THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF INVESTMENT IN AGRICULTURAL BIOTECHNOLOGY RESEARCH

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Abstract

Synthetic chemicals are the principle method being used to control weeds, insects, and soil born diseases on agricultural crops. Chemical applications to control pests are expensive with negative environmental impacts. In some cases, pesticides are not available to control pests on certain crops. Environmental concerns have caused the EPA to place other chemicals on the ban list. An alternative to synthetic chemicals in pest control is becoming increasingly important.

Biotechnology research and evolving technologies promise the production of an economic and environmentally friendly alternative to synthetic chemicals in controlling soil-born pests. Research in this area has focused on extracted toxic biochemicals from plant tissues has tested their effect on controlling pests. Glucosinolates contained in cruciferous crop tissues (B*rassica napus*) produce a number of chemicals when mixed with soils that are effective in controlling soil borne diseases, insects, and weeds. Present varieties of cruciferous crops such as: mustard seeds, rapeseeds, oil radish, etc. contain different amounts of glucosinolates and release different levels of toxic biochemicals. The application of these varieties as green manure have shown various degrees of success in controlling weeds and soil born diseases. Tissue culture technique is being used to develop new varieties of cruciferous crops with higher glucosinolate contents that are more effective in controlling weeds and soil born diseases.

Glucosinolates contained in the tissue of several varieties of oil radishes and white mustard release toxic biochemicals that have been very effective in controlling several species of nematodes common on potatoes and sugarbeets in the Pacific Northwest (PNW) region of the United States. Nematodes most associated with potato production are root-knot (*Meloidogne chitwoodi, M. hapla*), root lesion (*Paratrichodrus*), and potato rot (*Ditylenchus destructor*). Sugarbeet cyst nematode (*Heterodera schachtii*) is the most destructive plant parasitic nematode

species. An estimated 50 percent of the potato and sugarbeet acreage in the PNW is infested with these nematodes. Of this, 50 percent requires highly toxic fumigants, at a cost of $572 per hectare ($260 per acre).

Lab and field experiments show that glucosinolates contained in the tissue of the Adagio variety of oil radish, when used as green manure, release sufficient quantity of toxic biochemicals that have reduced the population of these nematodes by 92 percent, increased yield, and eliminated the needs for toxic fumigants on potato and sugarbeet fields. Estimated cost of the green manure is $307.43 per hectare ($124.51 per acre).

An *ex-ante* approach is used to evaluate the benefit of investments in the development and implementation of the nematode biocontrol method. The results of the benefit-cost model, with probability distributions, show an internal rate of return at 81 percent to investment in the program. Annual net benefit to potato and sugarbeet producers in the PNW exceed $45 million. In addition to the direct economic benefit, the nematode biocontrol method will eliminate 9.25 million kilograms (20.4 million lbs) of active toxic materials from the PNW soils with significant reduction in ground water pollution.

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Introduction

Soil-born organisms cause significant losses to most agricultural crops. Synthetic pesticides are the only control method at high cost and resulting in contamination of soil and groundwater. Present chemical fumigants used to control soil-born organisms are highly toxic and at a cost exceeding $618 per hectare ($250 per acre) in some cases. In order to prevent future contamination of soil and ground water, and reduce the cost of controlling soil-born organisms, there has been an increasing emphasis in agriculture to reduce the use of synthetic pesticides and develop a bio-control alternative for soil-born organisms, which cannot be controlled by other means. Biotechnology research in this area has focused on the development of bio-chemicals as an economic and environmentally sound alternative to synthetic pesticides.

Many plants produce compounds (*alleclochemicals*), which directly or indirectly impact their biological environment. Interest in glucosinolates has been generated because of the possibility of using plant tissues as a substitute for synthetic pesticides in soils. Glucosinolates occur throughout an agronomically important family, the Brassicaceae. There is sufficient evidence to suggest that glucosinolates contained in Brassicaceae tissues produce a variety of allelochemicals that are effective pesticides. However, to use these tissues in a biocontrol strategy and avoid possible negative environmental consequences it is imperative to determine the fate of glucosinolate degradation products in soil.

Glucosinolates themselves possess limited biological activity until they are hydrologized by the endogenous enzyme myrosinase (β-thioglucoside glucohydrolase; EC 3.2.3.1). Enzymatic hydrolysis of glucosinates produces D-glucose, sulfate, and a variety of potential allelochemicals depending on the specific aglycon chain structure and reaction conditions. Potential allelochemicals include isothiocyanates, nitriles, thiocyanates, epithionitriles, oxazolidinethiones, amines, and additional compounds. The soil environment is critical to the degradative process and subsequent release of breakdown products.

