The Economic and Environmental Impacts of Nematodes Bio-Control Method

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Abstract

Nematodes cause significant loss in both quality and yield of sugarbeets, potatoes, and alfalfa. Nematodes on sugarbeets and potatoes are presently controlled with expensive and toxic fumigants. No effective control is available for alfalfa. The objective of this study was to develop bio-control methods for nematodes on potatoes and sugarbeets and to select new alfalfa resistant varieties. A series of experiments were conducted to determine the effect of several varieties of oil radish and white mustard used as green manure on the population of several nematode species common to potatoes and sugarbeets. The Adagio variety of oil radish reduced nematodes population by 92 percent, significantly increased yield, and eliminated the need for fumigants. Several lines of alfalfa were tested and six new nematode resistant varieties were selected. The new varieties are significantly higher yielding with better seed and hay qualities compared to the present varieties that are susceptible to nematodes. Investment in the nematodes program will eliminate an estimated 13.6 million pounds of active toxic material from the environment and will benefit the Idaho agricultural industry by over $43 million annually. It will cost potato and sugarbeet producers about $14 million annually for the green manure. Net annual benefit is over $29 million and the projected present value of the flow of net benefit is $162 million. For every dollar invested in the program, net benefit to the Idaho agricultural industry is estimated to exceed $52.

The Economic and Environmental Impacts of Nematodes Bio-Control Method

Since the mid-1950's economists have analyzed the economic impacts of investments in agricultural research for a wide range of individual commodities (Ruttan 1982; Araji et al 1995) Return to investments in all research activities conducted by the State Agricultural Experiment Station has also been documented (Araji, 1990). Very little attention has been devoted to assessing the simultaneous economic and environmental benefits of agricultural research and the role of extension in the successful implementation of research results.

Nematodes are a serious problem in potatoes, sugarbeets, and alfalfa in the Pacific Northwest (PNW). Recently it was also discovered that nematodes are becoming an increasing problem in irrigated wheat and barley fields. In general, nematodes cause significant loss in both quantity and quality of many agricultural products. The use of high cost and highly toxic chemical fumigants has been the only method to control nematodes. The objective of this study is to evaluate the economic and environmental benefit of investments in a coordinated diagnostic-research-extension program to control nematodes in several agricultural commodities.

METHODS

A coordinated diagnostic, research, extension program was established in Idaho in 1982 to identify all nematode species, determine nematode infestation level, and develop an environmentally friendly control method. Since its establishment, the program reported a total of 53 species of plant parasitic nematodes in the region (Table 1). Forty-seven species, including two previously unrecorded, were reported for the first time. Of the 53 species reported, five cause significant productivity and quality losses in major crops. These species are: (1) root knot nematodes (*Meloidogyne spp.*); (2) sugarbeet cyst nematode (*Heterodera Schachtii*); (3) lesion nematode (*Patylenchus Spp.);* (4) stubby root nematode (*Trichodorus spp.*) and (5) Stem nematode (*Ditylenchus Spp.*).

The results of the soil samples tested by the diagnostic lab since 1982 indicates that 50 percent of the sugarbeet acreage is infected with nematodes. Over 50 percent of the infested acreage requires chemical treatment at a cost of $200 to $260 per acre. The results also show that 30 percent of the potato acreage is infested with nematodes. Over 50 percent of the infested acreage requires chemical treatment at a cost of $200-$260 per acre. The results of the soil samples testing also show that 50 percent of the alfalfa acreage is infested with nematodes with significant yield loss and no economically feasible remedy.

In addition to identifying the nematode species and the extent of infestation in major crops, the program successfully developed and extended a bio-control method that is economical with significant environmental impact. The results of research experiments to develop the bio-control method is discussed by major crop in the following section.

Sugarbeets

Sugarbeet cyst nematode (SBCN), *Heterodera schachtii*, is the most destructive plant parasitic nematode species. This species causes yield losses of up to 60 percent in the endemic regions. The results of the research segment of the program indicate that incorporation of nematode-resistant crops such as oil radish or white mustard in sugarbeet rotation is the most economically and environmentally viable method for the management of sugarbeet cyst nematode. The results show that cultivars of oil radish and white mustard stimulate egg hatch while preventing completion of life cycles.

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

SBCN and sugarbeet yield. Results show 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, the experiment results demonstrate that establishing oil radish or white mustard in late summer, then chopping and plowing under in the fall prior to planting sugarbeets in the following spring, will significantly increase sugarbeet yield 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).

The effect of fall planting of different varieties of oil radish and white mustard on sugarbeet yield and SBCN population was analyzed in two field experiments (Table 3). 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 ton per acre. This is 42 percent higher yield compared to planting sugarbeets after fallow. Adagio is the most effective trap crop for reducing nematode populations while increasing sugarbeet yields. Three varieties of white mustard were used as trap crops followed by sugarbeets. The results show that compared to fallow the Maxi Variety reduced SBCN population by 85 percent in both experiments and increased yield by 6 ton per acre in the first experiment and by 8.4 ton in the second experiment.

