THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF NEMATODE BIOCONTROL METHODS: AN *EX-ANTE* APPROACH

A. A. Araji[1] and S. L. Hafez [2]

Department of Agricultural Economics,[1] and Department of Plant, Soils and Entomological Sciences,[2] University of Idaho, Moscow, ID 83844, U.S.A.

ABSTRACT

Araji, A. A., and S. L. Hafez. 2001. The economic and environmental impacts of nematode biocontrol methods: an *ex-ante* approach. Nematropica 31:181-193.

Nematodes in sugar beets and potatoes in the Pacific Northwest are presently managed with expensive and toxic soil fumigants. No effective method is available to control nematodes on alfalfa. A method was developed for the biological control (biocontrol) of several nematode pathogens common in potatoes and sugar beets. The new method reduced nematode numbers by more than 90 percent, improved 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. The objective of this study is to evaluate the economic and environmental benefits of investment in coordinated diagnostic-research-extension program to manage nematodes on potatoes, sugar beets and alfalfa. Investment in the development of the nematode biocontrol methods will eliminate an estimated 6.17 million kilograms (13.6 lb million) of active toxic material from the environment in Idaho. Idaho producers of potato, sugar beets, and alfalfa will have an estimated gross annual benefit >$43 million. It will cost potato and sugar beet producers about $14 million annually to implement the biocontrol method. The projected present value of the flow of gross annual benefits over the life expectancy of the technology is $217.63 million. The projected present value of cost over the life expectancy of the technology is $71.77 million. The internal rate of return is estimated at 81 percent.

Key words: alfalfa, biological control, cost-benefit analysis, economic analysis, integrated pest management, nematode management, potato, sugar beet.

RESUMEN

Arají, A. A. y S. L. Hafes. 2001. Impacto económico y ambiental de métodos biocontroladores de nematodos. Nematrópica 31:181-193.

Los fitonematodos asociados a la remolacha, azucarera y papa en la región Pacífico-Noroeste de U.S.A., se manejan principalmente a base de los costosos y muy venenosos fumigantes de suelo. No existe método efectivo para controlar a los nematodos de la alfalfa. Sin embargo, se ha desarrollado un método a base de biocontroladores para combatir a los fitonematodos más patogénicos de la papa y la remolacha. Este método redujo las poblaciones de nematodos a más del 90%, aumentó rendimientos y eliminó a los fumigantes. Varias líneas de alfalfa se probaron de donde se seleccionaron a seis nuevas variedades resistentes a nematodos. Estas variedades producen más, dan mejores semillas y poseen más calidad forrajera que las variedades actuales las que además son susceptibles a los nematodos. El propósito del presente estudio consistió en evaluar los beneficios económicos y ambientales como inversión de un programa donde se coordinan acciones de Diagnóstico-Investigación-Extensión para el manejo de nematodos asociados a papa, remolacha y alfalfa. Invirtiendo en el desarrollo de un método biocontrolador de nematodos se eliminaría el estimado de 6-17 millones de kilogramos (13-6 millones de libras) de ingredientes activos de plaguicidas en el medio ambiente de Idaho. Además, los productores de Idaho tendrían una ganancia buta superior a los 43 millones de dólares americanos al año. El costo para implementar este método a base de biocontroladores sería de 14 millones de dólares anuales para los productores de papa y remolacha del estado. El valor proyectado a precios actuales del flujo de beneficios brutos anuales, durante la vida útil esperada de la tecnología, es de 217-63 millones. El valor actual proyectado de los costos al cabo de la vida útil de la tecnología es de 71.77 millones. La tasa interna de retorno se calculó en 81%.

Palabras clave: Alfalfa, Análisis Costo-beneficio, Análisis económico, Control biológico, Manejo de nematodos, Manejo Integral de Plagas, Papa, Remolacha.

INTRODUCTION

Nematodes cause serious losses to most agricultural crops. Surveys of crop losses in response to phytoparasitic nematodes in the United States (U.S.) for 1994 show that annual crop losses due to nematodes exceed $90 billion (Koenning *et al.*, 1999). Nematodes are serious problems in potatoes, sugar beets, and alfalfa in the Pacific Northwest causing significant annual production loss (Hafez *et al.*, 1992). Until recently, the use of expensive and highly toxic chemical fumigants has been the only method to control nematodes on potato and sugar beets. No economically feasible chemical control method is available to control nematodes on alfalfa.