The biotechnology study developed the methods for identifying and quantifying glucosinolate hydrolysis products in the soil system. It provided the first conclusive evidence for isothiocyanate production in soil using infrared spectroscopy. This is significant since isothiocyanates are presumed responsible for observed biological effects. Later a comprehensive gas chromatographic method was developed that allowed quantification of various isothiocyanates, nitriles, and oxazolidinethione in less than 22 minutes. Effective soil extraction techniques for the allelochemicals were also developed.

These techniques were then used in studies to determine the effect of different soil characteristics on the formation and residence times of glucosinolate hydrolysis products. The results of these studies confirmed that isothiocyanates and nitriles are dominant products of glucosinolate hydrolysis and that pH values below 4.0 and the presence of Fe^{3+} promote the formation of nitrile at the expense of isothiocyanate. However the dominant product of glucosinolate hydrolysis in soil is isothiocyanate regardless of soil pH. Isothiocyanate is determined to be a very effective pesticide and thus glucosinolate-containing plant tissues are sources of compounds potentially valuable in the control of soil-borne pests. Effective control, however, requires a long enough residence time to achieve pest inhibition. Later efforts were thus directed towards quantifying allelochemicals half-lives in various soils. The half-lives for isothiocyanate range from 20 to 60 hours, whereas nitrile has a longer half of 80 to 120 hours.

The relatively rapid dissipation of isothiocyanate and nitrile in soil requires careful consideration to effectively use Brassicaceae tissues in pest control strategies.

Once the chemistry of the system is understood, laboratory bioassays were conducted with a wide range of soil-borne plant pests to determine the allelochemicals responsible for any observed biological response in the bioassay. This is accomplished by chemical analyses to establish the likely compounds causing the effect and further testing of the individual chemicals suspected to be of importance. In this manner, a dose response curve is generated for the respective chemical and plant pest combination. Glucosinolate concentrations of the plant tissues are then used to predict allelochemicals formation and pest control.

The effect of Brassicaceae on controlling insect pests was tested in the lab on wireworms (*Limonius californicus*) and the black vine weevil (*Otiorhynchus sulcatus*). Although ionic thiocyannate is a prominent product of glucosinolate hydrolysis and potentially important in pest control, bioassays with the pure chemical showed that concentrations produced by plant tissues do not result in chronic or acute toxicities to wireworms. In contrast, isothiocyanates are acutely toxic to both wireworms and the black vine weevil at concentrations expected from plant tissues. The studies also showed differential toxicities of isothiocyanates with larger molecular weight isothiocyanates producing greater mortality of black vine weevil eggs than lower molecular weight compounds. Thus not only are isothiocyanate concentrations of importance in achieving pest control, but the specific isothiocyanate is important as well. Breeding efforts, using tissue culture technology, to develop new cultivars of Brassicacaea for pest control are focused on increasing the concentrations of those glucosinolates predicted to be particularly effective towards the target organism.

The effect of members of the Brassicaceae to inhibit weed seed germination has also been addressed in laboratory bioassays. Bioassays with both defatted seed meal and vegetative tissues produced complete inhibition of lettuce (*Lactuca sativa*) germination. The responsible violatile and water-soluble agents were dominantly glucosinolate-hydrolysis products, but additional unidentified water-soluble compounds also inhibited germination. These results suggest that allelochemicals control of germination with glucosinolate-containing plants may contribute to reductions in synthetic pesticide usage if weed seeds are targeted.

Bioassays with fungal pathogens have been conducted with *Aphanomyces euteiches* f.sp. *pisi* in attempt to provide control of Aphanomyces root rot of peas. The results indicate that water-soluble compounds produced from the hydrolysis of glucosinolates in *B. napus* tissues reduce *A. euteiches* oospore infection potential and inhibit mycelial growth. Volatile compounds from *B. napus* meal completely suppress mycelial growth and zoospore germination. Pea (*Pisum sativum*) inoculated with zoospore suspensions and incubated in the presence of volatiles from rapeseed had 50 percent lower root rot disease severity than in the absence of meal. Pathogen studies were expanded to include *Fusarium oxysporum*, a pest in forest nurseries currently of concern because of the lack of effective and economical control measures. The laboratory bioassays show that specific isothiocyanates are effective against the pathogen.

The effect of members of the Brassicaceae plant tissues on egg hatch and the life cycles of sugarbeet cyst nematode (*Heterodera schachtii*), root-knot nematode (*Pratylenchus neglectus*), stubbly root nematode (*Paratrichodorus*), and potato rot nematode (*Ditylenchus destructor*) was analyzed over several years in several green houses and field experiments. The results show that Brassicaceae plant tissues incorporated in the sol as trap crop inhibited 92 percent of the nematode population in the soil. This bio-control method is receiving considerable interest by potato and sugarbeet producers for its economic and environmental benefit in controlling nematodes. The objective of this study is to analyze the economic and environmental impacts of investments in the development and implementation of the nematodes bio-control method on the potato and sugarbeet segments of the agricultural industry in Idaho.

