *H. avenae* in Idaho and eastern Oregon.

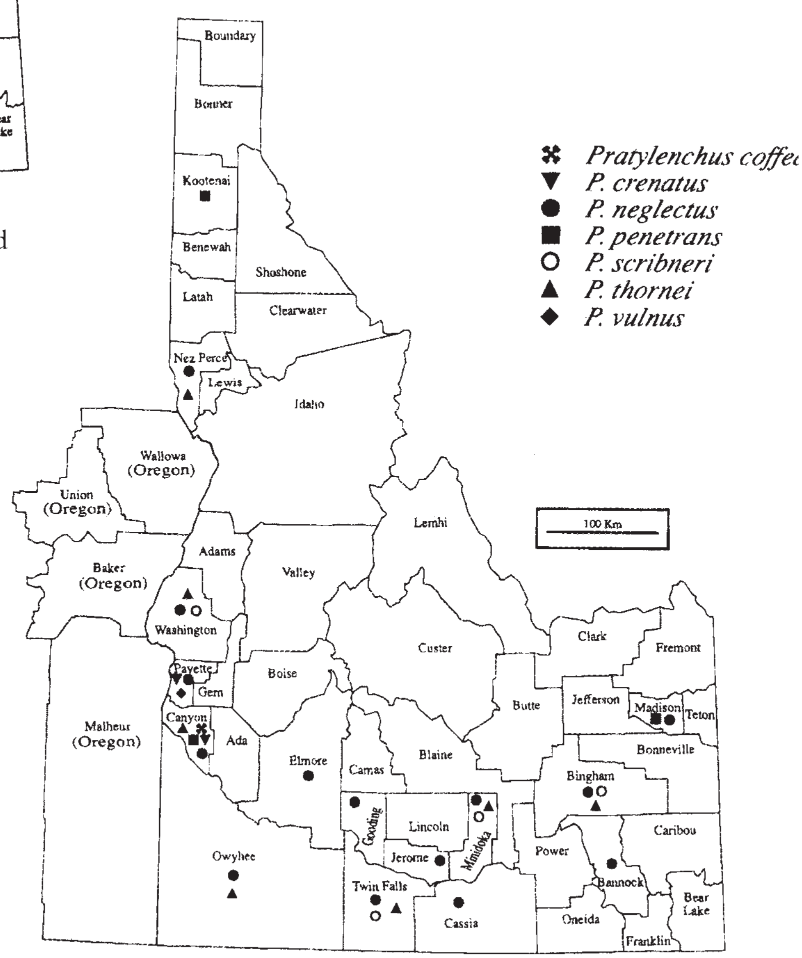


Fig. 2. Distribution map by county of seven different species of *Pratylenchus* in Idaho.

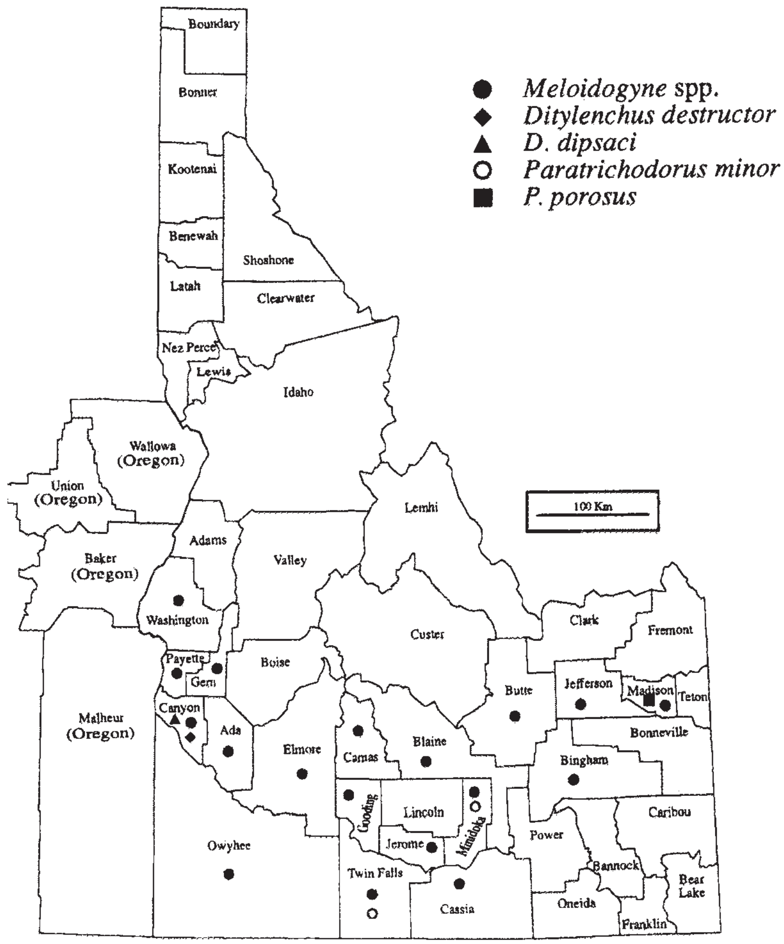


Fig. 3. Distribution map by county of *Meloidogyne* spp., *Ditylenchus destructor, D. dipsaci, Paratrichodorus minor* and *P. porosus* in Idaho.

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Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, LeRoy D. Luft, Director of Cooperative Extension System, University of Idaho, Moscow, Idaho 83844. The University of Idaho provides equal opportunity in education and employment on the basis of race, color, religion, national origin, age, genter, disability, or status as a Vienam-era veteran, as required by state and federal laws.

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