A nematode research-extension program was established in Idaho in 1982 to develop a biocontrol method for nematodes on potato and sugar beets and to select nematode resistant alfalfa varieties. During this time, 53 species of plant parasitic nematodes were identified, including several species shown to cause significant loss of productivity in the major crops in Idaho. The sampling data indicate that 50 percent of the sugar beet hectarage is infested with *Heterodera schachtii* A. Schmidt (Hafez, 1999). Over 50 percent of the infested hectarage requires chemical treatment at a cost of $494 to $642 per hectare. Thirty percent of potato hectarage is infested with *Meloidogyne chitwoodi* Golden *et al.*, *M. hapla* Chitwood, *Pratylenchus neglectus* (Rensch) Filipjev & Schuurmans Stekhoven, *Paratrichodorus* sp. and *Ditylenchus destructor* Thorne (Hafez *et al.*, 1992). Over 50 percent of the infested hectarage requires chemical treatment at a cost of $494 to $642 per hectare. Half of the alfalfa hectarage is infested with *Ditylenchus dipsaci* (Kuhn) Filipjev, *Meloidogyne* spp., and *Pratylenchus penetrans* (Cobb) Filipjev & Schuurmans Stekhoven. Studies have shown 6-13 percent yield losses in alfalfa due to these pathogens for which there is no economically feasible remedy (Hafez and Mohan, 1990).

Research to evaluate the use of biological control tactics (e.g., cultivar resistance, trap crops and green manures) in commercial crops in Idaho has revealed that incorporation of nematode-resistant crops such as oil radish (*Raphanus sativus* L.) or white mustard (*Sinapis alba* L.) in sugar beet rotation stimulated egg hatch while preventing completion of life cycles (Hafez and Sundaraj, 1998; Hafez, 1999; Hafez and Sundaraj, 1999). Incorporation of the plant material in soil followed by sugar beet resulted in yield increases of 22-25% and reduction of nematodes numbers by 84-92%, compared to fallow treatments. The use of oil radish and rapeseed (*Brassica campestris* L.) as green manures have provided similar favorable results for management of *M. chitwoodi* in potato (Al-Rehiayani *et al.*, 1999). Recently developed alfalfa varieties that are resistant to nematodes consistently produce yields 10-15 percent higher than those of the standard varieties in trials throughout the state (Hafez *et al.*, 2000). Thus, growers of several major crops in Idaho now have an opportunity to use a variety of non-chemical tactics to manage losses from plant parasitic nematodes.

Evaluation of the economic impact of new management methods provides important information for grower decision-making and for public and private entities that invest in pest management research and development. The objective of this study was to develop a quantitative model to evaluate the economic and environmental benefits derived from the development and implementation of the nematode biocontrol methods in sugarbeet, potato and alfalfa in Idaho.

MATERIALS AND METHODS

An *ex-ante* model with probability distribution was developed to project annual gross benefits, present value of expected flow of benefits, present value of the flow of costs, and the internal rate of return to investments in the development, extension, maintenance, and implementation of the nematode bio-control method. An identity equation was developed and used to estimate the quantity of active toxic materials projected to be eliminated from the environment due to the adoption of the biocontrol method on nematodes infested sugar beet and potato fields.

Economic Model

The economic model is outlined in a set of equations in this section. The gross annual benefit is estimated using Equation 1.

$$\sum_{j=1}^{3} \beta_{jt} = \sum_{j=1}^{3} A_{jo}\{\Delta P_{jt}V_{jt} + (V_{jt} - Vjo)\} \quad (1)$$

Where:

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

A_{jo} = the expected total hectares of the j^{th} product affected by the adoption of the results of the nematode program in the base year

j = 1,2,3 products affected by the nematode control method

ΔP_{jt} = the expected change in fumigation cost and in net productivity of the j^{th} product due to the adoption of the results of the nematode control method in year t

V_{jt} = 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, and

$V_{jt} = \{V_{jo} + V_{jo}\ (f\Delta P_{jt})\}$

where f is the flexibility ratio and V_{jo} is the price per unit of the j^{th} product in the base year.

The flexibility ratio is the inverse of price elasticity and it gives the percentage change in price associated with a percent change in quantity.