Experimental Data

The nematode program in Idaho identified a total of 53 species of plant parasitic nematodes. Of the 53 nematode species reported in the region five cause significant productivity loss in major crops produced in Idaho. These species are: (1) root knot nematode (*Meloidogyne spp.)*, (2) sugarbeet cyst nematode (SBCN) (*Heterodera Schachtii)*, (3) lesion nematode *(Pratylenchus spp.)*, (4) stubby root nematode (*Trichodorus spp.)*, and (5) Stem nematode *(Ditylenchus spp).* The results of the soil samples tested by the nematode diagnostic lab for several years indicate that 50 percent of the sugarbeet acreage is infested with sugarbeen cyst nematode. Over 50 percent of the infested acreage requires chemical treatment with highly toxic fumigants at a cost of $494 to $642 per hectare ($200 to $260 per acre). The results also show that 30 percent of the potato acreage is infested with species of root-knot nematode. Over 50 percent of the infested acreage requires similar chemical treatment. The experimental results with Brassicaceae plant tissues to control nematode on sugarbeet and potato are discussed in the following sections.

Sugarbeets

Sugar beet cyst nematode (SBCN), *Heterodera schachtii* is the most destructive plant parasitic nematode species attacking sugarbeets. It causes yield loss of up to 60 percent in the endemic regions. The results of the greenhouse and field experiments over several years indicate that incorporation of nematode-resistant crop tissues such as oil radish or white mustard in sugar beet rotation is the most economical and environmentally viable method for the management of SBCN. The results show that cultivars of oil radish and white mustard stimulate egg hatch while preventing completion of life cycles (Hafez and Sundaraj, 1998; Hafez, 1999; Hafez and Sundaraj, 1999).

Oil radish and white mustard are referred to as trap crops in this study. A series of experiments were conducted during the 1992-1996 period to study the potential efficacy of Brassicaceae plant tissues as trap crops on the population of *Heterodera schachtii*, (SBCN) and sugar beet yield potential. Results show that sugar beet yield in plots previously planted with oil radish or white mustard was significantly higher as compared to fallow treatment. Compared to planting sugar beets after fallow, the experimental results 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 sugar beet yield and reduce nematode populations.

Average yield for the five-year experiments were summarized by Hafez (1999). The results show that using white mustard (*Simapis alba) cv. 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 *(Raphanus csativus) cv. 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 1).

The effect of fall planting of different varieties of oil radish and white mustard on sugar beet yield and SBCN population was analyzed in two field experiments (Table 2). Four varieties of oil radish cultivars were planted and plowed under prior to sugarbeets. These varieties are: (1)

Adagio, (2) Pigletta, (3) Ultimo, and (4) Remonta. The results show that the Adagio variety reduced nematode population by 92 percent and increased yield by 3.56 to 3.76 ton per hectare (1.4 to 1.5 ton per acre) (Hafez and Sundararaj, 1998). This is a 42 percent higher yield compared to planting sugarbeets after fallow. Adagio is the most effective Brassicaceae trap crop for reducing nematode populations while increasing sugar beet yield. Three varieties of white mustard were used as trap crops followed by sugar beets. The results showed that compared to fallow the Maxi Variety reduced SBCN population by 84 percent in both experiments and increased yield by 2.43 ton per hectare (0.98 tons per acre) in the first experiment and by 3.40 ton per hectare (1.38 ton per acre) in the second experiment (Hafez and Sundararaj, 1998).

The results of these experiments clearly indicate that in both late summer and fall planting, oil radish as a Brassicaceae trap crop seems to have the greater impact on nematode population and sugar beet yield. Cultivators of oil radish have more inherent ability to reduce SBCN populations (87-92%) compared to white mustard (62-84%) (Hafez and Sundararaj, 1998). This is primarily due to the inhibition of the nematode development in the root of the oil radish cultivars. The percent reduction in SBCN population density was highest in Adagio planted pots. Sugar beet yield was significantly higher in plots previously planted with any of the 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 sugar beet root systems while improving yield. In addition, the mineralization of organic nitrogen in the Brassicaceae trap crop tissues during the June-September period adds an estimated 363 kg of nitrogen per hectare (147 lbs per acre). This will reduce the application of synthetic nitrogen by the exact amount and save producers an estimated $109 per hectare ($44 per acre).