The results of these experiments clearly indicate that in both late summer and fall, oil radish as a trap crop seems to have the greatest impact on nematode population and sugarbeet yield. Cultivars of oil radish have more inherent ability to reduce SBCN populations (87 - 92%) compared to white mustard (62-84%). 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. Sugarbeet yield was significantly higher in plots previously planted with all cultivars than in fallow plots. The effects of trap crop as a green manure on reducing nematode population and on improving soil organic matter, moisture and nutrient content have reduced damage to sugarbeet root systems while improving yield.

Potatoes

Nematodes most associated with potato production in the region 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 potato fields. However, stubby root and potato rot nematodes are less ubiquitous.

Several research experiments were conducted under greenhouse, microplot, and field conditions to analyze the response of Columbia root-knot nematode to the application of trap crops and the impact of green manure on yield and quality of potatoes. The effect of oil radish and rapeseed as green manure on Columbia root-knot 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 wheat harvest, and incorporated in the soil in October 1996. Potatoes were planted, following the green manure incorporation in the soil, in April 1997, and harvested in September 1997. Nematode populations for each type of trap crop were determined before it was sowed into the soil, and after incorporation as a green manure in the soil. Nematode populations were also calculated before potato planting, after potato planting, and at potato harvest.

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

The incorporation of trap crops in the potato rotation system reduced nematode population, increased the organic matter, moisture, and nutrient content of the soil and thus significantly increased yield.

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 in alfalfa fields 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 is not effective in reducing populations of stem and root knot nematodes. Rotation is particularly not effective with root lesion nematodes because of their wide host range. Development and use of nematode resistant alfalfa cultivars are the only effective and economically viable method for management and control of nematodes in alfalfa.

Experiments were conducted under greenhouse conditions to evaluate dry matter production of alfalfa varieties planted in nematode-free and nematode-infested soils. Six commonly used alfalfa varieties were compared for their response to alfalfa stem nematodes (*Ditylenchus dispaci)* and northern root-knot nematodes (*Meloidogyne hapla).* All six varieties were susceptible to stem nematodes and showed significant reduction in yield (Table 5). The Ranger alfalfa variety exhibited the highest yield reduction of 12.8 percent. Other varieties in the stem nematode study had significantly less yield reduction. Washoe exhibited the least yield reduction of 5.5 percent.

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 yield was significantly reduced by root knot nematodes compared to the other varieties with the exception of Washoe (Table 5). 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.

The research segment of the nematode 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 six new varieties that are resistant to nematodes were developed. Table 6 shows the average yield per acre and the species of nematodes these new varieties are resistant to. 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 ton per acre for the Nemagone variety to a low of 9 ton per acre for the Zolis variety. Yields per acre for all the nematode resistant varieties are significantly higher than the yields of present commonly used varieties that are susceptible to nematodes.

Economic Model

The economic benefits and costs associated with the development of the nematode programs are analyzed in the following model. The flow of benefits 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:

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

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

ΔP_{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 program for the j^{th} product in year t.

B_{jt} 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 control method, (P(S)), and the probability of adopting the nematode control method by the j^{th} product (P(A)). The expected value of β_{jt} is defined as:

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

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

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

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 j^{th} 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:

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

Where:

C_{jt} = the present value of total costs associated with the development of the nematodes managed-control method.

R_{jt} = direct research investment in the development of the nematodes managed-control method.

T_{jt} = technology transfer cost to help the industry adopt the nematodes managed-control method.

I_{jt} = implementation cost by the industry to adopt the nematodes managed-control method.

M_{jt} = the cost of maintenance research required to sustain the effectiveness of the nematodes managed-control method.

The probability of research success in developing the nematode control method is 100 percent since all results are developed, extended, and are being implemented. The adoption of the method over time for each commodity was estimated in consultation with producers, field representatives, processors, and marketing agents. Expenditure in the development, transfer, implementation, and maintenance of the nematode control method for the j^{th} 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.

Environmental Model

The environmental benefits attributed to the nematode control program the is the elimination of the present fumigation of sugarbeet and potato fields to control nematodes. The amount of active toxic materials that are expected to be eliminated from the environment in Idaho is calculated by the following equation.

$$ATM = \{(AC)(I_n)(A_d)(P_T)(GL(T_X)\} \quad (5)$$

Where:

ATM = active toxic materials in each fumigant

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

I_n = Percentage of acreage infected with nematode (30 percent for potatoes and 50 percent for sugarbeets)

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

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

P_{MS} = Percent of I_n acreage using the chemical Metame Sodium (40 percent in potatoes)

P_{TM} = Percent of acreage using the chemical Temik (50 percent in sugarbeets)

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

GL_{MS} = Gallons of Metame Sodium used per acre (50 gallons in potatoes)

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

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

P_n/GL = Pounds per gallon (8.3 lb)

RESULTS

Several areas of benefits and costs associated with the development of the nematode program are analyzed. Gross annual benefits, implementation costs, net annual benefits and present value were estimated for sugarbeets, potatoes, and alfalfa in Idaho.