Data on hectarage affected, A_{jo} in Equation 1, are the 1997-98 average obtained from Idaho Agricultural Statistics (Idaho Department of Agriculture) and applied to the percentage of hectarage that requires fumigation outlined in the introduction section of this paper. The variable ΔP_{jt} in Equation 1 is derived from the experimental results of the effect of the biocontrol method. The biocontrol method eliminated the need for synthetic fumigation ($494-$642 per hectare), increased sugar beet yield (21.7 ton per hectare), increased potato yield (6 165 kg per hectare), and increased alfalfa yield by 10-15 percent as demonstrated in Tables 1-5. The expected price variable, V_{jt} in Equation 1, is the 1997-98 average price reported by Idaho Agricultural Statistics. Flexibility ratio for potato (-0.7053), sugar beet (-0.1086) and alfalfa (-0.0823) were obtained from Huang (1991).

Table 1. Effects of using white mustard and oil radish as green manure in late summer on sugar beet yield and nematode population.

Type of treatment	Yield (ton/ha)	Percent increase in yield	Percent reduction in nematode population[a]
Fallow	61.98	—	41
White mustard (*Sinapis alba*)	75.36	21.5	84
Oil radish (*Rapanus sativus*)	77.28	24.7	92

Source: Hafez, 1999.
[a]Reduction in population from previous season.

β_j is the benefit that accrues to producers as a result of adopting the nematode control method to the j[th] product. The outcome β_j is probabilistic because it depends on the probability of successful development and adoption of the nematode control method (P(S)), and the probability of adopting the nematode control method, $P(A \cap S)$. The expected value of β_j is defined as:

$$\sum_{j=1}^{3} E(\beta_j) = \sum_{j=1}^{3} \sum_{t=0}^{N} \beta_{jt} P(A \cap S) \qquad (2)$$

The present value of the expected flow of benefits from adopting the nematode control method by the j[th] product is calculated by discounting the right-hand side of Equation 2 as shown in Equation 3 below.

$$\sum_{j=1}^{3} PE(\beta_j) = \sum_{j=1}^{3} \sum_{t=0}^{N} \beta_{jt} \{P(A \cap S)\}/(1+r)^t \qquad (3)$$

Where:

$PE(\beta_j)$ = present value of the expected flow of benefit

r = the social discount rate

N = number of years for which the nematodes control method affects production

The probability of research success in this case is 100 percent since all research results and the nematode resistant alfalfa varieties are developed, extended, and are being implemented. A six percent social discount rate was used to discount the flow of future benefits. This is the risk free rate on government bonds recommended by several federal agencies. A 20-year productive life expectancy of the nematode control method and the new alfalfa variety is estimated in consultation with the nematologist, extension specialist, and representatives of the industry. It is assumed that a better technology will likely be available after 20 years.

The adoption profile of the nematode control method was estimated for each commodity based on the market structure of the commodity and in consultation with producers, field representatives, processors, and marketing agents (Fig. 1). Due to the large number of small farms in potato and sugar beet production, it was projected that a maximum of 70 percent of the infested acreage that presently requires chemical fumigation will adopt the biocontrol method. The availability of the new alfalfa seed to satisfy domestic and international demand will affect the maximum adoption rate. The marketing agents of the seed companies projected that 100 percent of Idaho demand for the new alfalfa

Table 2. Effects of fall planting of oil radish and white mustard cultivars on nematode population and sugar beet yield.

	Experiment I*			Experiment II**		
Treatment	Percent reduction in nematode population[a]	Yield (ton/ha)	Increase in yield (ton/ha)	Percent reduction in nematode population[1]	Yield (ton/ha)	Increase in yield (ton/ha)
A. Oil radish						
Adagio	92	77.53 a	22.97	92	91.85 a	21.74
Ultimo	89	69.63 a	15.06	89	82.47 c	12.34
Remonta	88	68.15 a	13.58	88	73.33 d	3.21
Pigletta	87	70.62 a	16.05	87	73.33 d	3.21
B. White mustard						
Metex	84	71.85 a	17.28	84	74.07 cd	3.95
Mexi	84	69.38 a	14.81	84	90.86 bc	20.74
Martigena	62	63.95 b		62	71.12 d	0.0
C. Fallow	41	54.57 b	—	41	70.12 d	—

Source: Hafez and Sundararaj, 1998.
*Means in a column followed by different letters are significantly different at the 0.05 level.
[a]Reduction in population from previous growing seasons.