Potatoes

Nematodes associated with potato production in the region are Columbia root-knot nematode (*Meloidogyne chitwoodi, M. hapla),* root lesion nematode *(Pratylenchus neglectus)*, stubby root nematode *(Paratrichodorus)* and potato rot nematode *(Ditylenchus destructor)*(Hafez et al., 1992). 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 Brassicaceae trap crops and the impact of the green manure on yield and quality of potatoes. The effects of oil radish and rapeseed as green manure on Columbia root-knot nematode population and potato yields were analyzed in the laboratory and under field conditions in two experiments conducted in 1996-97 (Al-Rehiayani, et al., 1999). 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 Brassicaceae trap crop were determined before it was sowed into the soil, and after incorporation of green manure into the soil. Nematode populations were also calculated before potato planting, after potato planting, and at potato harvest (Table 3).

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 declined by 92 percent for the oil radish plot (Table 3).

Potato plots treated with oil radish as a Brassicaceae trap crop had the highest yield of 17,796 kilograms per hectare (392 cwt. per acre) compared to 15,299 kilograms per hectare (337 cwt. per acre) for the fallow treatment. This is 16 percent higher yield with the lowest tuber infection of 26 percent . Potato plots treated with rapeseed as a Brassicaceae trap crop had a yield of 17,297 kilograms per hectare (381 cwt. per acre) and tuber infection of 45 percent. Potato plots with fallow treatment had 15,299 kilograms per hectare (337 cwt. per acre) and 62 percent tuber infection (Table 3).

The incorporation of trap crops in the potato rotation system significantly reduced nematode population and tuber infection. It also increased organic matter, moisture, and nutrient content of the soil and thus significantly reduced damage to the root systems and increased yield. The mineralization of organic nitrogen in the Brassicaceae plant tissues adds 363 kg of mineralized nitrogen per hectare (147 lbs per acre). This will reduce the application of synthetic nitrogen by the exact amount at a saving of $109 per hectare ($44 per acre).

Evaluation Methods

The two basic approaches used to evaluate agricultural research productivity are: (1) *ex-post* and (2) *ex-ante*. Several different methods are used within each approach. No one method is superior or considered standard in all situations (Norton and Davis, 1981). Most previous evaluation studies used the *ex-post* approach, evaluating past research. The *ex-ante* approach evaluates future performance and is based on the projected flow of future benefit and cost expected from the development and adoption of research results.

Several *ex-post* methods have been used in previous evaluation studies. These range from descriptive public relation studies to the more sophisticated production function and index number methods (Sim and Gardner in Araji, 1980; Norton and Davis, 1981; Alston, Norton, and Pardey, 1995). The production function method estimates the contribution of research in terms of its impact on improved production efficiency and it estimates marginal rates of return. It requires time series data, cross sectional data, or a combination of the two. Several mathematical models are used to estimate the production function, depending on the nature of the problem and the data. Sim and Araji (1981) used a Hybrid Production function to evaluate return to investments in wheat varietal development and management practice research in the United States (U.S.). Araji (1989) used the Cobb-Douglas production function to evaluate the benefit of investments to wheat research in the Western U.S. Araji, White, and Guenthner (1995) used a supply response model to analyze the spillover effects and return to potato research in six U.S. potato-producing regions. Araji and White (1996) used a Vector Autoregressions model, with time series and cross sectional date, to evaluate the impact of agricultural research on U.S. exports of agricultural products.

The index-number method estimates consumer and producer surpluses. It requires a supply shifter, price and quantity data before and after the supply shift, elasticity of demand coefficient, and elasticity of supply coefficient. The method estimates average rates of return. Araji and Gardner (1981) used the index number method to estimate the benefit of investment in the Dairy Herd Improvement Program to producers and consumers of milk. Araji and White

(1991) used the index-number method to estimate the benefit of research to consumers and producers of beef and pork in the U.S.

The *ex-ante* is a relatively new approach used in research evaluation. The four principle methods used in the *ex-ante* approach are: (1) benefit-cost method to estimates rate of return, (2) scoring method to ranks research activities, (3) simulation method, and (4) mathematical programming method to select an optimal mix of research activities. The benefit-cost method is based on probability distribution of research success and research adoption. The three other methods are based on a preference function.