Gross Annual Benefit

The gross annual benefit for each commodity is estimated using the 1997-98 acreage, production and price data. The nematode control method with the Adagio oil radish as trap crop 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 will reduce nematode population by 92 percent and thus the need for expensive fumigants. Second, the use of green manure increased yield by 9 ton per acre. The gross annual benefit is estimated for the sugarbeet acreage that presently requires fumigation and is based on $200 per acre reduction in fumigation costs and 2 ton per acre increase in yield. The estimated gross annual benefit is over $13.9 million.

The nematode control method with oil radish as trap crop will benefit the Idaho potato industry in three direct ways. First, the implementation of the method reduced the percentage of potato acreage that used to be rejected due to nematodes damage from 4 percent annually prior to 1996 to 0.1 percent in 1996 and thereafter. Second, the method reduced nematode infestation by 92 percent and thus the need for expensive fumigation. Third, the use of green manure increased yield by 55 cwt or 16 percent per. Annual gross benefit is estimated for the acreage's that presently require chemical fumigation. It is based on reducing rejection by 3.9 percent, reducing treatment cost by $200 per acre, and improving yield by 8 cwt per acre. The estimated annual gross benefit to Idaho potato producers is over $185 million.

The new alfalfa varieties are resistant to both stem and northern root-knot nematodes and significantly higher yielding than present varieties. Experimental and field tests of these varieties show that they are over 20 percent higher yielding than present susceptible varieties under similar conditions. Annual gross benefit to the Idaho alfalfa industry from the development of the new alfalfa varieties is estimated based on a 10 percent increase in yield under field conditions and only for those acres that are infested with nematodes. The annual gross benefit to Idaho alfalfa producers is estimated at about $10.8 million. The estimated total annual gross benefit to the Idaho agricultural industry is over $43.

Implementation Costs

The cost per acre to plant, grow, chop, and plow under the trap crop is estimated at $124.51. This cost includes $90.80 operating cost, $5.55 ownership cost, and $28.89 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.

Net Annual Benefit

The gross annual benefits, implementation costs, and net annual benefit for potatoes, sugarbeets, and alfalfa producers in Idaho are shown in Table 7 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. The net annual benefit is used to estimate the present value of the nematode control method to each crop.

Present Value

Present Value is the future flow of net annual benefit discounted by 6 percent social discount rate. The present value of the flow of net annual benefit, over a 20 year period, is estimated at $58,714,113 to potato producers, $39,924,331 to sugarbeet producers and $63,140,562 to alfalfa producers. The total present value to the Idaho agricultural industry is estimated at $161,779,006 measured at the 1998 purchasing value of the dollar at an annual present value of $8,088,950 (Table 7).

Research and Technology Transfer Costs

Since its establishment in 1982, the nematode program is coordinated as research, extension, and services. The services provided are diagnosis and soil testing. Several types of costs are incurred in the development and final transfer of the bio-control of nematode method. 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 nematode control method and the productivity of the new alfalfa resistant varieties, (4) diagnosis cost, and (5) indirect cost in overhead and administration.

Annual direct research and extension expenditures since the inception of the program in 1982 to 1998 are compiled by the College of Agriculture fiscal office. Expenditures from 1999 to 2005 in field demonstrations , extension, and refinement of the biocontrol method, are based on 1998 expenditures. All expenditures prior to 1998 were compounded by 6 percent social compounding rate to bring them to the 1998 purchasing power of the dollar.

Direct research and extension expenditures from 1982-1998, compounded at 6 percent social compound rate, are $1,655,020. Direct research and extension expenditures projected for the 1999-2005 period is $1,004,768. Total research and extension expenditures in the final development and transfer of the nematode control method for sugarbeets, potatoes, and alfalfa are projected at $2,659,787.

Departmental and college overhead and administrative costs are estimated at $17,656 per FTE for department of Plant, Soils, and Entomological Science Overhead cost from 1982 to 1998 was compounded by 6 percent. Total overhead cost from 1982-2005 is estimated at $441,406. Total cost from the inception of the program, not including implementation cost, is projected to reach $3,101,193 (Table 8).

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 8). The benefit-cost ratio indicates that for every $1 of expenditures in the development, transfer, and maintenance of the nematodes program, the 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 nematode control method will eliminate chemical fumigation to control nematodes on potatoes and sugarbeets. Two fumigants are used to control nematodes on potatoes. They are: (1) Telone II and (2) Metam Sodium. Two fumigants are also used to control nematodes on sugarbeets. They are: (1) Telone II and (2) Temick.