Table 3. The effects of oil radish, rapeseed, and fallow green manure treatments on the population of Columbia root-knot nematodes, potato yield, and tuber infection.

Treatment	Columbia root-knot nematode population* (ct. per 500-cc soil)				Yield		Tuber infection (percent)
	August 96	October 96	April 97	September 97	kg/ha	cwt/ac	
Oil radish	213 a	98 a	18 b	306	17 696 a	392	26 b
Rapeseed	253 a	61 a	60 ab	197	42 709 ab	381	45 ab
Fallow	293 a	106 a	82 a	610	37 777 b	337	62 a

Source: Al-Rehiayani and Hafez, 1999.
*Means in a column followed by different letters are significantly different at the 0.05 level.

Table 4. Seasonal average yield reductions caused by stem nematodes and northern root-knot nematodes for six common alfalfa varieties planted in Idaho.

	Seasonal average yield loss[z] (percent)	
Variety	Stem nematode	Northern root-knot nematode
Ranger	12.8 a	2.2 bc
EXP49	7.3 b	-2.6 d
EXP 107	7.0 b	0.6 cd
Lahontan	7.7 b	5.5 a
Appolo II	7.1 b	0.3 cd
Washoe	5.5 c	4.2 ab

Source: Hafez, 1998.
[z]Means in a column followed by different letters are significantly different at the 0.05 level.

seed will be satisfied in the year 2010. The adoption in 1998 and 1999 are the actual rates reported by producers.

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

$$C = \sum_{t=0}^{N} \{(R_t + T_t + I_t + M_t)/(1 + r)^t\} = \sum_{t=0}^{N} \{C_t/(1 + r)^t\} \quad (4)$$

Where:

C = the present value of total costs associated with the development, transfer, implementation, and maintenance of the nematode control method

R_t = direct expenditures in diagnosis, research, and development of the nematode control method. R_t is positive in t = 0 and zero in t = 1 to N

T_t = technology transfer cost to help the industry adopt the nematodes control method

I_t = implementation cost by farmers to adopt the nematodes control method in year t

M_t = the cost of maintenance research required to sustain the effectiveness of the nematode control method

The internal rate of return (IRR), or the rate that will equate the flow of benefit to the flow of cost, to investment in the nematode control method is expressed in the following equation.

$$\sum_{t=o}^{N} \left\{ \left(\left\{ \sum_{j=t}^{3} \beta_{jt} P(A \cap S) \right\} - C_t \right) / (1 + IRR)^t \right\} = 0 \quad (5)$$

Environmental Model

The environmental benefit attributed to the nematode control program is the elimination of the present fumigation of sugar beet and potato fields to control nematodes. The amount of active toxic materials that is expected to be eliminated from the environment in Idaho is estimated by the following equation:

$$ATM_{ji} = \{(AC_j)(I_{nj})(Ad_j)(P_{jt})(GL_{ji})(Tx_i)(P/GL)_i\}\{P(A)\} \quad (6)$$

Table 5. 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/ha)
Archer[x]	28.89
Vernema[y]	25.43
ABI 700[x]	29.38
Lahontan	22.22
Zolio[z]	27.90
Nemagone	31.36

Source: Hafez, 1998.
[x]Proprietary variety of Agri-Bio Sciences, Inc.
[y]Public Variety.
[z]Proprietary of Eureka Seeds, Inc.

Where:

ATM_{ji} = active toxic material in each fumigant. j = 1 for potato and j = 2 for sugar beet, and i = 1 for the chemical Telone-II, i = 2 for metam sodium, and i = 3 for Temik

AC_j = total acreage

I_{nj} = percentage of acreage infected with nematode (30 percent for potato and 50 percent for sugar beet)

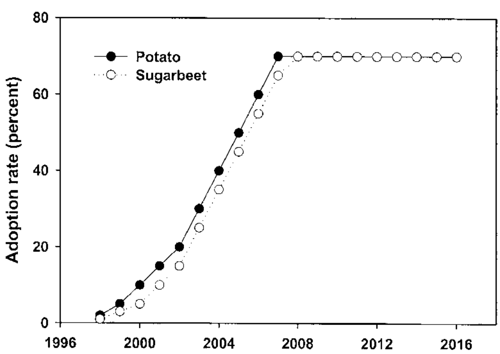

Fig. 1. Projected adoption profile of the nematode biocontrol method by commodities in Idaho.