The benefit-cost with probability distribution is the most widely used *ex-ante* method. Fishel (1971), based on a survey of scientists at the Minnesota agricultural experiment station, estimated probability distributions of costs and values of proposed research projects and projected rate of return to investment in agricultural research. Easter and Norton (1977) used scientist's estimates of yield, expected adoption rates, and costs of various research projects to estimate rate of return to proposed research investments in soybeans and corn production. Araji, Sim, and Gardner (1978) developed probability distribution for research success and adoption of research results and estimated rates of return to research and extension investments for nine major commodities in the western U.S. Araji (1988) developed probability distribution for research success and rate of adoption and estimated rates of return to investments in maintenance, applied, and basic research in the Idaho Agricultural Experiment Station. Araji (1990) applied an *ex-ante* benefit-cost approach with probability distribution to analyze the focus, function, and the productivity of the state agricultural experiment station system.

The Model

Given the nature of the problem and the projected flow of future benefits, *ex-ante* approach is the most appropriate evaluation procedure for this study. 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. The model is outlined in a set of equations in this section.

The annual gross benefit is estimated using Equation 1.

$$\sum_{j=1}^{3} \beta_{jt} = \sum_{j=1}^{3} A_{jo}\left\{\Delta P_{jt} V_{jt} + (V_{jo})\right\} \qquad (1)$$

Where:

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

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

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

ΔP_{jt} = the expected change 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.

V_{jt} = $\left\{V_{jo} + V_{jo}\left(f\Delta P_{jt}\right)\right\}$ where f is the flexibility ratio and V_o is the price per unit of the j^{th} product in the base year.

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

β_j is the benefit that accrues to producers and processors as a result of adopting and implementing 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 nematodes managed - control method, (P(S)), and the probability of adopting the nematode control method, $P(A \cap S)$. The expected value of β_{jt} is defined as:

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

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

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

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 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 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 (Table 7). 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 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:

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

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.

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

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 are expected to be eliminated from the environment in Idaho is estimated by the following equation:

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

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 Metame 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)

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

P_{ji}= percentage of A_{dj} using the chemical Telone-II (60 percent in potato and 40 percent in sugar beet), Metame 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 Metame 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 Metame Sodium, and 15 percent for Temik).

$(P/GL)_i$ = .996 kilograms per liter (8.31 lb per gallon) for Telone-II and Metame Sodium.

{P(A)}= maximum projected adoption rate.

Results

Several areas of benefits and costs associated with the development of the nematode bio control method are analyzed. 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 method are analyzed in this section.

Gross Annual Benefit

The gross annual benefit for each commodity is estimated using 1998-1999 average acreage, production and price data. The gross annual benefit is estimated for the sugarbeet and potato acreage that presently requires fumigation. For sugarbeet, 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, and 363 kg per hectare (147 lb per acre) reduction in synthetic nitrogen use. The estimated gross annual benefit to Idaho sugarbeet producers is over 14.65 million. For potatoes, the gross annual benefit is based on reducing treatment cost by \$494 tons 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 19.4 million (Table 5).

Present Value

The present value of future flow of 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 \$95,997,620 to potato producers and \$75,163,142 to sugarbeet producers. The total present value of the future flow of gross annual benefits to producers of potatoes and sugarbeets is estimated at $171,160,762 (Table 5).

Costs

Several types of costs are associated with the development, transfer, implementation, and maintenance of the nematode bio-control method. These costs are discussed below.

Direct Cost

The University of Idaho College of Agriculture fiscal office compiled annual direct expenditures in diagnosis, research, and extension, since the inception of the nematode program. Direct research and extension expenditures from 1982-1998 were compounded at 6 percent social compound rate. The present value of the direct 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 percent were $196,085. The present value of total 1982-1998 direct expenditures was $1,851,105 (Table 5).

Implementation Cost

The costs per acre to plant, grow, chop, and plow under the Brassicaceae trap crop is estimated at $307.43 per hectare ($124.51 per acre). This cost includes $222.42 ($90.80) in operating costs, $13.70 ($5.55) in ownership cost, and $71.33 ($28.89) 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 6).

The gross annual implementation cost calculated for the potato acreage that requires fumigation was $7,507,953 and for sugarbeet acreage that requires fumigation was $6,329,584 for a total of $13,837,537. 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 (Table 5).

Extension and Maintenance Cost

Annual maintenance and extension cost, over the 20-year life expectancy of the technology, is estimated by the nematodologist, the extension specialist, and industry representatives at $45,000 estimate. The present value of the maintenance and extension cost is $810,544 (Table 5).

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 $0.81.

Environmental Benefit

The development and adoption of the nematode control method will eliminate fumigation to control nematodes on potatoes and sugarbeets. Two fumigants are used to control nematodes on potatoes. They are: (1) Telone II and (2) Metame Sodium. Two fumigants are also used to control nematodes on sugarbeets. They are: (1) Telone II and (2) Temik.

The annual reductions in active toxic materials on potato fields by eliminating the use of Telone-II and Metame 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) of active toxic materials from the Idaho environment annually.