The annual reductions in active toxic materials on potato fields by eliminating the use of Telone-II and Metam Sodium are estimated at 5,519,134 lb. and 1,467,855 lb., respectively. The annual reduction in active toxic materials on sugarbeet fields by eliminating the use of Telone-II and Temik are estimated at 3,881,495 lb. and 93,281 lb., respectively. It is estimated that the development and adoption of the nematode control method will eliminate a total of 13,609,950 lb. of active toxic materials from the Idaho environment annually.

SUMMARY

Since its establishment in 1982, the nematode research and extension program served the agricultural industry in Idaho and the PNW very well. The program reported a total of 53 species of plant parasitic nematodes in this region. Forty-seven species, including two undescribed, are reported in this region for the first time. The nematode program also identified eight new nematode records in Idaho, and ten new nematode records in other states.

Of the 53 nematode species reported in the region, five species cause significant loss in productivity of major crops. These species are: (1) root knot nematodes (*Melzidogyne spp.*), (2) sugarbeet cyst nematode (*Heterodera Schachtii*), (3) lesion nematode (*Pratylenchus spp.*), (4) stubby root nematode (*Trichodorus spp.*), and (5) Stem nematode (*Ditylenchus spp).*

Sugarbeet cyst nematode is the most destructive plant parasitic nematode species causing yield loss of up to 60 percent in sugarbeet fields. The predominant nematodes 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 and Eastern Oregon fields.

Nematodes in sugarbeet and potato fields are presently being controlled with chemical nematicides at a cost of $200 - $260 per acre. Results of experiments conducted on potato and sugarbeet plots treated with oil radish as a green manure in the rotation system reduced nematode populations by 92 percent, tuber infection by 60 percent, and significantly increased yields.

The alfalfa Stem nematode *ditylenchus dipsaci*, root knot nematodes, *meloidogyne spp.*, and root lesion nematodes, *Pratylenchus spp.* are the most common nematodes found in alfalfa fields. All present alfalfa varieties are susceptible to nematodes. The nematode program, in cooperation with breeders in the alfalfa seed industry, successfully developed and tested several high yielding resistant varieties.

The results of this study show that the development of biocontrol with trap crop will eliminate the use of chemical fumigation and will contribute an estimated 13.90 million in annual gross revenue to the Idaho sugarbeet industry, $18.5 million to the potato industry, and $10.5 million to the alfalfa industry. Annual cost to plant, to grow and plow under the trap crop is estimated at $124.51 per acre. Net annual benefit to sugarbeet producers is $7.9 million, to potato producers is $10.8 million, and alfalfa to producers is $10.8 million. Total annual net benefit to the Idaho agricultural industry is over $29.7. The present value of the flow of benefit are $59 million to potato producers, $41 million to sugarbeet producers, and $63 million to alfalfa producers for a total of $163 million.

Direct research and extension expenditures in the development, transfer and maintenance of the nematode control method is estimated to be $2.7 million. Overhead and administrative cost is projected to exceed $441,000. Total projected cost will exceed $3 million. The benefit-cost ratio is about 53 indicating that for every $1 of investment in this program, Idaho agricultural industry is expected to benefit by an estimated $53.

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Table 1: Record of new nematodes identified by the nematode diagnostic-research-extension program.

New nematode record for Idaho

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

New nematode record for USA

Ditylenchus exilis

New nematode record for Colorado

Tylenchorhynchus capitatus

New nematode records for Alaska

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

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

Type of treatment	Yield (ton/acre)	Percent increase in yield	Percent reduction in nematode population†
Fallow	25.1	-	41
White Mustard (Metex)	30.5	21.5	84
Oil radish (Adagio)	31.3	24.7	92

†Reduction in population from previous season

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†	Yield ton per acre	Increase in yield ton per acre	Percent reduction in nematode population	Yield ton per acre	Increase in yield ton 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	0.0
C. Fallow	41	22.1	--	41	28.4	--

†Reduction in population from previous growing season

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-knot population (Ct per 500-cc soil)					
Treatment	August 96	October 96	April 97	September 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 (percent)	
Variety	Stem nematode	Northern rot-knot nemaode
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 (Ton/Acre)**
Archer†	11.69
Vernema‡	10.31
ABI 700†	11.85
Zahgntan	9.00
Zolio§	11.26
Nemagone	12.68

†Proprietary variety of Agri-Bio Tech, Inc.

‡Public Variety

§Proprietary of Eureka Seeds, Inc.

Table 7: 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 ($)	Present Value of Net Annual Benefits ($)	Annual Present Value ($)
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	8,008,950

Table 8: Benefit program and costs associated with the development and transfer of the diagnostic managed-control nematode.

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