Ad_j = percent of I_{nj} acrage that requires fumigation (50 percent for potato and 50 percent for sugar beet)

P_{ji} = percentage of Ad_j using the chemical Telone-II (60 percent in potato and 40 percent in sugar beet), metam sodium (40 percent in potato), or Temik (50 percent in sugar beet)

GL_{jt} = liters of Telone-II used per hectare (30.6 liters in potato and 30.6 liters in sugar beets), or (20 gallons per acre), liters of metam sodium used per hectare (76.5 liters in potato) or (50 gallons per acre) or kilograms of Temik used per hectare (11.35 kilograms in sugar beet) or (25 lb in per acre)

Tx_i = percent of active toxic materials (94 percent for Telone-II, 38 percent for metam sodium, and 15 percent for Temik)

$(P/GL)_i$ = 0.996 kilograms per liter (8.31 lb per gallon) for Telone-II and metam sodium

{P(A)} = maximum projected adoption rate

Several areas of benefits and costs associated with the development of the nematode biocontrol methods and the selection of the new alfalfa varieties were analyzed. These areas included: gross annual benefit, present value of gross annual benefit, direct cost, implementation cost, maintenance cost, and internal rate of return to investments in the development, extension, and implementation of the nematode biocontrol methods.

RESULTS AND DISCUSSION

Gross Annual Benefit: The gross annual benefit for each commodity is estimated using 1997-1998 average hectarage, production and price data. The gross annual benefit is estimated for the sugarbeet and potato hectarage that presently requires fumigation. For sugar beets, the gross annual benefit is based on $494 per hectare ($200 per acre) reduction in fumigation cost, 4.9 tons per hectare (2 tons per acre) increase in yield. The estimated gross annual benefit to Idaho sugarbeet producers is over $13.9 million. For potatoes, the gross annual benefit is based on reducing treatment cost by $494 per hectare ($200 per acre), improving yield by 896.79 kilograms per hectare (8 cwt. per acre), and reducing synthetic nitrogen use by 363 kg per hectare (147 lb per acre). The estimated annual gross benefit to Idaho producers is over $18.5 million.

The gross annual benefit to Idaho alfalfa producers 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 producers of potatoes, sugar beets, and alfalfa in Idaho is over $43 million (Table 6).

Present Value: The present value of future flow of gross annual benefits, discounted by a 6 percent social discount rate, was calculated using the projected adoption rate for each commodity. The present value of the flow of gross annual benefits, over a 20-year period, is estimated at $91 426 311 to potato producers, $71 583 945 to sugarbeet producers, and $54 619 437 to alfalfa producers. The total present value of the future flow of gross annual benefits to producers of potatoes, sugar beets, and alfalfa in Idaho is estimated at $217.6 million (Table 6).

Direct Cost: Annual direct expenditures in diagnosis, research, and extension, since the inception of the nematode program in 1982 through 1998 were compiled by the University of Idaho College of Agriculture fiscal office. Direct research and extension expenditures from 1982-1998 were compounded at 6 percent social compound rate. The present value of the direct research expenditures was $1 655 020. Departmental and college overhead and administrative costs were estimated at $17 656 per FTE per year for the Department of Plant, Soils, and Entomological Science. Overhead costs from 1982 to 1998, compounded by 6

Table 6. Benefit and costs associated with the development, transfer, implementation and maintenance of the nematode biocontrol methods.

Benefits or Costs	Value ($)
Annual gross benefit	43 197 872
Present value of annual gross benefit	217 629 693
Present value of total cost	1 851 105
Annual implementation cost	13 837 537
Annual maintenance costs	45 000
Total annual implementation, and maintenance costs	13 882 537
Present value of implementation and maintenance costs	76 556 596
Present value of total cost	78 407 701
Internal rate of return (percent)	81

percent were $196 085. The present value of 1982-1998 total expenditures was $1 851 105 (Table 6).

Implementation Cost: The costs per hectare to plant, grow, chop, and plow under the trap crop is estimated at $307.43 per hectare ($124.51 per acre). This cost includes $222.42 per hectare ($90.80 per acre) in operating costs, $13.70 per hectare ($5.55 per acre) in ownership cost, and $71.33 per hectare ($28.89 per acre) in non-cash costs. 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 (Table 7).