Adoption of the bio-control method will also reduce the use of synthetic nitrogen in potato and sugarbeet production by an estimated 88.4 million kg (194.5 million lbs) annually. About 30-50 percent of synthetic nitrogen leach as nitrates to groundwater. The nematode bio-control method will reduce nitrate leaches into Idaho groundwater by an estimated 26.5-44.2 million kg (58.3-97.2 million lbs) annually.

Summary

Soil-born organisms cause significant loss to most agricultural crops. Nematodes are one of the most damaging soil-born pests. Synthetic, highly toxic pesticides are the only control methods at high cost and resulting in contamination of soil, and groundwater. In order to prevent future contamination of soils and groundwater, there has been increasing emphasis in agriculture to produce bio-chemicals as an alternative to synthetic pesticides. Biotechnology research has discovered the basic information essential to the development of bio-control. Glucosinolates in Brassicaceae plants have been tested and have been found to be very effective in inhibiting the life cycle of several nematode species that cause significant loss to potatoes and sugarbeets.

Five nematode species were analyzed and were found to cause significant loss in productivity of the major crops. These species are: (1) root-knot nematodes (*Melzidogyne chitwoodi, M. hapla.*), (2) sugarbeet cyst nematode (*Heterodera Schachtii*), (3) lesion nematode (*Pratylenchus neglectus, P. penetrans.*), (4) stubby root nematode (*Paratrichodorus spp.*), and (5) stem nematode (*Ditylenchus dipsaci, D. destructor).*

Sugarbeet cyst nematode is the most destructive plant parasitic nematode species causing yield loss of up to 60 percent in sugar fields. The predominant nematodes associated with potato production in Idaho are root-knot nematodes *(Meloidogyne chitwoodi)*, root lesion nematodes *(Pratylenchus spp)*, stubby root nematodes *Paratrichodors spp.),* and potato rot nematode

(Ditylenchus destructor). The root knot and root lesion nematodes are relatively widespread problems in Idaho.

Nematodes in sugarbeet and potato fields are presently being controlled with synthetic chemicals at a cost of \$494-\$642 (\$200-\$260 per acre). Results of experiments conducted on potato and sugarbeet plots treated with oil radish as a Brassicaceae trap crop in the rotation system reduced nematode populations by 92 percent, reduced tuber infection by 60 percent, significantly increased yields, and reduced synthetic nitrogen use in potato and sugarbeet production by 363 kg per hectare (147 lb per acre).

This study used an *ex-ante* approach to evaluate the economic benefit of the development and adoption of the bio-control method. Benefit-cost model, with probability distribution used to estimate gross annual benefits, present value of gross annual benefits, present value of costs, and the internal rate of return to investment in the development, transfer and implementation of the nematode bio-control method. The results show that the bio-control method will have a total gross annual benefit of over \$34 million to sugarbeet and potato producers in Idaho. The present value of the flow of gross annual benefit, over the 20-year estimated life expectancy of the technology, is estimated at over \$171 million.

The present value of direct expenditures in the development of the nematode bio-control method from 1942 through 1998 was \$1.851 million. The gross annual implementation cost in the green manure for sugarbeet and potato producers is estimated at over \$13.38 million. The present value of the implementation cost, over the productive life of the technology, is over \$71.77 million. The gross annual cost in maintenance and extension is estimated at \$45,000 with a projected present value of \$810,544. The present value of total cost is over \$173 million. The internal rate of return to investments in the development, transfer, implementation, and maintenance of the nematode bio-control method is 81 percent.

The implementation of the nematode bio-control method will eliminate the present use of Telone-II and Metame Sodium fumigation in potato fields and Telone-II and Temik fumigation in sugarbeet fields. The estimated annual reduction in active toxic materials in both potato and sugarbeet fields in Idaho is 6,178,917 kilograms (13,609,950 lb). Adoption of the bio-control method will reduce an estimated 88.4 million kg (194.5 million lbs) of synthetic nitrogen application to potato and sugarbeet fields in Idaho. This will reduce annual nitrate leaches to groundwater in Idaho by an estimated 26.5-44.2 million kg (58.3-97.2 million lbs) with significant environmental impacts.

References

1. Al-Rehiayane, S., Hafez, S.L., Thornton, M., and Sundaraj, P. "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.

2. Alston, J. M., G. W. Norton, and P. G. Pardey. 1995. "Science Under Scarcity: Principles and Practices for Agricultural Research Evaluation and Priority Setting". Ithaca: Cornell University Press.

3. Araji, A.A. ed. 1980. "Research and Extension Productivity in Agriculture". Proceeding of a national symposium on research and extension productivity. Department of Agricultural Economics and Applied Statistics, University of Idaho, Moscow, ID.