The gross annual implementation cost calculated for the potato hectarage that requires fumigation was $7 507 953 and for sugarbeet hectarage that requires fumigation was $6 329 584 for a total of $13 837 537 (Table 6). The present value of the implementation cost over the 20-year productive life expectancy of the technology was $39 428 695 for potato producers and $32 345 399 for sugarbeet producers for a total of $71 774 094.

Extension and Maintenance Cost: Annual maintenance and extension costs, over the 20-year life expectancy of the technology, are estimated by the nematologist, the extension specialist, and industry representatives at $45 000 per year, for a total of $900 000 (Table 6).

Internal Rate of Return: The rate of return that will equate the benefit from the adoption of the nematode biocontrol method to the cost of diagnosis, development, transfer and maintenance of the method is estimated at 81 percent. In other words, for every dollar invested, the invested dollar is recovered plus $.81.

Environmental Benefit: The development and adoption of the nematode control methods 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 nematicides are also used to control nematodes on sugarbeets: Telone II and Temik.

The annual reductions in active toxic materials on potato fields by eliminating the use of Telone-II and metam sodium are estimated at 2 505 687 kilograms (5 519 134 lb) and 666 406 kilograms (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 1 762 198 kilograms (3 881 495 lb) and 42 349 kilograms (93 281 lb), respectively. It is estimated that the development and adoption of the biocontrol methods for nematodes on potatoes and sugar beets will eliminate a total of 6 178 917 kilograms (13 609 950 lb) of active toxic materials from the Idaho environment annually.

The economic and environmental benefits of the nematode program outlined above do not include the potential economic benefit of reducing nitrogen and sulfur use and the potential environmental benefit of reducing nitrate leaching to ground water. Potato producers in Idaho and the Pacific Northwest region apply 136 kg of synthetic nitrogen and 36 kg of sulfur per acre. Sugar beet producers apply 68 kg of synthetic nitrogen. The applied synthetic nitrogen is in mineral form. At the present irrigation practice, it is estimated that 30-50 percent of the mineral nitrogen will leach as nitrate to ground water with negative health and environmental consequences. Preliminary research results and data obtained from farmers implementing the biocontrol method show that organic nitrogen and sulfur in the plant tissues of the green manure gradually mineralize and provide all the nitrogen required for sugar beets, and all the sulfur and 50 per-

Table 7. Costs per hectare (ha) to plant, grow, chop, and plow green manure.

Cost Item	Quantity/ha	Unit	Cost/unit ($)	Cost/ha ($)
I. Operating Costs				
A. Irrigation:				
Power	7.00	ha	1.60	11.23
Labor	1.21	hr	19.00	9.31
Repairs	7.00	ha	1.40	9.68
B. Custom				
Custom fertilize	1.00	ha	13.20	13.16
C. Fertilize				
Nitrogen	110	kg	0.66	37.04
P_20_5	110	kg	0.50	28.39
D. Seed	1 762	kg	3.30	29.63
E. Labor				
Machine	2.91	hr	31.73	37.43
Non-machine	0.64	hr	19.38	5.63
F. Fuel-diesel	36.40	liter	2.72	17.08
H. Machinery repair				14.54
I. Interest at 9.501				6.66
Total Operating Cost:				222.42
II. Cash Ownership Cost				
A. General overhead:				7.18
B. Property tax (machinery)				4.79
C. Property insurance				1.70
Total Ownership Costs				13.70
III. Non-Cash Ownership Costs				
A. Depreciation and Interest on equipment				71.33
Total Cost/ha				307.43

cent of the nitrogen required for potatoes with minimum nitrate leaching.

The nematode control program analyzed in this study is applicable to other crops in other states in the U.S. and other parts of the world with some significant economic and environmental benefits. Annual loss due to nematodes in alfalfa in the U.S. is estimated at $11.11 billion (Koenning *et al.*, 1999). Nematode resistant alfalfa seeds are rapidly produced and shipped to all major alfalfa producing states and many countries of the world with nematode problems. Many of the chemicals presently used to control nematodes in the U.S. are, or will be, on the EPA de-registration list. The successful development and implementation of the nematode biocontrol methods on sugar beet and potato will provide agricultural scientists with the opportunity to test the effectiveness and determine the economic feasibility of applying this method to high value cash field crops with significant nematode losses. Crops such as soybean with an annual loss of $13.75 billion, cotton with an annual loss of $6.8 billion, vegetables with an annual loss of $6.04 billion, and peanut with an annual loss of $1.23 billion are a few examples in this regard.