4. _____. 1988. "Returns to investment in the Idaho Agricultural Experiment Station by principal functions". Idaho Agricultural Experiment Station Research Bulletin No. 144

5. _____. 1989. "Return to Public Investment in Wheat Research in the Western United States". *Canadian Journal of Agricultural Economic* 37(2):467479.

6. _____. 1990. "The Functions, Focus, and Productivity of the State Agricultural Experiment Station in the United States". *Agribusiness: An International Journal.* 6(6):633-642.

7. Araji, A. A., Sim, R.J., and R. L. Gardner. 1978. "Returns to agricultural research and extension programs: An *ex-ante* approach". *American Journal of Agricultural Economics* 60(5): 964-8.

8. Araji, A.A. 1981. "The Economic Impacts of Investment in Integrated Pest Management Programs in the United States". Idaho Agricultural Experiment Station Research Bulletin No. 115.

9. Araji, A.A., and R. I. Gardner. 1981. "Return to Public Investment in the Dairy Herd Improvement Program". Idaho Agricultural Experiment Station Research Bulletin No. 117.

10. Araji, A. A. and F. C. White. 1990. "The Benefit of Research to Producers and Consumers of Wheat". Idaho Agricultural Experiment Station Bulletin No. 717.

11. Araji, A. A. and F. C. White. 1996. "The Impact of Agricultural Research on United States Exports". Idaho Agricultural Experiment Station Bulletin No. 155.

12. Araji, A. A., White, F.C., and Guenthner, J. F. 1995. "Spillover and the Return to Agricultural Research for Potatoes". *Journal of Agricultural and Resource Economics* 20(20):263-276.

13. Arndt, T.M., D. G. Dalrymple, and V. W. Ruttan, eds. 1977. "Resource Allocation and Productivity in National and International Agricultural Research". Minneapolis: University of Minnesota Press.

14. _____. 1977. "The Organization and Productivity of the Federal-State Research System in the United States". In W.L. Perterson and J.C. Fitzharris (ed.) Resource Allocation and Productivity of National and International Agricultural Research. Minneapolis; University of Minnesota Press.

15. Bradley, E.B, and Duffy, M. 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.

16. Brown, E.B., Cook, W., and Hafez, S.L. 1995. "Nitrogen Nutrition of Gem County Alfalfa". Proceedings of the University of Idaho Winter Commodity School, 27:65-69.

17. Echeverria, R.G. 1990. "Assessing the Impact of Agricultural Research". Chapter in R.G. Echeverria ed. Methods for Diagnosing Research Systems Constraints and Assessing the Impact of Agricultural Research, Vol. 11. The Hague: International Service for National Agricultural Research. Vol. 11. The Hague: International Service for National Agricultural Research.

18. Evenson, R.E. 1967. "The Contribution of Agricultural Research and Extension to Agricultural Productivity". *Journal of Farm Economics*. 49:1415-439.

19. _____. 1968. "The Contribution of Agricultural Research and Extension to Agricultural Productivity". Unpublished Ph D dissertation, University of Chicago

20. Evenson, R.E., Waggoner, and V.W. Ruttan. 1979. "Economic Benefits from Research: An Example from Agriculture". *Science*. 205(14):1101-7.

21. Griliches, Z. 1964. "Research Expenditures, Education, and the Aggregate Agricultural Production Function". *American Economic Review*. 54:961-74.

22. Hafez, S.L. 1993. "Utilizing Alfalfa Nematode Resistant Varieties for Nematode Management". Proceedings of Nevada Regional Alfalfa Symposium, pp 57-61.

23. _____. 1998. "Alfalfa Nematodes in Idaho". Idaho Experiment Station. Bulletin No. 805.

24. _____. 1999. "Sugarbeet Nematodes in Idaho and Eastern Region". Idaho Cooperative Extension System. CIS No. 1072.

25. Hafez, S.L. and S.K. Mohan. 1990. "Alfalfa Stem Neamtode". Idaho Cooperative Extension System. CIS No. 875.

26. Hafez, S.L., Golden, A.M., Rashed, F., and Hondoo, Z. 1992. "Distribution of Plant Parasitic Nematodes Associated with Crops in Idaho and Eastern Oregon". *Nematropica.* 22:193-204.

27. 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. Pp.10.

28. Hafez, S.L., Miller, D., and Sundararaj, P. 2000. "Screening of Alfalfa Cultivars to the Lesion Nematode *Pratylenchus penetrtans* for Commercial Release". *Nematologia Mediterranea.* (in press)

29. Hafez, S.L. and Sundararaj, P. 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.

30. Hafez, S.L. and Sundararaj, P. 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.

31. Latimer, R.L. 1964. "Some Economic Aspects of Agricultural Research and Extension in the U.S." Unpublished PhD dissertation, Purdue University.