LITERATURE CITED

AL-REHIAYANE, S., S. L HAFEZ., M. THORNTON, and P. SUNDARARAJ. 1999. Effects of *Pratylenchus neglectus, Bacillus megaterium,* and oil radish or rapeseed green manure on reproductive potential of *Meloidogyne chitwoodi* on potato. Nematropica 29:39-51.

BRADLEY, E. B., and M. DUFFY. 1982. The Value of Plant Resistance to Soybean Cyst Nematode: A Case Study of Forest Soybeans. Rep. No. AGES820919. USDA, Natural Resource Economic Division, Economic Resource Service, Washington D.C., U.S.A.

BROWN, E. B., W. COOK, and S. L. HAFEZ. 1995. Nitrogen nutrition of gem county alfalfa. Proceedings of the University of Idaho Winter Commodity School, 27:65-69.

GRILICHES, Z. 1964. Research expenditures, education, and the aggregate agricultural production function. American Economic Review. 54:961-74.

HAFEZ, S. L. 1993. Utilizing alfalfa nematode resistant varieties for nematode management. Proceedings of Nevada Regional Alfalfa Sympo-sium. Pp. 57-61.

HAFEZ, S. L. 1998. Alfalfa Nematodes in Idaho. Idaho Experiment Station Bulletin No. 805, Parma, ID, U.S.A.

HAFEZ, S. L. 1999. Sugarbeet Nematodes in Idaho and Eastern Region. Idaho Cooperative Extension System, CIS No. 1072, Parma, ID, U.S.A.

HAFEZ, S. L., and S. K. MOHAN. 1990. Alfalfa Stem Nematode. Idaho Cooperative Extension System, CIS No. 875, Parma, ID, U.S.A.

HAFEZ, S. L., A. M. GOLDEN, F. RASHED, and Z. HONDOO. 1992. Distribution of plant parasitic nematodes associated with crops in Idaho and eastern Oregon. Nematropica. 22:193-204.

HAFEZ, S. L., and MILLER, D. 1986. The effect of stem and northern root-knot nematodes on different alfalfa varieties. Proceedings of the 30th North American Alfalfa Improvement Conference, July 27-31. St. Paul, MN, U.S.A.

HAFEZ, S. L., D. MILLER, and P. SUNDARARAJ. 2000. Screening of alfalfa cultivars to the lesion nematode *Pratylenchus penetrans* for commercial release. Nematologia Mediterranea. 28:157-161.

HAFEZ, S. L., and P. SUNDARARAJ. 1998. Differential reaction and antagonistic potential of trap crop cultivars in the management strategy of sugarbeet-cyst nematode. International Journal of Nematology. 8:145-148.

HAFEZ, S. L., and P. SUNDARARAJ. 1999. Exploitation of nematicidal efficacy of trap crops for the management of *Heterodera schachtii* under sugarbeet ecosystem. International Journal of Nematology. 9:1, 27-23.

HUANG, K. S. 1991. Demand for Food: A Complete System of Quantity Effects on Prices. United States Department of Agriculture, Economic Research Service. Technical Bulletin No. 1795.

IDAHO DEPARTMENT OF AGRICULTURE. 1998-1999. Idaho Agricultural Statistics, Boise, ID, U.S.A.

KOENING, S. R., C. OVERSTREET, J. W. NOLING, P. A. DONALD, J. O. BECKER, and B. A. FORTNUM. 1999. Survey of crop losses in response to phytoparasitic nematodes in the United States for 1994. Supplement to the Journal of Nematology 31:587-618.

NORTON, G. W., and J. S. DAVIS. 1981. Evaluating returns to agricultural research: A review. American Journal of Agricultural Economics. 3:685-99.

PROT, J. C. 1993. Monetary value estimates of nematode problems, research proposal and priorities: the rice example in south and southeast Asia. Fundamentals and Applied Nematology. 16:385-388.

WHITE, F. C., and J. HAVLICEK, JR. 1981. Interregional Spillover of Agricultural Research Results and Interregional Finance: Some Preliminary Results in Evaluation of Agricultural Research. Miscellaneous publication No. 8, Agricultural Experiment Station, University of Minnesota, St. Paul, MN, U.S.A.

Received: 15.XI.2000 *Accepted for publication:* 8.VIII.2001

Recibido: *Aceptado para publicación:*