32. Lu, Y.C. and Cline, P. 1977. "The Contribution of Research and Extension to Agricultural Productivity and Growth". Paper presented at the American Agricultural Economic Association Annual Meeting, San Diego, CA.

33. Metlitskii, O.Z. 1990. "Economics and Nematode Control". *Zashchita-Rastenii.* No. 8,9.

34. Norton, G. W., and J. S. Davis. 1981. "Evaluating Returns to Agricultural Research: A Review". *American Journal of Agricultural Economics.* 3(4):685-99.

35. Norton, G.W. and Paczkowski, R. 1993. "Reaping the Return to Agricultural Research and Education". Virginia Polytechnic Institute and State University Information Series 93.

36. Osteen, A.W., Johnson, and Dowler, C.C. 1982. "Applying the Economic Threshold Concept to Control Lesion Nematodes on Corn". USDA, Economic Research Service. Technical Bulletin No. 1670.

37. 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(5):385-388.

38. Schultz, T.W. 1971. "The Allocation of Resources to Research". W.L. Fishel (ed.) Resources Allocation in Agricultural Research. Minneapolis: University of Minnesota Press. Pp 90-120.

39. Sims, R.J. and A. A. Araji. 1981. "The Economic Impact of Public Investment in Wheat Research in the United States, 1939-1976". Idaho Agricultural Experiment Station. Research Bulletin No. 117.

40. Tang, A. 1963. "Research and Education in Japanese Agricultural Development". *Economic Studies Quarterly.*

41. White, F.C. and Havlicek, J. 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.

42. White, F.C., and A. A. Araji. 1991. "Multimarket Effects of Technological Change". Review of Agricultural Economics 13(1):99-107.

Table 1: Effect of using white mustard and oil radish as green manure in late summer on sugarbeet 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*)	77.34	24.7	92

Source: Hafez, 1999

[a)]Reduction in population from previous season

Table 2: Effect 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 (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	77.53a	22.96	92	91.85a	21.73
Ultimo	89	69.63a	15.06	89	82.47c	12.34
Remonta	88	68.15a	13.58	88	73.33d	3.21
Pigletta	87	70.62a	16.05	87	73.33d	3.21
B. WhiteMustard						
Metex	84	71.85a	17.28	84	74.07cd	3.95
Mexi	84	69.38a	14.81	84	90.86bc	20.74
Martigena	62	63.95b	9.38	62	71.12d	0.0
C. Fallow	41	54.57b	--	41	70.12d	--

Source: Hafez and Sundararaj, 1998

*Means in a column followed by different letters are significantly different at the .05 level

[a)]Reduction in population from previous growing season.

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 population* (Ct. per 500-cc soil)				Yield		Tuber infection (percent)
	August 96	October 96	April 97	September 97	kg/ha	cwt/ac	
Oil radish	213a	98a	18b	306	17,796a	392	26b
Rapeseed	253a	61a	60ab	197	42,709ab	381	45ab
Fallow	293a	106a	82a	610	37,777b	337	62a

Source: Al-Rhiajani and Hafez, 1999
*Means in a column followed by different letters are significantly different at the .05 level

Table 4: Projected adoption profile of the nematode biocontrol method by commodities in Idaho

Year	Adoption Rates (percent)	
	Potato	Sugarbeet
1998	2	1
1999	5	3
2000	10	5
2001	15	10
2002	20	15
2003	30	25
2004	40	35
2005	50	45
2006	60	55
2007	70	65
2008	70	70
2009	70	70
2010	70	70
2011	70	70
2012	70	70
2013	70	70
2014	70	70
2015	70	70
2016	70	70

Table 5: Benefit and costs associated with the development, transfer, implementation and maintenance of the nematode biocontrol method.

Benefits or Costs	Value ($)
Annual gross benefit	34,050,000
Present value of annual gross benefit	171,160,762
Present value of direct cost	1,851,105
Annual implementation cost	13,837,537
Annual maintenance and extension cost	45,000
Total annual implementation, maintenance and extension costs	13,882,537
Present value of implementation, maintenance and extension costs	76,556,596
Present value of total cost	78,407,701
Internal rate of return (percent)	81

Table 6: 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:	7.00	ha	1.6	11.23
Power	1.21	hr	19.0	9.31
Labor	7.00	ha	1.4	9.68
Repairs				
B. Custom:				
Custom fertilize	1.00	ha	13.2	13.16
C. Fertilize:				
Nitrogen	110	Kg	0.66	37.04
P205	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:	36.4	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